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China's Industrial and Military Robotics Development

by

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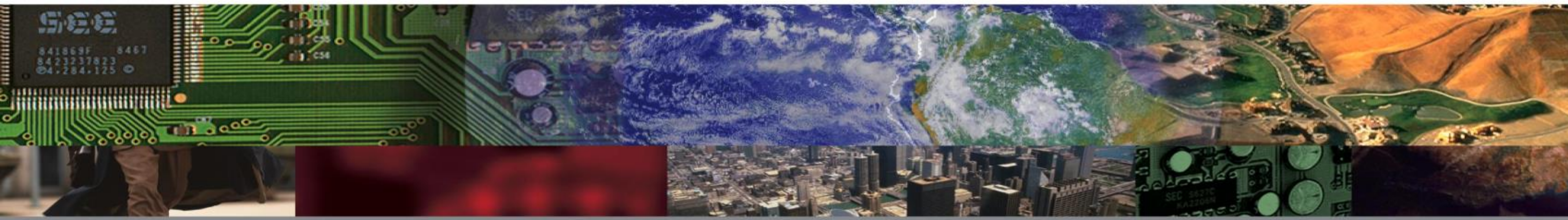

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Acronyms

Acronym	Full Name
A2/AD	Anti-Access/Area Denial
ACTUV	Continuous Trail Unmanned Vessel
AFM	Atomic Force Microscopy
AGIC	Asia-Germany Industrial Promotion Capital
AI	Artificial Intelligence
AIP	Air-Independent Propulsion
AMP	Advanced Manufacturing Partnership
ARV	Autonomous and Remotely Operated Vehicle
ASBM	Anti-Ship Ballistic Missile
ASW	Anti-Submarine Warfare
AUV	Autonomous Underwater Vehicle
AVIC	Aviation Industry Corporation of China
AWS	Amazon Web Services
BAT	Baidu, Alibaba, and Tencent
BINN	Chinese Academy of Sciences Beijing Institute of Nanoenergy and Nanosystems
BIS	Bureau of Industry Security
BIT	Beijing Institute of Technology
BUAA	Beijing University of Aeronautics and Astronautics
CAA	Chinese Association of Automation
CAAI	Chinese Association for Artificial Intelligence
CAC	Chengdu Aircraft Industry Group
CADI	Chengdu Aircraft Design Institute
CAE	Chinese Academy of Engineering
CAS	Chinese Academy of Sciences
CASIC	China Aerospace Science and Industry Corporation
CAST	China Association for Science and Technology
CCF	China Computer Federation
CCW	Convention on Certain Conventional Weapons
CEO	Chief Executive Officer
CFIUS	Committee on Foreign Investment in the United States
CMIF	China Machinery Industry Federation
CMS	China Military Science
CNC	Computer Numerical Control
COCOM	Coordinating Committee for Multilateral Export Controls
CRIA	China Robot Industry Alliance
CSIC	China Shipbuilding Industry Corporation
DARPA	Defense Advanced Research Projects Agency
DLMU	Dalian Maritime University
DOJ	United States Department of Justice
DSV	Deep Sea Submergence Vehicle
EMW	Electromagnetic Maneuver Warfare
EOD	Explosive Ordnance Disposal
FYP	Five Year Plan
GAD	General Armament Department
GM	General Motors
GPS	Global Positioning System
GPU	Graphics Processing Unit
GSD	People’s Liberation Army General Staff Department
HEU	Harbin Engineering University
HIT	Harbin Institute of Technology
HRG	Harbin Institute of Technology Robot Group

IFR	International Federation of Robotics
IIM	Institute of Intelligent Machines
IPR	Intellectual Property Rights
ISR	Intelligence, Surveillance, and Reconnaissance
IT	Information Technology
ITA	International Trade Administration
LAWS	Lethal Autonomous Weapon Systems
MEMS	Microelectromechanical Systems
MHC	Meaningful Human Control
MIIT	Ministry of Industry and Information Technology
MLP	National Medium- and Long-Term Plan for the Development of Science and Technology
MOST	Ministry of Science and Technology
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NDRC	National Development and Reform Commission
NORINCO	China North Industries Group Corporation
NSFC	Natural Science Foundation of China
NUAA	Nanjing University of Aeronautics and Astronautics
NUDT	National University of Defense Technology
NWPU	Northwest Polytechnic University
OS	Operating System
PLA	People’s Liberation Army
PLAAF	People’s Liberation Army Air Force
PLAN	People’s Liberation Army Navy
PLARF	People’s Liberation Army Rocket Force
PLC	Programmable Logic Controller
PRC	People’s Republic of China
R&D	Research and Development
RI	Research Institute
RMA	Revolution in Military Affairs
RMB	Renminbi
ROUV	Remotely Operated Underwater Vehicles
ROV	Remotely Operated Vehicle
S&T	Science and Technology
SADI	Shenyang Aircraft Design Institute
SASAC	State-owned Assets Supervision and Administration Commission
SASTIND	State Administration for Science, Technology and Industry for National Defence
SCO	Shanghai Cooperation Organization
SEAD	Suppression of Enemy Air Defenses
SIA	Shenyang Institute of Automation
SMS	Science of Military Strategy
SMU	Shanghai Maritime University
SVAIL	Baidu Silicon Valley AI Laboratory
TCAIPR	China Computer Federation Artificial Intelligence and Pattern Recognition Committee
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Aerial Vehicle
UGV	Unmanned Ground Vehicle
U.S.	United States
USD	United States Dollar
USITC	United States International Trade Commission
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VC	Venture Capital

WFOE	Wholly Owned Foreign-Owned Enterprise

Contents

Executive Summary

China's commercial and military robotics industries are rapidly growing in size and quality as the country upgrades its manufacturing sector and military capabilities. In 2013, China surpassed Japan to become the world's largest market for industrial robots, and by 2018 will account for over a third of the industrial robots installed worldwide. China's military is also fielding larger numbers of increasingly capable unmanned systems in the air, land, and sea domains that may bolster its anti-access/area denial (A2/AD) capabilities. To support both commercial and military systems, China is investing heavily in emerging technologies such as artificial intelligence (AI) and nanotechnology that will fundamentally change the capabilities of these systems.

The growth of China's robotics industry presents opportunities and challenges to U.S. economic and security interests. Chinese demand for industrial robots and high-end robotic components as well as U.S.-China bilateral investment in AI research all present market and collaboration opportunities for the United States. However, industrial robots may also improve the competitiveness and quality of China's manufacturing sector, erode U.S. competitive advantages, and contribute to China's defense industrial capabilities. The Chinese military's deployment of increasingly capable unmanned systems may provide A2/AD capabilities that degrade the U.S. military's ability to operate freely in the Western Pacific. Chinese countermeasures against unmanned systems are also an under studied subject that may complicate the U.S. military's increasing deployments of such weapons as part of the Third Offset strategy.[1] China's persistent acquisition of foreign technologies through illicit, informal, and formal means extends to robotics and may jeopardize many U.S. technological advantages.

To support the needs of analysts and policymakers, this report assesses the history, current status, and trends of China's robotics industries and unmanned systems. It characterizes the policies, leading entities, and the economic and technical challenges they face. Analyses of different sectors also consider how foreign developments shape China's choices on robotics, such as global developments in advanced manufacturing, U.S. deployments of unmanned systems, and advances in AI. The key findings of this report are the following:

Industrial and Service Robotics:

- Since 2010, China's industrial robotics demand, research, and production have surged and are likely to continue to do so for the foreseeable future. From 2010 to 2014, China's demand for industrial robots increased by approximately 40 percent annually. Despite this rapid growth in demand, China's supply of industrial robots met less than 30 percent of domestic demand until 2015. In the past, China's automobile industry led industrial robotics development, but demand in other industries such as "3c" (computers, communications, and consumer electronics) is on the rise.

[1] The Third Offset Strategy is a U.S. Department of Defense initiative to offset adversaries' anti-access and area denial capabilities with U.S. advantages in technology areas including human-machine collaboration, human-machine combat teaming, assisted human operations, and network-enabled, cyber-hardened weapons, each of which will likely utilize unmanned systems and robotics.

- Chinese definitions of industrial robots are congruent with U.S. terms, and include any robot deployed in a manufacturing setting. Their primary roles include welding, transport, assembly, processing, and spraying. These functions make them inherently dual-use technologies, as these capabilities may support commercial production of cars and aircraft or military production of tanks and fighter jets.

- Since 2006, at least six major Chinese state plans have supported and set targets for China's industrial robotics sector. Made in China 2025 is the most ambitious to date, and aims to comprehensively upgrade China's manufacturing sector. This plan promotes the use and production of industrial robots, and aims to address long-standing challenges such as China's dependence on imports for key components and technologies, the poor quality of domestically produced systems, and a lack of elite talent.

- While these policies indicate strong leadership and industry support for industrial robots, challenges remain. In June 2016, a leading Chinese official commented that the country's industrial robotics industry is "plagued by low quality, overinvestment and too much duplication." Some Chinese robotics industry experts argue that the country is behind global leaders such as Germany, Japan, and the United States by twenty years. There is no consensus among these experts concerning the impact of robotics technology on Chinese and global labor markets.

- Within China, the service robotics sector has grown rapidly over the past ten years. Service robots assist people with completing tasks other than production and manufacturing. Chinese unmanned aerial vehicle (UAV) manufacturers are at or near international standards for industrial, commercial, and recreational consumer drone systems. There is significant Chinese research into driverless vehicles, led by the Chinese Internet firm Baidu. Other focal points of Chinese service robot development include public security, medical and rehabilitation, and educational and personal assistant robots.

Military Robotics and Unmanned Systems:

- Chinese military leaders and strategists believe that the nature of warfare is fundamentally changing due to unmanned platforms. High-level support and generous funding for robotics and unmanned systems R&D have led to a myriad of institutes within China's defense industry and universities (both civilian and military) conducting robotics research.

- China's military UAV industry is robust and growing rapidly. A market analysis from 2014 predicts that from 2013 to 2022, Chinese demand for military UAVs will grow 15 percent annually on average, increasing from USD 570 million in 2013 to USD 2 billion in 2022. Unmanned ground and sea (underwater and surface) vehicles are making technical progress and appear more frequently in military exercises, system tests, and industry competitions.

- There are no available authoritative comparisons of Chinese and U.S. unmanned military systems, as both countries closely guard the related technical data and performance parameters. However, Chinese language and other materials provide insights into broader trends of this competition. First, Chinese manufacturers and their customers appear to emphasize lower price points and quantity over increased technical capabilities. Second, Chinese scientists and U.S. Department of Justice (DOJ) reporting on espionage cases indicate that technologies for propulsion, autonomous operation, advanced sensors, and data links will be critical for China to close the technological gap between U.S. and Chinese unmanned systems.

- China's unmanned systems will likely improve A2/AD capabilities by providing intelligence, surveillance, and reconnaissance support to long-range precision strikes and anti-submarine warfare capabilities. For example, one Chinese analyst claims that the Soar Dragon UAV could provide guidance for the DF-21D anti-ship ballistic missile.

- Chinese strategists consider the U.S. military to be increasingly dependent upon unmanned systems, making countermeasures against these weapons a necessity. Chinese military researchers publish extensively on "soft-kill" countermeasures that blind, confuse, or jam unmanned systems and force them to return to their bases of operations. As the U.S. military emphasizes unmanned systems in its Third Offset strategy, China's countermeasure development and deployments will likely intensify.

Artificial Intelligence and Nanorobotics

- China's leaders consider the field of AI as an opportunity to become more globally competitive in technological capabilities and commercial production, and have labeled AI research as a national priority.

- Leading Chinese AI research institutions and professional associations demonstrate close ties between civilian and military research in this field, raising questions about the national security implications of U.S.-China AI research partnerships in Silicon Valley and China.

- Chinese journals and other media identify promising civilian applications for nanotechnology in medicine (such as diagnostics), computing, energy, the environment (such as oil spill remediation), and industry, while defense applications could include advanced sensors, UAVs, and "micro spy" robots. Scientists in China have made major research accomplishments on nanorobotics technologies, including nanomanipulators, nanomotors, and nanogenerators.

Acquisition of Foreign Robotics Technology

Illicit Technology Acquisitions:

- China's cyber espionage against the U.S. Government and companies reportedly includes multiple manufacturers of military unmanned systems and their component technologies. Media coverage of Operation Beebus, the reported hack of QinetiQ North America, and cyber intrusions facilitated by Su Bin all indicate an active and coordinated campaign against leading suppliers of unmanned systems.

- Numerous individuals in the United States have attempted to illegally export unmanned systems and their relevant high-end components and materials to China. In some cases, co-conspirators in China directed U.S. residents on which items to target.

Informal Technology and Knowledge Transfer:

- China actively acquires U.S. technology through informal means that are extralegal, or not clearly defined and regulated by current legislation. These means include a vast open source intelligence apparatus, recruitment of leading talents from around the world, and academic exchanges.

Formal Technology Acquisitions and Investments:

- Chinese state-owned conglomerates, companies, and venture capital firms are actively acquiring and investing in AI and foreign robotics technologies companies, particularly in Europe. National plans seem to guide these acquisitions by enumerating which advanced technologies Chinese firms should acquire.

Recommendations

Based on these findings, this report puts forth the following recommendations to ensure that the United States both enjoys the benefits of China's surging robotics industries and safeguards its own economic growth and national security.

1. The U.S. Government should promote advanced manufacturing and robotics technologies by implementing the recommendations of the AMP2.0 Steering Committee Report and by supporting initiatives and expansion of the National Network for Manufacturing Innovation (NNMI).

2. U.S. defense planners should monitor and account for Chinese advances in unmanned systems and electronic countermeasures that may improve A2/AD capabilities such as long-range precision strike and anti-submarine warfare.

3. The U.S. Government should conduct an interagency review with economic, scientific, and regional experts to assess U.S.-China cooperation and bilateral investments in AI to ensure that such arrangements do not put the United States at a disadvantage in AI research, breakthroughs, and applications.

4. The U.S. Government should increase awareness among federal agencies, defense contractors, and research universities that Chinese research institutes actively collect their published materials, designs, specifications, and graphics to assess U.S. military systems and guide Chinese research.

5. The U.S. Government should fully implement the Cybersecurity National Action Plan (CNAP) and incorporate input from companies and research institutes that develop unmanned systems, robots, and their relevant technologies.

6. To help counter Chinese espionage against unmanned systems and other sensitive technologies, the U.S. Government should better exploit China's state plans, procurement practices, defense plans, and other Chinese language materials. Such sources identify technologies that the PRC is seeking to acquire, and would provide advance warning to U.S. law enforcement.

7. To address informal technology transfers, U.S. Government sponsors of academic exchanges and research in emerging technologies should consider requirements to more thoroughly vet foreign participants for military or other undisclosed defense affiliations.

8. The U.S. Government, in particular the Committee on Foreign Investment in the United States (CFIUS), should monitor and when necessary investigate China's growing foreign investments in robotics and AI companies, and consider the security implications of transactions and acquisitions involving emerging technologies such as AI and nanorobotics.

Scope and Limitations

This report is an open source investigation of China's industrial, service, and military robotics, as well as China's AI and nanorobotics research. It extensively utilizes Chinese language materials, including academic publications, corporate websites, news media, and other online content. The tremendous scale and rapid development of China's robotics industry make any full cataloguing of companies and products beyond the scope of this report. Instead, this report highlights key entities, broader trends, challenges, and other information that is most useful for U.S. stakeholders.

The industrial and service robotics chapters emphasize broader trends and highlights. This focus accounts for resource constraints and a lack of reliable data at a more granular level. The corporate profiles provided in the chapters and appendices are for the reader's reference. The military robotics and unmanned systems chapter discusses China's systems in the land, air, and sea (surface and underwater) domains. Because unmanned aerial vehicles have received considerable attention in other English-language analyses, this report provides additional emphasis and original reporting on the other domains. Where possible, this report includes Chinese and other reporting on any comparisons between PRC and U.S. unmanned systems. The discussions of Chinese military strategy, ethics, and other considerations for unmanned systems draw from journals and publications that DGI analysts deem to be the most authoritative and credible based on over a decade of experience analyzing Chinese language materials. When necessary, footnotes provide details on publications for the reader's reference.

Introduction

Speaking in June 2014, Chinese President Xi Jinping emphasized the importance of science and innovation to the "great rejuvenation of the Chinese nation," as well as the growing importance of robotics and unmanned systems. Xi said he had read reports that the "robotics revolution" (机器人革命) promised to become the "Third Industrial Revolution," and that people around the world regard industrial robots as the "jewel in the crown of manufacturing" (制造业皇冠顶端的明珠). He added that "military unmanned aerial vehicles, self-driving cars, and housekeeping robots are already a reality," and that key enabling technologies for these systems such as artificial intelligence (AI) are advancing rapidly.[2]

Xi's comments are not surprising, as China is experiencing a period of rapid growth in its research, production, and use of intelligent systems and robotics. China was a late entrant into the robotics market in the 1970s, but as of 2013 China has become the largest market for industrial robots. High-level support from China's leaders and government planning will likely sustain this demand and drive China's own production of robotics and unmanned systems. Chinese leaders consider these technologies to be essential for China's economic growth as the world enters "Industry 4.0" that emphasizes automation and data exchange in manufacturing technologies. This surge in industrial robotics could have profound impacts on China and the world's economy as changes in China's manufacturing model influence domestic and global production and labor markets.

China's leaders also consider robotics as imperative for national security as the "world revolution in military affairs" proceeds to a new stage that emphasizes unmanned systems. The vast research, development, and deployment of China's military unmanned systems is fueling concerns in the United States that the People's Liberation Army (PLA) could "rapidly close the technology gaps and become a formidable global competitor in unmanned systems."[3] These weapons and countermeasures against such systems will also pose new challenges for the U.S. military as it increasingly emphasizes the role of unmanned systems in its Third Offset strategy.

To assess these trends and their implications systematically, this report utilizes taxonomies found in Chinese literature. Major categories of robotics include industrial robotics (工业机器人) and service robotics (服务机器人). Industrial robots include any robot deployed in a manufacturing setting, and their primary functions entail welding, transport, assembly, processing, and spraying. Service robots encompass any robot not used in a manufacturing setting, and leading areas for them are household assistance, entertainment, and general assistance such as elderly care. Specialized service robots (特种服务机器人) include advanced unmanned systems that can be used for civilian and military purposes. For example, unmanned aerial vehicles can assist with land surveys or contribute to a military's ISR and strike capabilities. This category also includes military robots (军用机器人) such as ordnance disposal robots.

[2] "习近平：把关键技术掌握在自己手里" [Xi Jinping: Grasp Key Technologies in Our Own Hands], 新华网 Xinhua Net, June 9, 2014, accessed July 7, 2016, http://news.xinhuanet.com/politics/2014-06/09/c_126597413.htm. Note: Throughout this report, brackets indicate unofficial English translations provided by the authors, and parentheses indicate official English translations and English translations provided by the source.

[3] Defense Science Board, U.S. Department of Defense, "The Role of Autonomy in DoD Systems," (Washington, DC: July 2012), 71.

Chapter 1 assesses China's industrial robotics industry, including the history, policies, and challenges that have led to the country becoming the largest market, as well as those influencing the industry's future. Chapter 2 analyzes how the rapid growth in demand and applications for service robots could lead to even faster growth for this sector in China.

Chapter 3 explains how in the military domain, Chinese strategists see robotics as one of the major technologies causing revolutionary changes in military doctrines and operations. China has long followed U.S. development and deployment of unmanned systems, studied their features and characteristics, and researched countermeasures. This interest will likely continue and increase as the United States implements its Third Offset strategy, which relies on technologies like robotics and unmanned systems to counter strategic advantages held by China and Russia.

AI is a key emerging technology for all robotics systems and will determine their ability to learn and operate autonomously. Chapter 4 assesses the widespread AI research underway in numerous Chinese research institutes and companies, as well as the structure and implications of Chinese partnerships with U.S. entities to jointly research AI. As nanotechnology progresses and the use of nanorobots becomes increasingly widespread, China is investing in these technologies and exploring their applications, as described in Chapter 5.

Chapter 6 addresses China's active pursuit of foreign technologies through illicit acquisitions, informal knowledge and technology transfers, and formal transfer arrangements. Through means ranging from cyber intrusions to academic conferences to foreign investments, China is actively addressing local deficiencies in robotics with foreign technology and expertise.

Chapter 7 presents the opportunities and challenges of China's robotics revolution for the United States and puts forth policy recommendations for relevant stakeholders. With these recommendations, the United States can advance and protect its economic interests and national security.

Chapter One: Industrial Robotics in China

China's leaders consider industrial robotics as essential for the future of the country's manufacturing sector and numerous other industries. Industrial robots (工业机器人) include any robot deployed in a manufacturing setting, and their primary functions are welding, transport, assembly, processing, and spraying. While China is already the world's largest market for industrial robots, it is still dependent upon foreign (particularly European and Japanese) companies to supply advanced industrial robots and key components. In 2014, Chinese companies made only 28 percent of the over 57,000 industrial robots installed in the country.[4] U.S. industrial robot exports account for a small percentage of China's imports (less than three percent), but innovations in applications and components may provide commercial opportunities.[5]

Chinese leaders and national plans clearly want China to become the world's largest producer of industrial robots and to master technologies for key components, a longstanding challenge for China's robotics industry. This chapter assesses the history of Chinese industrial robotics from its "cradle period" to its status today as the world's largest market and the government policies guiding that process. It also assesses the current features of China's industrial robotics industry, such as the sectors leading their adoption and the challenges the industry faces. Finally, it assesses the impact of the industry on China and the world's labor markets and profiles China's leading industrial robotics companies.

The key findings of this chapter are as follows:

- Since 2011, China's industrial robotics demand, research, and production have grown rapidly and are likely to continue to do so. The Chinese industrial robotics market became the world's largest in 2013 and continues to be the fastest growing market worldwide. Chinese industries are fueling this demand because of requirements to reduce labor costs, increase productivity, and ensure quality control. Despite this demand, until 2015 China's robotics companies supplied less than 30 percent of industrial robots, making the country overwhelmingly dependent on foreign suppliers, namely European companies.
- President Xi Jinping and Premier Li Keqiang openly discuss the importance of robotics to China's economy and "national rejuvenation." Numerous state plans include financial support, policy incentives, and output targets for China's industrial robotics sector, the most of ambitious of which is Made in China 2025. This initiative heavily emphasizes the adoption of robotics across China's entire manufacturing sector to improve competitiveness, innovation, technology, quality, reliability, and "green-ness."
- China's automobile industry has historically been the leading driver behind China's industrial robotics market, but there is rising demand from industries including "3c" (computers, communications, and consumer electronics), machinery, electrical and electronics industries, rubbers and plastics, food industries, and logistics.

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[4] "Industrial Robot Statistics," International Federation of Robotics, accessed June 21, 2016, http://www.ifr.org/industrial-robots/statistics/.

[5] "深度: 从进出口数据看我国工业机器人发展情况" [In Depth: Looking at the Development Situation of China's Industrial Robots from Import Export Data], 高工机器人 GG Robot, June 22, 2016, accessed September 30, 2016, http://gg-robot.com/asdisp2-65b095fb-57048-.html.

- Despite its rapid growth, China's robotics industry remains comparatively underdeveloped because of lower degrees of industrial automation.
- China's industrial robotics industry faces numerous challenges, including a lack of elite talent, an overemphasis on basic R&D and designs, the poor quality of domestically produced systems, a lack of coordination among Chinese companies, and a long-standing dependence on imports for key components and technologies.
- There is not yet a consensus among analysts regarding the expected impact of increases in China's use of industrial and service robots on the Chinese and global labor markets. Optimists argue that robotic automation will make Chinese manufacturers more competitive, enhance China's position within the global manufacturing industry, and raise living standards. Pessimists fear that robots in the manufacturing and service sectors will diminish opportunities for blue collar jobs and lead to widespread unemployment.

History and Political Support for China's Industrial Robots

From the 1970s to today, China's industrial robotics field has progressed from non-existent to the largest market in the world. These trends are likely to continue as Chinese industries require robots to reduce labor costs, increase productivity, and ensure quality control. Recent policies and programs under President Xi Jinping are the culmination of these historical trends, and will likely sustain the growth in this industry.

> "*…our country will become the largest market for robots, but can our technology and manufacturing capabilities respond to this competition? We not only must raise our standards for robotics, but also as much and in as many areas as possible hold the market. These types of new technologies and new fields are still numerous; we must take stock of the situation, comprehensively consider it, pay special attention to plans, and make solid progress*."
>
> \- Xi Jinping, June 9, 2014

History of Industrial Robots in China

Since the 1970s, China's industrial robotics industry has gone through five phases, and it is poised to accelerate in growth. From the 1970s to 2000, China's production and installation of industrial robots was negligible. As of 2000, China only marketed 380 platforms. Since 2000, China's market for industrial robots has grown rapidly, and by 2013 China became the largest market for industrial robots.[6] Key factors for this growth have been government plans, foreign suppliers and partnerships, and China's growing economy. These phases in the history of China's industrial robotics industry provide context and insight into current features and policies.

1970s: "Budding Period" of Exploring Basic Technologies

[6] Cai Zixing 蔡自兴, "中国机器人学 40 年" (Robotics in China Daring [sic] the Past 40 Years), *Science & Technology Review* 科技导报 , no. 21 (2015): 23.

Chinese robotics industry and academic experts consider the 1970s to be the "budding period" (萌芽期) or "cradle period" during which China first conducted basic research on industrial robots.[7] China began researching industrial robots in 1972, 20 years after the United States and five years after Japan.[8] Because the Coordinating Committee for Multilateral Export Controls (COCOM) restricted exports of advanced technologies by Western countries to China,[9] China's initial imports were limited.[10]

1980s: "Opening Up and Theoretical Research Period" of Importing and Exploring Basic Designs

In the 1980s, China imported and explored basic designs for industrial robots, leading some to call it an "Opening Up Period" (开发起期) or a "Theoretical Research Period" (理论研究阶段).[11] Along with other high-technology fields, China's robotics technology development and research began to receive national and government attention and support. Two new expert committees were formed and met annually or biennially to help set program development plans for the Seventh and Eighth Five Year Plans (FYPs, covering 1986-1990 and 1991-1995 respectively). They also helped create relevant technical standards and advised on robotics-related development plans for the 863 Program.[12] China initiated the High-Technology Research and Development Plan (863 Program) in March 1986 to support the development of advanced sciences and technologies in strategic areas deemed necessary for China's economic competitiveness and national security. The 863 Program was and continues to be a key source of funding for Chinese research on industrial and intelligent robots.[13]

During China's Seventh FYP, the government promoted industrial robots research and development ("工业机器人开发研究") as one of 76 national key technology breakthrough

[7] Cai, "Robotics in China Daring [sic] the Past 40 Years," 23; Cao Xiangkang 曹祥康 and Xie Cunxi 谢存禧, "我国机器人发展历程" [The Process of Development of China's Robots], *Robot Technique and Application* 机器人技术与应用, no. 5 (2008): 44.

[8] Cai, "Robotics in China Daring [sic] the Past 40 Years," 23; Li Weiling 李伟岭, "中国工业机器人发展的前景分析与研究" [Prospects Analysis and Research on China's Industrial Robotics Development], no. 6 (2015): 22-23; Cai Zixing 蔡自兴 and Guo Fan 郭璠, "中国工业机器人发展的若干问题" [Development and Basic Problems of China's Industrial Robotics Development], *Robot Technique and Application* 机器人技术与应用, no. 3 (2013): 9.

[9] The Coordinating Committee for Multilateral Export Controls (COCOM), was an informal multilateral organization that coordinated national controls for exports of strategic materials and technologies to Communist countries. COCOM ceased to function in 1994. The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies (Wassenaar Arrangement) succeeded COCOM, and includes some robots with advanced processing capabilities, robots specifically designed for underwater and military use, and unmanned aerial and underwater vehicles.

[10] Cao and Xie, "The Process of Development of China's Robots," 44.

[11] Zhao Jie 赵杰, "我国工业机器人发展现状与面临的挑战" (Development and Challenge of Chinese Industrial Robot), *Aeronautical Manufacturing Technology* 航空制造技术, no. 12 (2012): 27-28.

[12] Cao and Xie, "The Process of Development of China's Robots," 44.

[13] Cai, "Robotics in China Daring [sic] the Past 40 Years," 24; Zhang Kun 张坤 and Cui Yongyang 崔永样, "我国工业机器人发展状况以及未来发展战略" [Current Development Situation and Future Development Strategy of China's Industrial Robotics Development], *Journal of Henan Science and Technology* 河南科技, no. 6, (2014): 130; Cao and Xie, "The Process of Development of China's Robots," 44.

programs (国家重点科技攻关项目).[14] During this time, China researched fundamental technologies and components, different types of structures, and application engineering for industrial robots.[15] Research institutes made progress on technologies for spraying, spot welding, arc welding, and transport robots.[16] For components, China developed technologies and structures for industrial robotics systems including mechanical arms, control systems, propulsion transmission units, and designs for testing and manufacturing systems. While research institutes and companies produced these systems on a small manufacturing scale, China's achievements were largely limited to prototypes and grasping basic technologies.[17]

1990-2000: "Prototype Development Period" of Initial Designs and Limited Production

During the mid-1990s, China prioritized R&D of the engineering applications of welding robots and in the late 1990s laid the foundation for the commoditization of domestically produced robots and the promotion of industrial robots.[18] By the end of the 1990s, China had invested in or started nine robot industrialization bases and seven R&D bases.[19] China also made progress in key technologies and equipment for computer numerical control (CNC) lathes, relevant technologies for excavation and tunneling robots, and assembly automation robots.[20] During this time, some of China's leading robotics manufacturers emerged, including Shenyang Siasun (沈阳新松机器人自动化股份有限公司), Harbin Boshi Automation (哈尔滨博实自动化设备有限责任公司), and the Beijing Research Institute of Automation for Machinery Industry (北京机械工业自动化所).[21]

2001-2010: "Initial Industrialization Stage" of Applying and Incorporating Industrial Robots

Chinese authors refer to the 2000s as the "initial industrialization stage" (初步产业化阶段) when Chinese companies began to debut indigenous industrial robots for wider consumption.[22] In 2001, the 863 Program, under the Tenth FYP (2001-2005), focused on helping China get closer to international standards in robotics and other related fields, which included equipment self-design and manufacture, major complementing equipment systems integration and development, and mass production and application of high-capability components.[23]

The Tenth FYP also focused and made progress on key technologies including deep sea manned submersible tools, high-precision cutting digital control processing equipment, hazardous assignment robots, counterterrorism ordnance disposal robots, and human-like and bionic (仿人仿生) robots. Progress on technologies for five-axle joint movement, quiet pressurized

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[14] Cao and Xie, "The Process of Development of China's Robots," 45; Zhang and Cui, "Current Development Situation and Future Development Strategy of China's Industrial Robotics Development," 130.
[15] Cai, "Robotics in China Daring [sic] the Past 40 Years," 23.
[16] Li, "Prospects Analysis and Research on China's Industrial Robotics Development," 22-23.
[17] Cai, "Robotics in China Daring [sic] the Past 40 Years," 23.
[18] Ibid.
[19] Rui Gongye 睿工业 and Liu Peng 柳鹏, "我国工业机器人发展及趋势" [Development and Trends of China's Industrial Robotics], *Robot Technique and Application* 机器人技术与应用, no. 5 (2012): 21.
[20] Rui and Liu, "Development and Trends of China's Industrial Robotics," 21.
[21] Ibid.
[22] Zhao, "Development and Challenge of Chinese Industrial Robot," 27.
[23] Cao and Xie, "The Process of Development of China's Robots," 45.

transmissions, and high-speed and high-precision processing only partially satisfied industrial and defense demands.[24]

For the Eleventh FYP (2006-2010), development foci included advanced industries, structures and propulsion, sensors and information fusion, and key technologies for intelligent controls and human-robot interaction. This FYP also called for increased development of bionic, disaster relief, medical, and public security systems. There was also greater emphasis on robotics and automation technologies for industries including integrated circuits, ships, automobiles, light fabrics, household electrical appliances, and foodstuffs.[25]

2011 to Today: "Surging Development and Application Period" for China's Industrial Robotics Industry

Since 2011, China's purchases, production, and applications for industrial robotics systems has surged. In 2013, China overtook Japan to become the world's largest market for industrial robotics.[26] Rising labor and materials costs led electronics and other labor-intensive industries to become more automated in order to increase work efficiency and decrease costs. Different industries and major companies operating in China publicly announced their investments in robotics, such as in 2011 when the CEO of the Taiwan firm Foxconn (manufacturer of the iPhone) announced the "One Million Robot Plan" to install a million robots over three years.[27] Rising labor and materials costs have led electronics and other labor-intensive industries to become more automated to increase work efficiency and decrease costs.[28] China's drive to expand its use and indigenous development of robotics has been fueled by clear political support and—for the first time—comprehensive economic plans specifically focused on China's robotics industry.

Chinese Leadership Openly Supports Industrial Robotics

In June 2014, Xi Jinping spoke to the Chinese Academy of Sciences (CAS) and the China Academy of Engineering Physics on the importance of science and technology, including robotics, to China's "national rejuvenation."[29] Some analysts consider the speech to be the "first time Xi had espoused a new vision for upgrading and transforming China's manufacturing sector."[30] Xi's subsequent Made in China 2025 initiative is an implementation of this vision. Leading industrial countries such as the United States and Germany have previously launched initiatives to promote advanced manufacturing technologies such as robotics and automation, but China's initiative is considerably larger in scale.

In the speech, Xi said he had read reports that the "robotics revolution" (机器人革命) would become the "Third Industrial Revolution" (第三次工业革命), and that people around the world

[24] Ibid., 46.
[25] Ibid.
[26] "Global Robotics Industry: Record Beats Record," International Federation of Robotics, accessed August 12, 2016, http://www.ifr.org/industrial-robots/statistics/.
[27] Rui and Liu, "Development and Trends of China's Industrial Robotics," 20.
[28] Ibid.
[29] "习近平：把关键技术掌握在自己手里" [Xi Jinping: Grasp Key Technologies in Our Own Hands], 新化网 Xinhua Net, June 9, 2014, accessed July 7, 2016, http://news.xinhuanet.com/politics/2014-06/09/c_126597413.htm.
[30] Lu Kuo-chen "Made in China 2025: Decoding Beijing's Intentions," *CommonWealth*, no. 573, June 5, 2015, accessed July 1, 2016, http://english.cw.com.tw/article.do?action=show&id=14946.

people regard industrial robots as the “jewel in the crown of manufacturing” (制造业皇冠顶端的明珠).[31] The following year, Premier Li Keqiang made similar remarks to a State Council meeting, and both leaders wrote welcome letters to the 2015 World Robot Conference that emphasized the importance of robotics to China and the world. This annual international conference attracts robotics leaders from around the world. It is cohosted by the China Association for Science and Technology (CAST), MIIT, and the Beijing municipal government.[32]

Chinese Policies for Industrial Robots are Equally Ambitious

The ambition, scope, and goals reflected in China’s state-directed plans match Xi’s rhetoric. Made in China 2025 is the most ambitious program to date, and it is the culmination of multiple plans that have sought to address longstanding problems in China’s robotics industry, especially its dependence upon imports for key high-precision components. Previous plans, detailed below, included robotics as a priority industry, but their achievements have generally been lackluster. Given China’s growing emphasis on robotics, the success of Made in China 2025 and other recent plans such as the Robotics Industry Development Plan (2016-2020) will be critical for China’s robotics industries. Key state plans guiding China’s industrial and service robotics industries since 2006 include the following:

National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020) (国家中长期科学和技术发展规划纲要 (2006—2020 年))

In February 2006, the State Council announced the National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020) (MLP) with the goal of increasing China’s innovation, economic growth, and military security.[33] The MLP laid out China’s long-term vision to become a world leader in innovation and emphasized the supply side by defining fields for increased R&D.[34] The plan called for China to become a global leader by 2020 in fields including biology, information industry, materials technologies, and advanced manufacturing technology.[35] The MLP included intelligent robotics under the category of information technology but did not provide any additional emphasis on robotics.[36]

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[31] “习近平：把关键技术掌握在自己手里” [Xi Jinping: Grasp Key Technologies in Our Own Hands], 新化网 Xinhua Net, June 9, 2014, accessed July 7, 2016, http://news.xinhuanet.com/politics/2014-06/09/c_126597413.htm.
[32] “李克强主持国务院专题讲座 讨论加快发展先进制造与 3D 打印等问题” [Li Keqiang Leads a State Council Special Topic Discussion: Discusses Accelerating the Development of Advanced Manufacturing, 3D Printing, and Other Issues], Chinese Government Network 中国政府网, August 23, 2015, accessed July 1, 2016, http://www.gov.cn/guowuyuan/2015-08/23/content_2918394.htm; “习近平致信祝贺 2015 世界机器人大会在京开幕 李克强也作出批示表示祝贺” [Xi Jinping Wrote Congratulations to the 2015 World Robot Conference in Beijing, Li Keqiang also Wrote Comments Expressing Congratulations], *Xinhua Online* 新华网, November 23, 2015, accessed July 8, 2016, http://cpc.people.com.cn/n/2015/1123/c64094-27845750.html.
[33] State Council of the People’s Republic of China, “国家中长期科学和技术发展规划纲要 (2006-2020)” (National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020)), accessed July 7, 2016, http://www.gov.cn/jrzg/2006-02/09/content_183787.htm.
[34] Sylvia Schwaag Serger and Magnus Breidne, “China’s Fifteen-Year Plan for Science and Technology: An Assessment,” *Asia Policy*, no. 4 (July 2007): 135–164.
[35] State Council of the People’s Republic of China, “National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020).”
[36] Ibid.

While the MLP has been an important guideline for China's S&T development since 2006, its results have been mixed, and support for the plan has waned under Xi Jinping. In 2012, a high-level review of the MLP found that duplication of activities and a deeply fragmented bureaucracy led to chronic waste and poor implementation of supporting plans. With the retirement of the plan's chief architect, Premier Wen Jiabao, in 2013, Xi's administration has emphasized Made in China 2025 and initiatives such as Internet Plus.[37]

Twelfth Five Year Plan for Intelligent Manufacturing (智能制造科技发展"十二五"专项规划)

In 2011, the Ministry of Science and Technology (MOST) released this plan, which stated that China was overly dependent upon imports for both high-end equipment and key components for domestically produced high-end equipment.[38] It also identified a lack of fusion between "industrialization" and "informatization." To address these deficits, the plan called for China's manufacturing to be more automated (such as using robots) and intelligent (or incorporating information technology). The plan called for developing specific technologies, including robotics, sensors, industrial communication networks, and controllers, while also seeking to improve reliability, equipment manufacturing techniques, digital controls and digitized manufacturing, complex manufacturing systems, and intelligent information management technology.[39] No analysis could be found crediting this plan with China's success in robotics, but 2011 is widely considered the beginning of a "surge" in China's demand, development, and application of robotics, and in 2013 China surpassed Japan to become the world's largest robotics market.[40]

Guideline on Promoting the Development of the Industrial Robot Industry (关于推进工业机器人产业发展的指导意见)

In 2013, MIIT announced its "Guideline on Promoting the Development of the Industrial Robot Industry" (关于推进工业机器人产业发展的指导意见) to address weaknesses in China's industrial robotics industry and promote the adoption of industrial robots.[41] The guidance document identifies four key weaknesses in China's industrial robotics industry. The first is that the industrial base is weak and relies on imports for key components. Second, China's common service platforms, standards, and personnel need to be improved. Third, the market

[37] Tai Ming Cheung, Thomas Mahnken, Deborah Seligsohn, Kevin Pollpeter, Eric Anderson, and Fan Yang, *Planning for Innovation: Understanding China's Plans for Technological, Energy, Industrial, and Defense Development*, report prepared for the U.S.-China Economic and Security Review Commission (2016): 30-34.
[38] "智能制造科技发展"十二五"专项规划" [Twelfth Five Year Plan for Intelligent Manufacturing), Ministry of Science and Technology 科技部, accessed July 1, 2016, http://www.most.gov.cn/tztg/201204/W020120424327129213807.pdf.
[39] "解读智能制造科技发展"十二五"专项规划" [Interpreting the Twelfth Five Year Plan for Intelligent Manufacturing], Ministry of Science and Technology 科技部, May 7, 2012, accessed July 1, 2016, http://www.most.gov.cn/kjbgz/201205/t20120507_94189.htm.
[40] "Global Robotics Industry: Record Beats Record," press release from the International Federation of Robotics, accessed August 12, 2016, http://www.ifr.org/industrial-robots/statistics/.
[41] "工业和信息化部关于推进工业机器人产业发展的指导意见" [Guiding Suggestions from MIIT on Promoting the Development of the Industrial Robotics Industry], Ministry of Industry and Information Technology 工业和信息, as posted at Sina 新浪, December 30, 2013, accessed July 1, 2016, http://finance.sina.com.cn/stock/y/20131230/170417797233.shtml.

competitiveness of China's own brands of industrial robots is weak. Fourth, market competition is intensifying, making duplication more evident. The guideline calls for improving technologies, personnel, service platforms (such as design and testing platforms), and coordination between industries. The guideline outlines goals for China to reach by 2020, including to: develop three to five globally competitive robot manufacturers; create eight to ten industrial clusters for the industry; reach 45 percent domestic market share for Chinese high-end robots; and increase robot penetration to 100 per 10,000 workers.[42] No commentary could be found discussing the effectiveness of this plan, but given that China announced the Made in China 2025 and the subsequent Robotics Industry Development Plan (2016-2020) two years later, it may be assumed that these plans have supplanted this original MIIT guideline.

Thirteenth Five Year National Economic and Social Development Plan (2016–2020) (国民经济和社会发展第十三个五年规划纲要)

The Thirteenth FYP (2016-2020) calls for numerous developments related to robotics, and includes "robotics equipment" (机器人装备) in a section of eight areas for "high-end equipment innovation, development, and engineering" (高端装备创新发展工程). The section calls for the large-scale development of industrial robots, service robots, surgical robots, and military-use robots, as well as encouraging the development of China's own high-precision reducers, high-speed and high-capability controllers, and high-capability electrical servomotors and drivers. This section also promotes the commercial use of AI in these areas. It calls for breakthroughs in advanced information and networking technologies, including big data and cloud computing, autonomous controllable operation systems, high-end industries and large scale management software, and AI.[43] Some Chinese observers note the Thirteenth FYP is the first FYP to use the term "artificial intelligence," indicating its growing importance.[44] In January 2016, Wan Gang, Minister of China's Ministry of Science & Technology (MOST), listed "intelligent manufacturing and robots" as one of the Science & Technology Innovation 2030 – Mega Projects (科技创新2030——重大项目). Wan said the Party Central Committee and the State Council determined these priorities, which also include aero-engines, quantum communications, deep space and deep sea probes, major new materials, and neurosciences.[45] Xi Jinping previously listed these same technologies as priorities at the Fifth Plenum of the Eighteenth Communist Party Congress in November 2015.[46]

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[42] Ibid.

[43] "中华人民共和国国民经济和社会发展第十三个五年规划纲要" (The Thirteenth Five-Year Plan for National Economic and Social Development of the People's Republic of China), Xinhua Net 新华网, March 17, 2016, accessed July 1, 2016, http://www.gov.cn/xinwen/2016-03/17/content_5054992.htm.

[44] Qu Ting 屈婷, Liu Wei 刘伟, and Yang Dingmiao 杨丁淼, "'十三五'：中国开启人工智能商用新纪元" [The Thirteenth FYP: China Starts a New Era of Commercial Use for Artificial Intelligence], Xinhua Net 新华网, March 8, 2016, accessed July 7, 2016, http://news.xinhuanet.com/fortune/2016-03/08/c_1118271033.htm.

[45] "万钢：面向 2030 遴选启动航空发动机等一批科技创新重大项目" [Wan Gang: Facing 2030, Choices on Launching Aero-Engines and Other Science & Technology Innovation Megaprojects], Xinhua Net 新华网, March 8, 2016, accessed July 7, 2016, http://news.xinhuanet.com/fortune/2016-01/11/c_1117739527.htm.

[46] "习近平 关于"中共中央关于制定国民经济和社会发展第十三个五年规划的建议"的说明" [Xi Jinping: Explanation of the 'Recommendations of the Party Center on the Thirteenth Five-Year National Economic and Social Development Plan'], Xinhua, November 3, 2015, accessed July 7, 2016, http://news.xinhuanet.com/politics/2015-11/03/c_1117029621.htm.

Made in China 2025 (中国制造 2025)

In May 2015, China's State Council announced Made in China 2025, a major initiative to improve the competitiveness, innovation, technology, quality, reliability, and "green-ness" of China's manufacturing sector.[47] This plan differs from previous state plans because it focuses on the entire manufacturing sector and processes, not just specific industries. The plan calls for intelligent manufacturing that uses information technology tools for production and draws inspiration from Germany's "Industry 4.0" plan, the U.S. Advanced Manufacturing Initiative, and the French Nouvelle France Industrielle.[48] It addresses what Miao Wei, minister of MIIT, called a "double press" (双重挤压), where China needs to compete with both developed countries using advanced technologies and developing countries with cheaper labor. Miao identified industrial robots as one of the key technologies that can increase quality and reliability in China's manufacturing sector.[49] This plan is also likely influencing China's foreign acquisitions and investments in robotics companies, particularly in Europe as discussed on page 104. One scholar characterizes this plan and another as a "shopping list" for foreign investment targets that could help China acquire key technologies and licenses to improve its own industries.[50]

Robotics Industry Development Plan (2016-2020) (机器人产业发展规划（2016-2020 年）)

In April 2016, China's MIIT, Ministry of Finance, and the National Development and Reform Commission jointly released the Robotics Industry Development Plan (2016-2020) (机器人产业发展规划（2016-2020 年）), calling for advances in China's industrial and service robotics industries. The plan states that since the international financial crisis of 2008, other countries have made robotics a strategic priority, and finds that China is overly dependent upon imports for key components including high-precision reducers, servomotors, and controllers. The plan calls for China to produce 100,000 industrial robots and 50,000 industrial robots with six-axis movement or greater annually, a robotic density of 150 robots per 10,000 employees, and RMB 30 billion (USD 4.49 billion) in sales of service robots (including applications in medicine and elderly care) by 2020.[51] Some analysts criticized the plan for focusing on existing technologies and components instead of AI, which is considered the key enabling technology for robotics in the long term.[52]

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47 "国务院关于印发《中国制造 2025》的通知" [State Council Releases "Made in China 2025" Announcement], May 8, 2015, accessed July 11, 2016, http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm.
48 Scott Kennedy, "Made in China 2025," Center for Strategic and International Studies, June 1, 2015, accessed June 1, 2016, https://www.csis.org/analysis/made-china-2025); Miao Wei 苗圩, "世界制造业发展趋势和我国装备制造业状况" [World Manufacturing Industry Development Trends and the Current Situation of China's Manufacturing], *Shishi Baogao (Dangwei Zhongxinzu Xuexi)* 时事报告 (党委中心组学习), no. 1 (2016): 33.
49 Miao Wei 苗圩, "中国制造 2025：建设制造强国的行动纲领" [Made in China 2025: An Action Plan for Building a Manufacturing Great Power], *理论参考 Journal of Theoretical Reference*, no. 7 (2015): 40.
50 Sebastian Heilmann, "Europe Needs Tougher Response to China's State Led Investments," post at *Financial Times*, June 9, 2016, accessed July 1, 2016, http://blogs.ft.com/beyond-brics/2016/06/09/europe-needs-tougher-response-to-chinas-state-led-investments/.
51 "机器人产业发展规划（2016-2020 年）发布" [Robotics Industry Development Plan (2016-2020) Release], accessed July 11, 2016, http://www.sdpc.gov.cn/zcfb/zcfbghwb/201604/t20160427_799898.html.
52 He Huifeng, "China's Five-Year Plan to Transform Its Robotics Industry," *South China Morning Post,* April 6, 2016, accessed July 1, 2016, http://www.scmp.com/news/china/policies-politics/article/1934071/chinas-five-year-plan-transform-its-robotics-industry.

Overall Trends in China's Adoption of Industrial Robots

Statistics from the International Federation of Robotics (IFR), a Germany-based professional nonprofit organization established in 1987, show that robotics markets are growing rapidly, both internationally and within China. Global industrial robot sales increased 29 percent from 2013 to 2014, reaching 229,261 units, an annual increase that the IFR described as "by far the highest level ever recorded for one year." Approximately 16,000 units, or 28 percent, were from Chinese suppliers, while the rest were from foreign companies, primarily in Europe.[53] Figure 1 depicts annual global industrial robot sales totals from 2002, showing rapid growth in sales since 2011. There is better data available for industrial robots than for service robots, due in part to the relative maturity of the industrial robot market, which is more established than the service robot market.

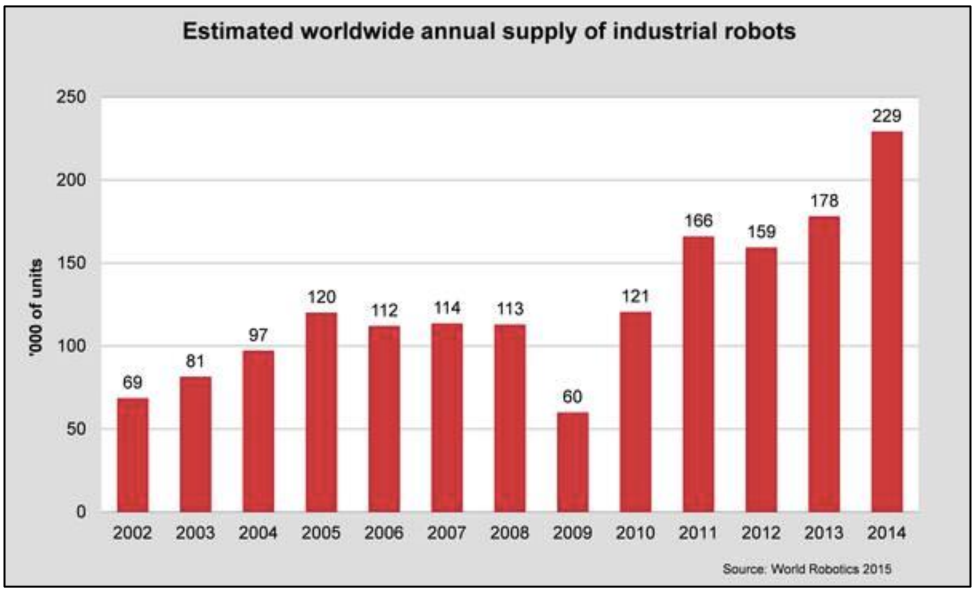

Figure 1: Estimated annual global industrial robot sales, 2002-2014. Source: IFR (World Robotics 2015 Report).[54]

The robotics industry within China is growing especially quickly, even compared to positive international market trends. In 2014, 57,096 industrial robots were sold in China, an increase of 56 percent over 2013.[55] This gain is apparent in Figure 2, which shows annual robot sales in China from 2005 to 2014. IFR notes that China is now the world's largest market for industrial robots, comprising 25 percent of the global market, and that it is also the fastest growing market worldwide.[56] From 2010 to 2014, U.S. demand for industrial robots doubled, while China's quadrupled.[57] From 2010 through 2014, China's total supply of industrial robots increased by approximately 40 percent annually on average.[58]

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[53] "Industrial Robot Statistics," International Federation of Robotics.
[54] Ibid.
[55] Ibid.
[56] Ibid.
[57] "China Enforces Historic Robot Boom," International Federation of Robotics, accessed August 29, 2016, http://www.ifr.org/news/ifr-press-release/china-enforces-historic-robot-boom-776/.
[58] Industrial Robot Statistics," International Federation of Robotics.

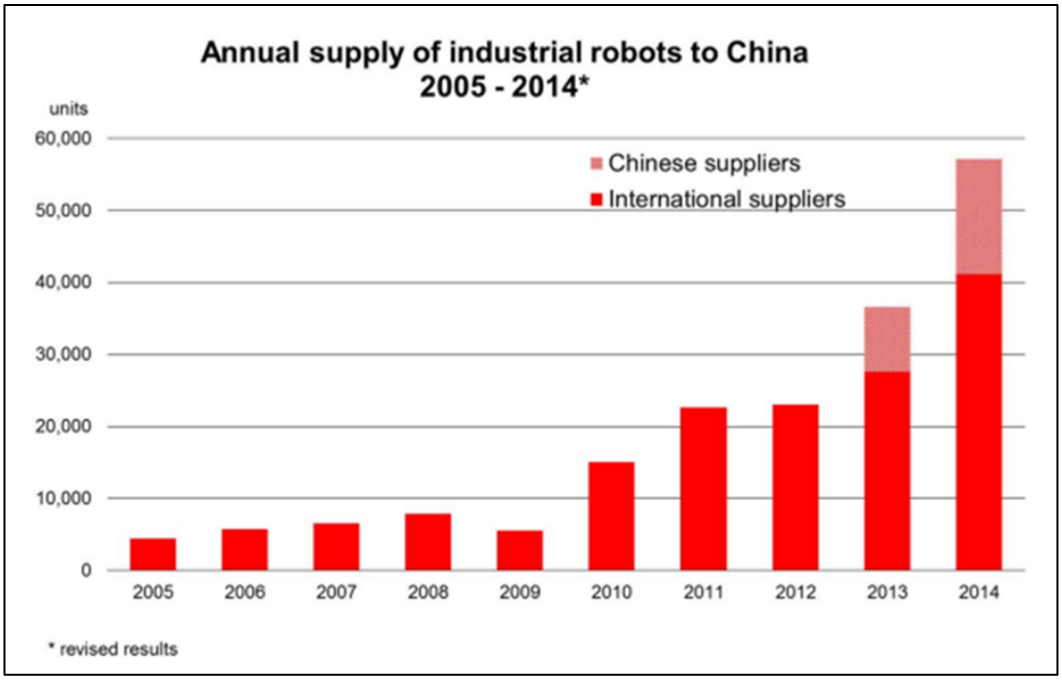

Figure 2: Estimated annual industrial robot sales within China, 2005-2014. Source: IFR (World Robotics 2015 Report).[59]

Characteristics and Leading Industries of China's Robotics Market

Chinese industry reports, government plans, and news media consider the following to be the main characteristics of China's industrial robotics market:

1. Since 2000, China's automobile industry has driven development of the industrial robot market.

China's auto industry entered a rapid period of growth, becoming an industry that emphasizes automation and is both capital and technology intensive.[60] In 2008, China's annual production reached 9.5 million vehicles, nearly eight times its production in the mid-1990s, making it the largest automobile manufacturer in the world.[61] In 2014 and 2015, annual production continued to grow to 23.7 and 24.5 million vehicles respectively, over twelve million more vehicles than the United States, the second largest producer.[62] These trends have made the industry a key driver in the growth of industrial robotics and their application in China. According to IFR, the robot density in China's automotive industry is still moderate and will increase as firms modernize. Numerous applications such as assembly, painting, and welding will likely drive this demand. To emphasize the importance of the automobile industry for China's robotics, it is worth noting that Miao Wei (

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[59] Ibid.

[60] Rui and Liu, "Development and Trends of China's Industrial Robotics," 20; Shen Xuming 沈绪明 and Dong Peng 董鹏, "我国机器人发展现状、需求及产业化探讨" [An Investigation of China's Robotics Development Situation, Requirements, and Industrialization], *Logistics Technology (Equipment)* 物流技术 (装备版), no. 22 (2012): 69-70.

[61] Rachel Tang, *The Rise of China's Auto Industry and Its Impact on the U.S. Motor Vehicle Industry* (CRS Report No. R40924) (Washington, DC: Congressional Research Service, 2009), 3, accessed August 17, 2016, https://www.fas.org/sgp/crs/row/R40924.pdf.

[62] "World Motor Vehicle Production by Country and Type (2014-2015)," Correspondents Survey by the International Organization of Motor Vehicle Manufacturers (OICA), accessed August 17, 2016, http://www.oica.net/wp-content/uploads//Total-2015-Q4-March-16.pdf.

苗圩) was an automobile executive before heading MIIT and becoming one of the premier voices for the Made in China 2025 initiative.[63]

2. Other industries with increasing demands for industrial robots include "3c" industries (computers, communications, and consumer electronics), machinery, electrical and electronics industries, rubbers and plastics, food industries, logistics, and manufacturing.[64]

Analysts believe that industries including automobiles, electronics and household appliances, tobacco, new energy batteries, and others will annually require more automated production lines, which will fuel China's continued demand for industrial robots.[65] This trend is in accordance with international trends, according to the IFR, as the supply of industrial robots has increased from 2012 to 2014 in the automotive; electrical/electronics; metal, chemical, rubber, and plastics; and food industries.[66] According to the IFR, much of the increase in industrial robotics sales in 2014 went to the Chinese and Taiwanese electronics industries and automotive electronic parts suppliers.[67]

3. Coastal economically developed districts are the primary markets for industrial robots.

Guangdong, Jiangsu, Shanghai, Beijing, and other coastal regions are China's leading manufacturing hubs and account for over half of China's industrial robots.[68] The Pearl River Delta region's application market is growing the most quickly. China's robot manufacturing base is growing most rapidly in Shenzhen, Changzhou (Jiangsu province), Tangshan (Hebei province), Chongqing, and Jincheng (Shanxi province).[69]

4. Wholly owned foreign-owned enterprises (WFOEs) and foreign joint venture enterprises have traditionally been the primary customers of industrial robots.

Foreign enterprises and joint ventures have higher automation rates, and in turn have higher demands for industrial robots.[70] In contrast, many Chinese companies and industries are slower to adopt robots because their production models are inflexible. While some cite relatively cheap labor as another obstacle for domestic industries, this calculus may be changing, as explained below.[71]

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[63] "工业和信息化部部长、党组书记 苗圩" [MIIT Minister and Party Secretary Miao Wei], Ministry of Industry and Information Technology 工业和信息化部, accessed July 1, 2016, http://www.miit.gov.cn/n1146285/n1146347/n1147601/index.html.
[64] Zhao, "Development and Challenge of Chinese Industrial Robot," 26.
[65] Rui and Liu, "Development and Trends of China's Industrial Robotics," 21.
[66] "Industrial Robot Statistics," International Federation of Robotics.
[67] Ibid.
[68] Shen and Dong, "An Investigation of China's Robotics Development Situation, Requirements, and Industrialization," 69-70.
[69] Rui and Liu, "Development and Trends of China's Industrial Robotics," 21.
[70] Shen and Dong, "An Investigation of China's Robotics Development Situation, Requirements, and Industrialization," 69-70.
[71] Zhang and Cui, "Current Development Situation and Future Development Strategy of China's Industrial Robotics Development," 129.

5. Rising labor costs are encouraging the entry of industrial robots into various industries, especially labor-intensive ones.[72]

Labor costs and other demands are rising as the costs of purchasing industrial robots decline.[73] Since 2001, hourly manufacturing wages in China, which are set by provincial governments, are reported to have increased 12 percent each year.[74] In 2016, Guangdong announced it would freeze minimum wage increases for two years.[75] In 2015, in a survey of 300 manufacturers in the Pearl River Delta (a key manufacturing hub that includes Guangdong), 85 percent of respondents thought that labor shortages were not improving, and that minimum wages would continue to climb.[76] Forty-five percent of those surveyed indicated that investments in automation was a main strategy to address these rising labor costs.[77]

6. China's rapidly growing industrial robotics market attracts many of the world's leading robot manufacturers.

Numerous foreign companies are selling industrial robots to China and investing in China's indigenous industry. Companies set to export more to China include Germany's KUKA, Japan's Yaskawa (安川电机), and Swedish-Swiss multinational corporation ABB. Yaskawa announced in 2012 that it would build an industrial robot manufacturing plant in Changzhou, Jiangsu province to produce welding robots for China's and other Asian countries' automobile plants by 2013.[78] In 2013, company representatives explained that China had a fraction of the number of robots of Japan, the United States, or Germany, and (correctly) predicted China would become the largest market for industrial robots.[79]

China's Robotics Industry Remains Comparatively Underdeveloped

Despite these trends of rapid growth in China's robotics industry, significant room for expansion remains. In 2014, China, Japan, the United States, South Korea, and Germany were the five leading markets in terms of industrial robot sales, accounting for 70 percent of total industrial robot sales worldwide. The relative maturity of the robotics industries in the other four markets, besides China, can be illustrated by comparing these markets' robotic density, a measure equal to the number of industrial robots in use per 10,000 persons employed in the industry.

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[72] Shen and Dong, "An Investigation of China's Robotics Development Situation, Requirements, and Industrialization," 69-70.
[73] Rui and Liu, "Development and Trends of China's Industrial Robotics," 21.
[74] Jiaxing and Yangon, "A Tightening Grip: Rising Chinese Wages Will Only Strengthen Asia's Hold on Manufacturing," *The Economist*, March 14, 2015, accessed August 14, 2016, http://www.economist.com/news/briefing/21646180-rising-chinese-wages-will-only-strengthen-asias-hold-manufacturing-tightening-grip.
[75] "Wages and Employment," *China Labour Bulletin* (中国劳工通讯), accessed August 18, 2016, http://www.clb.org.hk/content/wages-and-employment.
[76] "Higher Wages in China Show Better Productivity," *China Daily* (Europe edition), May 23, 2015, accessed August 14, 2016, http://europe.chinadaily.com.cn/business/2015-05/23/content_20798291.htm.
[77] Ibid.
[78] Cai and Guo, "Development and Basic Problems of China's Industrial Robotics Development," 10-11.
[79] Pang Lijing 庞丽静, "争夺中国机器人" (The Fight for China's Robots), *The Economic Observer* 经济观察报, September 4, 2013, accessed August 15, 2016, http://www.eeo.com.cn/ens/2013/0913/249730.shtml and http://www.eeo.com.cn/2013/0904/249353.shtml.

Robotic density gives an indication of the degree to which an industry has incorporated robots into its processes as a replacement for manpower; a higher robotic density signifies a higher degree of industry automation. It is useful when comparing the use of robots in markets or countries with significantly different population sizes or manufacturing sector sizes.

As of 2015, the average global robot density was estimated at approximately 66 industrial robots installed per 10,000 manufacturing industry employees. South Korea, Japan, and Germany were the highest-ranking countries in terms of robotic density. South Korea's robotic density was estimated at 478 in 2014, followed by Japan with a robotic density of 314, and Germany with a robotic density of 292. The United States had a robotics density of 164 in 2014.[80]

China's robotic density was much lower, at approximately 33 installed robots per 10,000 employees, placing it well below both global and Asian averages. This data is summarized in Table 1.[81]

Table 1: Robotic density per 10,000 employees in key markets, 2014. Source: IFR.[82]

Market	Robotic Density
South Korea	478
Japan	314
Germany	292
United States	164
Global Average	66
Average within Asia	54
China	33

Problems in China's Industrial Robotics Industry and Research

Despite this rapid growth in China's demand for industrial robots, its production and quality still lag behind. Until 2015, Chinese companies produced less than 30 percent of the industrial robots installed in China, and 60 percent of the industrial robots produced were considered low-end models. These problems led MIIT Vice Minister Xin Guobin to comment in June 2016 that despite the growth of China's demand for industrial robots, the industry is "plagued by low quality, overinvestment and too much duplication."[83]

The consensus of Chinese academics is that China's industrial robotics industry is not as advanced as those of the United States, Japan, and Germany, but they differ on how far behind China lags. Some scholars, such as Professor Zhao Jie at the Harbin Institute of Technology, argue the current

[80] International Federation of Robotics, "Statistics."
[81] Ibid.
[82] Ibid.
[83] Mandy Zuo, "China's Robot Industry 'Plagued by Low Quality, Overinvestment and Too Much Duplication'," *South China Morning Post*, June 17, 2016, accessed August 29, 2016, http://www.scmp.com/news/china/economy/article/1976825/chinas-robot-industry-plagued-low-quality-overinvestment-and-too; "工信部副部长辛国斌：机器人已有投资过剩隐忧" [MIIT Vice Minister Xin Guobin: Worries that Robotics Already Has Surplus Investment], Sina 新浪, June 16, 2016, accessed August 29 2016, http://finance.sina.com.cn/china/gncj/2016-06-16/doc-ifxtfrrc3709815.shtml.

state of the industry is similar to these countries in the 1990s,[84] while others argue that China is closer to the 1980s because of a lack of high-precision machinery, low efficiency in processes, and continued dependence on foreign imports for key components.[85] In sum, these authors assess the foundations of China's robotics industry as still relatively weak, technological levels as relatively backward, and the disparity with other countries as still large. One expert summarizes these problems with the following themes:[86]

> **"Heavy on imitation and light on brands."** Chinese brands of industrial robots imitate international brands, and consequently China lacks recognized national brands. The exception to this trend may be welding robots.
>
> **"Heavy on following and light on innovation."** Chinese companies are not innovating new designs and applications, and consequently are lacking on intellectual property.
>
> **"Heavy on prototypes and light on markets."** Chinese entities are proficient at producing prototypes of equipment but not competitive for mass production of indigenous products.
>
> **"Heavy on equipment and light on talent."** Chinese robotics research institutes and companies lack elite talent.

The following are more detailed descriptions and assessments of challenges that hinder China's robotics industry. While the list focuses on industrial robotics, some issues (such as dependence on foreign imports for key components) are prevalent in China's service robotics industry as well.

Lack of Elite Talent

China has not cultivated local expertise and does not have sufficient educational opportunities for its robotics industry. Chinese researchers consider the U.S. educational system to be adapting more quickly to the needs of the growing robotics industry.[87] They claim that since 2013, opportunities and training for robotics experts have been growing in the United States, and the number of undergraduate, graduate, and PhD holders is expected to double before 2030.[88] A major problem for China will be how its education system can adapt and respond to the market demand for AI and robotics experts. In addition to subject matter expertise, these researchers argue China's robotics industry lacks personnel for management, operations, and sales, though it is unclear why this industry in particular lacks such talent in China.

Lack of Balance between Basic and Applied Research

China's investment in robotics research has emphasized basic research at the expense of applied research. Basic research includes robotic arms and controllers that could be used in various

[84] Zhao, "Development and Challenge of Chinese Industrial Robot," 28.
[85] Cai and Guo, "Development and Basic Problems of China's Industrial Robotics Development," 10; Sun Yingfei 孙英飞 and Luo Aihua 罗爱华, "我国工业机器人发展研究" (Development Research on China's Industrial Robot), *Science Technology and Engineering* 科学技术与工程 12, no. 12 (April 2012): 2915.
[86] Cai, "Robotics in China Daring [sic] the Past 40 Years," 26.
[87] Ibid., 28; Zhang and Cui, "Current Development Situation and Future Development Strategy of China's Industrial Robotics Development," 129.
[88] Ibid. No authoritative statistics could be located to corroborate this claim.

industries and designs, while applied research would focus on components and functions specific to the end-user and industry. To illustrate the disparity, one analysis claims that China has numerous entities for basic research for general machine designs, but has fewer institutes for research on key components, likely including high-precision reduction drives, servo (small electric motor) electrical machinery, and controllers (discussed below). Consequently, China's industrial robotics R&D base lacks breakthroughs in key core technologies and is not competitive. One symptom of this larger problem is the small number of Chinese industrial robots and key components with their own IPR.[89]

Poor Quality of Domestically Produced Systems

According to some analyses, a lack of quality in China's robotics and fierce competition among producers curtail growth in the industry. Because many firms lag behind global standards, the reliability of nationally produced industrial robots is lower than those from international competitors. Specifically, Chinese companies have had difficulties producing precise, fast, and efficient key components.[90] Poor quality or precision for components can reduce the service life of robotics systems and make higher quality foreign brands more attractive.

Intense Competition among Chinese Companies

According to one criticism, China has too many manufacturing parks that fiercely compete and do not coordinate efforts. This competition leads them to blindly manufacture and import robotics, in contrast to the successful robotics industries in other countries, where there are only a couple of leading entities for robotics, instead of many.[91] According to CRIA, China has built or started construction on 40 new robot industrial parks since 2014.[92] The problem, according to some commentators, is failing to encourage the rapidly increasing number of companies to identify market niches and not blindly compete over the same robot types or industries.[93]

Chinese Consumers Not Using Robots Made in China

The quality of many Chinese robotics manufacturing brands is considered low enough that Chinese companies investing in automation continue to prefer imported robots. For example, while the automobile industry has been a major impetus for China's industrial robotics industry, as of 2012, Chinese analysts write that the industry still widely preferred leading foreign brands such as ABB and FANAC, which hinders the development of domestic brands. Over the past 10 years, the cost of imported robots has drastically declined, making Chinese firms unable to compete with imported basic robots.[94]

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[89] Cai, "Robotics in China Daring [sic] the Past 40 Years," 26.
[90] Ibid.
[91] Ibid., 27.
[92] Mandy Zuo, "China's Robot Industry 'Plagued by Low Quality, Overinvestment and Too Much Duplication'," *South China Morning Post*, June 17, 2016, accessed August 29, 2016, http://www.scmp.com/news/china/economy/article/1976825/chinas-robot-industry-plagued-low-quality-overinvestment-and-too.
[93] Ibid.,"工信部副部长辛国斌：机器人已有投资过剩隐忧" [MIIT Vice Minister Xin Guobin: Worries that Robotics Already Has Surplus Investment], *Sina* 新浪, June 16, 2016, accessed August 29 2016, http://finance.sina.com.cn/china/gncj/2016-06-16/doc-ifxtfrrc3709815.shtml.
[94] Cai, "Robotics in China Daring [sic] the Past 40 Years," 26; Zhao, "Development and Challenge of Chinese Industrial Robot," 28; and Sun, Wang, and Zhang, "On the Development Status and Tendency of Industrial Robots," 62.

Dependency on Imports for Key Components and Technologies

Despite advancements in industrial robotics, China lags in core technologies such as high-precision reduction drives, servo (small electric motor) electrical machinery, controllers, and other key components. China still primarily relies on imported industrial robots and these key components from Japan, Sweden, Germany, Italy, and the United States; the primary companies include FANUC, YASKAWA, ABB, COMAU, KUKA, and Staubli.[95] Until 2014, foreign suppliers, namely European companies, supplied China with over 70 percent of its industrial robots.[96] Some argue that basic research receives the most support, while insufficient support for research on key components leaves them in the experimental stage.[97] Consequently, Chinese industrial robotics companies rely too heavily on foreign imports, especially in high-precision manufacturing. For example, by 2012 the Chinese automobile manufacturer Chery had designed its own robots, but it still needed to import a more advanced Japanese reduction drive.[98]

In addition to components for industrial robots, China also lags in key technologies for controlling them. Notably, China remains behind international standards in programmable logic controller (PLC) and changing frequency controls products.[99] Other technology areas considered to be behind international standards include multiple sensor information fusion control technology, remote control plus local autonomous system remote control robots, intelligent assembly robots, and robotized machinery.[100]

Chinese Robotics Software Development

Chinese military researchers have led the country's development of robotics software, leveraging open source software and demonstrating the inherent dual-use nature of this technology. The country's initial efforts at robotics software started in 1994 under the 863 Program to support the development of robotic reconnaissance capabilities.[101] This program funded efforts at Tsinghua University, Dongnan University, Harbin Institute of Technology, CAS SIA, and CAS Hefei Intelligence Institute. In 1996, efforts expanded to the General Staff Department's Beijing Defense Research Institute, supported by a National Defense Pre-Research Fund, and later to Shanghai Jiaotong University and Beihang University.[102]

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[95] Chen Shaofei 陈韶飞, "我国工业机器人发展问题分析及对策研究" [Analysis and Recommendations Research on Problems with China's Industrial Robotics Development], *Technology Innovation* 科技创新, no. 31 (2015): 81; Rui and Liu, "Development and Trends of China's Industrial Robotics," 21; Sun, Wang, and Zhang, "On the Development Status and Tendency of Industrial Robots," 62; and Zhao, "Development and Challenge of Chinese Industrial Robot," 29.

[96] Zuo, "China's Robot Industry 'Plagued by Low Quality, Overinvestment and Too Much Duplication'," *South China Morning Post*, June 17, 2016; "MIIT Vice Minister Xin Guobin: Worries that Robotics Already Has Surplus Investment], *Sina* 新浪, June 16, 2016.; "Industrial Robot Statistics," International Federation of Robotics, accessed June 21, 2016, http://www.ifr.org/industrial-robots/statistics/.

[97] Cai, "Robotics in China Daring [sic] the Past 40 Years," 25; Zhao, "Development and Challenge of Chinese Industrial Robot," 29.

[98] Zhang and Cui, "Current Development Situation and Future Development Strategy of China's Industrial Robotics Development," 129; Sun and Luo, "Development Research on China's Industrial Robot," 2916.

[99] Rui and Liu, "Development and Trends of China's Industrial Robotics," 21.

[100] Cai and Guo, "Development and Basic Problems of China's Industrial Robotics Development," 10-11.

[101] Cao Xiaosong 曹小松, "危险品探测移动机器人平台的研制" [Research and Development of Hazardous Material Probing Mobile Robotic Platforms], master's thesis submitted to Yangzhou University on April 1, 2009, 7-8, accessed September 30, 2016, http://wk.baidu.com/view/1b8fc4f34693daef5ef73d20?pcf=2#1.

[102] Ibid.

To develop "indigenous" dual-use military and civilian software for robotics, the National University of Defense Technology (NUDT) often modifies open source software. Previously, NUDT researchers modified the open source computer operating system FreeBSD, developed at the University of California at Berkeley, and named it Kylin. In the area of robotics, NUDT is leveraging the open source software Robotics Operating System (ROS), developed by the U.S. Open Source Robotics Foundation. NUDT professor Xiao Junhao (肖军浩) teaches this operating system to students and hosts a translated developers guide on the NUDT official website.[103]

The PLA also provides funding to civilian academics to develop robotics software, further demonstrating the dual-use nature of these technologies. The PLA General Staff Department funded the Nanjing University of Science and Technology's Cai Yunfei (蔡云飞), who served as chief engineer on a GSD robotics software project ("总参 xxx 型号机器人软件总师").[104] A 2016 NUDT forum on the development of robotics and AI software included experts from both civilian and military robotics circles. One such expert, Xu Ying (许莹), participates in projects for the Engineering and Physical Sciences Research Council of the United Kingdom, while also working on what she describes as "GSD military industry projects" (总参军工项目) and 863 Program projects.[105]

Impact on Chinese and Global Labor Markets

There is not yet a consensus among analysts regarding the expected impact of increases in China's use of industrial and service robots on the Chinese and global labor markets. Optimistic voices argue that robotic automation will compensate for changing worker job expectations driven by improving education levels, raising average living standards, making Chinese manufacturers more competitive, enhancing China's position within the global manufacturing industry, and providing necessary support for China's aging population.[106]

Supporters of the optimistic viewpoint tend to focus on the demand-side factors that encourage Chinese manufacturing and service businesses to improve their automation capabilities through the use of robotics. China's push for industrial automation is arguably a natural response to higher employee wages and education levels that have come as a result of the country's economic development. An October 2015 report by analysts at Credit Suisse, for example, notes that "[Workers'] education has improved significantly from those of their fathers or older brothers.

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[103] VolodjaNiu [username], "Subject: 机器人操作系统(ROS)浅析--我校肖军浩博士新书免费下载" [Subject: Introduction to Robotics Operation System (ROS)—Free Download from Our School's Dr. Xiao Junhao], discussion forum on NUDT's website, October 9, 2015, accessed September 30, 2016, http://micros.nudt.edu.cn/ros/forums/3/memos/425.

[104] "蔡云飞" [Cai Yunfei], profile on website of the School of Computer Science and Engineering at Nanjing University of Science and Technology, September 2, 2013, accessed September 30, 2016, http://cs.njust.edu.cn/_s62/25/7c/c1734a9596/page.psp.

[105] "CCF YOCSEF 长沙将举办"AlphaGo 对 IT 产业的影响"专题报告会与 Club" [CCF YOCSEF Changsha Will Host a Special Topic Lecture and Club on "The Influence of AlphaGo on the IT Industry], accessed September 30, 2016, http://www.yocsef.org.cn/sites/yocweb/changsha.jsp?contentId=2921522701877.

[106] Vincent Chan, et al, "Young China," Credit Suisse Securities Research & Analytics, Asia Pacific/China Equity Research," October 28, 2015, accessed June 21, 2016, https://doc.research-and-analytics.csfb.com/docView?sourceid=em&document_id=x664312&serialid=3g3x0rbHmtcamHop4hXBySkZeWPAws2edmUg8RKDmiw%3d.

Therefore, it will be increasingly difficult to find enough labor for jobs that are exposed to high temperatures, danger and a poisonous environment, and such vacancies will naturally need to be replaced by robots and automation systems."[107] Liu Yunhui, a professor of mechanical and automation engineering at the Chinese University of Hong Kong, similarly observes, "In the Pearl Delta area such as Zhejiang and Jiangsu, it's very hard to find workers."[108] Leading policy guidelines and plans such as Made in China 2025 also claim benefits of increased quality and capabilities to manufacture high-end items.[109]

Other analysts note that it can be challenging for Chinese companies to manage blue collar employees because of low loyalty and retention rates. By one estimate, some factories experience turnover rates of up to 80 percent following the annual Chinese Lunar New Year holidays, when workers who return home elect not to return to their previous employers. This pattern diminishes production efficiency, introduces scheduling uncertainties, and raises costs associated with hiring and training new staff.[110] All of these problems could theoretically be addressed by replacing or supporting more workers with robot systems.

Conversely, pessimists fear that adding robots in the manufacturing and service sectors will diminish opportunities for blue collar jobs and will lead to widespread unemployment. In late May 2016, for example, the *South China Morning Post* reported that Taiwanese component manufacturer Foxconn had laid off 60,000 employees in Kunlun (a mainland China manufacturing city in Jiangsu province) and replaced them with industrial robots.[111] Xu Yulian, a public relations official for Kunlun, added that additional companies are expected to follow suit.[112] The cuts amounted to only a small fraction of Foxconn's remaining 1.2 million employees, and a Foxconn official stated that the company plans to maintain a significant workforce in China. However, the story was widely reported by domestic and international media, reflecting keen public interest and concern. In June 2016, the *New York Times* reported that the Chinese government had updated its censorship lists applied to online media platforms (such as Tencent's WeChat mobile messaging app) to ban discussions of rumors regarding robots taking over industries and displacing workers.[113]

Opportunities and Challenges for U.S. Industrial Robot Exporters

The U.S. market share of industrial robots in China is much smaller in comparison to European and Asian exporters, but there appear to be opportunities for innovation in components and

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[107] Ibid.
[108] Lucinda Shen, "This is the Future of China," Business Insider Finance, November 16, 2015, accessed June 21, 2016, http://www.businessinsider.com/robotics-in-china-2015-11.
[109] "国务院关于印发《中国制造 2025》的通知" [State Council Releases 'Made in China 2025' Announcement], May 8, 2015, accessed July 11, 2016, http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm.
[110] Ibid.
[111] Mandy Zuo, "Rise of the Robots: 60,000 Workers Culled from Just One Factory as China's Struggling Electronics Hub Turns to Artificial Intelligence," *South China Morning Post*, May 21, 2016, accessed July 7, 2016, http://www.scmp.com/news/china/economy/article/1949918/rise-robots-60000-workers-culled-just-one-factory-chinas.
[112] Jane Wakefield, "Foxconn Replaces '60,000 Workers with Robots,'" *BBC News*, May 25, 2016, accessed July 7, 2016, http://www.bbc.com/news/technology-36376966.
[113] Javier C. Hernandez, "China Censors WeChat Rumors, Including the One About Robots Taking Over," *The New York Times*, June 24, 2016, accessed July 7, 2016, http://www.nytimes.com/2016/06/25/world/what-in-the-world/china-wechat-censor-rumors.html?_r=0.

applications. According to an analysis of Chinese trade data, in 2015 the leading countries of origin for China's industrial robots were Japan (78.36%), Germany (5.38%), South Korea (3.77%), and Sweden (2.79%), leaving the United States with a negligible share of the market.[114] Despite the small percentage of market share, data from the International Trade Administration (ITA) of the U.S. Department of Commerce shows that since 2011 China has been the third- or fourth-largest market for U.S. exports of multi-purpose industrial robots.[115] Exports to Mexico and Canada are consistently between two and four times as large, while China and Germany alternate as the third- and fourth-largest export destinations.[116]

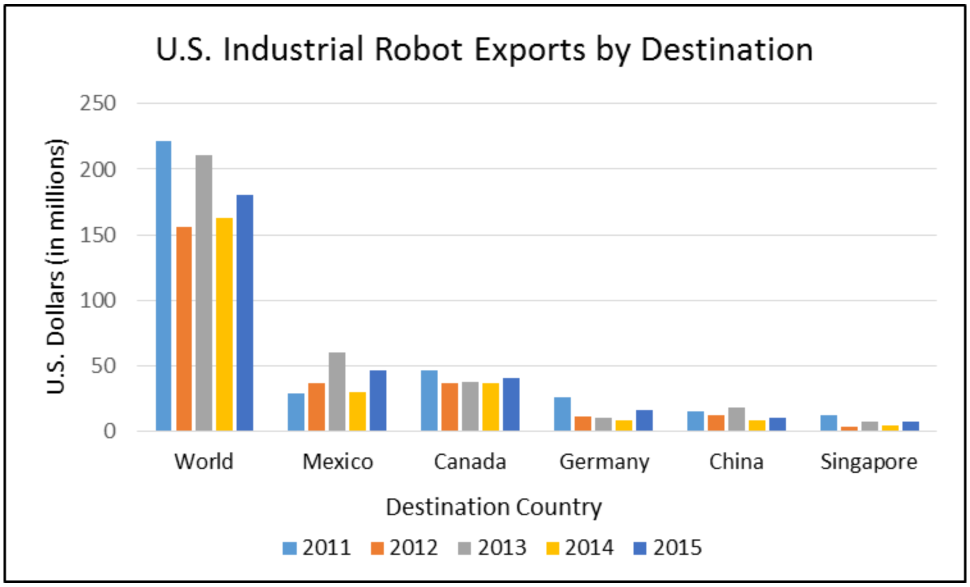

Figure 1: U.S. Industrial Robot Exports by Destination, Amount, and Year. Source: International Trade Administration, U.S. Department of Commerce.

According to a trade memo from the U.S. International Trade Commission (USITC) in 2014, the United States itself sources its own industrial robots from imports and from foreign producers operating in country.[117] Commercial leaders of the industrial robotics industry are predominantly based in Europe and Japan. Major foreign suppliers with U.S. plants and subsidiaries include Japanese firms Fanuc, Kawasaki, and Yaskawa-Motoman; the German company Kuka; and Switzerland's ABB and Stäubli. Similar to their operations in China, these companies are investing in the United States to maintain a closer presence to their customer bases.

Instead of completed robots, half of the value of U.S. exports and 26 percent of U.S. imports of industrial robots are parts.[118] These numbers indicate that the United States is not a significant

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[114] "深度: 从进出口数据看我国工业机器人发展情况" [In Depth: Looking at the Development Situation of China's Industrial Robots from Import Export Data], 高工机器人 GG Robot, June 22, 2016, accessed September 30, 2016, http://gg-robot.com/asdisp2-65b095fb-57048-.html.
[115] Trade data from TradeStats Express, hosted by the International Trade Administration of the U.S. Department of Commerce, http://www.tse.export.gov, accessed October 2, 2016.
[116] Additional research may parse the numbers of U.S. exports to China by company, company ownership (U.S. company or multinational), application, and fully assembled robot versus components.
[117] Michael Stanton-Geddes and Dennis Fravel, "U.S. Manufacturing Companies Are Global Leaders in Industrial Robot Consumption," USITC Executive Briefing on Trade, May 2014.
[118] Ibid.

producer of completed industrial robots for the global market, including China, but rather a part of global supply chains for the industry. While it is unclear what parts are included in this analysis, China's dependence upon imports for advanced components could present an opportunity for U.S. exporters.

The United States can also be a leader in finding new applications for industrial robots, as well as in innovating how operators use them. For example, SoftWear Automation Inc., an Atlanta-based robotics startup, has developed robots that can sew garments, the first of their kind.[119] Rethink Robotics, whose founder helped produce the iconic Roomba at iRobot, introduced Baxter in 2012 to create a new category of automation called collaborative robotics.[120] While European and Asian manufacturers are established leaders and were the first to commercialize traditional industrial robots, U.S. innovations may be the first of their kind and generate interest in international markets, including China.

In an industry analysis report in April 2016, ITA identified market access and content localization as two barriers that may affect U.S. exports of industrial automation equipment, including robots, to China.[121] ITA regularly engages with trade partners, including China, to lower tariffs and make U.S. products more competitive. The ITA also monitors all calls for content localization, such as Made in China 2025, to assess for their effects on U.S. exports.

Leading Industrial Robot Companies and R&D Entities

Based on market analyses, state plans, and corporate information, the following entities are considered the most influential for China's industrial robotics industry. Leading entities receive longer introductions and analysis below, while all other important identified entities are included in Appendix I: Leading Industrial and Service Robotics Manufacturers, Research Institutes, and Professional Associations in China.

Siasun (沈阳新松机器人自动化股份有限公司)

Shenyang Siasun is a market-listed high technology company administratively subordinate to the CAS. The company specializes in robotics technology, particularly digital smart manufacturing equipment. It advertises one of the world's most complete robot product lines and claims to be China's largest robot industrialization base. It operates campuses in Shenyang, Hangzhou, and Qingdao, subsidiaries in Beijing and Shenzhen, and an international headquarters in Shanghai. The company currently has more than 1,600 personnel in its research teams, and claims to be the world's third largest company by total market value in its industry.[122]

Siasun was established on the basis of work performed at the CAS Shenyang Automation Research Institute. It currently operates under a "one core, two wings, three feet" development model, where the CAS is the core, the company's industrial bases in Hangzhou and Shenyang are its wings, and three major research centers in Beijing, Guangzhou, and Shenzhen are the feet. Currently Siasun's

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[119] James Hagerty, "Meet the New Generation of Robots for Manufacturing," *The Wall Street Journal*, June 2, 2015.
[120] "About," Rethink Robotics, accessed September 30, 2016, http://www.rethinkrobotics.com/about/.
[121] Andrew Moyseowicz, "2016 Top Markets Report Industrial Automation: A Market Assessment Tool for U.S. Exporters," International Trade Administration, April 2016, 10.
[122] "企业介绍" [Introduction to the Company], Siasun 新松, accessed May 10, 2016, http://www.siasun.com/about/Introduction.htm.

chairman and president are affiliated with the CAS Shenyang Automation Research Institute.[123] The intertwined history and corporate leadership strongly suggest that the private enterprise's objectives are also in line with state-directed policies and programs.

The company's four main business groups focus on robot components, robot product series, industrial systems solutions, and "Industry 4.0." Robot product lines include industrial robots, mobile robots, cleaning robots, specialty robots, and service robots, and the company offers a total of more than 80 types of robot products. Among these, industrial robot performance is said to have reached international standards, and the company claims to be China's only product and solution provider for cleaning and maintenance robots, having made headway in a market long dominated by foreign products from Japan, Korea, and Europe. Siasun's mobile robots reportedly hold a market share of greater than 90 percent within China's automotive and electrical power markets and they have been mass-produced for export abroad. Service robots are said to be a major point of growth for the company. Two-thirds of the company's customers are foreign-invested enterprises in China.[124]

Siasun was named one of General Motor's suppliers in 2007, which greatly increased the company's international sales. Ha Enjing, Siasun's director of global branding, said that the GM deal "radically changed China's domestic robot industry, which until then had only imported robots and not exported them."[125] The company has supplied automated guided vehicles to Shanghai General Motors and exported 42 automated guided vehicle robots to GM's U.S. headquarters in 2010.[126]

The Siasun website provides an extensive catalog of the company's robotics and smart manufacturing products. Robotics products include industrial robots, parallel robots, room cleaning robots, automated guide vehicles, smart service robots, and mechanical processing automation systems. Smart manufacturing products include smart logistics, automated assembly and testing production line, laser equipment, energy saving and environmental protection equipment, rail and transport systems, and energy industry equipment.[127]

Harbin Boshi Automation (哈尔滨博实自动化设备有限责任公司)

Harbin Boshi Automation's products are used in petroleum, chemical, fertilizer, salt chemical engineering, coal chemical engineering, metallurgical, port logistics, precise chemical engineering, food product, and animal feed product industries.[128] It develops robots for oil

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[123] "Brand Story," Siasun 新松, accessed May 26, 2016, http://www.hzsiasun.com/en/brand.php.
[124] "企业介绍" [Company Introduction], Siasun 新松, accessed May 10, 2016, http://www.siasun.com/about/Introduction.html.
[125] Liu Ce, "Innovation Brings Rewards for Siasun," *China Daily*, April 7, 2015, accessed May 26, 2016, http://usa.chinadaily.com.cn/epaper/2015-04/07/content_20016379.htm.
[126] "China's Siasun Expands to Seize More of The Domestic Market," robotics business review, October 8, 2012, accessed May 26, 2016, http://www.roboticsbusinessreview.com/article/chinas_siasun_expands_to_seize_more_of_the_domestic_market/China. More recent statistics could not be located.
[127] "企业介绍" [Company Introduction], SIASUN 新松, accessed May 10, 2016, http://www.siasun.com/about/Introduction.html.
[128] "博实" (Boshi), accessed May 11, 2016, http://www.boshi.cn/.

exploration and extraction and has been expanding into the agricultural automation and 3D printing fields. The company was established in September 1997 with Harbin Institute of Technology (a leading Chinese engineering university) as its main shareholder. In addition to its headquarters in Harbin, the company operates branches in Beijing, Shanghai, Shandong, Lanzhou, and Xinjiang.[129]

Harbin Boshi Automation is a major provider of Chinese-made equipment for the Chinese oil industry. It is a tier-one supplier enterprise to Sinopec and its products are used by other major Chinese oil companies. Its offerings range from single products and systems products to full sets of equipment. Its products have also been exported to Hong Kong, Macau, Taiwan, and ten countries including Russia, Kazakhstan, and Thailand.[130]

Harbin Boshi Automation was listed at No. 34 on the Forbes China's Top 100 Publicly Traded Small Businesses for 2014.[131] China International Capital Corporation estimated in 2014 that Boshi's revenues would rise by 39.7 percent to RMB 1.07 billion (USD 160.49 million) by 2015.[132] Boshi's products have been sold within China as well as internationally to customers in more than 10 countries in Europe, Asia, and Africa.[133]

Beijing Research Institute of Automation for Machinery Industry (北京机械工业自动化所)

The Beijing Research Institute of Automation for Machinery Industry (the Beijing Automation Institute) was established in 1954 as a comprehensive research institution under the former Ministry of Machine Industry. It was reorganized in 1999 and is now a large science and technology enterprise under the State Council's State-owned Assets Supervision and Administration Commission (SASAC).[134]

The Beijing Automation Institute has made a number of notable contributions to the development of China's engineering technologies. It produced China's first hydraulic servomotor painting robot, stereoscopic warehouse, high power electric direct linear accelerator, indigenously developed RMP II software, MIC series of programmable controllers, and other high technology products. It has completed more than 500 official research achievements and thousands of national key projects and custom equipment engineering projects for business customers. It performed ground simulation vibration testing for China's first manmade Earth satellite and it was involved in the Three Gorges Dam project. It developed smart electrical transformer systems for the T3 terminal

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[129] "Harbin Boshi Automation Equipment Co., Ltd." Global Companies, accessed May 26, 2016, http://www.companiess.com/harbin_boshi_automation_equipment_co_ltd_info1841828.html.

[130] "博实：机器人及智能装备'排头兵'" [BOSHI: Robots and Intelligent Equipment 'Frontline Troops'], Boshi 博实, accessed June 3, 2016, http://www.boshi.cn/News_More.aspx?ID=1514.

[131] Russell Flannery, "Forbes China's Top 100 Publicly Traded Small Businesses for 2014 (Full List)," *Forbes*, January 7, 2014, accessed August 31, 2016, http://www.forbes.com/sites/russellflannery/2014/01/07/forbes-chinas-top-100-publicly-traded-small-businesses-for-2014-full-list/#50687f9217a2.

[132] Yue Wang, "China Automation Companies Advance as Beijing Pledges New Policy Support," Forbes, November 3, 2014, accessed May 26, 2016, http://www.forbes.com/sites/ywang/2014/11/03/china-automation-companies-advance-as-beijing-pledges-new-policy-support/#1cd7ceeb7854.

[133] "博实：机器人及智能装备'排头兵'" [BOSHI: Robots and Intelligent Equipment 'Frontline Troops'], Boshi 博实, accessed June 3, 2016, http://www.boshi.cn/News_More.aspx?ID=1514.

[134] "北京机械工业自动化所简介" [Introduction to the Beijing Research Institute of Automation for Machinery Industry], Beijing Research Institute of Automation for Machinery Industry, accessed May 12, 2016, http://www.riamb.ac.cn/html/Page/101/101.html.

at Beijing Capital Airport as well as China's first robot painting production line. It produced what was at the time the world's largest glass fiber production line. It also developed a flexible, automated production line for automotive engines that reached international standards.[135]

The company's website indicates that the company has developed welding robots, cutting robots, coating robots, handling robots, palletizing robots, assembly robots, smart robots, and specialized robots of many types. It has created robotic production lines for businesses in many industries including the automotive, machinery, home appliance, metallurgy, aerospace, defense, and biotechnology industries.[136]

Shougang Motoman Robot Co. Ltd. (首钢莫托曼机器人有限公司)

Shougang Motoman Robot Co., Ltd. is a joint venture between China-based Shougang Group (中国首钢（集团）总公司), Japan-based Yaskawa, and Japan-based Iwatani Co. (岩谷产业株式会社) set up in Beijing's Economic and Technology Development Zone as China's first company specializing in production robot products. It has USD 7 million in registered capital and is currently one of China's largest and most advanced robot production enterprises, capable of manufacturing 800 robots and systems annually.[137] Shougang Motoman mainly engages in technology development, production, and sales of robots, robotic workstations, and large-scale robotic automated systems for welding, assembly, painting, handling, cutting and grinding operations used in the automotive, motorcycle, engineering machinery, chemical engineering, home appliance, and construction industries. It also provides peripheral equipment and components and technology services for its customers.[138]

Shougang Motoman makes industrial robots in China to service the national market and establishes its own technology standards. The "SG-MOTOMAN" robot products incorporate the latest SK-series robot technologies from Yaskawa and are identical to international-grade Yaskawa Motoman robot products in function and quality.[139] The company's SG-MOTOMAN-SK series of industrial robots, including the SK120, SK16, and SK6, are used for arc welding, point welding, transport, painting, and assembly applications.[140]

China Robot Industry Alliance (中国机器人产业联盟)

The China Robot Industry Alliance (CRIA) is a nonprofit national industry association for China's robotics industry, including educational and research institutions as members as well as robotics users and other interested parties. The alliance was formed in April 2013 and now has 152 member organizations. The CRIA's secretariat is set up at the China Machinery Industry Federation, and the CRIA also uses the CMIF as its headquarters.[141]

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[135] Ibid.
[136] Ibid.
[137] "Shougang Motoman Robot Co. Ltd." [首钢莫托曼机器人有限公司], accessed May 16, 2016, http://etc.gdut.edu.cn/source/amt/PART3/sg-motoman/.
[138] Ibid.
[139] Ibid.
[140] "机器产品" [Robotic Products], Shougang Motoman Robot Co. Ltd, accessed May 16, 2016, http://etc.gdut.edu.cn/source/amt/PART3/sg-motoman/product2.htm.
[141] "联盟简介" [Alliance Introduction], China Robot Industry Alliance 中国机器人产业联盟, accessed May 23, 2016, http://cria.mei.net.cn/gylm.asp.

The CRIA follows both national industrial policies and market trends and seeks to upgrade the research and development, production and manufacturing, integrated application, and maintenance service levels of its members. It seeks to expand the application of robotics technology in all fields and to improve national robotics industry chains. It endeavors to promote the healthy development of China's robotics industry and enhance its competitiveness.[142]

The Alliance's main objective is to carry out national industrial policy; promote exchange among its members in terms of technology, markets, and intellectual property; encourage partnerships between research, industry, and academia; promote industry self-governance; and coordinate to avoid overlap within the industry. It develops and sets up platforms for robot industry information exchange, application promotion, educational training, and exhibitions to promote the effective use of resources. It works to encourage partnerships between the robotics industry and other Chinese industries and to accelerate the popularization of robot technology and products.[143]

[142] Ibid.
[143] Ibid.

Chapter Two: Service Robots in China

The International Robotics Federation (IRF) defines service robots as partially- or wholly-autonomous robotic devices that assist people with completing tasks other than production and manufacturing. Service robots are generally divided further into professional service and domestic use categories. Professional service robots complete work in particular work settings and include, for example, nuclear power plant inspection and emergency response robots, deep sea and space exploration robots, counterterrorism and counter-explosion robots, military robots and unmanned autonomous vehicles, and search and rescue robots. Domestic service robots assist people with tasks related to life and home management. Examples include elder and handicapped caretaker robots, medical rehabilitation robots, cleaning robots, nursing robots, surgery robots, and entertainment and education interactive robots.[144]

Within China, the service robot sector has grown rapidly over the past ten years. While sector-specific data is not available due in part to the sector's broad definition and the expanding inclusion of new applications, Chinese officials have indicated that they expect the sector to continue to grow and become more prominent within the overall robotics industry in the future. China's aging population is expected to increase demand for service robots as the number of elderly dependents within China increases. Improving living standards are also increasing demand for service robots, which can offer comparatively inexpensive domestic services and serve as a status symbol for members of the growing middle class.[145] New service robot applications are also driven by technology "push" factors, such as the advent of improved AI and cloud computing technologies that greatly enhance service robot sophistication and their ability to act independently. Smart autonomous vehicles, logistics systems, and medical service robots are expected to continue to improve due to these advances.

The key findings of this chapter are as follows:

- Chinese companies and research institutes are actively developing and marketing service robots for a broad variety of applications essentially spanning the entire service robot sector. The service robot sector appears to be growing more rapidly than other robotics industry sectors.
- Chinese Internet and information technology firms such as Baidu, Alibaba Group, JD.com, Lenovo, and LeEco play a relatively important role in the service robot industry compared to the industrial robot industry due to their AI, cloud computing, and big data resources. Due to the comparative newness of service robot technologies that combine information technologies with robotic hardware, there is significant innovation within the sector.
- Chinese UAV manufacturers are at or near international standards for industrial, commercial, and recreational consumer drone systems. Note that this finding does not express an assessment of Chinese military UAV technology or its competitiveness with U.S. systems, which are addressed in a separate section of this report.

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144 "《服务机器人科技发展"十二五"专项规划》解读" [Explanation of Service Robot Technology Development Twelfth Five Year Plan Special Program], China Robot Industry Alliance Web 中国机器人产业联盟网, May 7, 2012, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=1550.

145 Melanie Ehrenkranz, "This Rich Chinese Guy Traveling with 8 Robot Maids is Redefining Luxury," *Tech.Mic*, April 20, 2016, accessed July 7, 2016, https://mic.com/articles/141369/this-rich-chinese-guy-traveling-with-8-robot-maids-is-redefining-luxury.

- Other focal points of Chinese service robot development include public security, medical and rehabilitation, and educational and personal assistant robots.

Policy Guidance Specific to the Service Robot Sector

Chinese service robots have attracted attention recently as increasingly intelligent automated devices have entered the market with greater frequency and as Chinese-made service robots enter higher profile applications. Recent gains have not occurred spontaneously, however, and a review of Chinese science and technology policies shows that service robots have been a focus of government-sponsored research and development efforts for at least the past decade. Looking ahead, the Thirteenth FYP (2016-2020) briefly mentions service robots, while the Guideline on Promoting the Development of the Industrial Robot Industry sets ambitious targets for the industry. China's National Medium- to Long-Term Science and Technology Development Plan (2006-2020) includes service robots specifically as a focal point of development, calling for China to , "…focus on service robot application requirements [and] research common basic technologies including design methods, manufacturing techniques, and smart manufacturing and application systems."[146]

Services robots were the focus of a special development program (《服务机器人科技发展"十二五"专项规划》) put forward by China's Ministry of Science and Technology (MOST) during the Twelfth FYP period, which ran from 2011 through 2015. A MOST document explaining the program noted that Chinese developers made advances in service robot technology during the Eleventh FYP (2006-2010), such as achievements related to public security robots, bio-mimetic robots, and medical and rehabilitation robots. For example, Chinese security officials used counterterrorism robots (such as ordnance disposal robots) for the Beijing 2008 Olympic Games and the 2010 Asia Games, and firefighters used fire-fighting and disaster relief robots in more than 20 provinces throughout China. Medical and surgery robots entered clinic use, and "smart pill" ingestible robots entered mass production.[147] MOST said that during the Twelfth FYP, research efforts would focus on public security robots, bio-mimetic robots, medical and healthcare robots, and component modularization. In terms of public security robots, priority projects included robots for public safety, resource protection, and emergency rescue. Military-civilian dual-use robot systems were also listed in the development program, with "large, high-speed, all-terrain mobile robot platforms," "large, variable structure, sea and aircraft platforms," and "nuclear, biological, and chemical defense and operations robot platforms" included within this category.[148]

Looking toward 2020, the Thirteenth FYP mentions service robots, but the Guideline on Promoting the Development of the Industrial Robot Industry treats the industry in greater detail. The Guideline notes the growing applications of service robots in various spheres and sets development

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[146] "国家中长期科学和技术发展规划纲要 (2006-2020)" [National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020)], State Council of the People's Republic of China, accessed July 7, 2016, http://www.gov.cn/jrzg/2006-02/09/content_183787.htm.

[147] "《服务机器人科技发展"十二五"专项规划》解读" [Explanation of Service Robot Technology Development Twelfth Five Year Plan Special Program], Ministry of Science and Technology of the PRC, accessed June 25, 2016, http://www.most.gov.cn/kjzc/zdkjzcjd/201205/t20120504_94140.htm.

[148] "服务机器人科技发展"十二五"专项规划" [Service Robot Technology Development Twelfth Five Year Plan Special Program], China Robot Industry Alliance Web 中国机器人产业联盟网, July 29, 2013, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3&f=2.

targets for China's indigenous industry. By 2020, China aims to sell over RMB 30 million (USD 4.5 million) worth of service robots annually and to achieve small-scale production of service robots for elderly and disabled care as well as healthcare applications. It also calls for China's service robots to achieve international standards in the industries of healthcare, home service, counterterrorism and ordnance disposal, disaster relief and rescue, and scientific research.

Service Robot Economic Trends

Due in part to the wide range of applications for service robots and the broader array of organizations involved in their development and sales, statistics regarding sales and production trends for service robots are harder to determine compared to the industrial robot industry. At an April 2016 press conference for MIIT's release of its Robot Industry Development Plan 2016-2020, Song Xiaogang (宋晓刚), the acting director and secretary general of the China Robot Industry Alliance (CRIA), said that specific data has not yet been compiled regarding the Chinese service robot sector. Song instead pointed out that global industrial robot sales reached approximately USD 10.7 billion in 2014 and that global service robot sales in 2014 were USD 6 billion, and said that the ratio within Chinese industry was likely approximately the same.[149]

Despite the lack of firm figures, evidence points to the growing importance of service robots within the overall Chinese robotics industry and a possible shift in the industry's focal point towards service robots even as the industrial robot sector also grows. In December 2015, for example, CRIA, China's main government-sponsored robotics industry association, formally established a service robot expert committee (服务机器人专业委员会) in order to oversee and promote the healthy development of the service robot sector.[150]

International and Chinese analysts have pointed to China's aging population as a key reason to encourage the domestic service robot industry and why there is strong potential for growth in the Chinese service robot market. CRIA recently cited data showing that China as of 2016 has over 221.82 million citizens aged 60 years old or older, amounting to 16.15 percent of the total population.[151] The CRIA article notes that international standards for whether a country has an "aging society" include a population of 60 years old or older amounting to at least 10 percent of the total population, or a population of 65 years old or older amounting to at least 7 percent of the total population, standards China already meets. These numbers are set to grow. The United Nations predicted in 2015 that 44.5 percent of China's population will be 60 years or older by the year 2050.[152] As China's society ages, the ratio of elderly citizens who must rely on employed

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[149] "《机器人产业发展规划（2016－2020 年）》新闻发布会文字实录" [Record of Press Conference for Robot Industry Development Plan 2016-2020], China Robot Industry Alliance Web 中国机器人产业联盟网, May 11, 2016, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3418.

[150] "中国机器人产业联盟成立服务机器人专业委员会筹备小组" [China Robot Industry Alliance Sets Up Small Group for Service Robot Expert Committee], China Robot Industry Alliance Web 中国机器人产业联盟网, December 10, 2015, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3107.

[151] "质疑和虚火 中国服务机器人不需要" [Doubts and False Fire – Chinese Service Robots Not Needed), China Robot Industry Alliance Web 中国机器人产业联盟网, April 27, 2016, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3369.

[152] United Nations Department of Economic and Social Affairs (Population Division), *World Population Prospects: Key Findings & Advance Tables (2015 Revision)*, ESA/P/WP.241 (2015): 27, accessed August 19, 2016, https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf.

workers for support must increase. Robots are thought capable of addressing this problem by increasing manufacturing productivity (in the case of industrial robots) and by freeing up service personnel from work related directly or indirectly to elder care to engage in more productive endeavors (in the case of service robots).[153]

Another CRIA report notes that as of 2016, China has approximately 60 million handicapped citizens who are either limited in their capabilities or who require nursing care, affecting approximately one in ten Chinese households.[154]

Quality of life improvements brought about by China's developing economy are also leading to increasing demand for service robots. On the one hand, there are reports that fewer employees are willing to perform very low-end menial or difficult tasks now that education levels are increasing and opportunities for other types of work are more apparent. On the other hand, higher living standards, wages, and more leisure time are increasing interest in service robot technologies that can make life more comfortable or entertaining such as robotic vacuum cleaners, intelligent laundry machines, and smart toys.[155]

Educational demands are also cited as a reason for growth in service robot demand. Robots are seen as an entertaining and innovative way of improving education for early, pre-school learners, and educational robotics systems are also considered a way to improve training at research universities.[156]

Other factors contributing to China's interest in service robotics include problems with the environment.[157] Service robots can help identify and clean pollution, reduce amounts of pesticides required for farming, and assist operators in dangerous environments.

Chinese Organizations Involved in Service Robot Research and Development

While the broader Chinese robotics industry still lags behind the United States, Japan, and European countries, the gap within the service robot industry is thought to be comparatively smaller. A CRIA article states that Chinese companies are five to ten years behind international competitors in terms of key components. For reference and benchmarking, CRIA considers global

[153] "三大国内服务机器人需求分析" [Analysis of Three Major Domestic Service Robot Needs], China Robot Industry Alliance Web 中国机器人产业联盟网, March 1, 2016, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3282.
[154] Ibid.
[155] Ibid.
[156] Ibid.
[157] "质疑和虚火 中国服务机器人不需要" [Doubts and False Fire – Chinese Service Robots Not Needed], China Robot Industry Alliance Web 中国机器人产业联盟网, April 27, 2016, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3369.

leaders to be the U.S. companies iRobot and Remotec and German entities German Aerospace Center (DLR) and KUKA.[158]

One advantages U.S. firms have in the services robotics industry is their brand recognition as the original pioneers of products and applications. For example, iRobot receives substantial attention from Chinese media as an innovator for service robots because of its broad scope of products, the use of their products in disasters that garner media attention, and their original applications for these systems. Examples include the global popularity of the Roomba vacuum cleaning robot, U.S. researchers' use of iRobot's unmanned underwater vehicle (UUV) Seaglider to assess the Deep Horizon Oil Spill in 2010, and Japanese rescue workers' deployment of PackBot robots during the Fukushima nuclear disaster in 2011.[159] China is determined to develop its own indigenous brands with the same international brand recognition.

One of China's leading service robot research institutes is the State Key Laboratory of Robotics and System at HIT (profiled in Appendices I and IV), which develops a number of fundamental technologies that can be used throughout China's service robotics industry.[160] Its research directions for service robots include structure design and optimization, propulsion and control methods, and components such as sensors and controllers. The lab is also a leading researcher of technologies for human-machine interaction, and remote and network controls.[161]

Leading manufacturers of China's service robots include Shenyang Siasun, one of China's most established robotics companies (profiled in Chapter One as an industrial robotics leader and in Appendix I). Siasun released one of its leading products in 2012, an unmanned helicopter that can carry out aerial inspections of powerlines under difficult conditions such as thunderstorms, heavy rain, or heavy electro-magnetic interference. The unit weighs 120 kg (264.56 lbs), has a rotor diameter of 3.29 m (10.79 ft) and a maximum speed of 100 km/hour (62.14 miles/hour). Siasun developed the system in response to a series of winter storms that resulted in large-scale power outages throughout China in 2008.[162]

In addition to traditional robotics industry firms and research institutions, Chinese Internet and information technology enterprises are increasingly active in the service robot sector. Large Internet companies such as Baidu, Alibaba Group, JD.com, Lenovo, and LeEco are all investing in robotics startups or internal projects spanning a full spectrum of service robot applications. These firms have advantages in terms of AI, cloud computing, and big data resources that give

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[158] "三大国内服务机器人需求分析" [Analysis of Three Major Domestic Service Robot Needs], China Robot Industry Alliance Web 中国机器人产业联盟网, March 1, 2016, accessed June 25, 2016, http://cria.mei.net.cn/news.asp?vid=3282.

[159] "给力高交会开启机器人家居新时代" [The Awesomeness of iRobot Will Start a New Era for Robotic Households], China Finance 中国财经, November 18, 2011, accessed September 29, 2016, http://finance.china.com.cn/roll/20111118/262674.shtml.

[160] Ibid. It is unclear, however, to what extent or how the laboratory shares these advancements with commercial entities.

[161] "研究方向" [Research Directions], Harbin Institute of Technology State Key Laboratory of Robotics and System, accessed August 29, 2016, http://robot.hit.edu.cn/75/dc/c279a95708/page.htm.

[162] "SIASUN UAV," Rundae, accessed May 26, 2016, http://www.rundae.com/docs/automobiles/automotive%20styling%20features/vehicle%20design/aircraft%20configurations/rotorcraft/helicopters/military%20helicopters/unmanned%20helicopters/siasun%20uav/.

them an edge in developing autonomous devices. In addition to producing consumer electronics, e-commerce firms see opportunities to increase their operating efficiency by automating delivery and logistics systems with service robots.

Chapter Three: China's Military Robotics and Unmanned Systems

Chinese military leaders and strategists believe that the nature of warfare is changing fundamentally and relying more heavily upon robotics and unmanned systems. These weapons are appearing in all domains—land, air, and sea (both surface and underwater)—and necessitate that China develop its own systems. High-level support and generous funding for robotics and unmanned systems R&D have created a myriad of research institutes within China's defense industry and numerous universities, both civilian and military. Rapid deployments of increasingly capable systems present challenges to U.S. military forces operating in the Asia-Pacific region, particularly as U.S. defense planners implement the Third Offset strategy.

The U.S. Third Offset strategy will invest in and incorporate breakthroughs in fields including robotics, autonomous systems, miniaturization, big data, and advanced manufacturing, including 3D printing. It continues the U.S. military's tradition of leveraging technological advantages against previous adversaries' numerical or other advantages. The "First Offset" strategy began at the start of the Cold War in the 1950s when the Communist bloc countries enjoyed numerical and geographical advantages over Western Europe. U.S. defense planners offset these advantages with nuclear superiority. After the Soviet Union caught up with its own nuclear forces, the U.S. "Second Offset" strategy in the 1970s and 1980s leveraged precision-guided weapons, stealth technology, and space-based military communications and navigation to again counter the Soviets' numerical advantages. The most recent Third Offset strategy, though still under development, aims to counter Russian and Chinese advancements in those technologies, cyber and electronic warfare, and other A2/AD capabilities. The new technology areas emphasize the role of unmanned systems and robotics and include deep-learning systems, human-machine collaboration, human-machine combat teaming, assisted human operations, and network-enabled, cyber-hardened weapons.[163]

This chapter assesses the drivers behind China's interest in military robotics and unmanned systems, with emphasis on its views of the U.S. military. This report treats unmanned systems and robotics systems together based on taxonomies in Chinese texts.[164] It assesses the trends, status, leading entities, and challenges of China's own systems in the land, air, and sea domains. Its key findings are as follows:

- China's defense planners and military analysts consider robotics and unmanned systems to be part of an ongoing revolution in military affairs that increasingly relies on long-range, precise, smart, stealthy, and unmanned weapons platforms.
- Chinese analysts have paid considerable attention to U.S. deployments of unmanned systems in Afghanistan, Iraq, Pakistan, and Libya.
- Chinese analysts believe the U.S. Department of Defense is investing in and placing greater emphasis on unmanned systems. They posit that key drivers for this trend include stresses on U.S. defense budgets, the advantages of the systems themselves, and the demands of the U.S. rebalance to Asia and Third Offset strategy.

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[163] Katie Lange, "3rd Offset Strategy 101: What It Is, What the Tech Focuses Are," DoDLive, March 30, 2016, accessed August 18, 2016, http://www.dodlive.mil/index.php/2016/03/3rd-offset-strategy-101-what-it-is-what-the-tech-focuses-are/.

[164] This chapter also discusses the role of autonomy of these systems, which will largely depend upon advances in AI, as discussed in this chapter and Chapter Four.

- China's defense industry and military research institutes are actively publishing on "soft-kill" countermeasures that blind, confuse, or jam unmanned systems and force them to return to their bases of operations. This research often cites U.S. systems such as the X-47B and Global Hawk unmanned combat aerial vehicles.
- No authoritative comparison of Chinese and U.S. unmanned systems could be located, but two trends are noteworthy. First, Chinese manufacturers and their customers (both domestic and abroad) appear to emphasize lower price points and quantity over increased capabilities. Second, Chinese scientists and DOJ reporting on espionage cases indicate that technologies for propulsion, autonomous operation, advanced sensors, and data links will be critical for China to close the technological gap between U.S. and Chinese unmanned systems.

Chinese Assessments and Choices for Unmanned Systems

China has made tremendous strides in military robotics technologies in recent years. Consider that in 2009 a robotics expert with the Beijing Institute of Technology commented that the defense industry lacked a plan or strategy, needed to break through technologies for key components, lacked standardized systems (such as standardized software, platforms, and protocols that would facilitate modularization), had research results that could not be used within their limited scope or application, and relied on imports for some components.[165] Nonetheless, as of July 2016, China has tested or fielded advanced unmanned systems for the air, sea (underwater and surface), and land domains.

Chinese Leadership and Policies Supporting Unmanned Systems

Chinese leaders and policies strongly support the development of unmanned systems for the PLA. In November 2015 Xi Jinping told the State Council at a meeting on military reform that the Chinese military must "stand in strategic commanding heights of future military competitions."[166]Although he did not specify any technologies or "high grounds," many PLA officers consider unmanned systems to be one of these new strategic technologies.[167] One of the PLA's original instructors for UAVs claimed that Xi Jinping told a group of soldiers at the 2016 National People's Congress, "Unmanned aerial vehicles are an important combat force for modern battlefields. You all must carry out your responsibilities well, and develop good talent."[168]

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165 Huang Yuancan 黄远灿, "国内外军用机器人产业发展现状" [The Current Development Situation of Foreign and Chinese Military Robotics Industries], *Robot Technique and Application* 机器人技术与应用, March 30, 2009, 25-31.

166 "习近平:全面实施改革强军战略 坚定不移走中国特色强军之" [Xi Jinping: Fully Implement Reforms to Strengthen Military Strategy, Unflinchingly Walking the Road of a Strong Military with Chinese Characteristics], Xinhua Net 新华网, accessed July 8, 2016, http://news.xinhuanet.com/politics/2015-11/26/c_1117274869.htm.

167"解放军大校：军队改革要抢占未来战争制高点" [PLA Senior Colonel: Military Reforms Must Seize the High Ground of Future Wars], Sina 新浪军事, accessed July 8, 2016, http://mil.news.sina.com.cn/2015-11-27/1447845072.html; "李银祥：新型作战力量——未来战争制高点" [Li Yinxiang: New Type of Combat Strength--Controlling the High Ground of Future Wars], Guancha 观察者, accessed July 8, 2016, http://www.guancha.cn/LiYinXiang/2015_11_27_342799.shtml.

168 "解放军金牌无人机操控手：向习近平立军令状" [PLA Gold Medal UAV Controller: Following Xi Jinping's Military Orders], *China Daily* 中国日报, accessed July 8, 2016, http://cnews.chinadaily.com.cn/2016-04/04/content_24270271.htm.

Chinese plans and directives for military robotics have deepened "military-civilian fusion" (军民融合), in which military, commercial, and academic entities are encouraged to jointly develop and share breakthroughs in technologies.[169] Robotics is an ideal use of this "fusion" as commercial companies are outpacing their military counterparts in technologies such as autonomous operation and navigation, AI, and advanced components. In China, military robotics R&D has historically received support from numerous government plans and funding programs, including the 2006-2020 National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020), the 863 Program, "State Council Suggestions on Accelerating the Invigoration of Equipment Manufacturing," the National Natural Science Foundation of China, and defense preliminary research programs.[170] Most recently, the Thirteenth FYP (2016-2020) also lists military robotics, as discussed on page 24.

Due to strong political and financial support, numerous Chinese companies and universities, both civil and military, are establishing research centers for unmanned systems and robotics. For example, after the MLP and 863 Program included a "high-capability quadrupedal bionic robot" (高性能四足仿生机器人), nearly ten universities and research institutes conducted research on that type of technology.[171] One of China's challenges will be sustaining this support and balancing the vast output from so many entities with the actual demands of its military.

A "New Stage" in the World Revolution in Military Affairs

China's defense planners and strategists consider robotics and unmanned systems to be part of a broader trend in the nature of warfare becoming more precise, long-range, and networked. Articles featured on China's Ministry of Defense (MOD) website and authoritative texts like the *Science of Military Strategy* (战略学, *SMS*) emphasize the growing importance of long-range, precise, smart, stealthy, and unmanned weapons platforms.[172] China's 2015 Defense White Paper on "National Security Situation" claims the "…world revolution in military affairs (RMA) is proceeding to a new stage. Long-range, precise, smart, stealthy and unmanned weapons and equipment are becoming increasingly sophisticated."[173]

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[169] For more on "military-civilian fusion" and China's civil-military integration (CMI) policies, see Daniel Alderman, Lisa Crawford, Brian Lafferty, and Aaron Shraberg, "The Rise of Chinese Civil-Military Integration" in Tai Ming Cheung (ed.), *Forging China's Military Might: A New Framework for Assessing Innovation* (Baltimore, MD: Johns Hopkins University Press, 2014), 109-135.

[170] Huang, "The Current Development Situation of Foreign and Chinese Military Robotics Industries," 30.

[171] This research could be in response to the "BigDog" rough-terrain quadrupedal robot developed by U.S. company Boston Dynamics. See "BigDog–The Most Advanced Rough-Terrain Robot on Earth," Boston Dynamics, accessed July 7, 2016, http://www.bostondynamics.com/robot_bigdog.html; and Zhang Peng 张鹏 and Peng Kuang 彭况, "军网记者亲身体验中国军用机器人" [Chinese Military Network Reporters Personally Experience China's Military-Use Robots], China Military Network 中国军网, February 27, 2015, accessed July 7, 2016, http://www.81.cn/jmywyl/2015-02/27/content_6372686_5.htm.

[172] Xiao Tianliang 肖天亮, "顺应军事变革潮流把握改革主动" [Adapting Military Affairs with the Changing Tide and Taking Initiative in Reforms], Liberation Army Daily 解放军报, January 5, 2016, accessed July 8, 2016, http://www.mod.gov.cn/intl/2016-01/05/content_4635280.htm.

[173] "National Security Situation," Ministry of National Defense of the People's Republic of China, accessed July 8, 2016, http://eng.mod.gov.cn/Database/WhitePapers/2015-05/26/content_4586688.htm.

An analysis in *China Military Science* (*中国军事科学*, *CMS*) in 2015 argued that unmanned systems are as revolutionary as steam engines, tanks, airplanes, missiles, and the Internet.[174] The authors, all senior analysts at NUDT, believe weapons are becoming more precise, smarter, stealthier, and unmanned.[175] The most recent edition of *SMS* elaborates that "…intelligent technology, unmanned technology, stealth technology, and other types of new concept technology are integrating together, and will perhaps give future warfare "unmanned, intangible, and silent" characteristics."[176]

Chinese analysts view this trend towards unmanned systems as affecting all strategic domains and as attractive to militaries around the world. Across the world, militaries are increasingly utilizing unmanned systems with intelligent technology, nanotechnology, and micromechanical technology in the land, sea, air, and space domains. Concurrent advances in stealth, blinding, jamming, trajectory alteration, and other technologies make unmanned systems even more difficult to detect and defend against, and in turn even more attractive to defense planners.[177] By one estimate, over 70 countries have military robotics plans, and there are over 4,000 types of UAVs on the global market.[178] The 2013 *SMS* notes that part of Russia's military modernization plans includes increased weapons research and development on "future aviation (including unmanned) systems."[179] Other analysts follow developments in unmanned systems, particularly UAVs, in Israel, the United Kingdom, India, and others.[180]

Key trends identified by Chinese analysts include the following:[181]

- Control technology for unmanned operational systems is changing into intelligence fusion, and full autonomous control.

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[174] Zhu Qichao 朱启超, Liu Jifeng 刘戟锋, and Zhang Huang 张煌, "科技革命视野中的军事战略创新" (Military Strategic Innovations from the Perspective of Scientific and Technological Revolution), *China Military Science* 中国军事科学 3, no. 135 (2014): 75-81, 92. The textbook *Science of Military Strategy* and the journal *China Military Science* are both produced by the staff of the Academy of Military Science, the PLA's highest-level research and education institute. Both texts represent officially endorsed (or at least sanctioned) views of military affairs and of developments in international security and science and technology. Both the textbook and the journal are used as primary source materials in the instruction and education of the PLA's senior officer corps.

[175] Ibid

[176] Shou Xiaosong 寿晓松, *战略学 (The Science of Military Strategy)* (Beijing: Academy of Military Science Press, 2013), 97-98.

[177] Ibid.

[178] Pang Hongliang 庞宏亮, "智能化军事革命曙光初现——从美'第三次抵消战略'解读军事技术发展轨迹" [The Smart Military Revolution Is Dawning–Interpreting the Track of Military Technology Development from the U.S. "Third Offset Strategy"], *PLA Daily* 解放军报, January 28, 2016, accessed May 10, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm.

[179] Shou, *Science of Military Strategy*, 54.

[180] Tao Chuanhui 陶传辉, "各国军队竞相发展无人作战平台 已渗入陆海空等空间" [Every Country's Military Competing in Development of Unmanned Combat Platforms Has Already Entered Land, Air, and Sea Spaces], *National Defense Reference* 国防参考, May 27, 2014, accessed July 8, 2016, http://www.mod.gov.cn/wqzb/2014-05/27/content_4512254_2.htm; "深度：印度无人机差点飞中国 传回图像让印军不敢信" [Depth: India's UAV Short of Flying to China, Returning Images Cause India's Military to Not Dare], Sina 新浪军事, May 10, 2016, accessed July 8, 2016, http://mil.news.sina.com.cn/jssd/2016-05-10/doc-ifxryhhh1873725.shtml.

[181] Ibid.

- Single platform operations are transitioning to joint manned and unmanned systems, as well as multiple unmanned systems.
- New emphasis on integrating multiple platforms in operations over improving the capabilities of individual platforms.
- Platforms are becoming more standardized and interchangeable.

"Remote-Controlled Warfare": Chinese Assessments of U.S. Unmanned Systems Experience and Applications

Chinese authors have paid considerable attention to U.S. experience and applications for unmanned systems in warfare, and have long anticipated increasing U.S. investments, applications, and deployment of them. As U.S. defense officials laid out the Third Offset strategy and emphasized the role of unmanned systems, the Chinese reaction has not been surprise but rather a confirmation of their assessments of U.S. military trends and that such systems are aimed at China. This section evaluates China's analyses and perspectives on U.S. experience, strategy, and future plans for unmanned systems.

Chinese military strategists and officers have closely followed the U.S. deployment of UAVs in Iraq, Afghanistan, Pakistan, and Libya. One history of military UAVs by a PLAAF senior colonel and senior engineer examines the U.S. use of UAVs from the first Gulf War to Afghanistan. During Desert Storm, the Pioneer UAV was one of the first unmanned systems to complete missions that formerly required manned aircraft. Later in 2001, U.S. strikes in Afghanistan using RQ-1A Predator UAVs armed with Hellfire missiles were the first of their kind, and their success helped set the priorities and discussions for future use of military UAVs.[182] More recently, the 2013 *SMS* notes that the U.S. military employed UAVs to implement precision strikes in conjunction with multiple other weapons platforms in Afghanistan, Pakistan, and Libya.[183]

Chinese analysts consider the United States to be a leader in the application of unmanned ground systems as well. In addition to the over 8,000 UAV systems (especially the Global Hawk and Reaper UAVs) deployed in Iraq and Afghanistan, they point out the U.S military possesses over 12,000 unmanned ground vehicles (UGVs) total, and reportedly deployed over 5,000 UGVs to the two countries.[184] Analysts also follow and consider military roles for systems such as the Scorpion Small UGV, SWORDS armed system, Packbot, and Big Dog.[185] For the future of UGVs, a vice president at the PLA National Defense University sees the potential for these systems to serve as

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[182] Chen Guichen 陈贵春 (Ed.), Min Zengfu 闵增富, and He Yuesheng 何月生 (Asst. Eds.), *军用无人机* [Military Unmanned Vehicles] (Beijing: PLA Publishing House, 2008), 202-205.

[183] SMS (2013), 97-98.

[184] Pang Hongliang 庞宏亮, "智能化军事革命曙光初现——从美'第三次抵消战略'解读军事技术发展轨迹" [The Smart Military Revolution Is Dawning–Interpreting the Track of Military Technology Development from the U.S. "Third Offset Strategy"], *PLA Daily* 解放军报, January 28, 2016, accessed May 10, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm; Tao Chuanhui, [Every Country's Military Competing in Development of Unmanned Combat Platforms Has Already Entered Land, Air, and Sea Spaces], May 27, 2014.

[185] Lu Tiange 陆天歌, Hu Yajun 胡亚军, Wu Meng 武萌, "军用机器人迎来发展机遇期" [Military-Use Robots Forging Ahead in a Period of Favorable Development], *Liberation Army Daily* 解放军报, December 2, 2015, accessed July 8, 2016, http://news.mod.gov.cn/tech/2015-12/02/content_4631281.htm; Tao Chuanhui [Every Country's Military Competing in Development of Unmanned Combat Platforms Has Already Entered Land, Air, and Sea Spaces], May 27, 2014.

mechanized paratroopers that can land in a hostile environment and conduct search and rescue, surveillance, and explosive ordnance disposal (EOD) missions, as well as transmit video back to command centers and even conduct combat operations with personnel.[186]

Chinese analysts see the U.S. military as accelerating its adoption of unmanned systems as it transitions from Afghanistan and Iraq, copes with cuts to military spending, and rolls out the Third Offset strategy. In their view, by 2040 robots will outnumber people in the U.S. military.[187] In the "post-Afghanistan" era, three trends will be prevalent—innovation of new operational concepts, greater integration of technology and manpower (including unmanned systems), and decreasing support structures while optimizing force construction.[188] Following the U.S. budget debates of 2012 and sequestration cuts of 2013, Chinese analysts concluded that these budget cuts would increase the U.S. military's emphasis, if not dependence, upon its technological advantages. In 2012 Li Daguang, a senior colonel and theorist at NUDT specializing in technology and warfare, commented that even if the U.S. military budget decreases, it is still vast and the priority will be diminishing the number of personnel and traditional systems. In terms of capabilities, Li predicted "…national defense funds will flow to unmanned systems, stealth fighters, and electromagnetic interference systems in order to counter "anti-access challenges," and to emphasize carrying out "non-contact" operations."[189] Any decreases in budgets and personnel will only accelerate these trends.[190]

Looking towards the future, Chinese analysts consider the U.S. Navy as both leading the development of unmanned systems as well as the most dependent upon them. In 2012 Li Daguang cited the Navy's plans to develop large-scale long-deployment autonomous unmanned submersibles (USVs), the X-47B, and ship-launched unmanned aerial surveillance and attack systems.[191] By 2020 he estimated the U.S. military will have over 1,000 USVs, constituting an enormous underwater fleet. He and numerous other analysts track the U.S. Navy's development of UUVs and USVs, such as the Remus-600, GhostSwimmer, and Knifefish.[192] With these changes and other plans, Li predicted "remote-controlled warfare" (遥控战争) to be a distinct possibility, with unmanned systems drastically changing the nature of modern warfare.[193]

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[186] Xiao Tianliang 肖天亮, "顺应军事变革潮流把握改革主动" [Adapting Military Affairs with the Changing Tide and Taking Initiative in Reforms], *PLA Daily* 解放军报, January 5, 2016, accessed July 8, 2016, http://www.mod.gov.cn/intl/2016-01/05/content_4635280.htm.
[187] Hu Yiming 胡一鸣, "剑指未来，"白头鹰"再掀革新风暴" [Sword of the Future, "Bald Eagle" Raising a Storm of Innovation Again], *PLA Daily* 解放军报, February 27, 2016, accessed July 8, 2016, http://www.mod.gov.cn/wqzb/2016-02/27/content_4645032.htm.
[188] "后阿富汗战争时代—— 美国陆军进一步加快改革" [After the Afghanistan War Era -- U.S. Army Takes One Step Further in Accelerating Reform], *PLA Daily* 解放军报, July 31, 2015, accessed July 8, 2016, http://www.mod.gov.cn/opinion/2015-07/31/content_4612091.htm.
[189] Li Daguang 李大光, "A Strategic Analysis of US Future Defense Orientation" [美国未来防务走向战略分析], *China Military Science* 中国军事科学, no. 5, 2012, 142.
[190] Ibid.
[191] Ibid.
[192] Qiang Dong 钱东, Tang Xianping 唐献平, and Zhao Jiang 赵江, "UUV 技术发展与系统设计综述" (Overview of Technology Development and System Design of UUVs), *Torpedo Technology* 鱼雷技术 22, no. 6 (December 2014): 401-414.
[193] Li Daguang 李大光, "A Strategic Analysis of US Future Defense Orientation" [美国未来防务走向战略分析], *China Military Science* 中国军事科学, no. 5 (2012): 147.

Discussing U.S. deployments of such systems as the X-47B and MQ-8C Fire Scout,[194] one analyst claims the U.S. military is rapidly upgrading and replacing systems with stealth combat robots in order to meet requirements of the "pivot" and "rebalance" to Asia. These new types of robots change the deterrence and attack methods at the U.S. military's disposal, particularly for coastal states. The concern is that these machines can operate stealthily in surveillance mode, using GPS, radar guidance, infrared and laser sensors, but then at the flip of a switch use small caliber guns or other weaponry on board. Underwater robots are also becoming a "favorite" of the U.S. Navy that can operate stealthily and carry torpedoes and missiles. The author worries that this integration of air, surface, and underwater machines is a way for the U.S. Navy to implement Air-Sea Battle[195] deterrence and attacks.[196]

China also follows U.S. developments for unmanned surface vehicles (USVs), in particular the ASW Continuous Trail Unmanned Vessel (ACTUV) program funded by the U.S. Defense Advanced Research Projects Agency (DARPA).[197] The ACTUV system is a "vessel optimized to robustly track quiet diesel electric submarines."[198] In April 2016 DARPA unveiled the first ACTUV system, Sea Hunter, which is undergoing tests.[199] Numerous Chinese research and military institutes (such as the PLA Navy Equipment Department and CSIC 719 Research Institute) have tracked the system's development with the assumption that it is designed to track China's diesel attack submarines.[200]

Other U.S. Navy concepts being followed include Electromagnetic Maneuver Warfare (EMW), formally announced in 2015 as a concept to blend "fleet operations in space, cyberspace, and the electromagnetic spectrum with advanced non-kinetic capabilities to create warfighting

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194 The MQ-8C is an unmanned autonomous helicopter designed for the U.S. Navy to provide reconnaissance, situational awareness, aerial fire support, and precision targeting support.

195 Air Sea Battle was a U.S. integrated battle doctrine for countering A2/AD threats, and in 2015 was renamed Joint Concept for Access and Maneuver in the Global Commons (JAM-GC). See Sam LaGrone, "Pentagon Drops Air Sea Battle Name, Concept Lives On," *USNI News*, January 20, 2015.

196 Li Jie 李杰, ""山姆大叔" 大力发展无人机欲重返亚太" ["Uncle Sam" Is Rapidly Developing UAVs as it Looks to Return to Asia], *National Defense Reference* 国防参考, May 21, 2014, accessed June 15, 2016, http://www.mod.gov.cn/opinion/2014-05/21/content_4510641.htm.

197 The Defense Advanced Research Projects Agency (DARPA) is a DOD agency responsible for developing emerging technologies for use by warfighters. The agency has sponsored projects that made technological breakthroughs in unmanned system technologies, battlefield robotics, computer networking, and artificial intelligence among many others.

198 Scott Littlefield, "Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV)," Defense Advanced Research Projects Agency, accessed June 1, 2016, http://www.darpa.mil/program/anti-submarine-warfare-continuous-trail-unmanned-vessel.

199 Rick Stella, "Ghost Ship: Stepping Aboard Sea Hunter, the Navy's Unmanned Drone Ship," *Digital Trends*, April 11, 2016;
"人艇作战使用分析" [Analysis of U.S. Anti-Submarine Unmanned Surface Vehicles Operations and Uses], *Ship Electronic Engineering* 舰船电子工程, no. 8 (2012).

200 Wang Chuan 汪川, "DARPA: 美军战略优势的技术创新支柱" (DARPA: The Technological Innovation Backbone of the U.S. Military's Strategic Advantages), *Military Digest* 军事文摘 (June 2015): 51-54; Tian Jun 田军, She Yajun 余亚军, and Cai Long 蔡龙, "针对持续性跟踪无人艇的探测技术" (Research on Detection Technology on ACTUV), *Ship Science and Technology* 舰船科学技术 35, no. 4 (2013).

advantages."[201] Systems for these operations could include the EP-3 signals reconnaissance aircraft, MQ-4C Triton UAV, and MQ-8B/C Fire Scout UAVs for better ISR, connectivity, and flexibility in the electromagnetic domain.[202]

Chinese Reaction to the Third Offset

In November 2014 then Secretary of Defense Chuck Hagel announced the Defense Innovation Initiative that would develop into the Third Offset strategy.[203] To date, Chinese analysts have primarily concerned themselves with describing and parsing out the offset strategy, but some are beginning to assess strategic choices China must make in response to it, including in relation to unmanned systems. Chinese media covered Hagel's speech, as well as subsequent ones by Deputy Secretary of Defense Bob Work, who is leading the initiative, and are aware of this history.[204] In articles appearing on China's MOD website, analysts write that using technological innovation to offset important strategic advantages of adversaries has been the U.S. military's "time-tested method since the end of World War II."[205] In their view, the U.S. advantages include innovation, cutting edge systems, contributions from independent think tanks, and a strong military-civilian integrated national defense industrial base.[206] They also assess that challenges to this innovation include pressures on defense budgets, weakening economic strength relative to other countries, the lack of "home field advantage" as the U.S. military must project forces farther, and more complex and multi-faceted challenges.[207]

Discussions of how China should respond to the Third Offset are limited but primarily focus on management of China's defense industry. Li Jian, a retired PLA Lieutenant Colonel and current Director of China's Knowfar Institute for Strategic and Defense Studies, proposes that as China understands the U.S. strategy, it should also work to improve efficiency, governance and

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[201] "Forward, Engaged, Ready A Cooperative Strategy for 21st Century Seapower" (Washington, DC: Department of the Navy, 2015), 21.

[202] Zhang Yueliang 张岳良, Wu Qirong 伍其荣, and Zhu Dan 朱丹, "An Analysis of the 'All-Domain Access' Concept of the US Navy" [美国海军"全域进入"概念探析], *China Military Science* 中国军事科学, no. 4 (2015): 138.

[203] "Secretary of Defense Speech, Reagan National Defense Forum Keynote, As Delivered by Secretary of Defense Chuck Hagel, Ronald Reagan Presidential Library, Simi Valley, CA, Nov. 15, 2014," U.S. Department of Defense, accessed July 8, 2016, http://www.defense.gov/News/Speeches/Speech-View/Article/606635.

[204] Wang Weihua 王卫华, "美国第三次"抵消战略"呼之欲出" [America's Third "Offset Strategy" Is on the Verge of Coming Out], *PLA Daily* 解放军报, January 16, 2016, accessed May 11, 2016, http://www.mod.gov.cn/opinion/2015-01/16/content_4565007.htm; "美第三次"抵消战略"述评" [Discussion on the U.S. Third 'Offset Strategy'], *Guangming Daily* 光明日报, March 2, 2016, accessed July 7, 2016 as posted at http://news.xinhuanet.com/world/2016-03/02/c_128767225.htm.

[205] Wang Weihua, [America's Third 'Offset Strategy' Is on the Verge of Coming Out], *PLA Daily* 解放军报, January 16, 2016.

[206] Ibid; Chen Hanghui 陈航辉, "智库：美国军队的'最强外脑'" [Think Tanks: The U.S. Military's "Strongest Outside Minds"], *PLA Daily* 解放军报, November 20, 2015, accessed May 11, 2016, http://www.mod.gov.cn/opinion/2015-11/20/content_4629292.htm.

[207] Wang Weihua, [America's Third "Offset Strategy" Is on the Verge of Coming Out], *PLA Daily* 解放军报, January 16, 2016.

management of its own defense policies and industries. Otherwise, the government and military will not be able to implement any strategy Chinese leaders decides upon.[208]

Zhang Xiaobin, an author affiliated with the State Administration for Science, Technology and Industry for National Defence (SASTIND), presents a more detailed response, arguing that the offset strategy presents three challenges and three solutions for China.[209] The first challenge is that the United States is making it increasingly difficult for China to match U.S. leaps in innovation. The United States uses DARPA to leverage technological, industrial, and military revolutions together, leading to rapid advances in technologies such as electromagnetic rail guns and lasers. These types of "technological surprises" (技术突袭) can increase the disparity between U.S. and Chinese military technologies. Second, the offset puts pressure on China's national defense industry to develop weaponry and equipment. Specifically, unmanned combat and underwater combat can be asymmetric advantages for the United States that increase the gap between U.S. and Chinese equipment. Third, the offset strategy complicates China's decisions on core capabilities for its national defense industrial base. As a warning, he cites the financial stress on the Soviet Union in the 1980s in response to the second offset and the "Star Wars" program.[210]

To respond to these challenges, the author suggests first that China focus on the effectiveness of core capabilities and equipment that can effectively counter the U.S. military. Second, he proposes that China allow innovation to drive the development of strategy and seek technological advantages in key areas and counter those of the United States. Finally, he proposes strengthening defense planning to raise the standards of designs by the national defense industry.[211]

Is "Unmanned" Unethical? Chinese Considerations for Unmanned Systems

Chinese military analysts have published few opinions on the morality of unmanned and lethal autonomous weapon systems (LAWS), which may decide independently whether to use lethal force on a target. Discussions on the deployment of controlled unmanned systems in combat center on sovereignty, include ample criticism of U.S. deployments of UAVs against targets in Pakistan, and rarely touch on ethical considerations for PLA units. Chinese military authors are largely silent on the use of LAWS, in sharp contrast with a robust debate in the United States. The PRC's arms control diplomacy, however, suggests that the PLA's capabilities do not warrant such discussions yet, and that strategists are more concerned with lagging behind U.S. capabilities.

Chinese military writings condemn U.S. strikes with UAVs as violations of other countries' sovereignty, but recent events may challenge China's restraint from taking similar actions. In 2014, Chinese law experts wrote in *China Military Science* on international law and the ethics of UAV operations, using U.S. UAV operations in Pakistan as a case study. They speak positively of the advantages of these systems, namely their stealth and tracking capabilities, the lack of international

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[208] Li Jian 李健, "新抵消战略：美国以技术优势谋求持续军事优势的老套路和新思考" (New Offset Strategy: An Old Means with New Thinking for the U.S. to Maintain Military Dominance), *Air & Space Power* 空天力量杂志 (simplified Chinese version) 9, no. 2 (2015): 96.
[209] SASTIND is the government agency in charge of defense industrial policy in China.
[210] Zhang Xiaobin 张晓斌, "美国'第三次抵消战略'对国防科技工业的挑战与应对" (The Challenge Imposed by the Third U.S. Offset Strategy on the Development of Defense Science and Technology Industry and Contermeasures [sic]), *National Defense Science & Technology* 国防科技 36, no. 6 (December 2015): 74-76.
[211] Ibid.

laws governing their use (making it easier to use them), their advantages in hazardous environments, and the lack of casualties for pilots. They criticize the strikes based on sovereignty, claiming that the United States conducts such attacks in Pakistan without that country's approval. The authors question whether UAV operators are subject to international laws governing warfare, and conclude that U.S. UAV operations in Pakistan, a state that is not at war with the United States, constitute war crimes.[212]

These views may change as China faces more transnational threats, and weighs the same advantages of UAVs and other unmanned systems. A relevant case study is China's pursuit of Naw Kham, a Burmese drug trafficker accused of killing thirteen Chinese sailors in 2011. According to media reports, one plan was to kill Naw using "an unmanned aircraft to carry twenty kilograms of TNT to bomb the area."[213] Relevant authorities rejected the plan and an operation later captured Naw alive in 2012. Some reporters claimed leaders rejected the UAV strike option because of concerns it would spark international controversy akin to U.S. strikes in Pakistan, while others claimed China's UAV technologies may not have been advanced enough to carry out the mission.[214]

Chinese public opinion has been largely opposed to such strikes but this attitude may also be changing. According to a global survey, from 2012 to 2014 between 52 and 62 percent of the Chinese public opposed the U.S. use of UAVs to conduct missile strikes against extremists in countries such as Pakistan, Yemen, and Somalia.[215] However, the proportion approving of the strikes has increased from 25 percent to 35 percent. As China's interests abroad grow and its capabilities mature, the likelihood of and support for Chinese UAV operations abroad could increase. The Chinese public's support for the PRC's territorial claims in the East and South China Seas could also translate into support for UAV operations in the region.

At least one article discusses the humane considerations for UAV strikes, arguing that the increase in precision does not make the weapons more "humane." In 2013, NUDT scholars wrote in *China Military Science* on the "paradox" of wars increasingly revolving around "surgical strikes" with unmanned systems. On the one hand, these systems make the operators more detached from the war itself, dehumanize adversaries, and lower the threshold for use. On the other hand, the advantages of unmanned systems such as stealth, precision, and low risk to operators can reduce

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[212] Xie Dan 谢丹 and Ming Chenyan 明晨燕, "无人机作战的国际法问题研究", *China Military Science* 中国军事科学 3, no. 135 (2014): 139-145.

[213] "中国抓糯康难度超猎杀拉登 曾欲派无人机斩首" [China Catching Nuo Kang Was More Difficult than Killing Bin Laden, Previously Desired to Use a UAV to Behead], Global Times Online 环球网, February 18, 2013, accessed July 8, 2016, http://mil.huanqiu.com/paper/2013-02/3650584.html; Liu Chang, "Manhunt for Deadly Drug Kingpin" Global Times, February 19, 2013, accessed July 8, 2016, http://www.globaltimes.cn/content/762449.shtml.

[214] "China Considered Drone Strike on Foreign Soil in Hunt for Drug Lord" *South China Morning Post*, February 19, 2013, accessed July 8, 2016, http://www.scmp.com/news/china/article/1153901/drone-strike-was-option-hunt-mekong-drug-lord-says-top-narc; Jane Perlez, "Chinese Plan to Kill Drug Lord with Drone Highlights Military Advances" *New York Times*, February 20, 2013, accessed July 8, 2016, http://www.nytimes.com/2013/02/21/world/asia/chinese-plan-to-use-drone-highlights-military-advances.html?_r=0.

[215] "Global Opposition to U.S. Surveillance and Drones, but Limited Harm to America's Image, Many in Asia Worry about Conflict with China" Pew Research Center, July 14, 2014, accessed July 8, 2016, http://www.pewglobal.org/files/2014/07/2014-07-14-Balance-of-Power.pdf.

collateral damage and protect military personnel. The authors conclude these weapons do not make war more "humane" (慈化) because the fundamental problems and suffering continue.[216]

No analysis could be found considering problems with escalation control using unmanned systems. As unmanned systems become more advanced, and AI enables more rapid and autonomous responses to different scenarios, it will be important for military leaders to take risks of escalation into consideration. The only evidence of Chinese thinking on the matter is an article reposted to the Ministry of Defense's website that states unmanned intelligent systems may "change escalation control avenues."[217] This lack of literature may indicate a need for international dialogue on the implications of unmanned systems in crisis situations.

Leading military publications and journals are also largely silent on the issue of an autonomous system independently determining to kill a target. This silence contrasts sharply with the in-depth analysis by U.S. defense planners, think tanks, and media on the definitions, benefits, ethical dilemmas, and other aspects of increasingly autonomous systems. One of the leading challenges for U.S. and other defense planners is deciding whether or not to allow autonomous unmanned systems to independently use lethal force, an issue no PLA strategist or technical expert appears to discuss in open source publications.[218] The lack of authoritative Chinese discussions may reflect either ongoing internal debates among PLA leadership or that China's unmanned systems are not developed enough to necessitate decisions on the roles of autonomous weapons systems.

China's diplomatic positions on LAWS also suggest Chinese leaders are ambivalent on the use of LAWS or concerned with a gap between U.S. and Chinese capabilities. In 2013 China, the United States, and numerous other countries agreed to discuss LAWS within the framework of the 1980 United Nations Convention on Certain Conventional Weapons (CCW).[219] These discussions, namely the Meetings of Experts on LAWS, seek to define and set norms for the use of LAWS. There is a consensus that there is no agreed upon international definition, and the military advantages and possibilities for these systems are growing. One analysis puts United States and China into two separate "groups" with separate narratives on LAWS. The U.S. group of "established 'Western' military powers"[220] does not want the CCW discussions to preclude technological developments, and is hesitant to discuss meaningful human control (MHC). A separate group of "other established military powers" (most notably, China, India, and Russia) also values increasingly autonomous systems, but they "fear that an arms race on LAWS would widen the capability gap between them and the USA." Given that China's opening and closing

[216] Zhang Huang 张煌, Zhu Qichao 朱启超, Li Po 李坡, "信息化战争阈下武器演进的伦理悖论" (The Ethical Paradox of the Evolution of Weapons against the Backdrop of Informationized Warfare), *中国军事科学 China Military Science* 5, no. 131 (2013): 140-146.

[217] Xiao Tianliang 肖天亮, "顺应军事变革潮流把握改革主动" [Adapting Military Affairs with the Changing Tide and Taking Initiative in Reforms], *Liberation Army Daily* 解放军报, January 5, 2016, accessed July 8, 2016, http://www.mod.gov.cn/intl/2016-01/05/content_4635280.htm.

[218] For example, see Jim Garamone, "DoD Studies 'Terminator' Weapons Conundrum, Selva Says," *DoD News*, August 26, 2016, accessed August 29, 2016, http://www.defense.gov/News/Article/Article/927792/dod-studies-terminator-weapons-conundrum-selva-says; and Paul Scharre and Michael C. Horowitz, *An Introduction to Autonomy in Weapon Systems*, Working Paper for the Center for a New American Security, February 2015.

[219] Vincent Boulanin, "Mapping the Debate on LAWS at the CCW: Taking Stock and Moving Forward," Non-Proliferation Papers no. 49, EU Non-Proliferation Consortium, March 2016.

[220] These countries include Australia, Canada, France, Israel, the United Kingdom and the United States.

statements for these meetings are not available online (unlike other countries), it is difficult to verify this narrative.[221] If accurate, China's public stance has been to acknowledge the humanitarian and legal concerns of other countries and seek to curtail U.S. development of such systems.

Applications for China's Unmanned Systems

Chinese military analysts and strategists agree that unmanned systems can enhance the capabilities of individual services and address key deficits. This section examines discussions by Chinese military strategists and analysts of applications and missions for China's unmanned systems. It then follows with examples of unmanned system missions observed to date.

Applications and Roles under Discussion

Chinese analysts see tremendous utility and advantages of unmanned systems. Some repeat the "DDD" (dull, dirty, and dangerous) discussion found in U.S. literature.[222] In other words, unmanned systems can operate for long periods of time doing mundane tasks (dull), go into unpleasant environments (dirty), and take risks in place of the human operator (dangerous). Additionally, at least one author claims that an UAV can have a greater capability than its human counterpart, as it can withstand up to 20G of pressure, over twice that of a manned aircraft, giving it much greater agility. Finally, designers can customize the size and capabilities of unmanned systems to use less power or achieve greater flexibility for different roles and missions.[223]

The PLA Air Force (PLAAF) includes UAVs in its priorities for future military systems. In the 2013 *SMS*, authors write the PLAAF should focus on building the following capabilities, all of which can utilize or incorporate UAVs:[224]

- Integrated information systems for surveillance, early warning, and command and control platforms;
- Medium and long-range precision strike systems that extend PLA strike capabilities to the second island chain and deny adversary attacks; and
- Develop systems for combat that include platforms such as fourth-generation aircraft, aerial refueling aircraft, long-range reconnaissance aircraft, early-warning and command aircraft, and UAVs, as well as guided munitions such as air-launched cruise missiles and anti-radiation missiles.

The PLAAF is already working on defenses against UAVs. The 2013 *SMS* calls for improved defenses against UAVs in addition to stealth fighters and missile threats.[225] The air force has already set up a specialized unit dedicated to detecting and countering small unmanned aircraft, in particular slow-moving drones flying at altitudes of less than 1,000 meters. According to official

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[221] "2016 Meeting of Experts on LAWS," The United Nations Office at Geneva, accessed July 8, 2016, http://www.unog.ch/80256EE600585943/(httpPages)/37D51189AC4FB6E1C1257F4D004CAFB2?OpenDocument.
[222] Dai Hao 戴浩, "无人机系统的指挥控制" (Command and Control for Unmanned Aerial Vehicles), *Journal of Command and Control* 指挥与控制学报 2, no. 1 (March 2016): 5-7.
[223] Pang Hongliang 庞宏亮, "智能化军事革命曙光初现——从美'第三次抵消战略'解读军事技术发展轨迹" [The Smart Military Revolution Is Dawning–Interpreting the Track of Military Technology Development from the U.S. "Third Offset Strategy"], *PLA Daily* 解放军报, January 28, 2016, accessed May 10, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm.
[224] Shou, *Science of Military Strategy*, 223-224.
[225] Ibid., 224.

news media, "the unit performs drills against a squadron equipped with multiple types of drones to simulate reconnaissance, infiltration or strike operations." The unit's commander said his men have been closely following developments in the international aviation industry and keep improving their drone database.[226]

Unmanned systems could also vastly improve ISR and attack capabilities of the PLA Navy (PLAN). The 2013 *SMS* calls for development of "naval (surface, underwater, and aerial) unmanned operation/combat platforms."[227] As recently as 2015, an article in *China Military Science* bemoaned that while China has strategic level guidance on systems combat, at an operational level, implementation and practice are insufficient. Operations in the electromagnetic and network domains, reconnaissance and early warning, and command and control all face challenges of being "unable to see far" ("看不远"), "unable to distinguish clearly" ("辨不清"), "unable to connect ("联不通"), and "unable to maintain" ("稳不住").[228] UAVs can contribute to ISR capabilities and solutions for each of these challenges.

The PLAN is pursuing underwater robotics that can increase its anti-submarine warfare (ASW) capabilities. A Chinese article from 2015 calls for an "undersea Great Wall" (水下长城) and discusses China's "undersea monitoring system" (水下观测系统).[229] Such a monitoring network can detect both natural disasters such as typhoons and adversary underwater systems. Pictures on Chinese social media claim that UUVs would play a leading role in maintaining this network and detecting adversary submarines. Some Chinese media reports claim that UUVs would provide offensive and defensive capabilities for this system.[230] If true, such a network could help improve China's ASW capabilities, long considered a weakness of the PLA.

Applications to Date of Chinese Unmanned Systems

<u>Counterterrorism</u>

- During Peace Mission 2014, an anti-terror drill held by the Shanghai Cooperation Organization (SCO), an unnamed UAV fired missiles at targets.[231] The exercise included troops from China, Russia, Kazakhstan, Kyrgyzstan and Tajikistan.

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[226] Zhao Lei, "PLA Air Force Sets Up Anti-Drone Unit," *China Daily*, February 19, 2016.
[227] Shou, *Science of Military Strategy*, 213.
[228] Zhang et al., "An Analysis of the 'All-Domain Access' Concept of the US Navy," 135-142.
[229] "构建我国海洋水下观测体系的思考" (Thoughts on Building China's Ocean Undersea Monitoring System), *China Ocean News* 中国海洋报, December 2, 2015, accessed July 8, 2016, http://www.oceanol.com/keji/ptsy/yaowen/2015-12-02/53812.html.
[230] "深度：中国列装水下监视系统 美潜艇无处藏只能上浮" [In Depth: China Sets Up Underwater Surveillance System, U.S. Submarines Have Nowhere to Hide and Have to Surface], Sina 新浪军事, June 7, 2016, accessed July 8, 2016, http://mil.news.sina.com.cn/jssd/2016-06-07/doc-ifxsvenx3546265.shtml.
[231] "China Unveils Most Advanced Drone at 2014 Peace Mission Drill," *CCTV English* 央视网, August 27, 2014, accessed July 8, 2016, http://english.cntv.cn/2014/08/27/VIDE1409091365559432.shtml.

Intelligence, Surveillance, and Reconnaissance

- According to news outlets, satellite imagery shows the deployment of the Harbin BZK-005 long-range reconnaissance UAV on Woody Island, which is also claimed by the Republic of China (Taiwan) and by Vietnam.[232]

Long-Range Precision Strikes

- According to one market analysis, the "Soar Dragon" High Altitude Long Endurance (HALE) UAV is ideal for surveillance and could be used for guidance for the DF-21D anti-ship ballistic missile (ASBM).[233]

Military Exercises

- A Chinese military exercise, FIREPOWER 2015, simulated enemy attacks on Chinese air defense units in a complex electromagnetic environment with systems including UAVs.[234]

Border Patrol

- In October 2015 an unspecified PLA unit from the Shenyang Military District demonstrated a few prototype UGVs with a mounted rifle, described as the first prototype test in its R&D cycle.[235] The coverage indicated the system could be ideal for reconnaissance and monitoring, fire attacks, logistics assurance, logistics support, and unmanned alert and protection assignments. The UGV could conduct such operations in harsh environments. The users and program manager noted that mobility, stealth, survivability, agility, and endurance were all key advantages for such systems.
- In February 2016, border defense units in Xinjiang organized a training exercise for using UAVs to improve ISR capabilities.[236]

Explosive Ordnance Disposal

- In April 2016, China's State Council and Central Military Commission authorized a third campaign for removing mines on the Sino-Vietnamese border, operations that will include EOD robots. The previous two campaigns were conducted from 1992 to 1994 and 1997 to

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232 Ankit Panda, "South China Sea: China's Surveillance Drones Make it to Woody Island" *The Diplomat*, June 1, 2016, accessed July 8, 2016, http://thediplomat.com/2016/06/south-china-sea-chinas-surveillance-drones-make-it-to-woody-island/; Imogen Calderwood, "Satellite Image Reveals China Has Begun Using Drones with Stealth Capabilities in the South China Sea," *Daily Mail Online*, May 27, 2016, accessed July 8, 2016, http://www.dailymail.co.uk/news/article-3613173/Satellite-image-reveals-China-begun-using-drones-stealth-capabilities-South-China-Sea.html.

233 Feng Fuzhang 冯福章, "无人机行业进入快速发展期" [The UAV Industry Is Entering a Period of Rapid Development], 证券研究报告 · 行业深度 [Securities Research Report · Industry in Depth], China Securities 中信建设证券¸ September 15, 2014, 14.

234 Office of the Secretary of Defense, "Military and Security Developments Involving the People's Republic of China 2016," (Washington, DC: U.S. Department of Defense, 2016), 5.

235 "解放军单兵机器人亮相中朝边境 射击弹无虚发" [PLA Single Soldier Robot Makes Appearance at China-Korea Border, Fires Munitions without False Fire], Sina 新浪军事, October 30, 2016.

236 Guo Fahai 郭发海, Xiong Zhenxiang 熊振翔, Sun Liwei 孙力为 (Ed.), "'无人机'飞进边关哨所助力边防管控" ["UAV" Flies at Border Station Post and Assists in Border Defense Control], Ministry of Defense Online 国防部网, February 29, 2016, accessed July 8, 2016, http://www.mod.gov.cn/hdpic/2016-02/29/content_4645198.htm.

1999 respectively. The new campaign will commence in August 2016 in border counties in Guangxi and Yunnan Province, and use EOD robots.[237]

- In July 2015, the Armored Force Engineering Institute (装甲兵工程学院) unveiled a six-wheeled robot for rough terrain that can become the basis for future EOD disposal robots.[238]

Combat Support

- In October 2015 *The Global Times* website posted a photo of PLA special forces using new types of equipment including a hand-launched UAV.[239]

Research and Production of Chinese Military Robotics

China's investments into unmanned systems are considerable and will likely yield larger numbers of increasingly capable platforms. Vast support through government programs has led numerous universities, companies, and research institutes, civilian and military, to establish centers for work on unmanned systems. This section addresses the research, development, and deployment of UAVs, UUVs, USVs, and UGVs. No authoritative comparison of Chinese unmanned systems to U.S. systems could be located, but Chinese scientists and DOJ reporting on espionage cases indicate that technologies for propulsion, autonomous operation, advanced sensors, and data links will be critical for China to match U.S. capabilities.[240]

Unmanned Aerial Vehicles

China has invested considerable resources into the research, development, and deployment of UAV capabilities. Though no official estimates of the PRC's spending on UAVs was found, one market analysis from 2014 predicts that from 2013 to 2022, Chinese demand for military UAVs will grow 15 percent annually on average, increasing from USD 570 million in 2013 to USD 2 billion in 2022.[241] Many U.S. analysts are closely following this sector and have published authoritative analyses on the organizations tasked with developing UAV mission requirements, design and R&D institutes, the production infrastructure, and specific systems.[242] More recently, analysts are assessing the personnel behind China's UAV capabilities, including their education,

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237 "解放军机器人中越边境执行任务:越南乐开花" [PLA Robot Conducts Mission on China-Vietnam Border: Vietnam is Happy], Sohu 搜狐, April 25, 2016, accessed July 8, 2016, http://m.sohu.com/n/446034214/?wscrid=32576_2.

238 Yang Ru 杨茹, "解放军部队列装新六轮机器人 可轻松上下楼梯" [PLA Troops Fielded Six New Robots that can Easily Go Up and Down Stairs], *Xinhua*, July 27, 2015, accessed July 8, 2016. http://news.xinhuanet.com/mil/2015-07/27/c_128061364.htm.

239 "解放军特种部队单兵无人机曝光" [PLA Special Forces Single Soldier UAV Exposed], *Global Times Online* 环球网, October 22, 2015, accessed July 8, 2016, http://mil.huanqiu.com/photo_china/2015-10/2806047.html.

240 Zhao Lei, "Foreign Buyers Eye Chinese Drones," *China Daily USA*, June 20, 2013; Department of Justice, "Summary of Major U.S. Export Enforcement, Economic Espionage, Trade Secret and Embargo-Related Criminal Cases (January 2010 to the present: updated June 27, 2016)," June 2016 accessed July 1, 2016, 4, https://www.justice.gov/nsd/files/export_case_list_june_2016_2.pdf/download.

241 Feng Fuzhang [The UAV Industry Is Entering a Period of Rapid Development], China Securities¸ September 15, 2014, 14.

242 Ian Easton and L.C. Russell Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," report by the Project 2049 Institute, March 11, 2013; and Kimberly Hsu, Craig Murray, and Jeremy Cook, "China's Military Unmanned Aerial Vehicle Industry," U.S.-China Economic and Security Review Commission, June 13, 2013.

training, and organization.[243] Then and today, the roles and numbers of UAVs are expanding under the PLAAF, PLAN, PLAA, and the PLA Rocket Force (PLARF).

Trends and Challenges

Chinese defense companies have demonstrated different models of unmanned combat aerial vehicles (UCAVs), but their status remains unclear. UCAVs are ideal systems for high-risk missions such as suppression of enemy air defenses (SEAD). China's UCAVs seen to date include Lijian (利剑 / Sharp Sword), which completed taxi tests in May 2013; the Anjian (暗剑 / Dark Sword), which is reported to be capable of supersonic speeds and carry air-to-air weapons; and the Zhanying (战鹰 / Warrior Eagle), designed for SEAD missions.[244] The general trend is that defense companies will display models at air shows (such as the Zhuhai Air Show) that bloggers and reporters photograph, and then low-quality images of an actual system test eventually follow. The actual technical parameters, capabilities, and status of these programs are difficult to discern from open sources. In general it appears that Chinese manufacturers and its customers (both domestic and abroad) emphasize lower price points over increased capabilities, especially compared to the more expensive and capable U.S. systems.[245]

While China's deployment of UAVs is increasing in scope and application, technical challenges appear to hinder their development. In 2013, Wang Yangzhu, deputy director of the Unmanned Aircraft System Institute under Beihang University, gave Chinese UAVs a "5 or 6" on a ten-point scale for automation capabilities. He elaborated that China's efforts to develop advanced drones are consistently running into problems with engines and data links, noting that the country's aviation industry has yet solve many technical challenges. Wang also said data links and airborne electronic devices used on Chinese drones still lag behind those of their U.S. counterparts, leaving models such as the RQ-4 Global Hawk and the forthcoming X-47B as the top designs.[246] Other articles from an author with the Shenyang Aircraft Design Institute cite DARPA work as evidence that China must develop more advanced materials such as high grade carbon fiber.[247] Although those calls are dated (2005), in April 2016, U.S. authorities arrested an individual attempting to acquire high-grade carbon fiber used in aerospace and military applications.[248]

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243 Elsa Kania and Kenneth Allen, "The Human and Organizational Dimensions of the PLA's Unmanned Aerial Vehicle Systems," *China Brief* 16, no. 8 (May 11, 2016): 10-17.
244 Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 10.
245 Adam Rawnsley, "Meet China's Killer Drones," *Foreign Policy*, January 14, 2016, accessed August 29, 2016, http://foreignpolicy.com/2016/01/14/meet-chinas-killer-drones/.
246 Zhao Lei, "Foreign Buyers Eye Chinese Drones," *China Daily USA*, June 20, 2013.
247 Chen Shaojie 陈绍杰, "Composite Materials and UAVs" [复合材料与无人飞机], *Hi-tech Fiber & Application* 高科技纤维与应用, no. 2 (2003); and Chen Shaojie 陈绍杰, "Brief Discussion of Shaping Technologies for Composite Structures" [浅谈复合材料整体成形技术], *Aeronautical Manufacturing Technology* 航空制造技术, no. 9 (2005).
248 Department of Justice, "Summary of Major U.S. Export Enforcement, Economic Espionage, Trade Secret and Embargo-Related Criminal Cases," 7.

Leading Research and Production Entities

Northwest Polytechnic University (西北工业大学)

Northwest Polytechnic University (NWPU) is a leading technical university that conducted China's first research into UAVs in the 1950s.[249] Currently, NWPU's 365th Research Institute (西北工业大学第365研究所), also known by its commercial name Xi'an ASN Technology Group (西安爱生技术集团公司), is one of China's leading UAV design and manufacturing entities.[250] The NWPU 365th RI's work includes design optimization, system integration and controls, takeoff and landing, and comprehensive performance tests.[251] It is reported to be China's largest UAV production company and R&D base, and designed all three of the UAVs featured in China's 60th National Day Military Parade in 2009.[252] The RI hosts the Key Laboratory of UAV Special Technology (无人机特种技术重点实验室), as well as a provincial level laboratory dedicated to advanced air layout and controls aviation technologies.[253]

Beihang University (北京航空航天大学)

Beihang University (formerly the Beijing University of Aeronautics and Astronautics/BUAA) is the PRC's first university dedicated to air and space, and is directly under MIIT.[254] In 1959 it tested China's first UAV, and in 1962 established the UAV Institute (无人机所 or 无人驾驶飞行器设计研究所), China's first UAV R&D center.[255] The institute is vast and includes laboratories or design centers for vehicle design and integration center, testing, simulations, and electronics and countermeasures. The institute is responsible for the BZK-005 UAV and Changying (长鹰) UAV programs.[256]

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249 Li Caixiang 李彩香 and Liu Yinzhong 刘银中, "探访西北工业大学无人机事业发展之路" [Looking at Northwestern Polytechnical University's UAV Development Road], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1091/6411.htm.

250 Wang Fanhua 王凡华 and Guo Youjun 郭友军, "我校研制生产的无人机参加国庆阅兵载誉归来" [UAVs Developed and Manufactured by Our School in the National Day Troop Review], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1091/4169.htm.

251 "无人机特种技术重点实验室" [UAV Special Technology Key Lab], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1266/12808.htm.

252 Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 8; "学校简介" [School Introduction], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/xxgk/xxjj.htm; Wang and Guo, "UAVs Developed and Manufactured by Our School in the National Day Troop Review."

253 "无人机特种技术重点实验室" [UAV Special Technology Key Lab], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1266/12808.htm; "西北工业大学重点实验室一览表" [Northwestern Polytechnical University Key Lab -- Table], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1157/9868.htm.

254 "学校简介" [Introduction to the University], Beihang University, accessed July 8, 2016, http://www.buaa.edu.cn/bhgk/index.htm#1.

255 "北京航空航天大学无人驾驶飞行器设计研究所简介" [Beihang University UAV Design Research Institute Introduction], Beihang University 北京航空航天大学, November 14, 2013, accessed July 8, 2016, http://wrjs.buaa.edu.cn/zxgg/49517.htm.

256 Easton and Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project," 6; "北京航空航天大学无人驾驶飞行器设计研究所简介" [Beihang University UAV Design Research Institute Introduction], Beihang University 北京航空航天大学, November 14, 2013, accessed July 8, 2016, http://wrjs.buaa.edu.cn/zxgg/49517.htm.

Nanjing University of Aeronautics and Astronautics (南京航空航天大学)

Nanjing University of Aeronautics and Astronautics (NUAA) has specialized in tactical UAVs since its founding.[257] Its UAV Institute (南京航空航天大学无人机研究院) is reported to be responsible for designing the Changkong (长空) and BZK-002 UAV series, as well as unmanned helicopters.[258]

Unmanned Underwater Vehicles

Since the 1980s China has developed UUV technologies, beginning with remote operated vehicles (ROVs) and improving to the Zhishui (智水) series of UUVs that are reportedly in service with the PLAN. This report uses UUVs as an umbrella term encompassing China's civilian and military remotely operated underwater vehicles (ROVs/ROUVs), autonomous underwater vehicles (AUVs), and autonomous and remotely operated vehicles (ARVs). As China's UUV systems have matured, so have their capabilities to travel farther and deeper, and perform more complex tasks and missions. China has made drastic progress on UUV technologies, as evidenced by increases in the numbers of teams working on the relevant technologies at major research institutes and universities, increased funding (mainly from the PLA), and recent technological breakthroughs.[259] UUVs, deep sea submergence vehicles (DSVs), and other underwater robotics systems are useful for commercial activities such as laying and repairing undersea cables that facilitate global exchanges of information, and exploring natural resources. In 2016, Chinese UUVs carried out exploration missions in the southwest Indian Ocean searching for sulfide deposits and precious metals.[260] Countries may also, however, use these vehicles to wiretap, disrupt, or sever undersea cables, as well as deploy them for anti-submarine warfare applications.

China is actively exploring newer concepts for UUV designs and technologies. In 2014, the School of Mechanical Engineering (天津大学机械工程学院) and the National Ocean Technology Center in Tianjin completed a sea trial for the Haiyan (海燕) AUV in the northern area of the South China Sea.[261] This AUV is an underwater glider, which uses small changes in buoyancy and its wings to convert vertical motion into horizontal motion. This system is slower but more energy efficient, enabling longer surveillance and exploration missions.

China has also made considerable advances in technologies for manned and unmanned DSVs. The *Jiaolong* manned DSV has made over one hundred dives to date, reaching depths of more than

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[257] Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 8.

[258] Easton and Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project," 7.

[259] Michael S. Chase, Kristen A. Gunness, Lyle J.Morris, Samuel K. Berkowitz, and Benjamin S. Purser III, "Emerging Trends in China's Development of Unmanned Systems," (Arlington, VA: RAND Corporation, 2015), 3.

[260] "Chinese Submersible Explores Indian Ocean for Precious Metals," *Economic Times*, March 24, 2016, accessed July 8, 2016, http://economictimes.indiatimes.com/news/international/world-news/chinese-submersible-explores-indian-ocean-for-precious-metals/articleshow/51542348.cms; "China may build seabed 'space station' to help hunt for minerals in South China Sea," *Japan Times*, June 8, 2016, accessed July 8, 2016, http://www.japantimes.co.jp/news/2016/06/08/asia-pacific/china-may-build-seabed-space-station-help-hunt-minerals-south-china-sea/.

[261] "天津大学研发水下滑翔机技术创多项国内纪录" [Tianjin University Developed Underwater Glider Technology and Created Multiple Units in Domestic Record], CERNET China Education and Research Network 中国教育和科研计算机网, May 26, 2014, accessed July 8, 2016, http://www.edu.cn/cheng_guo_zhan_shi_1085/20140526/t20140526_1119599.shtml.

seven km (4.35 miles).[262] This depth lags behind the world records set by the Australian DSV *Deepsea Challenger* and Italian DSV *Trieste* at approximately 11 km (6.84 miles), but China is keen to catch up.[263] Shanghai Ocean University, a leading developer of manned and unmanned submersibles, is working on the Rainbow Fish (彩虹鱼), which aims to reach a depth of 11 km (6.84 miles) in 2016 and will have a manned and unmanned lander.[264] If this vehicle is successful and can conduct experiments (such as sample collection), China will be on par with world leaders on DSV technology.

The Zhishui series of AUVs is poorly documented in open sources but may currently be in service with the PLA Navy. Zhishui is likely a shortened version of 智慧 (*zhihui*, intelligent) and 水下机器人 (*shuixia jiqiren*, underwater robot). According to a military enthusiast website, the Zhishui III entered service with the PLAN in 2000, and is a large 2,000 kg UUV with twin propellers and two cross-tunnel thrusters for maneuvering.[265] According to authors with Harbin Engineering University (HEU), in 2003 the university's Underwater Intelligence Robot Technology Laboratory (水下智能机器人技术实验室) had recently completed the "Zhishui-IV" underwater robot. The design incorporated a large number of more advanced sensors, including ones for depth, elevation, GPS, compasses, velocity, collision avoidance sonar, 3D imaging sonar, and TV.[266]

Strengths, Trends, and Weaknesses

China's progress to date on UUVs demonstrates both increasingly sophisticated designs and steadily improving performance parameters such as maximum depth and duration of operation. Although no authoritative comparison of U.S. and Chinese UUVs was found in the open source, academic publications and recent espionage cases suggest that the U.S. military maintains an advantage in UUV technologies, particularly with advanced software, autonomous operation, and sensors. These activities also indicate, however, that China is actively improving these capabilities and seeking to close any gap with U.S. systems. Recent Chinese technical publications indicate that technologies under development focus on software components, greater autonomous operation, and navigation. Some representative article titles include the following:

- "Training and Examining System About Military UUV Support";[267]
- "Comparative Study on the Propulsive Performance of Underwater Bionic Thrusters With Different Transmission Methods";[268]

[262] Zhang Xin 张 欣, "'彩虹鱼'：中国深潜新利器" ["Rainbow Fish": China's New Deep Submersible Weapon], *People's Daily* Overseas Edition 人民日报外版, March 26, 2016, accessed July 8, 2016, http://www.people.gov.cn/rmrbhwb/html/2016-03/26/content_1664324.htm.

[263] "Deepsea Challenge," *National Geographic*, accessed August 29, 2016, http://www.deepseachallenge.com.

[264] Zhang Xin ["Rainbow Fish": China's New Deep Submersible Weapon].

[265] "Zhishui," NavalDrones, accessed July 8, 2016, http://www.navaldrones.com/Zhishui.html.

[266] Zhao Jiamin 赵加敏, Xu Yuru 徐玉如, and Lei Lei 雷磊, "用于水下机器人智能路径规划的仿真器的建立" (A Simulator for the Test of Intelligent Path Planning of AUV), *Journal of System Simulation* 系统方针学报 16, no. 11 (November 2004): 2448-2450.

[267] Li Jing 李婧, Chen Hao 陈浩, "军用 UUV 保障训练考核系统" (Training and Examining System about Military UUV Support), *Ordnance Industry Automation* 兵工自动化 31, no. 11 (2012): 1-5.

[268] Xu Haijun 徐海军, Pan Cunyun 潘存云, Zhang Daibing 张代兵, Xie Haibin 谢海斌, "不同水下仿生推进器性能影响的比较" (Comparative Study on the Propulsive Performance of Underwater Bionic Thrusters with Different Transmission Methods), *Machine Design and Research* 机械设计与研究 26, no.1 (February 2010): 93-96.

- "AUV Fault-Tolerant Technology Based on Inertial Navigation and Underwater Acoustics Assisted Navigation System";[269] and
- "The Research Status and Progress of Cooperative Navigation for Multiple AUVs."[270]

A recent espionage case could also indicate a need for more advanced components and electronics. As discussed on page 97, in June 2016, Yu Amin, AKA Amy Yu, pleaded guilty to acting in the United States as an illegal agent of a foreign government and obtaining systems and components from U.S. companies for marine submersible vehicles, likely including UUVs.[271] According to the indictment, one of Yu's co-conspirators was a professor and agent of HEU, and beginning in 2002 served as "…the Chief Technology Expert of a key PRC national research project concerning the development of an unmanned underwater vehicle (UUV)." From at least 2002 to approximately February 2014, Yu purchased and re-exported items to HEU, including underwater acoustic locator devices, underwater cables and connectors, PC104 computer processing units, 907 multiplexers, underwater pressure sensors, and control sticks and button strips.[272]

Leading Research and Production Entities

Chinese Academy of Sciences' Shenyang Institute of Automation (中科院沈阳自动化研究所)

The Chinese Academy of Sciences' Shenyang Institute of Automation (CAS SIA，中科院沈阳自动化研究所) in Shenyang, Liaoning Province, is a leading research institute and publisher on UUVs. Its Autonomous Underwater Vehicle Laboratory (自主水下机器人技术研究室) conducts research on all aspects of UUV technologies, including complicated environment recognition and pattern establishment, and advanced intelligence and autonomous behavior. It also researches platform designs (including analysis of designs, simulations, hydrodynamics, and structures), controller technologies, and various types of AUVs and USVs. It was responsible for China's first UUV, the CR-01, to reach a depth of 6,000 m.[273]

Harbin Engineering University (哈尔滨工程大学)

HEU's College of Shipbuilding Engineering (船舶工程学院) is home to the National Defense S&T Key Laboratory of Military-Use Underwater Intelligent Vehicle Technology (军用水下智能机器人技术国防科技重点实验室). [274] HEU was formerly known as the PLA Military

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[269] Zhang Tao 张 涛, Xu Xiaosu 徐晓苏, Li Yao 李 瑶, and Gong Shuping 宫淑萍, "基于惯导及水下声学辅助系统的 AUV 容错导航技术" (AUV Fault-Tolerant Technology Based on Inertial Navigation and Underwater Acoustics Assisted Navigation System), *Chinese Journal of Inertial Technology* 中国惯性技术学报 21, no. 4 (August 2014): 512-516.

[270] Xu Bo 徐博, Bai Jinlei 白金磊, Hao Yanling 郝燕玲, Gao Wei 高伟, and Liu Yalong 刘亚龙, "多 AUV 协同导航问题的研究现状与进展" (The Research Status and Progress of Cooperative Navigation for Multiple AUVs), *Acta Automatica Sinica* 自动化学报 41, no. 3 (March 2015): 445-459.

[271] Department of Justice, "Summary of Major U.S. Export Enforcement, Economic Espionage, Trade Secret and Embargo-Related Criminal Cases," 4.

[272] "United States of America v. Amin Yu," United States District Court Middle District of Florida Orlando Division, accessed July 8, 2016, https://www.justice.gov/usao-mdfl/file/843506/download.

[273] "自主水下机器人技术研究室" [Independent Underwater Robot Technology Research Lab], Shenyang Institute of Automation Chinese Academy of Sciences 中国科学院沈阳自动化研究所, accessed July 8, 2016, http://www.sia.cn/jgsz/kyxt/zzsxjqrjsysj/.

[274] The college's website describes the lab as "军用水下 xx 重点实验室" (Military-Use Underwater XX Key Laboratory), but author affiliations on articles include the full name of the lab. For example, see Ju Lei 鞠磊, Su

Engineering Institute, established in Harbin in 1953, and is currently an R&D base for China's shipbuilding industry, naval armaments, and ocean development and exploitation.[275] It has seven research institutes and multiple laboratories dedicated to shipbuilding and ocean engineering, and recruits leading foreign experts in these fields through China's 111 Plan, described in more detail in the Talent Acquisition section on page 102.[276] Key systems developed by HEU include the Zhishui series of AUVs, discussed on page 66.

Unmanned Surface Vehicles

Although some Chinese research institutes have made progress on USV systems, military strategists appear to have minimal interest in such systems. An explanation for this lack of interest could be China's maritime militia forces, an understudied component of Chinese naval forces.[277] This militia force comprises a large reserve of civilian mariners whom China can mobilize for a variety of missions. With this militia, China can deploy large numbers of smaller and distributed units which have, in the words of a garrison commander, "low sensitivity and great leeway in maritime rights protection actions."[278] China's maritime militia can conduct "support the front" (支前) missions, including medical rescue and retrieval of casualties, emergency repairs or refitting of vessels, cover and concealment operations, mine warfare, blockades, and in the future information and electronic warfare.[279] The U.S. Navy has already encountered this force in the 2009 *Impeccable* incident, during which a Chinese maritime militia unit harassed a U.S. surveillance ship. Assuming that this militia force can successfully continue to distribute more lethality, swarm and harass targets, and advance China's territorial claims, USVs will likely be viewed as a 'boutique' and redundant accessory.

Despite the lack of need for USVs, China has made advancements in this field, most notably with its Jinghai (精海) series. In July 2016 Xinhua reported on the progress of Jinghai-series models, developed under the leadership of Shanghai University's Unmanned Vessel Engineering Institute (上海大学无人艇工程研究院).[280] These activities included the following:

- In 2013 the Jinghai-1 USV accompanied a Chinese coast guard vessel around the Paracel and Spratly Islands in the South China Sea, completing topographical and hydrological surveys.[281] Prior reporting was limited to a 2013 report on an unnamed vessel in which the Ministry of Transportation was inspecting a "surface unmanned intelligent surveying

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Yumin 苏玉民, Zhao Jinxin 赵金鑫, Liu Yebao 刘业宝, and Cui Tong 崔桐, "船桨干扰定常空化性能数值模拟" (Steady Interaction Numerical Simulation of Cavitating Turbulent Flow between Ship Hull and Propeller), *Journal of Ship Mechanics 船舶力学* 6, no. 16 (2012).

[275] "学院简价" [College Introduction], College of Shipbuilding Engineering 哈尔滨工程大学船舶工程学院, accessed July 8, 2016, http://heusei.hrbeu.edu.cn/index.php?m=content&c=index&a=lists&catid=2.

[276] Li Xiaohua, "China to Undergo Brain Gain through Plan 111," China Internet Information Center 中国网, September 14, 2006, accessed July 8, 2016, http://www.china.org.cn/english/China/181075.htm.

[277] Andrew S. Erickson and Conor M. Kennedy, "China's Maritime Militia," unpublished paper hosted by the Center for Naval Analyses (CNA), accessed July 8, 2016, https://www.cna.org/cna_files/pdf/Chinas-Maritime-Militia.pdf.

[278] Ibid., 1.

[279] Ibid., 5.

[280] "无人艇：在江河湖海中展露身手" [Unmanned Vessel: Showing Skill in All Waters], Xinhua 新华社, July 7, 2016, accessed July 7, 2016, http://news.xinhuanet.com/2016-07/07/c_1119182583.htm.

[281] Ibid; "Unmanned ships deemed helpful in survey and patrol of South China Sea," *Global Times* 环球网, July 8, 2016, accessed July 9, 2016, http://www.globaltimes.cn/content/993071.shtml.

platform engineering prototype." The prototype reportedly could chart a course, had advanced stabilization features, and had a maximum of 18 knots.[282]

- In 2014 the Jinghai-2 accompanied the "Snow Dragon" (雪龙) on China's 31st expedition to the South Pole, conducting topography surveys. Shanghai University, the Donghai Navigation Safety Administration, and Qingdao Beihai Shipbuilding Heavy Industry Co., Ltd. jointly developed the model.[283]
- The Jinghai-3 uses a highly modularized design and the most advanced "intelligent obstacle avoidance guidance systems." Shanghai University developed the model and will deliver it to the State Oceanic Administration.[284]

Leading Research and Production Entities

Shanghai University Unmanned Vessel Engineering Research Institute (上海大学无人艇工程研究院)

Founded in 2010, this research institute is China's first research organization to focus on USVs and integrate the fields of machinery, control, communications, mechanics, materials, and computers.[285] The research institute produces the "Jinghai" series of USVs which include multiple different models, and it is currently working on development of the Jinghai-7.[286]

China Shipbuilding Industry Corporation (CSIC) 701st Research Institute (中国船舶重工集团公司 701 所 or 中船重工 701 所)

Also known as the China Ship Research and Design Center (中国舰船研究设计中心), the CSIC 701st Research Institute is the premier institution focusing on the research and design of warships and other naval vessels, and is a leader in air-independent propulsion (AIP) research.[287] The CSIC 701st Research Institute is one of several Chinese organizations competing in the manufacture and development of USVs.[288] Qingdao Beihai Shipbuilding Heavy Industry Co. Ltd. (青岛北海船舶

[282] Shen Wenmin 沈文敏 and Wang Shaoming 王绍明, "我国自行研发首艘无人测量艇诞生" [Our Country's Independently Developed First Unmanned Survey Vessel is Born], *People's Daily* 人民日报, June 5, 2013, accessed July 8, 2016, http://news.sciencenet.cn/htmlnews/2013/6/278700.shtm.
[283] "无人艇：在江河湖海中展露身手" [Unmanned Vessel: Showing Skill in All Waters], Xinhua 新华社, July 7, 2016, accessed July 7, 2016, http://news.xinhuanet.com/2016-07/07/c_1119182583.htm.
[284] Ibid.
[285] [Unmanned Vessel: Showing Skill in All Waters], Xinhua 新华社, July 7, 2016.
[286]Xie Yao 谢姚, "不经历风雨怎么见彩虹" [If You Don't Go Through the Storm, How Will You See the Rainbow], School of Mechatronic Engineering and Automation 机电工程与自动化学院, December 31, 2016, accessed July 8, 2016, http://old.auto.shu.edu.cn/Default.aspx?tabid=12022&ctl=Detail&mid=59127&Id=172263&SkinSrc=[L]Skins/jizi1/jizi1; [Unmanned Vessel: Showing Skill in All Waters], *Xinhua* 新华社, July 7, 2016.
[287] "首页" [Homepage], China Shipbuilding Industry Corporation 中国船舶重工集团公司, accessed July 8, 2016, http://www.csic.com.cn/.
[288] [Unmanned Vessel: Showing Skill in All Waters], *Xinhua* 新华社, July 7, 2016.

重工有限责任公司), a CSIC subsidiary, jointly develops the Jinghai series of USVs with Shanghai University.[289]

Unmanned Ground Vehicles

Unmanned ground systems (UGVs) are a priority in China's defense plans, but their deployment to date appears limited. UGVs encompass numerous vehicles that operate on land with a human operator or autonomously. They can execute military missions including combat, ordnance disposal, and transport. U.S. forces in Iraq and Afghanistan used UGVs such as TALON and Warrior "…to detect and defeat roadside bombs, gain situational awareness, detect chemical and radiological agents, and increase the standoff distance between Soldiers and potentially dangerous situations."[290]

Numerous Chinese civilian and defense companies, universities, and research institutes are developing UGVs and other unmanned ground systems. R&D on intelligent guidance for unmanned ground platforms is reported to receive support from China's 973 and 863 programs for high-technology development, as well as the Twelfth FYP of the General Armament Department (GAD).[291]

To spur these systems' development, in September 2016 the Chinese military will host the "2016 Leap Over Treacherous Paths" (跨越险阻 2016) contest. The contest will host five competitions for unmanned ground systems to simulate battle operations in different terrains and missions. The competition areas are rough terrain battlefield reconnaissance, rough terrain battlefield marching in formation, urban battlefield reconnaissance and search, transport in mountainous regions by bionic unmanned platforms, and transport in mountainous regions by non-bionic unmanned platforms. In 2014 the former GAD hosted the first such competition, which featured 21 vehicles from over ten research institutes. Teams from NUDT came in first and second place, a team from BIT came in third place, and a team from the PLA's Military Transportation University (军事交通学院) came in fourth place. It is unclear who will host the 2016 competition.[292]

Leading Entities and Trends

<u>China North Vehicle Research Institute (中国北方车辆研究所)</u>

In June 2014 the China North Vehicle Research Institute (中国北方车辆研究所), directly subordinate to the NORINCO Group, established the Weapons Unmanned Ground Vehicle R&D

[289] "北船承制无人艇获工博会创新金奖" [Qingdao Beihai Shipbuilding Heavy Industry Co. Manufactured Unmanned Vessel and Awarded Engineering Innovation Gold Medal], China Shipbuilding Industry Corporation 中船重工, December 28, 2015, accessed July 7, 2016, http://www.csic.com.cn/zgxwzx/zgcydt/314027.htm.

[290] Robert Karlsen and Bob Van Enkenvoort, "Heftier Unmanned Ground Vehicle Offers More Lifting, Hauling Strength," U.S. Army news item, June 4, 2013, accessed August 19, 2016, https://www.army.mil/article/104710. For more on TALON and other UGVs, see Peter W. Singer, *Wired for War: The Robotics Revolution and Conflict in the Twenty-First Century*, (New York: Penguin, 2009), 26-30.

[291] "北理工杨毅老师被授予第八届海淀区"十大杰出青年"称号" [Beijing Institute of Technology Professor Yang Yi Awarded the Eighth Haidian District "Ten Outstanding Youth" Title], Beijing Institute of Technology, accessed July 7, 2016, http://www.bit.edu.cn/xww/mtlg/105218.htm.

[292] "跨越险阻-2016"地面无人系统挑战赛等你来战！" [The 2016 Leap over Treacherous Paths Ground Unmanned Systems Competition Welcomes You to Come Compete!], *China Military Network* 中国军网, June 14, 2016, accessed July 7, 2016, http://www.81.cn/jmywyl/2015-02/27/content_6372686_5.htm.

Center (兵器地面无人平台研发中心). The center develops UGVs for military, police, security, defense industry, and commercial clients.[293] NORINCO Group's Deputy General Manager Yang Zhuo (杨卓), who spoke at the center's opening, said NORINCO was already working on a variety of unmanned ground vehicles for civilian and military use, and saw the center as a means to accelerate this work.[294]

The Weapons Unmanned Ground Vehicle R&D Center is reported to be developing the Chinese version of Big Dog, a rough-terrain robot with four legs developed by Boston Dynamics. Formally called the "Mountainous Four-Legged Bionic Mobile Platform" (山地四足仿生移动平台), the system can carry out transport, reconnaissance, attack, and search and rescue operations. Chinese media also colloquially refers to the system as "Big Dog" (大狗).[295]

Beijing Institute of Technology (BIT / 北京理工大学)

Beijing Institute of Technology (BIT) was established in 1940 focusing on science and technology, and is currently located in Beijing. One of BIT's missions is to support "national strategic needs" such as aerospace engineering, information technology, and mechanical engineering and automation. BIT is directly subordinate to MIIT and is part of China's national 211 and 985 projects, which are aimed at strengthening China's S&T capabilities at its universities.[296]

While no designated UGV program could be located for BIT, its success in the Leap Over Treacherous Paths contest and recent publications indicate a robust research program. Recent publications appear to focus on situational awareness and vision, operation when GPS signals are disrupted, and general autonomous operation in urban environments. Representative article titles include the following:

- "Research of Reconnaissance Technology about Reflector Based Vision for Unmanned Platform;"[297]

[293] Chen Yu 陈瑜，"兵器地面无人平台研发中心成立" [The Weaponry Ground Unmanned Platform R&D Center Is Established], *Science and Technology Daily* 科技日报, June 28, 2014.

[294] "中国兵器工业集团成立地面无人平台研发中心 为解放军研制无人作战车辆" [NORINCO Establishes Ground Unmanned Platform Research & Development Center to Develop Unmanned Combat Vehicles for the PLA], *Guanchazhe* 观察者, July 3, 2014, accessed July 7, 2016, http://www.guancha.cn/military-affairs/2014_07_03_243289_s.shtml.

[295] "BigDog–The Most Advanced Rough-Terrain Robot on Earth," Boston Dynamics; and Zhang Peng 张鹏 and Peng Kuang 彭况, "军网记者亲身体验中国军用机器人" [Chinese Military Network Reporters Personally Experience China's Military-Use Robots], China Military Network 中国军网, February 27, 2015, accessed July 7, 2016, http://www.81.cn/jmywyl/2015-02/27/content_6372686_5.htm.

[296] "学校简介" [School Introduction], March 26, 2013, accessed July 11, 2016, http://www.bit.edu.cn/gbxxgk/gbxqzl/xxjj/index.htm; "Welcome to Beijing Institute of Technology (BIT)" May 18, 2015, accessed July 11, 2016, http://english.bit.edu.cn/AboutBIT/GeneralInformation/index.htm.

[297] Wang Jian 王健, Zhang Zhenhai 张振海, Li Kejie 李科杰, Zhang Donghong 张东红, Li Jian 李剑, and Liu Xinyu 柳新宇, "无人车反射式全景视觉感知技术研究" (Research of Reconnaissance Technology about Reflector Based Vision for Unmanned Platform), *China Science Paper* 中国科技论文 10, no. 10 (May 2015): 1170-1173, 1183.

- “Window Constrained Markov Localization for Unmanned Ground Vehicle;”[298] and
- “System Design of Self-Driving in Simplified Urban Environments.”[299]

National University of Defense Technology (NUDT / 国防科技大学)
NUDT is under the dual leadership of the MOD and the Ministry of Education. The university was original founded as the Military Engineering Academy at Harbin in Heilongjiang Province, moved to Changsha, Hunan Province, and changed its name to NUDT in 1978. NUDT has numerous laboratories dedicated to technology development.[300] NUDT’s College of Mechatronic Engineering and Automation (机电工程与自动化学院) has a Department of Automatic Control (自动控制系), which conducts research on robotics, including guidance and controls.[301]

EOD Robotics Companies
Numerous Chinese defense companies and RIs have developed explosive ordnance disposal robots, including the Lingxi (灵蜥 or “quick lizard”) by the CAS Shenyang Institute of Automation, the Raptor EOD robot by the Beijing Bochuang Group (北京博创集团), the Snow Leopard-10 (雪豹-10) by China Aerospace Science and Industry Corporation (CASIC), and the uBot-EOD series by Shanghai HRSTEK Co., Ltd (上海合时智能科技有限公司).[302] It is unclear which of these models is in service.

Chinese Countermeasures against U.S. Unmanned Systems

As the United States pursues the Third Offset strategy and increases the use of unmanned systems in military operations, Chinese countermeasures against such systems are of particular concern. As China researches and deploys unmanned systems, military research institutes and the defense industry are also researching countermeasures against such systems. Authors of the 2013 *SMS* call for innovating countermeasures against UAVs, stealth aircraft, cruise missiles, carrier formations, and space-based platforms, as well as defenses against reconnaissance and surveillance, precision strikes, network attacks, outer space attacks, and new types of attacks.[303] Ongoing Chinese research into such countermeasures routinely use U.S. systems as examples and targets.

To counter U.S. unmanned systems, numerous publications assess ‘soft kill’ technologies, or non-kinetic means such as jamming and electronic countermeasures to degrade the system without destroying it. A consistent view is that if the unmanned system, such as a UAV, loses communications, guidance and navigation, different sensors, radar, and/or data link capabilities, it

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[298] Hu Yuwen 胡玉文, Jiang Yan 姜岩, Gong Jianwei 龚建伟, Xiong Guangming 熊光明, “应用于地面无人车辆的窗口约束马尔可夫定位” (Window Constrained Markov Localization for Unmanned Ground Vehicle), *Transactions of Beijing Institute of Technology* 北京理工大学学报 34, no. 4 (Apr. 2014): 353-357.
[299] Jiang Yan 姜岩, Zhao Xijun 赵熙俊, Gong Jianwei 龚建伟, Xiong Guangming 熊光明, and Chen Huiyan 陈慧岩, “简单城市环境下地面无人驾驶系统的设计研究” (System Design of Self-Driving in Simplified Urban Environments), *Journal of Mechanical Engineering* 机械工程学报 48, no. 20, (October 2012): 103-112.
[300] “学校概况” [Summary of the University], National University of Defense Technology 国防科技大学, accessed July 11, 2016, http://www.nudt.edu.cn/introduce.asp?classid=4.
[301] “自动控制系” (Department of Automatic Control), National University of Defense Technology, 国防科技大学, accessed July 11, 2016, http://www.nudt.edu.cn/ArticleShow.asp?ID=22.
[302] “排爆机器人” [Explosive Ordnance Disposal Robots], *百科 Baike*, accessed July 7, 2016, http://www.baike.com/wiki/%E6%8E%92%E7%88%86%E6%9C%BA%E5%99%A8%E4%BA%BA.
[303] Shou, *Science of Military Strategy*, 101.

will abort the mission and return to its base of operations. Spoofing the system (using false signals to confuse the system's radar) or concealing targets would have a similar effect.[304]

One of the most specific examples of this research is an article titled "Analysis of X-47B UCAS and Electronic Counter Measures," appearing in *Aerospace Electronic Warfare*, China's leading journal on electronic warfare that is published by CASIC's 8511 Institute. The authors assess the advantages and weaknesses of the system, the former including stealth technology, flexibility in operations it can execute, and the ability to carry out long-range precision strikes. The fundamental weakness, they argue, is that if the X-47B loses contact with controllers and/or is confused, its default is to return to base. Hence the proposed countermeasures include electronic interference to negate information collection capabilities, and deception and camouflage for targets. They also propose kinetic countermeasures such as air-based intercepts or obstacles (such as balloons), early warning aircraft and fighters with look-down/shoot-down capabilities,[305] and preemptively attacking the launch platform (such as an aircraft carrier).[306] If deployed, the totality of such countermeasures could test and severely degrade the ability the U.S. military's UAVs to operate in a contested environment, and the explicit proposal to attack launch platforms would risk escalation in any conflict.

Other publications discuss the vulnerability of U.S. systems, manned and unmanned, to losing GPS guidance, a capability targeted by other units in the PLA. Some analysts consider the U.S. Navy to be most vulnerable to the loss of space assets such as GPS satellites, claiming the loss of such systems would render an aircraft carrier "a turtle in a jar" (瓮中之鳖).[307] Another article in *Aerospace Electronic Warfare* from 2013 also argues that if satellite communications are lost, systems such as the Global Hawk would be unable to complete missions and be forced to return to base.[308]

These countermeasures are not just academic and could challenge the U.S. military's operations in the Western Pacific. In 2015 a U.S. press report claimed the PLA attempted to electronically jam a Global Hawk UAV operating over the South China Sea.[309] In 2014 Chinese authors emphasized the importance of network-electronic warfare with the example of Iran downing a U.S.

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304 Wu Xiaofang 吴晓芳, Tian Zhongcheng 田中成, and Liang Jingxiu 梁景修, "X-47B 无人空战系统及其对抗途径分析" (Analysis of X-47B UCAS and Electronic Counter Measures), *Aerospace Electronic Warfare* 航天电子对抗, vol. 29, no. 5 (2013): 11-13.

305 Look-down/shoot-down radar systems can detect, track, and guide a weapon at a target below the horizon seen by the radar. This technology is difficult because a radar pointed near the Earth's surface produce a large reflection that may overwhelm human operators and computing systems.

306 Ibid.

307 The Chinese equivalent of a "sitting duck." See Chen Baoquan 陈保权, Yang Guang 杨光, and Li Xuefeng 李学锋, "空间电子攻击的体系作战效用及发展对策" (Research on System Combat Effects and Develop Policy of Space Electronic Attack), *Aerospace Electronic Warfare* 航天电子对抗 28, no. 1 (2012): 11-13, 22-23.

308 Wu Zhijian 吴志建, Fang Shengliang 方胜良, and Wu Fuxiang 吴付祥, "高空无人机载 GPS/INS 系统干扰效能及对策研究" (Research on Interference Effectiveness Analysis of High-Altitude UAV Airborne GPS/INS System), *Aerospace Electronic Warfare* 航天电子对抗 2, no. 29 (2013): 16-19.

309 Gertz, Bill. "Chinese Military Using Jamming Against U.S. Drones–Global Hawk Targeted Over Disputed South China Sea Islands," *Washington Free Beacon*, May 22, 2015.

unmanned system by gaining access to the aircraft's navigation system.[310] With the increasing importance of UAVs and other unmanned systems to the U.S. military, Chinese research and capabilities for countermeasures will likely increase.

The emphasis on soft-kill or non-kinetic weapons and measures could indicate the strong desire of China's military planners to neutralize U.S. capabilities while avoiding escalation. Jamming and spoofing may achieve the operational effect of denying access to U.S. systems while avoiding crossing kinetic thresholds that may escalate into a broader conflict. U.S. defense planners should expect to see continued non-kinetic countermeasures against UAVs and other unmanned systems in peacetime, especially in regions such as the East and South China Seas.

[310] Wang Haoyu 王灏宇, Fan Hongshen 范宏深, and Zhao Guowei 赵国伟, "The Function Demand of Spacecraft by the Integration of the Net Electric for Space Warfare" (空间作战融合网电力量对航天器的功能需求), *Aerospace Electronic Warfare 航天电子对抗*, no. 5 (2014): 24-27.

Chapter Four: Artificial Intelligence

Artificial Intelligence (AI) is the computational science field of research that focuses on machine learning and smart decision-making. It is a major component of robotics R&D. This includes contributions from fields such as machine learning, natural language processing, pattern recognition, cluster algorithm improvement, and agent technology. China has seen the emerging field of AI applications as an opportunity for commercial start-ups and international partnerships. The development of AI technologies has broad applications for the manufacturing and service industries, and will largely determine the military effectiveness of unmanned systems.[311]

The key findings of this chapter are as follows:

- China is poised to enter a "golden age" for AI development based on government support for this research, growing public and commercial entity participation, and global partnerships that leverage the expertise of U.S. companies.
- China sees the developing field of AI as an opportunity to become more globally competitive in technological capabilities and commercial production, and the government has made developing these technologies and applications a national priority.
- Although Chinese researchers have published journal articles and news articles speculating on the likely uses of AI for enabling autonomous combat, there is little evidence of AI being applied to military-use systems. Even so, Chinese military institutions such as NUDT have invested in research on intelligent robotics.
- The development of AI products in China has been associated with the design of cloud computing platforms to support big data collection and processing.

Global and Chinese Interest in Artificial Intelligence

Recent developments have increased global interest in the progress and future prospects for AI, including in China. In March 2016, AlphaGo, an AI system designed by DeepMind (an AI lab in London owned by Google), made history by defeating the world's leading champion at the game Go. AlphaGo won four games to champion Lee Sedol's one, a feat not expected for another decade. The victory drew renewed international attention to AI, including in China, and established Google's reputation as a leader in AI development. Chinese media followed the event, and hinted at displeasure that it was a Western company and not a Chinese company that mastered the game invented in ancient China.[312]

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311 "《智能制造装备产业'十二五'发展规划》正式发布" ["Intelligent Equipment Manufacturing Industry 'Twelfth Five Year Plan' Development Plan" Formally Released], Wayrise Intelligent Tech. Co., Ltd. 上海维锐智能科技有限公司, November 19, 2012, accessed July 8, 2016, http://wayrise.com/index.php?_m=mod_article&_a=article_content&article_id=95.

312 "从 AlphaGo 和百度'四岁大脑'看人工智能未来" [Looking at the Future of AI from AlphaGo and Baidu's "Four Year Old Brain"], *Beijing Morning Post* 北京晨报, March 15, 2016, accessed August 19, 2016, http://www.nsfc.gov.cn/publish/portal0/tab92/info51906.htm; Du Yueying 杜悦英, "后 AlphaGo 时代"的中国人工智能路线图" [China's Artificial Intelligence Roadmap After the AlphaGo Era], *China Development Observation* 中国发展观察, accessed July 8, 2016, http://theory.people.com.cn/n1/2016/0607/c83865-28417972.html; and Cade Metz, "In Two Moves, AlphaGo and Lee Sedol Redefined the Future," *Wired*, March 16, 2016.

After AlphaGo's victory, the National Natural Science Foundation of China (NNSF), a leading government organization that funds Chinese scientific research in areas including AI, reposted a news article that posits three levels of AI: "weak person" (弱人) AI that can process specific tasks; "strong person" (强人) AI that can comprehensively simulate humans' thought processes; and "superhuman" (超人) AI that can quickly study, adapt, and surpass humans in all settings. Google has won the race towards the first benchmark of "weak person" AI by mastering a defined game with set parameters. Baidu founder and CEO Robin Li made clear that China is focused on the second level of AI, and claims that Baidu's AI has reached the capabilities of a three- or four-year-old child. Although that may not sound impressive, Li believes the capability to be state of the art, and that the next 5 to 10 years will be "a golden age for China's AI development."[313]

Chinese Government Support for AI Research

China's AI research receives support at the highest levels of Chinese leadership and policies. China's National Medium- to Long-Term Science and Technology Development Plan (2006-2020) lays out the government's priorities for S&T development for the future, and the section on robotics highlights the need for R&D of AI for use in intelligent robotics. This document emphasizes the need for technological development of personalized intelligent robots, robot-human interaction, and intelligent service robots.[314] The National Basic Science Development Five Year Plan (国家基础研究发展"十二五"专项规划) released in 2011 proclaimed brain and cognitive sciences, including AI, as a frontier science research priority for the following five years.[315] The growing number of AI research labs and partnerships (profiled below) indicate strong financial and political support, but major technical achievements of this plan could not be discerned.

The prioritization of state funding for AI research in China is done through its several national S&T programs, including the 863 Program, the 973 Program, and the NNSF. It is difficult to quantify specific funding amounts devoted to AI research within these programs, but the number of programs supporting this research indicate strong political and financial support. The scientists on the 863 Intelligent Robotic Technology Topic Expert Committee (智能机器人技术主题) guide the state-level research funding for the program, and this group is led by Zhao Jie (赵杰), the director of HIT Institute of Robotics (哈尔滨工业大学机器人研究所).[316] Other members of the expert committee are affiliated with BIT Key Laboratory of Intelligent Control and Decision of

313 "从 AlphaGo 和百度"四岁大脑"看人工智能未来" [Looking at the Future of AI from AlphaGo and Baidu's "Four Year Old Brain"], *Beijing Morning Post* 北京晨报, March 15, 2016, accessed July 8, 2016, http://bjcb.morningpost.com.cn/html/2016-03/14/content_390988.htm.

314 "五、前沿技术" [5. Front Line Technology], Xinhua 新华社, February 9, 2006, accessed July 8, 2016, http://www.gov.cn/jrzg/2006-02/09/content_183787_5.htm.

315 "国家基础研究发展'十二五'专项规划" [National Basic Research Development "Twelfth Five Year Plan" Special Programs], Ministry of Science and Technology of the People's Republic of China and the National Natural Science Foundation of China 中华人民共和国科学技术部 国家自然科学基金委员会, February 2012, accessed July 8, 2016, http://www.most.gov.cn/tztg/201206/W020120608514402969801.pdf.

316 "关于聘任"十二五"863 计划专家委员会和主题专家组专家的通知" [Notification Appointing "Twelfth Five Year Plan" 863 Program Experts Committee and Subject Experts Group Experts], Ministry of Science and Technology of the People's Republic of China, March 30, 2012, accessed July 8, 2016, http://www.most.gov.cn/tztg/201203/t20120330_93456.htm.

Complex Systems (复杂系统智能控制与决策实验室), CAS SIA, Shanghai Jiao Tong University, and Hunan University.[317]

National-level initiatives have also guided Chinese research toward advances in AI and cognitive science. The China Brain Project (中国脑计划) illustrates the Chinese government's emphasis on further understanding the human brain and how to imitate it through research on cognitive sciences such as AI, with applications for cognitive computing, robotics, and medicine.[318] The project was formed in 2015 as a response to U.S. and European national neuroscience and cognitive science initiatives and the need for China to gain competitiveness in the growing field.[319]

The Chinese government has recently made AI even more of a priority as a frontier technology to be developed indigenously through innovation and entrepreneurship. Premier Li Keqiang wrote welcoming remarks for the World Robot Conference (世界机器人大会) in Beijing in 2015, emphasizing the need to develop AI technologies through collaboration, entrepreneurship, and innovation.[320] As previously discussed on page 24, in November 2015, Xi Jinping listed "intelligent manufacturing and robotics" as one of the key priorities for China to achieve by 2030.[321] In January 2016, MOST Minister Wan Gang codified this research field as one of the "Science & Technology Innovation 2030 – Mega Projects" ("科技创新 2030——重大项目").[322]

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317 "黄强教授" [Professor Huang Qiang], Beijing Institute of Technology Key Laboratory of Intelligent Control and Decision of Complex Systems 北京理工大学复杂系统智能控制与决策国家重点实验室, November 7, 2013, accessed June 9, 2016, http://csicdgz.bit.edu.cn/xzdw/jq/27374.htm; "韩建达简介" [Han Jianda Introduction], Shenyang Institute of Automation Chinese Academy of Sciences 中国科学院沈阳自动化研究所, July 6, 2009, accessed June 9, 2016, http://www.sia.cas.cn/yjsjy/dsjj/bsds/mssb/200907/t20090706_2012286.html; "师资队伍概况" [Teacher Ranks Summary], School of Mechanical Engineering, Shanghai Jiao Tong University 机械与动力工程学院, accessed June 9, 2016, http://me.sjtu.edu.cn/sz_minglu/showDetail.aspx?cid=1&id=32; and "王耀南" [Wang Yaonan], College of Electrical and Information Engineering Hunan University 湖南大学电气与信息工程学院, November 30, 2013, accessed June 9, 2016, http://eeit.hnu.edu.cn/index.php/dsce/dcse-doctorial-tutor/24-2013-11-29-16-39-50.

318 Cui Xueqin 崔雪芹 and Huang Xin 黄辛, "'中国脑计划'酝酿启动 将从三大方向展开" ['China Computer Plan' Starts Brewing, Will Launch from Three Major Directions], ScienceNet 科学网, March 17, 2015, accessed July 8, 2016, http://news.sciencenet.cn/htmlnews/2015/3/315217.shtm.

319 "中国'脑科学计划'即将引领人工智能方向" [China "Computer Science Plan" On the Eve of Leading in the Direction of Artificial Intelligence], *Sina Science and Technology* 新浪科技, December 1, 2015, accessed July 8, 2016, http://www.shandongbusiness.gov.cn/public/html/news/201512/359272.html; "'中国脑计划'即将启动" ["China Computer Plan" About to Launch], *People's Daily* 人民日报, June 29, 2015, accessed July 8, 2016, http://paper.people.com.cn/rmrb//html/2015-06/29/nw.D110000renmrb_20150629_3-12.htm.

320 "习近平致信祝贺 2015 世界机器人大会在京开幕李克强也作出批示表示祝贺" [Xi Jinping Wrote Congratulations to the 2015 World Robot Conference in Beijing, Li Keqiang also Wrote Comments Expressing Congratulations], Xinhua Net 新华网, November 23, 2015, accessed July 8, 2016, http://cpc.people.com.cn/n/2015/1123/c64094-27845750.html.

321 "习近平 关于"中共中央关于制定国民经济和社会发展第十三个五年规划的建议"的说明" [Xi Jinping: Explanation of the 'Recommendations of the Party Center on the 13th Five-Year National Economic and Social Development Plan'], Xinhua, November 3, 2015, accessed July 7, 2016, http://news.xinhuanet.com/politics/2015-11/03/c_1117029621.htm.

322 "万钢：面向 2030 遴选启动航空发动机等一批科技创新重大项目" [Wan Gang: Facing 2030, Choices on Launching Aero-Engines and Other Science & Technology Innovation Megaprojects], Xinhua Net 新华网, March 8, 2016, accessed July 7, 2016, http://news.xinhuanet.com/fortune/2016-01/11/c_1117739527.htm.

The announcement called for an emphasis on "intelligent manufacturing and robotics" (智能制造和机器人) research.[323]

In May 2016, the National Reform and Development Commission (NRDC) announced the "Internet Plus" AI Three Year Implementation Plan ("互联网+"人工智能三年行动实施方案), which sets up Chinese rapid development of AI technologies and big data integration with cloud computing networks.[324] Foundational research areas promoted in this document include computer vision (计算机视觉), natural language processing (自然语言理解), intelligent decision control (智能决策控制), biometric recognition (生物特征识别), and intelligent voice processing (智能语音处理).[325] AI is also included as a central project in the Thirteenth FYP that guides S&T development until 2020.[326]

AI Trends in China

Cloud robotics (云机器人) is an emerging field that connects AI, data science, and computing technologies. The ability of AI to improve depends on the scalability of big data technology and cloud computing, which is an evident priority for China in the development of intelligent robots. Cloud service integration with robot data and software systems would allow intelligent robots to utilize remotely-stored data platform services. Simultaneous development of high-performance computing systems such as the Tianhe-2 and the Sunway TaihuLight supercomputers along with robotic mechanical manipulation give AI the potential to unleash smarter robotic devices that are capable of learning as well as integrating inputs from large databases.[327] Chinese start-up AI companies are integrating cloud services into their products in order to enhance the intelligent learning capabilities and human-machine interface of these devices. Examples of this in China include the three biggest IT companies in China—Baidu, Alibaba, and Tencent (collectively, "BAT")—and the development of cloud computing platforms to support each of their AI systems.[328]

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323 Ibid.

324 "'互联网+'人工智能三年行动实施方案印发" ["Internet+" Artificial Intelligence 3 Year Operation Implementation Program Published], *People's Post and Telecommunication* 人民邮电报, May 26, 2016, accessed July 8, 2016, http://news.xinhuanet.com/info/2016-05/26/c_135390662.htm; Du Yueying (杜悦英), "后 AlphaGo 时代"的中国人工智能路线图" [China's Artificial Intelligence Roadmap after the AlphaGo Era], *China Development Observation* 中国发展观察, accessed July 8, 2016, http://theory.people.com.cn/n1/2016/0607/c83865-28417972.html; "How Baidu, Tencent and Alibaba are leading the way in China's big data revolution," *South China Morning Post*, August 25, 2015, accessed July 8, 2016, http://www.scmp.com/tech/innovation/article/1852141/how-baidu-tencent-and-alibaba-are-leading-way-chinas-big-data.

325 "Internet Plus" Artificial Intelligence Three Year Implementation Plan," [互联网+"人工智能三年行动实施方案], Ministry of Industry and Information Technology of the PRC, accessed June 15, 2016, http://www.miit.gov.cn/n1146290/n1146392/c4808445/part/4808453.pdf.

326 "'中国脑计划'急需定好方向" ["China Computer Plan" Urgently Needs to Set a Good Direction], Shanghai Municipal Science and Technology Committee 上海市科学技术委员会, June 20, 2016, accessed July 8, 2016, http://www.stcsm.gov.cn/xwpt/kjdt/344990.htm.

327 Xing Linan 邢立楠, "中国超级计算机速度世界第一 军方参与芯片研制" [China Supercomputer Speed is World's First, Military Participated in Chip Development], China.com 中华网, June 22, 2016, accessed July 8, 2016, http://military.china.com/kangzhan70/zhjw/11173869/20160622/22920401_all.html.

328 "BAT 决战人工智能：百度全面开花，阿里注重赋能，腾讯闲敲棋子" [BAT Decisive Battle Artificial Intelligence: Baidu Fully Blossoms, Alibaba Emphasizes Formation, Tencent Leisurely Hits the Chess Pieces], *IT Times Online* IT 时代网, June 27, 2016, accessed July 9, 2016, http://www.ittime.com.cn/news/news_11662.shtml.

A major barrier to deep learning and AI is access to high-power computers and processors that are able to handle these tasks.[329] China is making tremendous investments, acquisitions, and progress in both capabilities that may facilitate its future breakthroughs in AI technology. In 2015 Baidu's Minwa supercomputer trained machine-learning software that set a new record for image recognition, beating previous records set by Google and Microsoft.[330] In June 2016 China's Sunway TaihuLight, which uses Chinese-designed processors, surpassed the Tianhe-2, a Chinese supercomputer with Intel chips, to become the world's fastest system at 93 petaflops. That same month, China also surpassed the United States to have the most supercomputing facilities in the world at 167, compared to 165 in the United States.[331] China's computing leaders are also aggressively seeking joint ventures with U.S. high-tech firms that facilitate technology transfers necessary for China's computing industry. Tsinghua Unigroup, China Electronics Technology Group Corporation (CETC), China Electronics Corporation (CEC), and the CAS enjoy Chinese political support and are signing deals with U.S. firms including HP, IBM, and Microsoft. Such deals facilitate China's access to expertise in mobile technology, storage, networking, ARM processors, and likely x86 chip technology.[332] These domestic improvements in supercomputing, combined with China's aggressive pursuit of foreign technology for its entire computing industry, may provide China with the hardware necessary for major advances in AI.

One of the major trends evident in the commercialization of AI technologies in China is the emergence of start-up companies that market AI household devices and chat platforms that are accessible to developers. These companies include Turing Robot, DFRobot, and Horizon Robotics, as well as companies focused on natural language processing and Chinese semantic processing such as iFLYTEK.[333] Chinese companies have shown a desire to become leaders in AI robotic technology to compete with Google and its AlphaGo AI system and Amazon's Web Services (AWS) Platform.[334] This competition has led to a push toward investment in existing companies abroad in addition to conducting their own R&D. In July 2015, Alibaba and Taiwanese firm

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329 Du Yueying (杜悦英), "后 AlphaGo 时代"的中国人工智能路线图" [China's Artificial Intelligence Roadmap after the AlphaGo Era], *China Development Observation* 中国发展观察, accessed July 8, 2016, http://theory.people.com.cn/n1/2016/0607/c83865-28417972.html.

330 Baidu researchers admitted that the team's submission procedures were not in accordance with the ImageNet Challenge guidelines, making a direct comparison to Google's and Microsoft's results more difficult. See Tom Simonite, "Baidu's Artificial-Intelligence Supercomputer Beats Google at Image Recognition," *MIT Technology Review*, May 13, 2015 (updated June 1, 2015), accessed August 19, 2016, https://www.technologyreview.com/s/537436/baidus-artificial-intelligence-supercomputer-beats-google-at-image-recognition/.

331 The leading U.S. supercomputer, Titan, has achieved 17.59 petaflops/s. See "Press Release: June 2016," Top 500, June 2016, accessed August 19, 2016, https://www.top500.org/news/new-chinese-supercomputer-named-worlds-fastest-system-on-latest-top500-list/.

332 Michael Kanellos, "With AMD Deal, China Has Everything It Needs In High Tech," *Forbes*, April 22, 2016, accessed September 2, 2016, http://www.forbes.com/sites/michaelkanellos/2016/04/22/with-amd-deal-china-has-everything-it-needs-in-high-tech/#2b8c02d9333e.

333 Eva Yoo, "You'll Have At Least One Robot by 2020: China Robotics Leaders" *Technode*, June 16, 2015, accessed July 8, 2016, http://technode.com/2015/06/16/entrepreneurs-look-robotics/.

334 Catherine Shu, "Alibaba's Cloud Computing Group Says Its New Artificial Intelligence Platform Is China's First" *TechCrunch*, August 25, 2015, accessed July 8, 2016, https://techcrunch.com/2015/08/25/aliyun-ai/.

Foxconn jointly invested 14.5 billion Yen in SoftBank, the major producer of Japanese robots.[335] Since this exchange, SoftBank's humanoid robot products have been expanded to the Chinese market by authorized distributor Tektronix.[336] Chinese semantic and natural language processing start-ups such as Xiaoi Robot and Turing Robot have started marketing products that integrate these robots with their own Chinese-language AI platforms.

Chinese AI Academic Research and Publications

In response to the government's recent initiatives to support AI R&D and commercialization, a broad range of Chinese national laboratories, university institutes, and companies have engaged in researching AI technologies and applications. The number of published Chinese journal articles increased from 1,834 in 2010 to 1,996 in 2012, and surged to 2,613 in 2015.[337] This upward trend matches global trends on AI publications, which reportedly have increased by 50 percent every five years from 1995 to 2010.[338]

Leading AI Companies, Professional and Research Associations, and Academic and Research Institutes

Based on market analyses, state plans, and corporate information, the following entities are considered the most influential for China's artificial intelligence industry. Leading entities receive longer introductions and analysis below, while all other important identified entities are included in Appendix III: Leading Artificial Intelligence Companies, Professional Associations, and Research Institutes in China.

Chinese Association for Artificial Intelligence (CAAI; 中国人工智能学会)

The main academic society for AI in China is the Chinese Association for Artificial Intelligence (CAAI; 中国人工智能学会).[339] CAAI is the only national-level professional society focused on scientific fields of research relating to AI in China.[340] It promotes academic exchange, publication, education, and research exhibition for the purpose of AI development in China.[341] CAAI was established in 1981 and is affiliated with Beijing University of Posts and Telecommunications.[342] Current CAAI leadership consists of experts from Chinese and foreign institutions, companies and

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[335] Emiko Jozuka, "Pepper, the 'Emotional Robot,' Sells Out in Under a Minute in Japan" *Motherboard*, June 22, 2015, accessed July 8, 2016, https://motherboard.vice.com/read/pepper-the-emotional-robot-sells-out-in-under-a-minute-in-japan.

[336] "公司介绍" [Company Introduction], NAO Robotics (NAO 机器人), accessed July 8, 2016, http://www.naorobotics.com/aboutus.asp.

[337] Information accessed at CNKI online academic journal database with subject search "人工智能" on July 11, 2016.

[338] Luke Muehlhauser and Jonah Sinick, "How Big is the Field of Artificial Intelligence? (initial findings)," blog post for the Machine Intelligence Research Institute, January 28, 2014, accessed September 6, 2016, https://intelligence.org/2014/01/28/how-big-is-ai/.

[339] "首页" [Home Page], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed July 8, 2016, http://www.caai.cn/.

[340] "中国人工智能学会简介" [Chinese Association for Artificial Intelligence Introduction] Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/index/id/2.html.

[341] Ibid.

[342] Ibid.

military organizations, including the emerging Chinese AI start-up Horizon Robotics (地平线机器人科技有限公司), the PLA General Staff Department (GSD), NUDT, National Defense University, and telecommunications corporation ZTE.[343]

CAAI established the China Intelligence Expo (中国智能博览会) and China Intelligent Industry Forum (中国智能产业高峰论坛), leads the National Intelligent Robot Innovation Alliance (全国智能机器人创新联盟), and organizes several academic competitions and other activities.[344] The society also sponsors the academic journal *CAAI Transactions on Intelligent Systems* (智能系统学报) and the *Robotics and Artificial Intelligence* (机器人与人工智能) book series.[345]

CAAI has 40 subcommittees focused on different fields within AI. These subcommittees include intelligent robotics, machine learning, natural language processing, discrete mathematics, intelligent control and management, knowledge engineering and distributed intelligence, smart medicine, intelligent agriculture, pattern recognition, bioinformation and intelligent life, and neural networks and computational intelligence. The subcommittees are chaired by expert scientists from a range of Chinese institutions, including universities, key laboratories, and government research institutes.[346]

CAAI is led by automation and AI expert Li Deyi (李德毅). English-language sources describe him as an academic and professor, but Chinese-language profiles also note that he is a Major General in the PLA. Author biographies in English-language textbooks co-authored by Li, as well as profiles on conference websites state that Li is affiliated with Tsinghua University in China, a member of the Chinese Academy of Engineering (CAE), and a member of the Euro-Asia International Academy of Science.[347] Chinese-language sources, however, include the fact that Li is a Major General (少将军衔), and deputy director, researcher, and doctoral advisor at the GSD 61st Research Institute (总参第六十一研究所), a PLA research organization that develops military training equipment including UAVs and simulation systems.[348] Li has worked on national

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343 "中国人工智能学会第七届理事会负责人名单" [Chinese Association for Artificial Intelligence Seventh Board Member Leadership Name List], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/detail/id/85.html; "中国人工智能学会 2016 副秘书长名单" [Chinese Association for Artificial Intelligence 2016 Vice-Secretary Name List], Chinese Association for Artificial Intelligence 中国人工智能学会. http://new.caai.cn/index.php?s=/Home/Article/detail/id/114.html.

344 "中国人工智能学会简介" [Chinese Association for Artificial Intelligence Introduction] Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/index/id/2.html.

345 Ibid.

346 "中国人工智能学会分支机构--览表" [Chinese Association for Artificial Intelligence Branch Organizations - Table], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/index/id/43.html.

347 Li Deren, Li Deiyi, and Wang Shuliang, *Spatial Data Mining: Theory and Application*, Springer-Verlag Berlin Heidelberg, 2015: xxvi; Li Deyi and Du Yi, *Artificial Intelligence with Uncertainty*, Chapman & Hall/CRC, 2008; "Plenary Speech," 3rd CIS & RAM on Cybernetics and Intelligent Systems Robotics, Automation, and Mechatronics, an IEEE conference, September 21-24, 2008, accessed June 9, 2016, http://www.cis-ram.org/2008/ple-spe.html.

348 "中国人工智能学会第七届理事会全体理事名单" [Chinese Association for Artificial Intelligence Seventh Board Member Full Board Name List], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed

defense electronics key engineering development projects, is deputy director of the All-Army Informatization Work Office (全军信息化工作办公室), and has been a member of the General Armament Department (GAD) Science and Technology Committee (总装备部科技委).[349]

China Robot Industry Alliance (CRIA; 中国机器人产业联盟)

Founded on April 21, 2013, CRIA is a non-profit organization consisting of 104 members that include companies, manufacturers, universities, research institutes, robotics associations, and government-sponsored organizations. The goal of CRIA is to serve as a cooperation platform for the industry, and thereby strengthen members' R&D capabilities, manufacturing, integration, application, customer services, education and training. It also organizes exhibitions and conferences, and works to expand robot applications in China. These goals are pursued with China's state industrial policies in mind, and CRIA tries to help organizations avoid redundant projects, facilitate the efficient use of resources, and popularize the application of robot technologies and products.[350]

There are 22 leading member organizations in CRIA, consisting of two director-level organizations, and 20 deputy director-level member organizations. Siasun (沈阳新松机器人自动化股份有限公司) and the China Machinery Industry Federation (CMIF; 中国机械工业联合会) lead CRIA, and the remainder are various tech and robotics companies, several of which are the China branches of foreign firms.[351] CRIA also has an experts committee (专家委员会). Including the director and three deputy directors, the experts committee consists of 25 members.[352] CRIA is headquartered at the China Machinery Industry Federation (CMIF; 中国机械工业联合会) in Beijing.[353]

Turing Robot (图灵机器人)

Turing Robot is a Chinese start-up that has developed and marketed AI products including robots, voice assistance, and chat robots. Turing Robot claims to have developed the leading Chinese

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June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/detail/id/16.html; “学会领导” [Association Leader], Chinese Institute of Command and Control 中国指挥与控制学会, accessed June 9, 2016, http://www.c2.org.cn/index.php?m=content&c=index&a=show&catid=21&id=87; “总参第六十研究所” [General Staff Department 61st Research Institute], *YingJieSheng.com* 应届毕业生网, accessed July 11, 2016, http://www.yjbys.com/mingqi/c8866.html.

[349] “学会领导” [Association Leader], Chinese Institute of Command and Control 中国指挥与控制学会, accessed June 9, 2016, http://www.c2.org.cn/index.php?m=content&c=index&a=show&catid=21&id=87; “专家介绍——李德毅” [Expert Introduction—Li Deyi], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed 9 June 2016, http://caai.cn/contents/108/1711.html.

[350] ”Introduction” China Robot Industry Alliance, accessed July 8, 2016, http://cria.mei.net.cn/English/introduction.asp.

[351] “中国机器人产业联盟成员” [China Robot Industry Alliance Members], China Robot Industry Alliance 中国机器人产业联盟, accessed June 9, 2016, http://cria.mei.net.cn/hyzx.asp.

[352] “专家委员会” [Experts Committee], China Robot Industry Alliance 中国机器人产业联盟, accessed June 9, 2016, http://cria.mei.net.cn/zjzl.asp.

[353] Ibid.

semantic language processing platform, Turing OS, which was developed in November 2015.[354] The platform boasts an accuracy rate as high as 95.1 percent and the company has provided services to over 150,000 developers and customers by publishing an open API platform.[355] Turing Robot uses cutting-edge natural language processing and semantic language analysis intelligent technologies to create robotic devices that are "friendly AI solutions."[356] Turing Robot sells the "Nao" robot, which the company markets as the world's most advanced humanoid robot.[357] Turing Robot also developed the "Hidi" voice assistant for HTC mobile phones, household robots, a QQ chat robot, and smart voice integration with Bosch vehicles.[358]

When Turing Robot came out with the "Xian'er" Buddha robot in early 2016, global media took note of the success of its AI platform that was able to converse with people.[359] Chinese media states that this robot and the Turing OS uses the Tianhe-2 supercomputer to integrate massive databases for its intelligent learning and processing system.[360] The growth in speed and capacity of China's supercomputers will likely enable more companies to create more capable AI platforms like "Xian'er."

According to Turing Robot founder Yu Zhichen (俞志晨), the application of AI to household robots is a real opportunity for China, since these types of products are only now starting to be commercialized globally.[361]

HIT Robot Group (HRG), Intelligent Cloud Robot Business Unit (哈工大机器人集团智能云机器人事业部)[362]

Founded in December 2014, HRG is a high-tech firm jointly established by the Heilongjiang provincial government, the Harbin municipal government, and the Harbin Institute of Technology.[363] HRG's focus is industrial robots, service robots, specialized robots, intelligent

354 "关于我们" [About Us], Turing Robot 图灵机器人, accessed June 9, 2016, http://www.tuling123.com/html/doc/About_us.html; "Turing OS" *Baidu Encyclopedia* 百度百科, accessed June 9, 2016, http://baike.baidu.com/item/Turing%20OS.

355 "图灵机器人发布 Turing OS:有情感 会思考 能交流" [Turing Robot Issued Turing OS: Has Emotion, Can Think, Capable of Communication], *Global Times Online* 环球网, November 11, 2015, accessed June 9, 2016, http://www.chinanews.com/cj/2015/11-09/7613545.shtml; "关于我们" [About Us], Turing Robot 图灵机器人, accessed June 9, 2016, http://www.tuling123.com/html/doc/About_us.html.

356 "Turing Robot" 图灵机器人, accessed June 9, 2016, http://www.tuling123.com/.

357 Ibid.

358 Ibid.

359 "龙泉寺贤二机器人成网红：第二代正在研发中" [Longquan Temple Xian Er Robot Goes Viral Online: Second Generation is in Development Now], *Sina* 新浪科技, April 21, 2016, accessed June 9, 2016, http://tech.sina.com.cn/it/2016-04-21/doc-ifxrpvcy4246627.shtml.

360 Song Yelei 宋业磊, "图灵机器人发 Turing OS 操作系统推儿童机器人玩具" [Turing Robot Issued turing OS Operating System Promoting Children's Robot Toy], *Phoenix* 凤凰网科技, November 6, 2015, accessed June 9, 2016, http://tech.ifeng.com/a/20151106/41502786_0.shtml.

361 Zhao Tingting, "Startup aims to place smart robots in every home" *The Telegraph*, December 7, 2015, accessed June 9, 2016, http://www.telegraph.co.uk/sponsored/china-watch/business/12033684/turing-home-robot-ceo-interview.html.

362 "智能云机器人事业部" [Intelligent Cloud Business Unit], HIT Robot Group 哈工大机器人集团, accessed July 8, 2016, http://www.hitrobotgroup.com/product/pro_list/6.

363 "哈工大机器人" [HIT Robots], HIT Robot Group 哈工大机器人集团, accessed July 11, 2016, http://www.hitrobotgroup.com/en/about?#about_02.

cloud robots, emerging intelligent equipment, intelligent plant projects and related technology transfer, and technical consulting and technology services.[364] HRG is headquartered in Harbin, has regional centers in Beijing, Shanghai, and Shenzhen, business bases in nine additional Chinese cities, and five overseas offices.[365] HRG has six business units: Smart Factory Business Unit, Industrial Robot Business Unit, Service Robot Business Unit, Special Robot Business Unit, Intelligent Equipment Business Unit, and Intelligent Cloud Business Unit. HRG uses five "brand" product lines to market the robots created by its business units: NOBODY, EVERYBODY, ROBOHIT, ZIWIROBOT, and E FLY.[366] HRG also has a ten-person consultant group of scientists, spanning what HRG claims to be the top Chinese scientists in robot research. They include academics, Changjiang scholars, Thousand Talents Plan finalists, and winners of various other premier science and technology-related awards.[367]

HRG's Intelligent Cloud Business Unit focuses on cloud computing applied to a wide variety of uses, including networking, Internet services, big data, artificial intelligence, pattern recognition, electromechanical integration, embedded data and information, physics fusion, service-oriented computing, robot motion control, power control, machine vision, location services, algorithm, data collection and analysis, and the identification and treatment of core control platforms.[368] Currently, its primary products are an Internet Plus product quality remote detection system, an intelligent flying robot for high-risk environments, and an intelligent cloud-based robot remote fault diagnosis system.[369] Established in March 2015 and located in Harbin, the division consists of 20 researchers, including one associate professor, four graduate students, and six doctoral students.[370]

Chinese Academy of Sciences (CAS) Institute of Intelligent Machines (IIM; 中国科学院合肥智能机械研究所)[371]

CAS IIM was founded on October 8, 1979, and is located on the eastern portion of Science Island in the Hefei Scientific Research Base. IIM's predecessor organization was the CAS East China Institute of Components and Instruments for Automation (中国科学院华东自动化元件及仪表

[364] Ibid.
[365] Ibid.
[366] "哈工大机器人" [HIT Robots], HIT Robot Group 哈工大机器人集团, accessed July 11, 2016, http://www.hitrobotgroup.com/en/about/service?#service_02.
[367] Ibid.
[368] Ibid.
[369] "Intelligent Cloud Business Unit," HIT Robot Group 哈工大机器人集团, accessed July 8, 2016, http://www.hitrobotgroup.com/en/product/product_show/11.
[370] "'互联网+机器人'产生中国的智能云质量检测系统" ['Internet + Robots' Produced Chinese Intelligent Cloud Quality Inspection System], *Science & Technology Review* 科技导报, accessed July 11, 2016, http://html.rhhz.net/kjdb/20152125.htm; "智能云质量检测系统："互联网+"理念再造 3000 万劳动力" [Intelligent Cloud Quality Inspection Systems: "Internet +" Idea Reuses Labor Force of 3000], HIT Robot Group 哈工大机器人集团, November 23, 2015, accessed July 11, 2016, http://www.hitrobotgroup.com/product/pronews_show/26.
[371] "所况简介" [General Introduction], Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://www.iim.cas.cn/skjs/skjj/.

研究所), established in 1962. IIM employs 213 personnel[372] and 24 research fellows,[373] focuses on artificial intelligence and sensor technology, and consists of four research branches: the Research Center for Biomimetic Sensing and Control, the Research Center for Biomimetic Functional Materials and Sensing Devices, the Research Center for Intelligent Information Systems, and the Research Center for Information Technology of Sports and Health.[374] IIM also stresses the importance of technology transfer and states that it "is the center source of the transformation and industrialization of the research products."[375]

IIM further boasts its dedication to "national critical scientific areas" that include biomimetic sensing, information acquisition, digital agriculture intelligence system, intelligent detection and control and micro-nano technology. It has completed nearly one thousand research projects through funding from the Natural Science Foundation of China (NSFC), the National 863 and 973 Programs, and the International Science and Technology Cooperation Program, and has won numerous awards for this work.[376]

IIM also collaborates with the University of Science and Technology of China, the Hefei Institute of Physical Science, and Anhui University, currently supporting 200 students pursuing graduate degrees in Pattern Recognition and Intelligent Systems, Instrumentation Technology and Automatic Devices, Precision Instrument and Machine and Information Acquisition and Control.[377]

Military AI Applications

AI has many potential applications for the military, including smart weapons, intelligent unmanned vehicles, and autonomous robotic soldiers. Much of the Chinese academic literature discussing military possibilities for AI technology has been largely abstract and speculative, and a majority of it references or focuses on DARPA's activities. The literature focusing on U.S. AI development ranges from forward looking pieces that cite U.S. academics in deep learning and AI,[378] to claims that the superiority of Chinese radar systems is forcing DARPA to create AI technologies to

[372] "Faculty and Staff," Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://english.iim.cas.cn/pe/fs/.
[373] "Research Fellow," Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://english.iim.cas.cn/pe/as/.
[374] "Brief Introduction," Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://english.iim.cas.cn/au/bi/.
[375] Ibid.
[376] Ibid.
[377] Ibid.
[378] Li Mi 李宓, "展望 2016，人工智能会做哪些事" [2016 Outlook, What Artificial Intelligence Will Do], *PLA Daily* 解放军报, January 4, 2016, accessed July 8, 2016, http://military.people.com.cn/n1/2016/0104/c172467-28006683.html.

counter it,[379] to prospective developments of AI in smart missile applications,[380] to a detailed analysis of the role AI will play in U.S. military strategy.[381]

An article published by NUDT in January 2016 titled "The Dawn of a Military Revolution in "Intelligentization" - Deciphering the Military Technology Development Trajectory in the U.S. "Third Offset Strategy"" includes a detailed survey of U.S. military AI applications, noting that the U.S. focus and investment into military applications for AI is rapidly increasing. From this survey and analysis, the author speculates that as a result of these developments, AI technologies will inevitably replace IT as the leading technology in military development. This is attributed not only to the fact that AI and IT are both widely used technologies in society, but because the development of AI is built on the foundation of IT and is vastly superior.[382]

Partnerships with U.S. Companies

Leading Chinese tech companies are making a concerted push to learn from the U.S. in the field of AI through strategic partnerships and initiatives. In 2011, Baidu founded its Baidu Silicon Valley AI Lab (SVAIL; 百度美国硅谷研发中心). In November 2015, the CAS formed its Artificial Intelligence and Advanced Computing Joint Lab (人工智能与先进计算联合实验室) with Dell. Located in Sunnyvale, CA, SVAIL focuses on fundamental research into next-generation infrastructure that will enable AI researchers to express their networks in computer code and train them on clusters of GPU's, with support from Baidu's Deep Learning Lab in Beijing. Similarly, the Beijing-based CAS-Dell AI lab focuses on developing advanced technologies relating to cognitive systems and deep learning.[383] Both partnerships are detailed below.

Baidu Silicon Valley AI Lab (SVAIL; 百度美国硅谷研发中心)

Baidu has expanded its AI research into California's Silicon Valley, giving its lab access to leading personnel with experience at top U.S. technology firms. Founded in 2011, the Baidu Silicon Valley AI Lab (SVAIL; 百度美国硅谷研发中心) is one of three research labs under Baidu Research, along with the Beijing Deep Learning Lab (百度深度学习实验室), formerly known as the Institute of Deep Learning, and the Beijing-based Baidu Big Data Lab (百度大数据实验室).[384]

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379 "解放军让 F22'摸瞎'后美国红了脸：将用人工智能对抗中国雷达" [U.S. Blushing after the PLA F22 "Fumble": Using Artificial Intelligence to Counter China's Radar], NetEase 网易, accessed July 8, 2016, http://dy.163.com/wemedia/article/detail/BH3MQLPU05158T9V.html.

380 Guan Shiyi 关世义, "导弹智能化技术初探" (Some Discussions about Smart Missile), *Tactical Missile Technology* 战术导弹技术, no. 4, (July 2004), 1-7.

381 Pang Hongliang 庞宏亮, "智能化军事革命曙光初现——从美'第三次抵消战略'解读军事技术发展轨迹" [The Smart Military Revolution Is Dawning–Interpreting the Track of Military Technology Development from the U.S. "Third Offset Strategy"], *PLA Daily* 解放军报, January 28, 2016, accessed May 10, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm.

382 Ibid.

383 Jack Clark, "Dell Expands in China with Venture Group, Creates AI Lab," *Bloomberg Technology*, September 9, 2015, accessed July 8, 2016, http://www.bloomberg.com/news/articles/2015-09-10/dell-expands-in-china-with-venture-group-creation-of-ai-lab; Mark Hanrahan, "Dell Inc Announces $125B Investment In China, Including Artificial Intelligence Lab," *International Business Times*, September 10, 2015, accessed July 8, 2016, http://www.ibtimes.com/dell-inc-announces-125b-investment-china-including-artificial-intelligence-lab-2090481.

384 Baidu, Inc., "Baidu Opens Silicon Valley Lab, Appoints Andrew Ng as Head of Baidu Research", PR Newswire, May 16, 2014, accessed June 24, 2016, http://www.prnewswire.com/news-releases/baidu-opens-silicon-valley-lab-

SVAIL is led by Andrew Ng, chief scientist and head of Baidu Research, and co-founder and chairman of the board of Coursera.[385] Ng previously worked on deep learning at Google, giving him experience working on AI applications at a top corporation.[386] Kai Yu of Baidu's Deep Learning Lab has stated that SVAIL's purpose is to focus on fundamental research, while the Deep Learning Lab will continue to target applications of deep learning to new and existing Baidu products.[387] Statements from key personnel in a promotional video for the lab reveal more details on what SVAIL would like to accomplish:[388]

Bryan Catanzaro, Systems Research Scientist: "We're focused on building the next generation infrastructure that will help AI researchers productively express their networks in computer code, and then efficiently train them on clusters of GPU's. So we're using technologies like MPI and CUDA to make that happen."

Carl Case, Machine Learning Research Scientist: "In particular, we're focusing on a class of techniques known as deep learning. These are models that take advantage of a huge amount of data and a lot of computing power to give much better results than people have seen before."

Baidu stated in May of 2014 that it will invest USD 300 million in the Silicon Valley lab over five years. The staff had grown to 100 personnel as of 2015.[389]

Dell and the Chinese Academy of Sciences (CAS; 中国科学院)

In September 2015, Dell announced that together with the CAS it would jointly establish the "Artificial Intelligence and Advanced Computing Joint Lab" (人工智能与先进计算联合实验室). The plan accompanied Dell's announcement that it would "invest $125 billion in China over the next five years, contributing $175 billion to imports and exports, sustaining one million jobs through the ecosystem and demonstrating its long-term commitment to the Chinese market."[390]. The Dell-CAS lab will focus on developing advanced technologies relating to cognitive systems

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appoints-andrew-ng-as-head-of-baidu-research-259539471.html; Di Wenting 翟文婷, "起底百度美国研发中心," [Breaking Ground on the Baidu-U.S. R&D Center], Sina S&T 新浪科技, February 3, 2015, accessed June 24, 2016, http://tech.sina.com.cn/i/2015-02-03/doc-iawzunex9713856.shtml.

[385] Tammy Parker, "Baidu's Silicon Valley R&D center targets deep learning," FierceWirelessTech, May 18, 2014, accessed June 24, 2016, http://www.fiercewireless.com/tech/story/baidus-silicon-valley-rd-center-targets-deep-learning/2014-05-18.

[386] Ibid.

[387] Ibid.

[388] "Welcome to SVAIL" Baidu Research, accessed June 24, 2016, http://research.baidu.com/silicon-valley-ai-lab/.

[389] Paul Mozur and Rolfe Winkler, "Baidu to Open Artificial-Intelligence Center in Silicon Valley: Former Stanford, Google Researcher Will Lead Efforts at $300 Million Facility," *Wall Street Journal*, May 16. 2014, accessed June 24, 2016, http://www.wsj.com/articles/SB10001424052702304908304579565950123054242; Di Wenting 翟文婷, "起底百度美国研发中心" [Breaking Ground on the Baidu-U.S. R&D Center], Sina S&T 新浪科技, February 3, 2015, accessed June 24, 2016, http://tech.sina.com.cn/i/2015-02-03/doc-iawzunex9713856.shtml; and Tammy Parker, "Baidu's Silicon Valley R&D center targets deep learning," FierceWirelessTech, May 18, 2014, accessed June 24, 2016, http://www.fiercewireless.com/tech/story/baidus-silicon-valley-rd-center-targets-deep-learning/2014-05-18.

[390] "Dell Announces Its New "In China, For China" Strategy to Support Job Creation; Propel Entrepreneurship and Innovation," press release by Dell, September 10, 2015, accessed September 29, 2016, https://www.dell.com/learn/us/en/vn/press-releases/2015-09-14-dell-announces-its-new-in-china.

and deep learning.[391] Michael Dell, founder and chief executive officer of Dell, left no room for speculation as to what this partnership will mean and likely accomplish for the PRC, having stated at the investment announcement that, "Dell will embrace the principle of 'In China, for China' and closely integrate Dell China strategies with national policies in order to support Chinese technological innovation, economic development and industrial transformation."[392]

The lab quickly announced the creation of an "enterprise-level deep learning computing and service platform" (人工智能与先进计算联合实验室).[393] Speaking to this, Xu Bo (徐波), director of the CAS Institute of Automation (中国科学院, 自动化所), said, "CAS has built an artificial intelligence ecosystem, including theoretical innovation, core science and technology, and technology to application transfer, achieving a series of breakthroughs in recent years," and that "Dell has provided CAS R&D with an advanced computing platform."[394]

On the progress of the joint lab, Huang Chenhong (黄陈宏), president of Dell China, told reporters in May 2016 that the joint lab is operating extremely well, and that "Dell and CAS creating the deep learning platform together is only the first step. Next, we will bring new technologies and new algorithms to businesses."[395]

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[391] "戴尔大中华区总裁黄陈宏：未来五年，戴尔将在中国投入 1250 亿美元" [Dell China Regional President Huang Chenhong: Next Five Years Dell Will Invest $ 125,100,000,000 in China], Global Times Online 环球网, March 12, 2016, accessed June 24, 2016, http://china.huanqiu.com/article/2016-03/8694357.html; Mark Hanrahan, "Dell Inc Announces $125B Investment In China, Including Artificial Intelligence Lab" *International Business Times*, September 10, 2015, accessed July 8, 2016, http://www.ibtimes.com/dell-inc-announces-125b-investment-china-including-artificial-intelligence-lab-2090481; and Jack Clark, "Dell Expands in China With Venture Group, Creates AI Lab" *Bloomberg Technology*, September 9, 2015, accessed July 8, 2016, http://www.bloomberg.com/news/articles/2015-09-10/dell-expands-in-china-with-venture-group-creation-of-ai-lab.

[392] Jack Clark, "Dell Expands in China With Venture Group, Creates AI Lab" *Bloomberg Technology*, September 9, 2015, accessed July 8, 2016, http://www.bloomberg.com/news/articles/2015-09-10/dell-expands-in-china-with-venture-group-creation-of-ai-lab.

[393] "中国科学院与戴尔开拓智能科技研发新领域" [Chinese Academy of Sciences and Dell Break New Territory in Intelligent S&T R&D], *China News* 中国新闻, May 26, 2016, accessed July 8, 2016, http://www.chinanews.com/it/2016/05-26/7884607.shtml.

[394] Ibid.

[395] Ibid.

Chapter Five: Nanorobotics

China has prioritized nanotechnology on the national level through national plans and government-supported research funding, leading to considerable research on nanorobotics. Nanorobotics focuses on the construction and manipulation of automated devices on the nanoscale (10^{-9} meters).[396] This definition covers automated functional machines called nanorobots or nanobots (纳米机器人), nanomachines (纳米机械人), molecular robots (分子机器人), and nanoscale mechanical manipulation to construct devices (纳米操作).[397] Nanorobots can be composed of multiple types of materials, most frequently carbon nanotubes, graphene, or other molecular components such as DNA. Nanorobot components can include microelectromechanical systems (MEMS) such as piezoelectric nanogenerators (压电式纳米发电机) that would provide self-sustaining power to nanoscale devices, and nanoscale biosensors that can be used to detect environmental variables.[398]

The key findings of this chapter are as follows:

- Chinese scientists have made major research accomplishments on nanorobotics technologies. Starting with the development of China's first nanomanipulation system in 2005, Chinese researchers at academic and government institutions have developed molecular nanorobotics systems and devices.
- Chinese journals and other media identify promising civilian applications for nanotechnology in medicine (such as diagnostics), computing, energy, environment (such as oil spill remediation), and industry, while defense applications could include advanced sensors, UAVs, and "micro spy" robots.
- There is very little evidence of the Chinese military applying nanorobotics technologies.

Trends in Nanorobotics Research and Applications

The global market for nanorobots is expected to reach USD 75 billion by 2020, according to recent estimates by NewGen Capital, a venture capital firm based in Silicon Valley.[399] The main application for these types of devices is for drug delivery and manufacturing and medical procedures, as well as nanoscale molecular motors for powering and mobilizing these devices.[400] In 2004, the 863 national funding program supported the development of the "OMOM" nanorobot endoscopy capsule, a camera device designed for internal medical imaging.[401] Chinese researchers

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396 "Nanorobotics," Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO), April 1, 2011, accessed July 11, 2016, http://english.sinano.cas.cn/rs/psk/201104/t20110401_67216.html.

397 Often written as "奈米机器人" in Taiwan.

398 Han Bingchen 韩秉宸, "安装在鞋底的纳米发电机有望成为现实" [Nanogenerator Installed at Sole Promising Turn into Reality], *People's Daily* 人民日报, July 29, 2013, accessed July 11, 2016, http://scitech.people.com.cn/n/2013/0729/c1007-22357576.html.

399 "硅谷 VC 重心转向前沿科技：纳米机器人市场 2020 年将达 758 亿美元" [Silicon Valley VC Shift to Cutting-Edge Technology: Nanorobot Market Will Reach 75.8 Billion USD by 2020], Eastmoney.com 东方财富网, June 27, 2016, accessed July 11, 2016, http://finance.eastmoney.com/news/1670,20160627637199290.html.

400 "纳米机械人——展望未来医疗" [Nanomachines—Future Outlook for Medicine], Chinese Academy of Sciences, March 13, 2002, accessed July 11, 2016, http://www.cas.cn/xw/zjsd/200906/t20090608_640243.shtml.

401 "纳米机器人钻进肚子治病 技术全球领先" [Nanorobot Gets into Stomach for Treatment, Treatment is First in the World], Luohe Central Hospital 漯河市中心医院. http://www.lhzxyy.com.cn/View.aspx?BillID=2179.

have also worked on nanorobot applications for oil spill remediation.[402] Another promising application for nanorobots is their use in nanoscale computing.[403]

One of the major challenges faced by developers of nanorobots is the construction of advanced sensors and electrical components that are able to function at nanoscale.[404] In addition, nanorobotics research is often partnered with research on the application of cloud computing technologies that are able to synthesize information from multiple sources and allow swarms of nanorobots to act accordingly.[405] The field of nanorobotics for medicine brings together developments in AI and DNA sequencing and assembly technology.[406] Similarly, the expansion of network technologies is key to the advancement of nanorobotics.[407] In addition, nanoscale power generation through nanogenerators has wide applications in the self-powering of nanobots in the body for medical purposes, and research addresses the technical challenges of energy storage and generation for nanoscale devices.[408]

Chinese Government Support for Nanorobotics Research

Many facets of Chinese nanorobotics research have been guided by national strategic plans. The Medium- to Long-Term Plan emphasizes nanotechnology strategic developments including nanorobotics-related fields such as nanomanipulation and nanodevices, intelligent materials and nanofabrication, and assembly technologies.[409] The National 863 Foundation has designated committees of experts to guide the prioritization of research funding. The Twelfth FYP included expert groups for both micro/nano-manufacturing technology (微纳制造技术) and nanomaterials and device technology (纳米材料与器件技术), led by some of the top Chinese experts on MEMS, sensors, and nanomaterials.[410]

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402 "纳米机器人 （小型机器人）" [Nanorobot (Small-Scale Robot)], *Baidu Encyclopedia* 百度百科, accessed July 11, 2016, http://baike.baidu.com/subview/95093/16805167.htm; "发展机器人产业 布局中国制造'工业 4.0'" [Development of Robotics Industry Lays Out Made in China "Industry 4.0"], China Trade News 中国贸易新闻网, December 1, 2015, accessed July 11, 2016, http://shengwuyiliao.juhangye.com/201512/news_4711067.html.

403 "纳米技术" [Nanotechnology], Ministry of Science and Technology (MOST), July 24, 2001, accessed July 11, 2016, http://www.most.gov.cn/kxjspj/gzkp/200702/t20070201_40778.htm.

404 "发展机器人产业 布局中国制造'工业 4.0'" [Development of Robotics Industry Lays Out Made in China "Industry 4.0"], China Trade News 中国贸易新闻网, December 1, 2015, accessed July 11, 2016, http://shengwuyiliao.juhangye.com/201512/news_4711067.html.

405 Ibid.

406 "硅谷 VC 重心转向前沿科技：纳米机器人市场 2020 年将达 758 亿美元" [Silicon Valley VC Shift to Cutting-Edge Technology: Nanorobot Market Will Reach 75.8 Billion USD by 2020], Eastmoney.com 东方财富网, June 27, 2016, accessed July 11, 2016, http://finance.eastmoney.com/news/1670,20160627637199290.html.

407 "发展机器人产业 布局中国制造'工业 4.0'" [Development of Robotics Industry Lays Out Made in China "Industry 4.0"], China Trade News 中国贸易新闻网, December 1, 2015, accessed July 11, 2016, http://shengwuyiliao.juhangye.com/201512/news_4711067.html.

408 Wang, Zhong Lin, "Self-Powered Nanotech," *Scientific American*, January 2008, accessed July 11, 2016, https://www.cs.virginia.edu/~robins/Self_Powered_Nanotech.pdf.

409 "五、前沿技术" [5. Front Line Technology], *Xinhua* 新华社, February 9, 2006, accessed July 8, 2016, http://www.gov.cn/jrzg/2006-02/09/content_183787_5.htm; "六、基础研究" [Basic Research], part of "国家中长期科学和技术发展规划纲要 (2006-2020)" [National Medium- and Long-Term Plan for the Development of Science and Technology (2006-2020)], State Council of the People's Republic of China, accessed July 6, 2016, http://www.gov.cn/jrzg/2006-02/09/content_183787_6.htm.

410 "关于聘任"十二五"863 计划专家委员会和主题专家组专家的通知" [Notification Appointing "Twelfth Five Year Plan" 863 Program Experts Committee and Subject Experts Group Experts], Ministry of Science and

The Chinese government has placed high priority on the indigenous development of nanotechnology, and this emphasis has influenced nanorobotics research due to its promising applications for medicine, computing, energy, environment, industry, and defense.[411] As part of this strategic push for development of the industry, China has established nanotechnology regional research centers, science parks, and R&D platforms.[412] Nanotechnology was singled out in the Twelfth National Basic Science Development Five Year Plan (国家基础研究发展“十二五”专项规划) in 2011[413] and as a key scientific research area in the Nano Research National Key Major Scientific Research Plan (纳米研究国家重大科学研究计划"十二五"专项规划) in 2012.[414] These plans also highlighted the important applications for nanotechnology and called for research in related areas including MEMS, sensors, and nanodevices and nanosystems.[415]

While the Made in China 2025 initiative does not specifically target nanorobotics as a field of strategic research and technology development, it does cover some of the common components of nanorobotics and nanomanipulation systems such as nanomaterials, sensors, and control systems.[416] Likewise, the Robotics Industry Development Plan 2016-2020 (机器人产业发展规划) does not specifically target the nanorobotics subfield, but lists research priorities such as sensors and high-performance control systems.[417]

Technology of the People's Republic of China 中华人民共和国科学技术部, March 30, 2012, accessed July 8, 2016, http://www.most.gov.cn/tztg/201203/t20120330_93456.htm; “陈大鹏” [Chen Dapeng], Hefei University of Technology School of Chemistry and Chemical Engineering 合肥市合肥工业大学化学与化工学院, accessed July 12, 2016, http://hgxy.hfut.edu.cn/website/index.php/cn/about-us/classmate/item/95; “黄庆安” [Huang Qing’an], Southeast University 东南大学, July 25, 2007, accessed July 12, 2016, http://www.seu.edu.cn/20/8a/c76a8330/page.htm; “刘胜 简介” [Liu Sheng Introduction], Chinese Journal of Sensors and Actuators 传感技术学报, accessed July 12, 2016, http://j.chinatransducers.com/Web/BwJianJie.aspx?id=24; “陈建峰——纳米材料专家” [Chen Jianfeng—Nanomaterials Expert], China Science & Technology Innovation Net 科技创新网, accessed July 12, 2016, http://www.zgkjcx.com/Article/ShowArticle.asp?ArticleID=14051.

411 “纳米研究国家重大科学研究计划‘十二五’专项规划” [Nano Research National Scientific Research Project “Twelfth Five Year Plan” Special Project Plan], Bioon News. June 21, 2012, accessed July 11, 2016, http://www.bioon.com/trends/law/526288.shtml.

412 Ibid.

413 “国家基础研究发展‘十二五’ 专项规划” [National Basic Research Development “Twelfth Five Year Plan” Special Project Plan]. Ministry of Science and Technology (MOST), accessed July 11, 2016, http://www.most.gov.cn/tztg/201206/W020120608514402969801.pdf.

414 “纳米研究国家重大科学研究计划‘十二五’专项规划” [Nano Research National Scientific Research Project “Twelfth Five Year Plan” Special Project Plan], June 21, 2012, Bioon News, accessed July 11, 2016, http://www.bioon.com/trends/law/526288.shtml.

415 Ibid.

416 “国务院关于印发《中国制造 2025》的通知” [State Council Releases “Made in China 2025” Announcement], May 8, 2015, accessed July 11, 2016, http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm.

417 “机器人产业发展规划（2016-2020 年）发布” [Robotics Industry Development Plan (2016-2020) Release], accessed July 11, 2016, http://www.sdpc.gov.cn/zcfb/zcfbghwb/201604/t20160427_799898.html.

Military Applications for Nanorobotics

For years, Chinese media has speculated on the military applications of micro and nanoscale robots, but little evidence of progress toward these cutting-edge technologies can be found. News outlets have followed press releases from U.S. organizations such as NASA and DARPA, announcing the investments made and research developments.[418] Although Chinese researchers from military organizations have published research on the promises of nanorobots for medical applications, there has been little visible progress. Suggested military applications in popular media include "smart dust" nanosensors, nanoscale UAVs, medical nanorobots, and nanoscale "micro spy" robots.[419]

Leading Chinese Nanorobotics Professional Associations, Research Institutes, and Companies

Many academic and government research institutes have investigated the design and construction of nanorobotics devices and related components. The organizations publishing the most in Chinese academic literature since 2010 include Hefei University of Technology, CAS Shenyang Institute of Automation (SIA), and CAS Institute of Intelligent Machines (IIM).[420] These research organizations frequently publish in international journals and collaborate with researchers abroad. Below is a profile of CAS SIA, while information on other leading Chinese institutions for nanorobotics may be found in Appendix IV: Leading Chinese Nanorobotics Institutions.

CAS Shenyang Institute of Automation (SIA; 中国科学院沈阳自动化研究所)

SIA has made the most significant research progress in micro- and nanorobotics and nanomanipulation in China. Founded in 1958, SIA is a government-funded institution that is a leader in advanced research on fields of robotics, automation, and electronics.[421] SIA has ten research departments and ten key laboratories and engineering centers and over 800 employees.[422] Its website asserts that it has made "significant contributions to society, the economy and national security."[423] SIA was responsible for creating China's first underwater robot, welding robot, laser processing robot, and industrial robots, and has made major accomplishments in wireless sensor network technology.[424]

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[418] "军警新科技：纳米机器虫部队" [New Technology for Military: Nano Machine Insect Army], MEMS Information Network MEMS 资讯网, January 20, 2010, accessed July 11, 2016, http://www.mems.ac.cn/xinwenzixun/2010/0120/军警新科技纳米机器虫部队.html; "美军纳米机器人的发展现状" [Current Situation of U.S. Military Nanorobot Development], November 29, 2011, accessed July 11, 2016, http://mil.sohu.com/20111129/n327284531.shtml.

[419] Ibid.

[420] Search of CNKI academic journal database on 1 June 2016 for "纳米" (nano) and "机器人" (robot), "纳米操作" (nanomanipulation), or "纳米马达" (nanomotor) subject search.

[421] "Brief Introduction of SIA," Chinese Academy of Sciences Shenyang Institute of Automation, December 30, 2013, accessed July 11, 2016, http://english.sia.cas.cn/au/bi/201312/t20131230_115083.html.

[422] Ibid.

[423] Ibid.

[424] "王越超：纳米操作机器人正在成为现实" [Wang Yuechao: Nanomanipulation Robots are Becoming a Reality], October 23, 2007, accessed July 11, 2016, Enorth.com.cn 北方网. http://news.enorth.com.cn/system/2007/10/23/002198104.shtml; "Brief Introduction of SIA," Chinese Academy of Sciences Shenyang Institute of Automation, December 30, 2013, accessed July 11, 2016, http://english.sia.cas.cn/au/bi/201312/t20131230_115083.html.

SIA and its subordinate laboratories and research groups, such as the Micro and Nano Robotics Group (微纳米自动化实验室 / 微纳米课题组) under the State Key Laboratory of Robotics (机器人学国家重点实验室), have focused their research on technology for manufacturing and manipulating devices in the nanoscale, with many applications for medical treatment. In 2005 SIA researchers established China's first nanorobotic operation and manipulation system, and were able to inscribe "China 863" with dimensions of 1x2 micrometers on a silicon surface by using a carbon nanotube robot.[425]

Since this accomplishment in 2005, the institute's subordinate labs have made progress in research on nanorobotics manipulation systems and have increased collaboration both at home and abroad.[426] In 2009 the State Key Laboratory of Robotics started collaboration with the PLA 307th Hospital to develop nanorobotics to manipulate molecules to improve targeted lymphoma drug delivery treatment.[427] In 2012, SIA's Micro-Nano Group worked with Xi Ning (席宁) at Michigan State University[428] and published a paper in *Applied Physics Letters* on their research using graphene to manipulate nanorobots with atomic force microscopy (AFM).[429] In 2013, the same team manipulated a 3-D virus structure with AFM technology.[430] Also in 2013 State Key

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425 "纳米机器人治疗癌症取得新进展" [Nanorobot Cancer Treatment Achieve New Developments], Bioon.com, November 17, 2011, accessed July 11, 2016, http://www.bioon.com/3g/id/6532511/; "我国成功研制纳米操作机器人" [China Succeeds in Developing Nanomanipulation Robot], *Xinhuanet* 新华网, April 14, 2005, accessed July 11, 2016, http://news.xinhuanet.com/newscenter/2005-04/15/content_2834613.htm.

426 "State Key Laboratory of Robotics" [机器人学国家重点实验室]. Chinese Academy of Sciences Shenyang Institute of Automation State Key Laboratory of Robotics 中国科学院沈阳自动化研究所机器人学国家重点实验室, accessed July 11, 2016, http://www.rlab.ac.cn/.

427 "'纳米操作机器人在癌症靶向治疗中的应用研究'取得新进展获权威刊物封面刊载" ["Nanomanipulation Robot Research Applications in Targeted Cancer Therapy" New Development Published on Journal Cover], November 16, 2011, accessed July 11, 2016, http://www.sia.cn/xwzx/kydt/201111/t20111116_3396890.html; "Drug-Induced Changes of Topography and Elasticity in Living B Lymphoma Cells Based on Atomic Force Microscopy," Sciencenet.cn 科学网, May 29, 2012, accessed July 11, 2016, http://doc.sciencenet.cn/DocInfo.aspx?id=11470; Wei-Jing, Zhang, "纳米操作机器人治疗淋巴瘤获进展" [Nanomanipulation Robot Lymphoma Therapy Developments], Sciencenet.cn 科学网, May 29, 2012, accessed July 11, 2016, http://news.sciencenet.cn/htmlpaper/201252915252947924670.shtm; Chinese Academy of Sciences, "沈阳自动化所利用纳米操作机器人靶向治疗淋巴瘤获进展" [Shenyang Institute of Automation Uses Nanomanipulation Robots for Lymphoma Therapy Development], May 28, 2012, accessed July 11, 2016, http://www.cas.cn/ky/kyjz/201205/t20120525_3585654.shtml. Editorial office of Acta Physico-Chimica Sinica, "Drug-Induced Changes of Topography and Elasticity in Living B Lymphoma Cells Based on Atomic Force Microscopy," accessed July 11, 2016, http://www.whxb.pku.edu.cn/EN/abstract/abstract28019.shtml.

428 "席宁：机器人产业发展需要新技术推动和新应用拉动" [Xi Ning: Robotics Industry Development Needs New Technology Push and New Applications], November 23, 2015, accessed July 11, 2016, http://www.worldrobotconference.com/cn/news/xingyexinwen/2015/1123/1173.html.

429 "中科院利用纳米操作机器人可控加工石墨烯获新成果" [Chinese Academy of Sciences Uses Nanomanipulation Robot to Manufacture with Graphene in New Accomplishment], December 20, 2012, accessed July 11, 2016, http://www.robot-china.com/news/201212/20/2901.html, "Graphene-Control Cutting Using an Atomic Force Microscope-Based Nanorobot," May 27, 2012, *Science China Press*, accessed July 11, 2016, http://www.eurekalert.org/pub_releases/2012-05/sicp-gcu052112.php.

430 "沈阳自动化所纳米机器人完成单分子病毒三维空间自由操作" [Shenyang Institute of Automation Nanorobot Completes Single Molecular Virus 3D Space Independent Manipulation], Chinese Academy of Sciences, May 30, 2013, accessed July 11, 2016, http://www.cas.cn/ky/kyjz/201305/t20130530_3853262.shtml; "单分子病毒

Laboratory of Robotics researchers published research on using voltage changes in cell membranes to power nanorobots, as well as published research on using AFM to determine cutting forces of a nanobot on graphene surfaces.[431]

SIA researchers have continued this progress on nanorobotics and nanomanipulation in recent years and have continued to lead the research field in China. In early 2015, SIA scientists used a programmable system of AFM manipulation to construct a nanorobot using DNA nanotubes.[432] Later that year, SIA researchers developed a set of nanorobots that ranged from 500-1,000 micrometers and could move at 5 millimeters per second.[433] This nanobot has applications for medical treatment opportunities such as automated remotely-operated activities in the bloodstream. Researchers also manipulated nanoparticles and carved the letters "SIA" with dimensions of 10x10 micrometers onto a layer of silicon.[434]

三维可控操作方法" [Method of controllable 3d manipulation for single virus], *China Science Bulletin*, accessed May 20, 2016, http://csb.scichina.com:8080/EN/abstract/abstract511091.shtml.

431 Zhang C L, Li P, Xie Y P, et al. "Nanorobot Synchronously Tracking Voltage-Induced Changes of Membrane Character" [纳米操作机器人同步追踪电压诱导膜特性改变], *China Science Bulletin* 科学通报, 2013, 58: 187–193; Zhang Y, Wang Y C, Zhou L, et al. "基于纳米操作机器人的石墨烯切割力各向异性研究" (Cutting Force Anisotropy Dependence on Lattice Structures of Graphene Based on Nanorobot"), *China Science Bulletin* 科学通报 , 2013, 58: 181–186.

432 Li Longhai 李龙海, Liu Lianqing 刘连庆, Dong Zaili 董再励, "面向可控自组装的 DNA 纳米管可编程 AFM 操作" (Programmable AFM Manipulation for DNA Nanotubes with the Controlled Self-Assembly)," *Micronanoelectronic Technology* 微纳电子技术, 2015, vol. 52, no.4, 240-245.

433 "微纳米机器人" [Nanorobots], Chinese Academy of Sciences Shenyang Institute of Automation, November 16, 2015, accessed July 11, 2016, http://www.sia.cas.cn/kxcb/kpwz/201511/t20151116_4465141.html.

434 "未来的体内纳米机器医生" [Future of Nanomachines Doctors Inside the Body], Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO), October 23, 2014, accessed July 11, 2016, http://www.sinano.cas.cn/kxcb/kpwz/201410/t20141023_4229456.html.

Chapter Six: China's Acquisition of Foreign Robotics Technology

China is actively acquiring components, technologies, and materials from abroad for its robotics systems and unmanned systems. With these acquisitions, China can not only improve its own industrial, service, and military robotics systems, but also develop countermeasures against foreign military systems.[435] This report categorizes these efforts into three sections for analysis:

> **Illicit Technology Acquisition** – This section discusses the illegal means through which China acquires key technologies from abroad, such as cyber intrusions and export control violations.
>
> **Informal Knowledge and Technology Transfers** – These informal transfers refer to China's acquisition of foreign technologies via open source collection, talent recruitment, and academic exchanges.
>
> **Formal Technology Acquisition and Investments** – These transfers involve Chinese companies acquiring or investing in foreign robotics companies or other entities to acquire relevant technologies.

Illicit Technology Acquisition

China actively seeks U.S. technology through illicit means, including cyber intrusions into sensitive U.S. defense contractors and suppliers, as well as by directing efforts to circumvent U.S. export controls. China's cyber campaign against the United States is well-documented, and details from specific cases demonstrate a targeted effort to steal U.S. designs for unmanned aerial and ground systems. The illegal export of sensitive equipment and technologies to China is a regular occurrence. What makes one case unique, however, is that the plea agreement explicitly states the defendant worked "at the direction of co-conspirators working for Harbin Engineering University (HEU), a state-owned entity in the People's Republic of China."[436]

Cyber Intrusions

China's cyber espionage against U.S. Government entities, companies, and universities includes manufacturers of military unmanned systems and their component technologies. In 2013 a U.S. cybersecurity company reported on a massive two-year operation dubbed Operation Beebus by Chinese hackers to steal U.S. designs and relevant technologies for UAVs.[437] Of the 261 attacks uncovered, 123 of them are reported to have targeted U.S. drone companies.[438] According to a manager of the investigation, "We believe the attack was largely successful."[439]

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[435] For more information on how China pursues emerging technologies such as artificial intelligence, see Dan Alderman and Jonathan Ray, "Best Frenemies Forever: Artificial Intelligence, Emerging Technologies, and Sino-U.S. Strategic Competition." Paper presented at the 2016 IGCC Conference on U.S.-China Strategic Competition in Defense Technological and Industrial Development, San Diego, California, July 2016.
[436] Department of Justice, "Summary of Major U.S. Export Enforcement, Economic Espionage, Trade Secret and Embargo-Related Criminal Cases," 4.
[437] Edward Wong, "Hacking U.S. Secrets, China Pushes for Drones," *The New York Times,* September 20, 2013.
[438] Alex Pasternack, "Hackers Are Helping China Build Cheap Clones of America's Drones," Motherboard, September 23, 2013, accessed July 6, 2016, https://motherboard.vice.com/blog/hackers-are-helping-china-build-cheap-clones-of-americas-drones.
[439] Dunn, John, "Chinese malware targeted US drone secrets, security firm alleges," *TechWorld,* February 4, 2013.

Other targets include companies such as QinetiQ North America, a major supplier of drones, satellites, helicopters, military robotics, and other systems for the U.S. military.[440] According to news reports, the hackers first targeted QinetiQ's drone and robotics technologies. In April 2012, the PLA displayed a bomb disposal robot similar to QinetiQ's Dragon Runner, likely reflecting the use of this stolen data.[441]

Most recently, in March 2016 Su Bin, a Chinese national, pleaded guilty to participating in a years-long conspiracy to hack into the computer systems of major U.S. defense contractors, namely Boeing.[442] According to U.S. media, Su transferred over 65 gigabytes of data, with Boeing's C-17 military cargo plane as the primary target.[443] Given Boeing's vast portfolio of unmanned air, sea, and space systems, it is possible that this massive amount of stolen data included information on unmanned systems.

Chinese cyber espionage also targets U.S. universities, though no known campaign against robotics research was discovered. In August 2015 the University of Virginia that it had reported a cyber intrusion originating from China, an attack that may be motivated by a university's ties to U.S. defense and intelligence agencies.[444] Previously in 2013 U.S. media reported that Chinese cyber campaigns increasingly target U.S. research universities, who receive thousands of patents and comprise some of the robust centers of information exchange in the world. According to Tracy Mitrano, the director of information technology policy at Cornell University, detection of the intrusions is "probably our greatest area of concern, that the hackers' ability to detect vulnerabilities and penetrate them without being detected has increased sharply."[445] The compromise of cutting-edge robotics research at U.S. research universities could jeopardize gains in these fields, and allow China to take advantage of U.S. time and resources invested into these technologies.

Export Control Violations

According to the U.S. Department of Justice (DOJ) and the Bureau of Industry Security (BIS) at the U.S. Department of Commerce, numerous individuals in the United States have attempted to illegally export unmanned systems and their relevant components and materials to China. Certain robotics for industrial purposes and materials processing are subject to the Export Administration Regulations (EAR), while unmanned aerial, ground, and water vehicles are subject to International Traffic in Arms Regulations (ITAR).[446] In many cases Chinese end-users directed the individual

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440 Riley, Michael and Elgin, Ben, "China's Cyberspies Outwit Model for Bond's Q," Bloomberg, May 1, 2013.
441 Ibid.
442 U.S. Department of Justice, "Chinese National Pleads Guilty to Conspiring to Hack into U.S. Defense Contractors' Systems to Steal Sensitive Military Information," Justice News, March 23, 2016, accessed July 6, 2016, https://www.justice.gov/opa/pr/chinese-national-pleads-guilty-conspiring-hack-us-defense-contractors-systems-steal-sensitive.
443 Matt Apuzzo, "Chinese Businessman Is Charged in Plot to Steal U.S. Military Data" *New York Times*. July 11, 2014.
444 Shane Harris and Alexa Corse, "Chinese Hackers Target U.S. University with Government Ties," *The Daily Beast*, August 21, 2015, accessed August 26, 2016, http://www.thedailybeast.com/articles/2015/08/21/chinese-hackers-target-u-s-university-with-government-ties.html.
445 Richard Pérez-Peña, "Universities Face a Rising Barrage of Cyberattacks," *The New York Times*, July 16, 2013.
446 As the Obama Administration's Export Control Reform Initiative enters its final phase in 2016, additional research may be conducted to determine specific controls over component technologies for these systems. See "Deemed Exports Webinar," presentation by the U.S. Department of Commerce Bureau of Industry and Security,

residing in the United States to acquire specific items. Since 2010, DOJ reporting includes six cases in which China has sought to acquire U.S. unmanned systems and their technologies.[447] These cases include the following:

1. *Systems and Components for Marine Submersible Vehicles* – On June 10, 2016, Amin Yu, AKA Amy Yu, pleaded guilty to acting in the United States as an illegal agent of a foreign government without prior notification to the Attorney General.[448] According to the plea agreement, Yu obtained systems and components from U.S. companies for marine submersible vehicles (such as UUVs). She then illegally exported the components to the PRC. She acted at the direction of co-conspirators working for Harbin Engineering University, profiled on page 67. According to the indictment, Yu illegally exported the following technologies:[449]
    - Underwater acoustic locator devices
    - Underwater cables and connectors, including AWQ/XSL and MSSK/MINL Marine Cables
    - PC104 computer processing units for mission, motion and video guidance computers
    - 907 Multiplexers for digital signal transmission through fiber optics
    - Underwater pressor [sic] sensor, conductivity and temperature sensor
    - Control sticks and button strips
2. *Unmanned Aerial Vehicle* – On June 10, 2016, Wenxia Man, AKA Wency Man, was convicted by a federal jury of conspiring to export fighter jet engines, a UAV, and related technical data to the PRC. The defense articles included the General Atomics MQ-9 Reaper/Predator B Unmanned Aerial Vehicle, capable of firing Hellfire Missiles, as well as Pratt & Whitney F135-PW-100 engines used in the F-35 Joint Strike Fighter, Pratt & Whitney F119-PW-100 turbofan engines used in the F-22 Raptor fighter jet, and technical data for each of these defense articles.[450]
3. *High-Grade Carbon Fiber* – On April 13, 2016, Fuyi Sun, AKA Frank Sun, was arrested in connection with a scheme to illegally export to China, without a license, high-grade carbon fiber that is primarily used in aerospace and military applications. The targeted Toray type M60JB-3000-50B carbon fiber ("M60 Carbon Fiber") has applications in UAVs and other government defense applications.[451]
4. *Drone, Missile and Stealth Technology* – In January 2015, Hui Sheng Shen, AKA Charlie Shen, and Huan Ling Chang, AKA Alice Chang, were sentenced after pleading guilty to

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August 29, 2007, accessed August 26, 2016, https://www.bis.doc.gov/index.php/forms-documents/doc_view/387-intermediate-deemed-exports-pdf; Robert Levinson, "Obama Administration Still Pushing on Export Control Reform," *Bloomberg*, December 1, 2015.

[447] Department of Justice, "Summary of Major U.S. Export Enforcement, Economic Espionage, Trade Secret and Embargo-Related Criminal Cases."

[448] Ibid.

[449] United States of America v Amin Yu, Case No. 6:16-cr-23-Orl-37GJK, (FL, United States District Court, Middle District of Florida, Orlando Division March 26, 2016), accessed on July 6, 2016, https://www.justice.gov/usao-mdfl/file/843506/download.

[450] Department of Justice, "Summary of Major U.S. Export Enforcement, Economic Espionage, Trade Secret and Embargo-Related Criminal Cases," 4.

[451] Ibid., 7.

count of conspiracy to violate the Arms Export Control Act and one count of conspiracy to import illegal drugs. Shen and Chang were interested in UAVs including the RQ-11b Raven, a small, hand-launched UAV used by the U.S. Armed Forces. They intended to export to China manuals for RQ-11b Raven and RQ-4 Global Hawk UAVs (provided by undercover FBI agents), and were arrested soon after.[452]

5. *Military Gyroscopes* – On April 17, 2013, Kevin Zhang, AKA Zhao Wei Zhang, was sentenced after pleading guilty for his role in a conspiracy to export defense articles from the United States to China without a license. The item he attempted to export, G-200 Dynamically Tuned Gyroscopes, can be used in tactical missile guidance systems and UAVs. [453]
6. *Military Technical Data and Trade Secrets* – On March 25, 2013, Sixing Liu, AKA Steve Liu, was sentenced for exporting sensitive U.S. military technology to China, stealing trade secrets, and lying to federal agents. While working as a senior staff engineer for Space & Navigation, a New Jersey-based division of L-3 Communications, Liu stole thousands of electronic files detailing the performance and design of guidance systems for missiles, rockets, target locators, and UAVs. Prior to his arrest, Liu traveled to China and made presentations on the technologies at several Chinese universities, the CAS, and conferences organized by government entities.[454]

In addition to DOJ reporting, BIS reports that between 2007 and 2008, Yaming Nina Qi Hanson and her husband Harold Dewitt Hanson illegally exported miniature UAV autopilots to Xi'an Xiangyu Aviation Technical Group in China. Such components are controlled for export to China for national security reasons.[455]

Informal Knowledge and Technology Transfers

China actively acquires U.S. technology through informal means that are extralegal, or not clearly defined and regulated by current U.S. legislation. These means include leveraging a vast open source intelligence apparatus, recruitment of leading talents from around the world, and academic exchanges. These means are not properly defined and regulated by existing U.S. legislation, but as one analysis states, "There is a thin line between stealing secrets and informal technology transfer, and China pursues the latter to the limit."[456]

Open Source Collection

China leverages a vast open source collection and exploitation system to spot, study, and acquire data concerning foreign technologies that China has not yet been able to develop on its own.[457] This system is rooted in the Chinese legacy of "*tiyong*" (体用) or "importing what is useful and

[452] Ibid., 32-33.
[453] Ibid., 60-61.
[453] Ibid., 60-61.
[454] Ibid., 61-62
[455] U.S. Department of Commerce, "Don't Let This Happen to You: Actual Investigations of Export Control and Antiboycott Violations," Bureau of Industry and Security, Export Enforcement, July 2015 Edition, 45-46.
[456] William C. Hanas, James Mulvenon, and Anna B. Puglisi, *Chinese Industrial Espionage: Technology Acquisition and Military Modernization*, (London: Routledge, 2013), 2.
[457] Ibid., 18-49.

keeping China's essence." In short, China takes what is useful from Western concepts for applications while keeping the essence of Chinese culture. China's open source collection raises this concept to a science, or formally "information/intelligence science" (情报学 *qingbaoxue*). The Chinese term *qingbao* can be translated as both information and intelligence because it includes both the input of original information and the output of processed intelligence.[458]

In practice this system features institutions that monitor foreign technical developments, disseminate information to relevant Chinese institutions, and model foreign R&D for domestic programs. The first of these institutions appeared in 1956, and in the 1960s contributed to Chinese advances in nuclear weapons, satellite launches, and computers. By 1985 60,000 Chinese workers were engaged in data processing, database mining, benchmarking, and reverse engineering. By 2005, over 50,000 networks hosted and distributed S&T information among 353 institutes, servicing 27 million "users" to obtain foreign S&T material.[459]

In the field of UAVs, a leading collection institute is the 310th RI under CASIC, a major defense conglomerate and manufacturer of UAVs. Also known by its civilian name, the Beijing Haiying Science and Technology Information Institute, the 310th RI closely follows research and development plans, technical specifications, tests, operations, technologies, materials, and techniques of UAVs, aircraft, and missiles in foreign countries. Its periodical, *Aerodynamic Missile Journal* (飞航导弹), "introduces intelligence on relevant foreign flying missiles, and advances the rapid development of China's flying missile industry." [460] In 2015, the 310th RI also co-hosted a meeting for the Association for Unmanned Vehicle Systems of China, attended by commercial, defense industry, and military representatives. [461] In publications and events, the institute's mission clearly is to distribute advances in foreign S&T research to relevant end-users.

Research and collection institutes such as the 310th RI regularly cite unmanned system "roadmaps" by the U.S. Department of Defense. These include the *Unmanned Aerial Vehicles Roadmap 2002-2027*, *Unmanned Aircraft System Roadmap 2005-2030*, *Unmanned System Roadmap 2007-2032*, and *Unmanned Systems Integrated Roadmap FY2013-2038*. [462] Such publications provide insights into U.S. plans, advances, and operations with unmanned systems.

This coverage of U.S. strategy and intent extends to contracts and programs for systems, such as UCAVs. As early as 2000, Chinese authors followed the U.S. Navy's request for UCAV

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458 Ibid.

459 Ibid.

460 "飞航导弹" (Aerodynamic Missile Journal), Wanfang Data Periodical Profile, accessed May 11, 2016, http://c.wanfangdata.com.cn/PeriodicalProfile-fhdd.aspx.

461 "发展历程" [Process of Development], Association for Unmanned Vehicle Systems of China 中国无人系统产业联盟, accessed May 13, 2016, http://www.auvsc.com/?p=487.

462 Zhang Yilin 张翼麟, Zhang Shaofang 张绍芳, and Li Pengfei 李鹏飞, "2012 年世界军用无人机发展动向及评述" [Trends and Commentary on Global Military UAVs in 2012], *Aerodynamic Missile Journal* 飞航导弹, no. 7 (2013); Wen Suli 文苏丽, Zhang Dongqing 张冬青, and Jiang Qi 蒋琪, "美国军用无人机的作战使用" [Operations and Use of U.S. Military UAVs], *Aerodynamic Missile Journal* 飞航导弹, no. 11 (2009); and Zhang Yilin 张翼麟, Guo Chaobang 郭朝邦, and Guan Shiyi 关世义, "军事转型背景下的国外陆军飞航武器发展" [Foreign Army Flying Weapons Development in the Context of Military Transformation], *Tactical Missile Technology* 战术导弹技术, no. 4 (2013).

technologies, and the subsequent awards to Northrop Grumman and Boeing to develop relevant systems.[463] Chinese authors also took note of relevant subcontractors. In 2005 an article noted the software firm that Boeing had selected for the real-time embedded operating system (RTOS) in its X-45C design.[464]

As DARPA sponsored initial development of UCAVs from 2000 to 2006, Chinese researchers discussed the strategic and technical challenges of the necessary technologies. For example, authors at Northwest Polytechnical University (NWPU, which hosts the China's largest UAV production and R&D base the Xi'an ASN Technology Group) discussed UCAV objectives and technologies such as navigating a path that accounts for different threats, and challenges of communication delays between UCAVs and ground control.[465] For China's own UCAV development, authors from the Shenyang Aircraft Design Institute cite these DARPA models as evidence of China's need for indigenous materials to build similar systems.[466]

Other Chinese researchers utilize publicly available images and data on U.S. programs, likely to advance their own research and to develop countermeasures. For UCAVs, Chinese researchers have modeled the X-47A prototype's slot-shaped inlet,[467] discussed the designs in context of decreased infrared signatures,[468] and simulated configurations and drag effects of what appears to be the X-45A's weapons bays.[469] For the X-47B system that will enter deployment, in 2013 researchers published "Analysis of X-47B UCAS and Electronic Counter Measures," an assessment of the X-47B's advantages and potential weak points for Chinese countermeasures.[470]

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[463] Liu Wensheng, "评析美军无人作战系统的发展" (Discussion and Analysis of the Development of U.S. Unmanned Combat Systems), *Conmilit* 现代军事, no. 12 (2000).
[464] Shi Zhaofeng 时兆峰, "X-45C 联合无人作战飞行器将配备实时操作系统" (X-45C UCAS Will Be Outfitted with Real-Time Embedded Operating System), *Aerodynamic Missile Journal* 飞航导弹, vol. 3 (2005).
[465] Gao Xiaoguang 高晓光 and Yang Youlong 杨有龙, " 基于不同威胁体的无人作战飞机初始路径规划" (Initial Path Planning Based on Different Threats for Unmanned Combat Air Vehicles), *Acta Aeronautica et Astronautica Sinica* 航空学报, vol.24, no. 5 (2003), 435-438; and "无人作战飞机通信延时仿真" (Research on the Simulation of Communication Time Delay for Uninhabited Combat Aerial Vehicles), *Fire Control and Command Control* 火力与指挥控制, August 2005.
[466] Representative articles include Chen Shaojie 陈绍杰, "Composite Materials and UAVs" [复合材料与无人飞机], *Hi-tech Fiber & Application* [高科技纤维与应用], (Issue 2, 2003); and Chen Shaojie 陈绍杰, "Brief Discussion of Shaping Technologies for Composite Structures" [浅谈复合材料整体成形技术], *Aeronautical Manufacturing Technology* [航空制造技术], no. 9 (2005).
[467] Zhang Hang 张航, Tan Huijun 谭慧俊, and Li Xiangping 李湘萍, "类 X-47 狭缝式进气道的流动特征与工作性能" [Flow Structure and Performance Characteristics of X-47-like Slot-shaped Inlet], *Acta Aeronautica et Astronautica Sinica* 航空学报 (December 2009), 2243-2249.
[468] Xu Xingguo 徐顶国, Sang Jianghua 桑建华, and Luo Mingdong 罗明东, "Research on Application of UAVS' Infrared Stealth Technology" [红外隐身技术在无人机上的应用研究], *Infrared and Laser Engineering* 红外与激光工程 (December 2012).
[469] Feng Qiang 冯强 and Cui Xiaochun 崔晓春, "Study on Integrated Flow Control for Weapons Bay of Flying Wing Configuration Aircraft" [飞翼布局飞机弹舱综合流动控制技术研究], *Acta Aeronautica et Astronautica Sinica* 航空学报 (May 2012).
[470] Wu Xiaofang 吴晓芳, Tian Zhongcheng 田中成, and Liang Jingxiu 梁景修, "X-47B 无人空战系统及其对抗途径分析" (Analysis of X-47B UCAS and Electronic Counter Measures), *Aerospace Electronic Warfare* 航天电子对抗, vol. 29, no. 5 (2013): 11-13.

Talent Acquisition

In order to boost Chinese indigenous R&D in critical technologies where China has not yet caught up to global leading standards, China actively recruits Chinese and foreign experts living abroad to work in China. This effort is organized and guided at the central government level, with active participation at lower levels. One of its leading programs is the Thousand Talents Program (千人计划). Launched in December 2008, the Thousand Talents Program recruits individuals outside China to work in China's major scientific development organizations, including key laboratories, companies, and research centers.[471] The goal of this national strategic plan is a five to 10 year push to target the indigenous development of cutting-edge technologies and bring 2,000 innovative and high-level talented individuals to China to lead its enterprises, laboratories, and S&T parks.[472] These recruits are experts in a range of fields, including medicine and biotechnology, energy and environment, economics, finance, and management, engineering and materials, chemical engineering, math and physics, information sciences, and high-technology industries.[473] As of May 2014, the program had introduced ten rounds of recruits to China, totaling over 4,180 individuals.[474]

There are several types of Thousand Talent recruits—long-term (长期), short-term (短期), foreign experts (外专), young scientists (青年), and entrepreneurs (创业).[475] These separate programs have different requirements of education and experience, and offer different levels of incentives to conduct research in China. Experts receive start-up funding for research and entrepreneurship once they begin positions at Chinese institutions.

Thousand Talent recruits maintain their positions overseas as they join academic and research teams in China, and their recruitment often leads to collaborative scientific research and publication with researchers from Chinese and overseas institutions with which the Thousand Talent is affiliated. This is evident in the field of robotics research, and many of China's top-level experts on robotics and related technologies are Thousand Talent professors at Chinese research institutes, laboratories, and centers with concurrent affiliations outside of China. In the case of robotics, many of these Thousand Talent recruits have educational and work experience outside of China in top-tier research institutions in Germany, Japan, and the United States.

Selected examples of Thousand Talent experts making major achievements in robotics in China include:

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[471] "千人计划介绍" [The Recruitment Program of Global Experts], accessed June 8, 2016, http://www.1000plan.org/qrjh/section/2?m=rcrd#.

[472] Hao Xin 郝炘, "中国：用高价从海外引进人才的做法引起极大不满" [China: The Method of Using High Prices to Attract Talent from Abroad Is Creating Discontent], *Science*, accessed June 8, 2016, http://www.sciencemagchina.cn/talentabroad.aspx.

[473] "人物库" [Characters library], Thousand Talent Plan, accessed July 12, 2016, http://www.1000plan.org/wiki/index.php?category.

[474] "History and Background," Thousand Talent Plan, accessed July 12, 2016, http://www.1000plan.org/en/history.html.

[475] Chinese Academy of Sciences Tianjin Institute of Industrial Biotechnology, "National Thousand Talents Program Recruitment," accessed July 12, 2016, http://english.tib.cas.cn/ju/ju/; Thousand Talent Plan, "2016 年国家'千人计划'申报工作的通知" [2016 National "Thousand Talents" Declaration of Work Announcement], May 30, 2016, accessed July 12, 2016, http://www.1000plan.org/qrjh/article/65766; Thousand Talent Plan, "The Recruitment Program for Innovative Talents (Long Term)," accessed July 12, 2016, http://www.1000plan.org/en/.

- Nanomanipulation expert from Japan working at Beijing Institute of Technology[476]
- Nanorobotics scientist affiliated with State Key Laboratory of Robotics after working as a professor at Michigan State University[477]
- Two nanorobotics lead researchers concurrently professors at Georgia Institute of Technology and major Chinese universities[478]
- Intelligent robotics scientist from German Aerospace Center working at HIT Robotics Research Institute with establishment of joint laboratory[479]
- Robotics scientist with experience at Japanese University and construction corporation affiliated with Tianjin University, HIT, and CAS SIA[480]

Another notable talent recruitment program is Plan 111 (高等学校学科创新引智计划 / 111 计划), jointly organized by the Ministry of Education and State Administration of Foreign Experts Affairs to attract leading experts.[481] For example, HEU, a leading university for military-use UUVs discussed on page 67, has a National Plan 111 Innovation and Attracting Talent Base (国家"111"创新引智基地).[482] Under this program HEU hosts leading international experts in submersibles technologies.

Academic Exchanges and Professional Conferences

Chinese research institutes and universities actively participate in and host international conferences on key technologies such as robotics and artificial intelligence. Although most of China's participation is likely benign in nature, some attendees participate on behalf of Chinese defense firms and military research institutes. For example, CAAI, as discussed on page 80, is a leader in promoting academic exchange, publication, education, and research exhibition for the

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476 "[Lecture] Toshio Fukuda Professor Lecture," [[讲座] Toshio Fukuda 教授讲座], Northwest Polytechnic University, accessed 9 June 2016, http://www.nwpu.edu.cn/info/1007/14666.htm.

477 "University of Chinese Academy of Sciences, "Individual Introduction," [个人简历], accessed July 12, 2016, http://people.ucas.ac.cn/~lianqingliu.

478 Chinese Academy of Sciences Beijing Institute of Nanoenergy and Nanosystems, "王中林----中国科学院北京纳米能源与系统研究所" [Wang Zhonglin—Chinese Academy of Sciences Beijing Institute of Nanoenergy and Nanosystems], accessed July 12, 2016, http://sourcedb.binn.cas.cn/zw/zjrck/yszj/201206/t20120608_3594969.html; Georgia Tech School of Civil and Environmental Engineering "Faculty Profile," accessed July 12, 2016, http://ce.gatech.edu/people/Faculty/1201/overview; Georgia Tech School of Civil & Environmental Engineering, "About Dr. Chen," accessed July 12, 2016, http://nanotech-sustainability.ce.gatech.edu/about; "南开大学陈永胜教授" [Nankai University Professor Chen Yongsheng], May 18, 2009, Polymer.cn 中国聚合物网, accessed July 12, 2016, http://www.polymer.cn/scholar/scholar150.html; "天津留学服务中心" [Tianjin Study Abroad Service Center], Tianjin Comprehensive Service Center for Talents 天津市人才综合服务中心, accessed June 9, 2016, http://www.tjlx.gov.cn/news/news.aspx?id=D496C280BDE91A56&lb=89F20989967E95DC8D26C800DAAC4EA.

479 '千人计划'专家刘宏：让机器人拥有灵巧的"手" ["'Thousand Talent Plan' Expert Liu: Let's Have a Dexterous Robot 'Hand'"], Recruitment Program of Global Experts, accessed June 9, 2016, http://www.1000plan.org/qrjh/article/61037.

480 "'Thousand Talent plan' expert Ma Shu-gen: Tangshan Robotics Industry Flourishes," ['千人计划'专家马书根": 让唐山机器人产业枝繁叶茂], accessed June 9, 2016, http://www.1000plan.org/qrjh/article/64789; "English Home Page of Dr. Shugen MA," accessed June 9, 2016, http://www.ritsumei.ac.jp/~shugen/ePage/shugenE.html.

481 Li Xiaohua, "China to Undergo Brain Gain through Plan 111," China Internet Information Center 中国网, September 14, 2006, accessed July 8, 2016, http://www.china.org.cn/english/China/181075.htm.

482 "学院简价" [College Introduction], College of Shipbuilding Engineering, accessed July 8, 2016, 哈尔滨工程大学船舶工程学院. .http://heusei.hrbeu.edu.cn/index.php?m=content&c=index&a=lists&catid=2.

purpose of AI development in China.[483] CAAI participants, however, include the former PLA GSD, National University of Defense Technology, and National Defense University. [484]

Furthermore, CAAI's leader is Li Deyi (李德毅), whom English-language sources describe as an academic and professor, but Chinese-language credentials openly state is a major general in the PLA. Author biographies in Li's own co-authored English-language textbooks as well as profiles on conference websites describe Li as a professor at Tsinghua University in China, a member of the Chinese Academy of Engineering, and a member of the Euro-Asia International Academy of Science.[485] Chinese-language sources, however, include the fact that Li is a major general (少将军衔), and deputy director, researcher, and doctoral advisor at the 61st Research Institute of the former GSD (总参第六十一研究所), a PLA research organization.[486] Li has worked on national defense electronics key engineering development projects, is deputy director of the All-Army Informatization Work Office (全军信息化工作办公室), and has been a member of the former General Armament Department's Science and Technology Committee (总装备部科技委).[487]

Li's military affiliation is an example of the tight relationship the Chinese AI academic and commercial community has with the PLA. Important for U.S. interests, however, is that individuals such as Li do not disclose their military affiliations in English materials. If military researchers obfuscate their military credentials and affiliations, they may gain access to events, conferences, publications, and above all knowledge sources that might otherwise be denied.

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483 "中国人工智能学会简介" [Chinese Association for Artificial Intelligence Introduction], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/index/id/2.html.

484 "中国人工智能学会第七届理事会负责人名单" [Chinese Association for Artificial Intelligence Seventh Board Member Leadership Name List], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/detail/id/85.html; "中国人工智能学会 2016 副秘书长名单" [Chinese Association for Artificial Intelligence 2016 Vice-Secretary Name List], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/detail/id/114.html; "公司概况" [Company Summary], Horizon Robotics, accessed July 8, 2016, http://www.horizon-robotics.com/company_cn.html.

485 Li Deren, Li Deiyi, and Wang Shuliang, *Spatial Data Mining: Theory and Application*, Springer-Verlag Berlin Heidelberg (2015): xxvi; Li Deyi and Du Yi, *Artificial Intelligence with Uncertainty*, Chapman & Hall/CRC, 2008; "Plenary Speech," 3rd CIS & RAM on Cybernetics and Intelligent Systems Robotics, Automation, and Mechatronics, an IEEE conference, September 21-24, 2008, accessed June 9, 2016, http://www.cis-ram.org/2008/ple-spe.html.

486 "中国人工智能学会第七届理事会全体理事名单" [Chinese Association for Artificial Intelligence Seventh Board Member Full Board Name List], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/detail/id/16.html; "学会领导: 李德毅" [Association Leader: Li Deyi], Chinese Institute of Command and Control 中国指挥与控制学会, accessed June 9, 2016, http://www.c2.org.cn/index.php?m=content&c=index&a=show&catid=21&id=87.

487 Ibid; "专家介绍——李德毅" [Expert Introduction—Li Deyi], Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://caai.cn/contents/108/1711.html.

Formal Technology Acquisition and Investments

Chinese state-owned conglomerates, companies, and venture capital (VC) firms are actively acquiring or investing in foreign AI and robotics companies. According to one U.S. financial advisory firm, Chinese investors are "poised to target artificial intelligence deals in [the] U.S.,"[488] and a recent Chinese investment in a U.S. AI firm illustrates some of these risks. Robotics is the latest trend of major Chinese investments in high-tech European companies. After China's Five Year Plan in 2011, "Chinese firms are following an edict to acquire advanced technology and high-quality brands from abroad that the government laid down." From 2010 to 2014 Chinese investment and acquisition deals in Europe rose nine-fold from USD 2 billion to USD 18 billion.[489]

While China's AI investments are more recent, its robotics investments trend are accelerating, as there has been a drastic increase of Chinese companies and VC firms trying to acquire or invest in European robotics companies. A benign explanation is that Chinese companies are investing capital abroad to acquire good investments. With Made in China 2025 and other state plans emphasizing robotics, these investments appear more targeted. One analysis characterizes the plans as a "shopping list" for foreign investment targets that could help China acquire key technologies and licenses to improve its own industries.[490]

Recent AI and robotics deals since 2015 include the following:

Haiyin Capital

In June 2016, Haiyin Capital invested $1.2 million in Neurala, a maker of AI software that will soon be integrated into UAVs, self-driving cars, and toys.[491] The software is capable of navigation as well as identifying, classifying, tracking, and avoiding obstacles. This software could benefit military end-users as the AI software in military UAVs must accomplish all these functions. As of 2014 Neurala has contracts with NASA and the U.S. Air Force to develop smart learning systems, which may support collision avoidance systems for UAVs and autonomous navigation systems for robots on Mars.[492] In October 2015 NASA awarded Neurala a $250,000 grant to commercialize autonomous navigation, object recognition, and obstacle avoidance technology in UGVs and UAVs.[493] Chinese investment in Neurala potentially poses at least two risks for the United States.

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488 "Chinese Investors Poised to Target Artificial Intelligence Deals in U.S.," blog post by Vasari Capital, January 30, 2016, accessed September 6, 2016, http://www.vasaricapital.com/chinese-investors-poised-to-target-artificial-intelligence-deals-in-u-s/.

489 "Chinese Firms in Europe: Gone Shopping," *The Economist*, March 28, 2015, accessed May 1, 2016, http://www.economist.com/news/business/21647331-more-european-businesses-are-coming-under-chinese-ownership-gone-shopping?fsrc=rss.

490 Sebastian Heilmann, "Europe Needs Tougher Response to China's State Led Investments," post at *Financial Times*, June 9, 2016, accessed July 1, 2016, http://blogs.ft.com/beyond-brics/2016/06/09/europe-needs-tougher-response-to-chinas-state-led-investments/.

491 Sara Castallanos, "Chinese Investors Bet on Boston AI Tech for Drones, Toys, Self-Driving Cars," *Boston Business Journal*, June 2, 2016, accessed September 6, 2016, http://www.bizjournals.com/boston/blog/startups/2016/06/chinese-investors-bet-on-boston-ai-tech-for-drones.html.

492 Dennis Keohane, "Tim Draper Backs Boston Robot Software Company Neurala," *The Boston Globe*, December 10, 2014, accessed September 6, 2016, http://www.betaboston.com/news/2014/12/10/tim-draper-backs-boston-robot-software-company-neurala/.

493 "Neurala Receives $250,000 NASA Grant to Bring Autonomous Software to Self-Driving Cars, Home Robots and Drones," Neurala press release, October 23, 2015, accessed September 6, 2016, http://www.neurala.com/nasa-phase-iie/.

One is that Chinese access to source code and underlying technologies behind Neurala systems could benefit PLA end-users. Another is that it is unclear if China's access to Neurala will prevent U.S. end-users from taking advantage of the company's technology, effectively wasting the original U.S. seed capital.

AGIC Capital

In 2015 Henry Cai, who is regarded as the "godfather of the China capital markets," cofounded Asia-Germany Industrial Promotion Capital (AGIC). The purpose of this private equity firm is to invest in European companies and facilitate greater sales to China of advanced technologies including robotics, high-end systems and components, and advanced materials and technologies.[494] In June 2016 Cai and other Chinese financial leaders said that with economic globalization and the internationalization of industries, the attractiveness of foreign assets to Chinese industries is increasing daily, and that Chinese companies should conduct foreign acquisitions. Such acquisitions would allow firms to expand markets, acquire resources, and introduce foreign technology.[495]

In June 2016 AGIC announced it would acquire a majority stake in Gimatic, a leading Italian supplier of end-of-arm tools for industrial automation and robotic applications.[496] The deal is reported to be worth USD 113 million.[497] These tools are ideal for industrial robots in the automotive, plastics, electronics, food, and pharmaceuticals industries, among others.

Before this acquisition, in January 2016 AGIC partnered with China National Chemical Corp. and Guoxin International Investment Corp. to acquire KraussMaffei Group for USD 1.045 billion, which to date is the largest investment by a Chinese company in a German one.[498] KrausMaffei is a leading producer of linear, industrial, and side-removal robots.[499]

Midea Group

In February 2016, Midea Group, a major Chinese producer of home appliances, began increasing its shares in the leading German robot manufacturer Kuka AG, and by July 7th held a majority stake in the company.[500] KUKA has been a leading supplier of industrial robotics for Chinese companies for a long time.[501] According to one analysis, this acquisition raises questions on

[494] "About Us," AGIC, accessed July 6, 2016, http://www.agic-group.com/about-us/; "EY Strategic Growth Forum China Speakers," Ernst & Young Global Limited, accessed July 6, 2016, https://webforms.ey.com/CN/en/Services/Strategic-Growth-Markets/EY-strategic-growth-forum-china-2016-speaker-henry-cai.

[495] Lin Jianwei 林建伟, Zheng Qize 郑淇泽, and Zhang Chaoyan 张朝妍, "湖北举办企业国际并购培训会 为企业"走出去"建言献策" [Hubei Hosts an International Business Merger and Acquisition Training Session; Provides Suggestions for Industries "Going Abroad"], *Hubei Daily* 湖北日报, June 28, 2016, accessed July 6, 2016, http://www.tcgyxx.gov.cn/Details.aspx?topicid=1095.

[496] "AGIC Capital Announces Acquisition of Gimatic Srl," press release by AGIC, June 13, 2016, accessed July 6, 2016, http://www.agic-group.com/agic-capital-announces-acquisition-of-gimatic-srl/.

[497] Eugene Demaitre, "China Continues to Invest in European Industrial Automation," Robotics Business Review, June 13, 2016, accessed July 6, 2016, https://www.roboticsbusinessreview.com/china-continues-invest-european-industrial-automation/.

[498] Ibid

[499] Ibid.

[500] "Midea, Kuka and the Rise of China's Robots," *The Economist*, July 12, 2016.

[501] Cai and Guo, "Development and Basic Problems of China's Industrial Robotics Development," 10-11.

technology transfers, because KUKA is a supplier for the European defense industry, including robots used in the construction of the Eurofighter.[502] Leading German officials, including Chancellor Angela Merkel herself, were skeptical or opposed the deal, arguing that KUKA should remain an independently German brand, and that China must "level the playing field" for foreign investors in China.[503] The deal could draw scrutiny from the U.S. Committee on Foreign Investment (CFIUS), because KUKA has subsidiaries and customers in the United States, including defense company Northrop Grumman Corp.[504] To date, however, it does not appear that CFIUS has reviewed or commented on Midea Group's acquisition of KUKA.

Other Recent Acquisitions and Investments

Since 2015 Chinese companies and venture capital firms acquired or invested in other robotics ventures in the United States, Russia, and the United Kingdom, including the following:

- In 2015 the Beijing-based company Ninebot acquired its U.S. rival Segway after securing USD 80 million in funding from investors including Xiaomi, Sequoia Capital, and Shunwei Foundation.[505]
- In 2015 Cybernaut Investment Group, one of China's largest VCs, announced a strategic partnership with the Skolkovo Foundation in Moscow. Cybernaut will invest USD 200 million to develop IT, space, telecommunication, and robotic products that can be manufactured and marketed in China.[506]
- In 2015 Zhuzhou CSR Times Electric, a subsidiary of state-owned conglomerate China South Rail, acquired the UK-based SMD. SMD is a provider of underwater ROVs and ROV systems, tractors, and trenchers for laying cable, sub-sea mining and oil and gas operations.[507]

[502] Sebastian Heilmann, "Europe Needs Tougher Response to China's State Led Investments," post at *Financial Times*, June 9, 2016, accessed July 1, 2016, http://blogs.ft.com/beyond-brics/2016/06/09/europe-needs-tougher-response-to-chinas-state-led-investments/.
[503] Arne Delfs and Patrick Donahue, "Merkel Confronts China Ambitions in Clash Over Robot Maker Kuka," *Bloomberg Technology*, June 10, 2016, accessed August 29, 2016, https://www.bloomberg.com/news/articles/2016-06-10/merkel-confronts-china-ambitions-in-clash-over-robot-maker-kuka; and Amie Tsang, "Midea of China Moves a Step Closer to Takeover of Kuka of Germany," *The New York Times*, July 4, 2016.
[504] Kane Wu, Eyk Henning, and Christopher Alessi, "China's Midea Offers $5 Billion for German Robot Maker Kuka," *The Wallstreet Journal*, May 18, 2016, accessed July 6, 2016, http://www.wsj.com/articles/chinas-midea-group-announces-bid-for-germanys-kuka-1463556160.
[505] Catherine Shu, "Beijing-based Ninebot Acquires Segway, Raises $80M From Xiaomi And Sequoia," Techcrunch, April 15, 2015, accessed July 6, 2016, https://techcrunch.com/2015/04/15/ninebot-segways-into-the-future/.
[506] Frank Tobe, "Chinese Shopping for Global Robotics Venture," *The Robot Report*, April 26, 2015, accessed July 6, 2016, https://www.therobotreport.com/news/chinese-acquiring-us-and-russian-robotics-related-technologies.
[507] Ibid.

Chapter Seven: Implications and Recommendations for the United States

China's advances in industrial, service, and military robotics, as well as artificial intelligence and nanorobotics present opportunities and challenges for U.S. stakeholders. This section lays out the implications of China's advancements in these sectors for the United States, including areas of opportunity such as cooperation or investments, and challenges to economic and security interests. These recommendations can help ensure that the United States enjoys the benefits of China's surging robotics industries while safeguarding its own economic growth and national security.

Recommendation 1: The U.S. Government should promote advanced manufacturing and robotics technologies by implementing the recommendations of the AMP2.0 Steering Committee Report and by supporting initiatives and expansion of the National Network for Manufacturing Innovation (NNMI).

China's Made in China 2025 and recent plans for industrial robotics are the most ambitious to date, and will likely sustain growth in this sector. These programs reflect Chinese economic and political leaders' strong desire to move up the value chain, relying on robotics investments as a means to increase productivity, quality, and cost-effectiveness. Rising Chinese labor costs make this transition increasingly necessary. Simply put, China is determined to become an advanced manufacturing power, with implications for how and in what sectors it will be more competitive vis-à-vis U.S. producers.

The long-term challenge for the United States will be maintaining its manufacturing advantages, particularly in high-end manufacturing. The United States has been the leading producer of manufactured goods for over a century, but in the next five to ten years, advances in China's manufacturing sector could erode long-held advantages. Chinese leaders and policies are launching some of China's most ambitious programs to date to improve high-end manufacturing, largely through the adoption and production of industrial robotics. Future increases in precision, quality control, and efficiency, when combined with relatively cheap labor, could make Chinese high-end products more competitive with their U.S. counterparts.

The United States is already heading in the right direction with the Advanced Manufacturing Partnership (AMP), a national effort to bring together industry, universities, and the federal government to invest in emerging technologies. Some analysts consider AMP and European manufacturing initiatives as inspirations for China's Made in China 2025 plan. The first AMP report in 2012 set three pillars for the United States to expand advanced manufacturing: (1) enable innovation, (2) secure the talent pipeline, and (3) improve the business climate. A second report from the AMP2.0 Steering Committee lays out detailed proposals for increasing coordination among U.S. Government, industry, and universities to secure and establish strategic advantages. Ranging from education and certifications for workers to coordinated plans and investment strategies, these plans if implemented could help ensure success for U.S. manufacturing.[508]

[508] Executive Office of the President, *Accelerating U.S. Advanced Manufacturing*, prepared by the Steering Committee of the Advanced Manufacturing Partnership 2.0 (AMP2.0) and adopted by the President's Council of Advisors on Science and Technology (PCAST) President's Council of Advisors on Science and Technology, October 2014. https://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/amp20_report_final.pdf

Building off these recommendations, the Network for Manufacturing Innovation (NNMI) brings together industry, academia, and government partners to achieve these goals.[509] These initiatives and legislation such as the Revitalize American Manufacturing and Innovation Act (signed into law on December 16, 2014) can help ensure that U.S. manufacturing maintains its technological edge and that U.S. workers have the tools needed to remain the most productive in the world.[510]

Recommendation 2: U.S. defense planners should monitor and account for Chinese advances in unmanned systems and electronic countermeasures that may improve anti-access/area denial (A2/AD) capabilities such as long-range precision strike and anti-submarine warfare.

Chinese advances in military robotics, unmanned systems, and electronic countermeasures may improve its air and naval capabilities, and in turn A2/AD capabilities such as long-range precision strike and anti-submarine warfare. China's research and deployment of unmanned systems in all domains can accomplish a variety of missions, but the bulk of these applications affect the United States, such as:

- If Chinese unmanned aerial vehicles (UAVs) can facilitate guidance and navigation of anti-ship ballistic missiles and if China's unmanned combat aerial vehicles become capable platforms, these systems can hold U.S. assets at risk at greater distances.
- As the United States implements the Third Offset strategy and deploys increasing numbers of unmanned systems, China's increasing electronic warfare and countermeasure capabilities warrant concern.
- In the future, Chinese advances in unmanned undersea vehicles and autonomous underwater vehicles, in combination with plans to increase undersea monitoring and improve anti-submarine warfare capabilities, may erode the U.S. Navy's long-held advantages in undersea warfare.

Recommendation 3: The U.S. Government should conduct an interagency review with economic, scientific, and regional experts to assess U.S.-China cooperation and bilateral investments in artificial intelligence (AI) to ensure that such arrangements do not put the United States at a disadvantage in AI research, breakthroughs, and applications.

The Baidu Silicon Valley AI Laboratory in California and the Dell-Chinese Academy of Sciences (CAS) joint Artificial Intelligence and Advanced Computing Joint Laboratory in China are unique initiatives that can benefit AI applications and research worldwide. One concern, however, is whether the Chinese government and military have an advantage in benefiting from this research. Baidu and CAS are China's national champions for AI research, and it is difficult to imagine a scenario in which either entity refuses government or military requests for assistance or information on breakthroughs. In contrast, private U.S. companies in Silicon Valley such as Google or Apple may refuse to do business with the U.S. Government for reputational or financial

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[509] Advanced Manufacturing National Program Office, "National Network for Manufacturing Innovation (NNMI)," accessed August 29, 2016, https://www.manufacturing.gov/nnmi/.
[510] Ibid.

considerations.[511] Financially, U.S. technology companies worry that compliance and procurement procedures with U.S. Government customers are too complicated and expensive.[512]

These differing relationships between industry and military in the United States and China could lead to an asymmetry in national-level implementation of AI research. The key question is whether the Chinese government and military hold a distinct advantage in gaining access to AI breakthroughs compared to their U.S. counterparts. The Chinese government and military hold tremendous sway over CAS and Baidu, and can influence research agendas, take advantage of breakthroughs, or demand access to technologies and source code.[513] Commercial entities in the United States, on the other hand, can refuse such requests. This possibility warrants attention from policymakers as AI research, application, and commercialization advance around the world.

Recommendation 4: The U.S. Government should increase awareness among federal agencies, defense contractors, and research universities that Chinese research institutes actively collect their published materials, designs, specifications, and graphics to assess U.S. military systems and guide Chinese research.

China leverages a vast open source collection apparatus to study science and technology (S&T) developments abroad and synthesize that information for domestic programs. U.S. Government agencies (such as the Defense Advanced Research Projects Agency), defense contractors, and research universities should increase awareness among their employees that Chinese research institutes actively collect and utilize their published materials, designs, specifications, and graphics. For entities engaged in unmanned systems and other research, abiding by U.S. classification guides and self-restraint in publishing are critical for keeping sensitive information out of China's defense research and development (R&D) complex. Regarding enforcement of such guidelines, any U.S. Government groups funding or supporting research into unmanned systems and robotics could consider more detailed guidelines on publications, rules on participation in conferences (especially those involving international travel), and penalties for violations such as the cancellation of funding.

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[511] Andrew Griffin, "Google joins Apple in refusing to hack into phones to give US government access to terrorist's messages" *Independent*, February 18, 2016, accessed July 8, 2016, http://www.independent.co.uk/life-style/gadgets-and-tech/news/google-joins-apple-in-refusing-to-hack-into-phones-to-give-us-government-access-to-terrorist-s-a6880926.html; Matt Apuzzo, David E. Sanger, and Michael S. Schmidt, "Apple and Other Tech Companies Tangle with U.S. Over Data Access," *New York Times*, September 7, 2015, accessed July 8, 2016, http://www.nytimes.com/2015/09/08/us/politics/apple-and-other-tech-companies-tangle-with-us-over-access-to-data.html?_r=0.

[512] Jon Harper, "Acquisition Process Undermining Silicon Valley Outreach Efforts," *National Defense Magazine*, June 2016, accessed July 8, 2016, http://www.nationaldefensemagazine.org/archive/2016/June/Pages/AcquisitionProcessUnderminingSiliconValleyOutreachEfforts.aspx; Sandra I. Erwin, "SecDef, Industry CEOs Exchange Views on Innovation, Acquisition Reforms," National Defense Magazine, March 29, 2016, accessed July 8, 2016, http://www.nationaldefensemagazine.org/blog/Lists/Posts/Post.aspx?List=7c996cd7-cbb4-4018-baf8-8825eada7aa2&ID=2141.

[513] For a discussion of the PRC government's influence on Baidu, see Brad Stone, "How Baidu Won China," *Reuters*, November 11, 2010, accessed September 30, 2016, http://www.bloomberg.com/news/articles/2010-11-11/how-baidu-won-china.

Recommendation 5: The U.S. Government should fully implement the Cybersecurity National Action Plan (CNAP) and incorporate input from companies and research institutes that develop unmanned systems, robots, and their relevant technologies.

According to news media, China's cyber espionage has already compromised leading U.S. and foreign defense companies, including those engaged in robotics and unmanned systems. When Chinese cyber actors fail to infiltrate leading U.S. defense contractors, they often shift tactics downstream to smaller suppliers and supporting contractors. Initiatives to share data on intrusions, reviews of best practices, and timely updates to identified vulnerabilities can help mitigate these risks. The Obama Administration's Cybersecurity National Action Plan (CNAP) incorporates lessons from cybersecurity trends, threats, and intrusions, and proposes actions to improve cybersecurity across the Federal Government, private sector, and individuals.[514] The U.S. Government should fully implement CNAP's recommendations and incorporate input, feedback, and participation of companies, research institutes, and universities engaged in robotics and unmanned systems research.

Recommendation 6: To help counter Chinese espionage against unmanned systems and other sensitive technologies, the U.S. Government should better exploit China's state plans, procurement practices, defense plans, and other Chinese language materials. Such sources identify technologies that the Chinese government is seeking to acquire and would provide advance warning to U.S. law enforcement.

China is actively seeking technologies it has trouble developing domestically, and targets U.S. companies and technological advantages in areas such as UAVs and unmanned undersea vehicles. The targets for such conspiracies often appear in Chinese state plans and academic publications in advance of acquisition efforts. State plans can read "like a shopping list" of foreign technologies China needs to acquire for specific industries, and Chinese publications are candid about what materials and technologies are lacking. Analysis of these plans, as well as procurement, defense, and other Chinese language materials may provide early warnings to U.S. law enforcement and industries that may be targets of espionage or conspiracies to commit export violations. The U.S. Government should invest in analysis of these plans, practices, and documents, and educate U.S. law enforcement agencies and supporting personnel to help prevent and prosecute Chinese espionage cases.

Recommendation 7: To address informal technology transfers, U.S. Government sponsors of academic exchanges and research in emerging technologies should consider requirements to more thoroughly vet foreign participants for military or other undisclosed defense affiliations.

Informal technology transfer from the United States to China is pervasive and may erode U.S. advantages in emerging technologies such as artificial intelligence. U.S. policy may not be able to address some of these tactics, such as generous funding and grants from the Chinese government for leading international experts to work at Chinese institutions. The U.S. Government can and

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[514] The White House, Office of the Press Secretary, "FACTSHEET: Cybersecurity National Action Plan," February 9, 2016, accessed August 30, 2016, https://www.whitehouse.gov/the-press-office/2016/02/09/fact-sheet-cybersecurity-national-action-plan.

should, however, insist on adequate vetting of foreign participants in federally-funded research and academic exchanges.

To be clear, the problem here is not Chinese participation in international conferences or academic exchanges, as both the United States and China benefit greatly from these interactions. Rather, the concern lies in the participation of Chinese military officers and other personnel who do not openly declare their military affiliations. As reported earlier, one of China's leaders in the field of artificial intelligence openly displays both his military rank and civilian credentials in Chinese-language media, but lists only his civilian affiliations in English-language publications. Federal funding for research in emerging, sensitive, or dual-use technologies should mandate more thorough vetting of participants to ensure that China's military R&D infrastructure does not benefit from leading experts in emerging technologies to the detriment and at the expense of the United States.

Recommendation 8: The U.S. Government, in particular the Committee on Foreign Investment in the United States (CFIUS), should monitor and when necessary investigate China's growing foreign investments in robotics and AI companies, and consider the security implications of transactions and acquisitions involving emerging technologies such as AI and nanorobotics.

As China increases its foreign investments in robotics and emerging technologies, the U.S. Government, in particular CFIUS, should monitor these trends and consider their security implications. Chinese companies will likely continue to invest in and acquire leading European robotics companies whose products are necessary to U.S. industries, including defense companies. CFIUS should consider the implications of these changes of ownership for the U.S. defense manufacturing base, and identify any areas, systems, or other capabilities that these changes may compromise. China is also "poised to target" AI companies in the United States, as seen in the recent investment in Neurala. CFIUS should ensure that its review processes account for new and emerging technologies, and consider reviewing this transaction. Other U.S. Government authorities and outside experts may provide detailed lists of technologies with security implications, as well as those targeted for acquisition by Chinese end-users. This review process will help ensure that foreign countries do not gain access to game-changing technologies at the expense of the United States.

Appendix I: Leading Industrial and Service Robotics Manufacturers, Research Institutes, and Professional Associations in China

Org. Name (EN/CN)	Summary
Companies	
Siasun 沈阳新松机器人自动化股份有限公司	• Siasun is China's largest robot maker by market value and states that the company is expanding its facilities to accommodate growing domestic demand.[515] • Siasun's robot product lines include industrial robots, mobile robots, cleaning robots, specialty robots, and service robots, and the company offers a total of more than 80 types of robot products.[516] • Siasun is a chair member organization for the China Robot Industry Alliance (中国机器人产业联盟) as well as a chair member organization for the China Robot Innovation Alliance (中国机器人创新联盟).[517]
Harbin Boshi Automation 哈尔滨博实自动化设备有限责任公司	• Harbin Boshi Automation's products are used in petroleum, chemical, fertilizer, salt chemical engineering, coal chemical engineering, and metallurgical industries, port logistics, precise chemical engineering, food product, and animal feed product industries. [518] • Harbin Boshi Automation is a major provider of Chinese-made equipment for the Chinese oil industry. It is a tier-one supplier enterprise to Sinopec, and exports equipment to international oil companies.[519] • Boshi's products have been sold within China as well as internationally to customers in more than 10 countries in Europe, Asia, and Africa. [520]
Shanghai Mechanical and Electrical Industry Company 上海机电一体化工程公司	• Shanghai Mechanical and Electrical Industry Company is a leading Chinese machine equipment manufacturing enterprise and a market listed company.[521] • It is an important subsidiary of Shanghai Electrical Group Company, a state-owned, Hong Kong- and Shanghai-listed company that is one of China's largest electrical equipment manufacturing groups.[522] • Its main business areas are elevator manufacturing, refrigeration equipment manufacturing, printing and packaging machinery manufacturing, welding equipment and materials manufacturing, artificial board-making machinery manufacturing, artificial board materials manufacturing, and engineering machinery manufacturing.[523]

515 "China's Siasun Expands To Seize More Of The Domestic Market," Robotics Business Review, October 8, 2012, accessed May 26, 2016, http://www.roboticsbusinessreview.com/article/chinas_siasun_expands_to_seize_more_of_the_domestic_market.
516 "企业介绍" [Company Introduction], Siasun 新松, accessed May 10, 2016, http://www.siasun.com/about/Introduction.html.
517 Ibid.
518 Boshi 博实, accessed May 11, 2016, http://www.boshi.cn/.
519 Ibid.
520 "博实：机器人及智能装备"排头兵" [Boshi: Robots and Intelligent Equipment "Frontline Troops"], Boshi 博实, accessed June 3, 2016, http://www.boshi.cn/News_More.aspx?ID=1514.
521 "上海机电股份有限公司" [Shanghai Mechanical and Electrical Industry Company], Baidu Baike 百度百科, accessed May 12, 2016, http://baike.baidu.com/view/1969738.htm.
522 Ibid.
523 Ibid.

FA Company **上海富安工厂自动化公司**	• FA Company was established in 1996 as a subsidiary of Shanghai Electric Group's subsidiary Shanghai Machine Tool Works, making it a state-owned enterprise.[524] • The company provides manufacturing automation control equipment and maintenance services for a variety of industries including automotive, molds, precision devices, printing machinery, medical machinery, textile machinery, motorcycle, bicycle, household appliances. Among these industries, the company's main target customers are producers of cars, appliances, and precision devices. [525] • FA Company's main products and services include digitally-controlled machine tools, digitally-controlled milling tools, digitally-controlled machining centers, digitally-controlled machine tool training equipment, digitally-controlled milling tools, digitally-controlled chip scribes, and digitally-controlled special devices. [526] • FA's production and manufacturing enterprise customers include: SAIC General Motors Co., Ltd., Shanghai Lunfude Auto Parts Company, Shanghai Hino Engine Co., Ltd., Shanghai Diesel Engine Company, Shanghai Huida Manufacturing Co., Delphi Shanghai Dynamics and Propulsion Systems Co., Ltd., Shanghai SAIC—Metzeler Sealing Systems Co., Ltd., Shanghai Jiao Yun Group. [527]
Harbin Welding Institute **哈尔滨焊接研究所**	• Harbin Welding Institute was founded in 1956 and was originally subordinate to the former Ministry of Machine Building. [528] • It operates as a comprehensive welding technology national scientific research institute and became a science and technology enterprise during reforms implemented in 1999. [529] • HWI is currently operated as a state-owned enterprise under the State-owned Assets Supervision and Administration Commission of the Chinese State Council (SASAC).[530]
Beijing Research Institute of Machinery and Electronic Technology **北京机电研究所**	• The Beijing Research Institute of Machinery and Electronic Technology was established in 1956.[531] • It is subordinate to the China Academy of Machinery Science and Technology (机械科学研究总院), a major technology group corporation under SASAC.[532] • It is a leading organization within China in the fields of metal forging, thermal processing, and die and mold technology development and technology transfer.[533] • It is recognized as a National High Technology Enterprise, National Torch Program Key Technology Enterprise, Beijing Patent Model Unit, and Zhongguancun Open Laboratory. [534]
Shougang Motoman Robot Co. Ltd.	• Shougang Motoman Robot Co., Ltd. is a joint venture between China-based Shougang Group (中国首钢（集团）总公司), Japan-

[524] "上海富安工厂自动化有限公司" [Shanghai Fu'an Factory Automation Co.], HC360 慧聪, accessed May 12, 2016, http://shanghaifuan.b2b.hc360.com/shop/show.html#.
[525] Ibid.
[526] Ibid.
[527] Ibid.
[528] "HWI Profile" Harbin Welding Institute, accessed May 12, 2016, http://en.hwi.com.cn/CorporateProfile.html.
[529] Ibid.
[530] Ibid.
[531] "企业简介" [Company Introduction], Beijing Research Institute of Mechanical & Electrical Technology 北京机电研究所, accessed May 16, 2016, http://www.brimet.ac.cn/CN/about.aspx?nid=13.
[532] Ibid.
[533] Ibid.
[534] Ibid.

首钢莫托曼公司	based Yaskawa, and Japan-based Iwatani Co. (岩谷产业株式会社), set up in Beijing's Economic and Technology Development Zone as China's first company specializing in producing robot products.[535] • It has USD 7 million in registered capital and is currently one of China's largest and most advanced robot production enterprises, capable of manufacturing 800 robots and systems annually. [536] • Shougang Motoman mainly engages in technology development, production, and sales of robots, robotic workstations, and large-scale robotic automated systems for welding, assembly, painting, handling, cutting and grinding operations used in the automotive, motorcycle, engineering machinery, chemical engineering, home appliance, and construction industries. It also provides peripheral equipment and components and technology services for its customers. [537]
Beijing Yaskawa Bei Ke Automation Engineering (BK Masic) **安川北科公司/北京北科麦思科自动化工程技术有限公司**	• Beijing-based BK Masic was set up in 1994 as Japanese robotics manufacturer Yaskawa's first authorized sales agent.[538] • It is overseen by the Beijing University of Science and Technology's school industry group and engages in automated control product development, manufacturing, integration, and sales.[539] • Many of the products sold by BK Masic are from its Japanese partner Yaskawa, including Yaskawa frequency converters (or frequency changers), Yaskawa servo motors, Yaskawa motion control systems, and a variety of other Yaskawa components related to frequency converters.[540]
Professional and Research Associations	
China Robot Industry Alliance **中国机器人产业联盟**	• The China Robot Industry Alliance (CRIA) is a non-profit, national industry association for China's robotics industry, including educational and research institutions as members as well as robotics users and other interested parties.[541] • CRIA seeks to expand the application of robotics technology in all fields, and to improve national robotics industry chains. It endeavors to promote the development of China's robotics industry and enhance its competitiveness. [542] • The Alliance's main objective is to carry out national industrial policy, promote the exchange of its members in terms of technology, markets, and intellectual property, encourage partnerships between research, industry, and academia, promote

[535] "Shougang Motoman Robot Co. Ltd." [首钢莫托曼机器人有限公司], accessed May 16, 2016, http://etc.gdut.edu.cn/source/amt/PART3/sg-motoman/.
[536] Ibid.
[537] Ibid.
[538] "公司简介" [Company Introduction], BK MASIC, accessed May 16, 2016, http://www.bkmasic.com/page/html/index.php.
[539] Ibid.
[540] Ibid.
[541] Ibid.
[542] "联盟简介" [Alliance Introduction], China Robot Industry Alliance 中国机器人产业联盟, accessed May 23, 2016, http://cria.mei.net.cn/gylm.asp.

	industry self-governance, and coordinate to avoid overlap within the industry.[543]
China Robot Industry Innovation Alliance **中国机器人产业创新联盟**	• The China Robot Industry Innovation Alliance was established in Beijing on March 16, 2013 by a consortium of over 40 robotics enterprises and research organizations.[544] • Shenyang Siasun (沈阳新松机器人自动化股份公司) serves as president of the organization and the National Robot Engineering Center (机器人国家工程中心) is deputy director.[545] • Zhang Meiying, vice chairman of the Eleventh National People's Political Consultative Committee, gave a speech at the organization's commencement and Li Yizhong, director of the Ministry of Industry and Information Technology (MIIT), also gave an address.[546]

543 "联盟简介" [Alliance Introduction], China Robot Industry Alliance 中国机器人产业联盟, accessed May 23, 2016, http://cria.mei.net.cn/gylm.asp.
544 "中国机器人产业创新联盟" [China Robot Industry Innovation Alliance], Baidu Encyclopedia 百度百科, accessed June 6, 2016, http://baike.baidu.com/view/10299596.htm.
545 Ibid.
546 Ibid.

Appendix II: Leading Chinese Research Institutes and Producers of Military Robotics and Unmanned Systems

Org. Name (EN/CN)	Summary
Unmanned Aerial Vehicles (UAVs)	
Northwest Polytechnic University 西北工业大学	• Northwest Polytechnic University (NWPU) is a leading technical university that conducted China's first research into UAVs in the 1950s.[547] • Currently, NWPU's 365th Research Institute (西北工业大学第365研究所), also known by its commercial name Xi'an ASN Technology Group (西安爱生技术集团公司), is one of China's leading UAV design and manufacturing entities.[548] The NWPU 365th RI's work includes design optimization, system integration and controls, takeoff and landing, and comprehensive performance tests.[549] • It is reported to be China's largest UAV production company and R&D base, and designed three of the UAVs featured in China's 60th National Day Military Parade.[550] • The RI hosts the Key Laboratory of UAV Special Technology (无人机特种技术重点实验室), as well as a provincial level laboratory dedicated to advanced air layout and controls aviation technologies.[551]
Beihang University 北京航空航天大学	• Beihang University (formerly the Beijing University of Aeronautics and Astronautics/BUAA) is the PRC's first university dedicated to air and space, and is directly under MIIT.[552] • In 1959 it tested China's first UAV, and in 1962 established the UAV Institute (无人机所 / 无人驾驶飞行器设计研究所), China's first UAV R&D center.[553]

547 Li Caixiang 李彩香, Liu Yinzhong 刘银中, "探访西北工业大学无人机事业发展之路" [Looking at Northwestern Polytechnical University's UAV Development Road], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1091/6411.htm.
548 Wang Fanhua 王凡华, Guo Youjun 郭友军, "我校研制生产的无人机参加国庆阅兵载誉归来" [UAVs Developed and Manufactured by Our School in the National Day Troop Review], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1091/4169.htm.
549 "无人机特种技术重点实验室" [UAV Special Technology Key Lab], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1266/12808.htm.
550 Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 8; http://www.nwpu.edu.cn/xxgk/xxjj.htm. http://www.nwpu.edu.cn/info/1091/4169.htm
551 "无人机特种技术重点实验室" [UAV Special Technology Key Lab], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1266/12808.htm; "西北工业大学重点实验室一览表" [Northwestern Polytechnical University Key Lab -- Table], Northwestern Polytechnical University 西北工业大学, accessed July 8, 2016, http://www.nwpu.edu.cn/info/1157/9868.htm.
552 "学校简介" [Introduction to the University], Beihang University, accessed July 8, 2016, http://www.buaa.edu.cn/bhgk/index.htm#1.
553 "北京航空航天大学无人驾驶飞行器设计研究所简介" [Beihang University UAV Design Research Institute Introduction], November 14, 2013, Beihang University 北京航空航天大学, accessed July 8, 2016, http://wrjs.buaa.edu.cn/zxgg/49517.htm.

	• The institute is vast and includes laboratories or design centers for vehicle design and integration center, testing, a simulations, and electronics and countermeasures.[554] • The institute is responsible for the BZK-005 UAV and Changying (长鹰) UAV programs.[555]
Nanjing University of Aeronautics and Astronautics 南京航空航天大学	• Nanjing University of Aeronautics and Astronautics (NUAA) has specialized in tactical UAVs since its founding.[556] • Its UAV Institute (南京航空航天大学无人机研究院) is reported to be responsible for designing the Changkong (长空) and BZK-002 UAV series, as well as unmanned helicopters.[557]
Aviation Industry Corporation of China (AVIC) 中航工业 / 中国航空工业集团公司	• Established in November 2008 after the merger of AVIC 1 and AVIC 2, AVIC is a large state-owned enterprise responsible for producing defense aviation equipment.[558] • AVIC is the premier Chinese military aircraft and weapons supplier, producing fighter jets, fighter-bombers, bombers, military transport craft, training aircraft, surveillance aircraft, helicopters, attack aircraft, general-purpose aircraft, UAVs, turboprops, turboshafts, turbojets, turbofan engines, air-air, air-surface, and surface-air missiles. • AVIC produces the J-10, JH-7, FC-1, L-15, and JL-9/ FTC-2000 fighter aircraft, as well as the Taihang, Qinling, and Kunlun engines.[559] • AVIC maintains over 140 subsidiaries, nearly 30 listed companies, and over 500,000 employees.[560]
Shenyang Aircraft Design Institute (SADI; 601 Aircraft Design Institute) 沈阳飞机设计研究所	• SADI is one of the largest subsidiaries of the defense conglomerate AVIC and supports the PLA's UAV program by specializing in advanced UCAV design.[561] • SADI is credited with designing the Lijian (Sharp Sword), Anjian (Dark Sword), and Zhanying (Warrior Eagle) UCAV models.[562]
Chengdu Aircraft Design Institute (CADI; 611 Design Institute) 成都飞机设计研究所	• Established in 1970, CADI is a subdivision of the Chengdu Aircraft Industry Group (CAC; 中航工业成都飞机工业(集团)有限责任公司), an AVIC subsidiary, and focuses on the design and research of advanced fighter aircraft, including UAV and UCAV design.[563]

554 Ibid.
555 Easton and Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," 6.
556 Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 8.
557 Easton and Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," 7.
558 "集团简介" [Group Introduction], Aviation Industry Corporation of China 中国航空工业集团公司, accessed July 8, 2016, http://www.avic.com/cn/gxwm/jqgk/jqjg/index.shtml.
559 Ibid.
560 "About Us," AVIC, accessed July 8, 2016, http://www.avic.com/en/aboutus/index.shtml.
561 Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 10; Easton and Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," 7.
562 Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 10.
563 "单位介绍" [Organization Introduction], AVIC Chengdu Aircraft Design & Research Institute 中航工业成都飞机设计研究所, accessed July 8, 2016, http://611.zhiye.com/a/AboutUs; Hsu, Murray, and Cook, "China's Military Unmanned Aerial Vehicle Industry," 9.

	• CADI claims to control the full design process of aircraft due to its expertise in over 120 fields, including overall pneumatic stealth, structural strength, vibration, aviation control, aviation electronics, electromechanical integration, aviation sensors, photoelectronics, advanced materials, information processing, advanced aerodynamic configuration, stealth technology, and virtual simulations.[564] • CADI is credited with development of the J-7 (歼-7), FC-1 (枭龙), J-10 series (歼十系列), and the Yilong/Pterodactyl 1 MALE UAV, also known as the Wing Loong.[565] • CADI partners with the Guizhou Aircraft Company (GAC), another subsidiary of AVIC, in the development of major UAV systems.[566]
Unmanned Underwater Vehicles (UUVs)	
Chinese Academy of Sciences' Shenyang Institute of Automation (CAS SIA) **中科院沈阳自动化研究所**	• The CAS SIA in Shenyang, Liaoning Province, is a leading research institute and publisher on UUVs.[567] • Its Autonomous Underwater Vehicle Laboratory (自主水下机器人技术研究室) conducts research on all aspects of UUV technologies, including complicated environment recognition and pattern establishment, and advanced intelligence and autonomous behavior. It also researches platform designs (including analysis of designs, simulations, hydrodynamics, and structures), controller technologies, and various types of AUVs and USVs. • It was responsible for China's first UUV, the CR-01,that achieved a depth of 6,000m.[568]
Harbin Engineering University **哈尔滨工程大学**	• HEU's College of Shipbuilding Engineering (船舶工程学院) is home to the National Defense S&T Key Laboratory of Military-Use Underwater Intelligent Vehicle Technology (军用水下智能机器人技术国防科技重点实验室).[569] • HEU was formerly known as the PLA Military Engineering Institute, established in Harbin in 1953, and is currently an R&D base for China's shipbuilding industry, naval armaments, and ocean development and exploitation.[570] • It has seven research institutes and multiple laboratories dedicated to shipbuilding and ocean engineering, and recruits leading foreign

564 "单位介绍" [Organization Introduction], AVIC Chengdu Aircraft Design & Research Institute 中航工业成都飞机设计研究所, accessed July 8, 2016, http://611.zhiye.com/a/AboutUs.
565 Ibid.
566 Easton and Hsiao, "The Chinese People's Liberation Army's Unmanned Aerial Vehicle Project: Organizational Capacities and Operational Capabilities," 8.
567 "自主水下机器人技术研究室" [Independent Underwater Robot Technology Research Lab], Shenyang Institute of Automation Chinese Academy of Sciences 中国科学院沈阳自动化研究所, accessed July 8, 2016, http://www.sia.cn/jgsz/kyxt/zzsxjqrjsysj/.
568 Ibid.
569 Ju Lei 鞠磊, Su Yumin 苏玉民, Zhao Jinxin 赵金鑫, Liu Yebao 刘业宝, and Cui Tong 崔桐, "船桨干扰定常空化性能数值模拟" (Steady Interaction Numerical Simulation of Cavitating Turbulent Flow between Ship Hull and Propeller), *船舶力学 Journal of Ship Mechanics*, vol. 6, no. 16 (2012).
570 "学院简价" [College Introduction], College of Shipbuilding Engineering 哈尔滨工程大学船舶工程学院, accessed July 8, 2016, http://heusei.hrbeu.edu.cn/index.php?m=content&c=index&a=lists&catid=2.

	experts in these fields through China's 111 Plan, described in more detail in the Talent Acquisition section on page 102.[571] • Key systems developed by HEU include the Zhishui series of AUVs, discussed on page 66.

[571] Li Xiaohua, "China to Undergo Brain Gain through Plan 111" China Internet Information Center 中国网, September 14, 2006, accessed July 8, 2016, http://www.china.org.cn/english/China/181075.htm.

Unmanned Surface Vehicles (USVs)	
Shanghai University Unmanned Vessel Engineering Research Institute 上海大学无人艇工程研究院	• Founded in 2010, this research institute is China's first research organization to focus on USVs and integrate the fields of machinery, control, communications, mechanics, materials, and computers.[572] • The research institute produces the "Jinghai" (精海) series of USVs which include multiple different models, and it is currently working on development of the Jinghai-7.[573]
China Shipbuilding Industry Corporation (CSIC) 701st Research Institute 中国船舶重工集团公司７０１所 (中船重工 701 所) AKA the China Ship Research and Design Center (中国舰船研究设计中心)	• The CSIC 701st Research Institute is the premier institution focusing on the research and design of warships and other naval vessels, and is a leader in in air-independent propulsion (AIP) research.[574] • The CSIC 701st Research Institute is one of several Chinese organizations competing in the manufacture and development of USVs.[575] • Qingdao Beihai Shipbuilding Heavy Industry Co. Ltd. (青岛北海船舶重工有限责任公司), a CSIC subsidiary, jointly develops the Jinghai series of USVs with Shanghai University.[576]
Harbin Engineering University 哈尔滨工程大学	• HEU's College of Shipbuilding Engineering (船舶工程学院) is home to the National Defense S&T Key Laboratory of Military-Use Underwater Intelligent Vehicle Technology (军用水下智能机器人技术国防科技重点实验室).577 • HEU is currently an R&D base for China's shipbuilding industry, naval armaments, and ocean development and exploitation.578 • It has seven research institutes and multiple laboratories dedicated to shipbuilding and ocean engineering, and recruits leading foreign experts in these fields through China's 111 Plan, described in more detail in the Talent Acquisition section on page 102.[579] • Key systems developed by HEU include the Zhishui series of AUVs, discussed on page 66.
Dalian Maritime University (DLMU) 大连海事大学	• Known as Dalian Maritime College until 1994, Dalian Maritime University (DLMU) is a "national key university" under China's Ministry of Transport.[580] • In March 2015, a delegation from the China Academy of Launch Vehicle Technology (中国运载火箭技术研究院) visited DLMU to discuss USV research and development and various other topics.[581] • DLMU conducts a program entitled "Small UAV Intelligent Control based on Beidou Satellite Navigation."[582]
Shanghai Maritime University (SMU) 上海海事大学	• Established in 2004 with predecessor institutions reaching back to 1909, SMU operates under the Shanghai municipal government and the Ministry of Transport.[583] • Shanghai Maritime University (上海海事大学), which hosts a state key laboratory for marine technology and controls, and has published on navigation and GPS guidance for USVs.[584] • The SMU Shipping Technology and Control Engineering Transportation Industry Key Laboratory Unmanned Surface Vessel Working Group (航运技术与控制工程交通行业重点实验室无人水面艇课题组) produces the Haiteng 01 (海腾 01) Intelligent High-speed USV, and it is also capable of being manually controlled.[585]

Unmanned Ground Vehicles (UGVs)	
China North Vehicle Research Institute 中国北方车辆研究所	• In June 2014 the China North Vehicle Research Institute (中国北方车辆研究所), directly subordinate to the NORINCO Group, established the Weapons Unmanned Ground Vehicle R&D Center (兵器地面无人平台研发中心). The center develops UGVs for

[572] "无人艇：在江河湖海中展露身手" [Unmanned Vessel: Showing Skill in All Waters], Xinhua 新华社, July 7, 2016, accessed July 7, 2016, http://news.xinhuanet.com/2016-07/07/c_1119182583.htm.

[573]Xie Yao 谢姚, "不经历风雨怎么见彩虹" [If You Don't Go Through the Storm, How Will You See the Rainbow], School of Mechatronic Engineering and Automation 机电工程与自动化学院, December 31, 2015, accessed July 8, 2016, http://old.auto.shu.edu.cn/Default.aspx?tabid=12022&ctl=Detail&mid=59127&Id=172263&SkinSrc=[L]Skins/jizi1/jizi1; "无人艇：在江河湖海中展露身手" [Unmanned Vessel: Showing Skill in All Waters], Xinhua 新华社, July 7, 2016, accessed July 7, 2016, http://news.xinhuanet.com/2016-07/07/c_1119182583.htm.

[574] "首页" [Homepage], China Shipbuilding Industry Corporation 中国船舶重工集团公司, accessed July 8, 2016, http://www.csic.com.cn/.

[575] "无人艇：在江河湖海中展露身手" [Unmanned Vessel: Showing Skill in All Waters], Xinhua 新华社, July 7, 2016, accessed July 7, 2016, http://news.xinhuanet.com/2016-07/07/c_1119182583.htm.

[576] "北船承制无人艇获工博会创新金奖" [Qingdao Beihai Shipbuilding Heavy Industry Co. Manufactured Unmanned Vessel and Awarded Engineering Innovation Gold Medal], China Shipbuilding Industry Corporation 中船重工, December 28, 2015, accessed July 7, 2016, http://www.csic.com.cn/zgxwzx/zgcydt/314027.htm.

[577] The college's website describes the lab as "军用水下 xx 重点实验室" (Military-Use Underwater XX Key Laboratory), but author affiliations on articles include the full name of the lab. For example, see Ju Lei 鞠磊, Su Yumin 苏玉民, Zhao Jinxin 赵金鑫, Liu Yebao 刘业宝, and Cui Tong 崔桐, "船桨干扰定常空化性能数值模拟" (Steady Interaction Numerical Simulation of Cavitating Turbulent Flow between Ship Hull and Propeller), *Journal of Ship Mechanics* 船舶力学, vol. 6, no. 16 (2012).

[578] "学院简价" [College Introduction], College of Shipbuilding Engineering 哈尔滨工程大学船舶工程学院, accessed July 8, 2016, .http://heusei.hrbeu.edu.cn/index.php?m=content&c=index&a=lists&catid=2.

[579] Li Xiaohua, "China to Undergo Brain Gain Through Plan 111"" China Internet Information Center 中国网, September 14, 2006, accessed July 8, 2016, http://www.china.org.cn/english/China/181075.htm.

[580] "学校简介" [School Introduction], Dalian Maritime University 大连海事大学, accessed July 7, 2016, http://www.dlmu.edu.cn/html/hdgk/xxjj/.

[581] "中国运载火箭技术研究院院长助理龚知明一行来访我校" [China Academy of Launch Vehicle Technology President's Assistant Gong Zhiming and Delegation Visit Our School], Dalian Maritime University 大连海事大学, March 27, 2015, accessed July 8, 2016, http://www.dlmu.edu.cn/html/2015/kydt_0327/884.html.

[582] "基于北斗卫星导航的小型无人飞行器的智能控制" [Small Model UAV's Intelligent Control Based on Beidou Satellite Navigation], Dalian Maritime University 大连海事大学, May 18, 2014, accessed July 8, 2016, http://www.dlmu.edu.cn/html/2014/hdyx_0518/50.html.

[583] "校情总览" [School General Overview], Shanghai Maritime University 上海海事大学, accessed July 8, 2016, http://www.shmtu.edu.cn/AboUt/AboUt.Htm.

[584] For example, see Xiong Yazhou 熊亚洲 and Wang Jianhua 王建华, "一种利用天水线感知无人水面艇运行环境的方法" (Acquiring Environmental Condition for Unmanned Surface Vehicle Using Skyline Information), *Journal of Shanghai Dianji University* 上海电机学院学报, vol. 18, no. 4 (2015); and Wu Yuping 吴玉平, Wang Jianhua 王建华, and Yang Zhao 杨钊, "基于双天线的高精度 GPS 定位测向系统及其在无人水面艇上的应用" (High Precision GPS System Based on Double Antennas and Its Application in Unmanned Surface Vessel), *Computer Measurement & Control* 计算机测量与控制, no. 4 (2015).

[585] "我院自主研发的——"海腾 01"号智能高速无人水面艇研发成功" [Our Academy's Independently Developed--'Haiteng01' Model Intelligent High-Speed Unmanned Surface Vessel Research and Development Success], Shanghai Maritime University Scientific Research Academy 上海海事大学科学研究院, November 28, 2014, accessed July 8, 2016, http://sra.shmtu.edu.cn/publish/detail.jspx?cid=156&contentid=650.

	military, police, security, defense industry, and commercial clients.[586] • NORINCO Group's Deputy General Manager Yang Zhuo (杨卓), who spoke at the center's opening, said NORINCO was already working on a variety of unmanned ground vehicles for civilian and military use, and saw the center as a means to accelerate this work.[587] • The Weapons Unmanned Ground Vehicle R&D Center is reported to be developing the Chinese version of BigDog, a rough-terrain robot with four legs developed by Boston Dynamics. Formally called the "Mountainous Four-Legged Bionic Mobile Platform" (山地四足仿生移动平台), the system can carry out transport, reconnaissance, attack, and search and rescue operations. Chinese media also colloquially refers to the system as "Big Dog" (大狗).[588]
Beijing Institute of Technology (BIT) 北京理工大学	• One of BIT's missions is to support "national strategic needs" such as aerospace engineering, information technology, and mechanical engineering and automation.[589] • BIT is directly subordinate to MIIT and is part of China's national 211 and 985 projects, which were aimed at strengthening China's S&T capabilities at its universities.[590] • Recent publications on UGVs appear to focus on situational awareness and vision, operation when GPS signals are disrupted, and general autonomous operation in urban environments. • BIT's team came in third place in the "2014 Leap Over Treacherous Paths" contest for UGVs.[591]
National University of Defense Technology (NUDT) 国防科技大学	• NUDT is under the dual leadership of the Ministry of Defense and the Ministry of Education, and has numerous laboratories dedicated to technology development.[592]

586 Chen Yu 陈瑜，"兵器地面无人平台研发中心成立" [The Weaponry Ground Unmanned Platform R&D Center Is Established], *Science and Technology Daily* 科技日报, June 28, 2014.
587 "中国兵器工业集团成立地面无人平台研发中心 为解放军研制无人作战车辆" [NORINCO Establishes Ground Unmanned Platform Research & Development Center to Develop Unmanned Combat Vehicles for the PLA], *Guanchazhe* 观察者, July 3, 2014, accessed July 7, 2016, http://www.guancha.cn/military-affairs/2014_07_03_243289_s.shtml.
588 "BigDog–The Most Advanced Rough-Terrain Robot on Earth," Boston Dynamics; and Zhang Peng 张鹏 and Peng Kuang 彭况, "军网记者亲身体验中国军用机器人" [Chinese Military Network Reporters Personally Experience China's Military-Use Robots], China Military Network 中国军网, February 27, 2015, accessed July 7, 2016, http://www.81.cn/jmywyl/2015-02/27/content_6372686_5.htm.
589 "学校简介" [School Introduction], March 26, 2013, accessed July 11, 2016, http://www.bit.edu.cn/gbxxgk/gbxqzl/xxjj/index.htm; "Welcome to Beijing Institute of Technology (BIT)" May 18, 2015, accessed July 11, 2016, http://english.bit.edu.cn/AboutBIT/GeneralInformation/index.htm.
590 "学校简介" [School Introduction], March 26, 2013, accessed July 11, 2016, http://www.bit.edu.cn/gbxxgk/gbxqzl/xxjj/index.htm; "Welcome to Beijing Institute of Technology (BIT)" May 18, 2015, accessed July 11, 2016, http://english.bit.edu.cn/AboutBIT/GeneralInformation/index.htm.
591 "跨越险阻-2016"地面无人系统挑战赛等你来战！" [The 2016 Leap Over Treacherous Paths Ground Unmanned Systems Competition Welcomes You to Come Compete!], *中国军网 China Military Network*, June 14, 2016, accessed July 7, 2016, http://www.81.cn/jmywyl/2015-02/27/content_6372686_5.htm.
592 "学校概况" [Summary of the University], 国防科技大学 National University of Defense Technology, accessed July 11, 2016, http://www.nudt.edu.cn/introduce.asp?classid=4.

	• NUDT's College of Mechatronic Engineering and Automation (机电工程与自动化学院) has a Department of Automatic Control (自动控制系), which conducts research on robotics, including guidance and controls.[593] • NUDT teams came in first and second place in the "2014 Leap Over Treacherous Paths" contest for UGVs.[594]
EOD Robotics Companies	Numerous Chinese defense companies and RIs have developed explosive ordnance disposal robots, including: [595] • Lingxi (灵蜥 or "quick lizard") by the CAS Shenyang Institute of Automation • Raptor EOD robot by the Beijing Bochuang Group (北京博创集团) • Snow Leopard-10 (雪豹-10) by China Aerospace Science and Industry Corporation (CASIC) • uBot-EOD series by Shanghai HRSTEK Co., Ltd (上海合时智能科技有限公司)

[593] "自动控制系" (Department of Automatic Control), 国防科技大学 National University of Defense Technology, accessed July 11, 2016, http://www.nudt.edu.cn/ArticleShow.asp?ID=22.

[594] "跨越险阻-2016"地面无人系统挑战赛等你来战！" [The 2016 Leap Over Treacherous Paths Ground Unmanned Systems Competition Welcomes You to Come Compete!], *China Military Network* 中国军网, June 14, 2016, accessed July 7, 2016, http://www.81.cn/jmywyl/2015-02/27/content_6372686_5.htm.

[595] "排爆机器人" [Explosive Ordnance Disposal Robots], Baike 百科, accessed July 7, 2016, http://www.baike.com/wiki/%E6%8E%92%E7%88%86%E6%9C%BA%E5%99%A8%E4%BA%BA.

Appendix III: Leading Artificial Intelligence Companies, Professional Associations, and Research Institutes in China

Org. Name (EN/CN)	**Summary**
	Companies
Turing Robot **图灵机器人**	• Chinese start-up that has developed and marketed AI products including robots, voice assistance, and chat robots. Turing Robot claims to have developed the leading Chinese semantic language processing platform, Turing OS, which was developed in November 2015.[596] • Turing Robot uses cutting-edge natural language processing and semantic language analysis intelligent technologies to create robotic devices that are "friendly AI solutions."[597] Turing Robot sells the "Nao" robot, which the company boasts is the world's most advanced humanoid robot.[598] • Chinese media states that Turing's "Xian'er" Budda robot and the Turing OS uses the Tianhe-2 supercomputer to integrate massive databases for its intelligent learning and processing system.[599]
Xiaoi Robot **小 i 机器人**	• Develops Chinese language chat robots and virtual voice assistants. • Strategic partners include Microsoft, Lenovo, Alibaba, Tencent, and China Unicom, China Telecom, and China Mobile. • Xiaoi sells cloud platform chat robots as well as hardware robots such as sweeping robots and humanoid robots such as "Nao" and "Ina."[600]
Horizon Robotics 地平线机器人	• Founded in 2015, Horizon Robotics focuses on developing and marketing intelligent chips for devices such as vehicles, service robots, toys, and household robots.[601]
iFLYTEK **科大讯飞股份有限公司**	• Software company focusing on intelligent speech technology, natural language processing, and speech recognition.[602] • Recipient of substantial Chinese government funding, iFLYTEK contributed to e-government system integration, and has attracted visits from high-level government leaders.[603]

596 "关于我们" [About Us], Turing Robot 图灵机器人, accessed June 9, 2016, http://www.tuling123.com/html/doc/About_us.html; "Turing OS" *Baidu Encyclopedia* 百度百科, accessed June 9, 2016, http://baike.baidu.com/item/Turing%20OS.

597 Turing Robot 图灵机器人, accessed June 9, 2016, http://www.tuling123.com/.

598 Ibid.

599 Song Yelei 宋业磊, "图灵机器人发 Turing OS 操作系统推儿童机器人玩具" [Turing Robot Issued Turing OS Operating System Promoting Children's Robot Toy], *Phoenix* 凤凰网科技, November 6, 2015, accessed June 9, 2016, http://tech.ifeng.com/a/20151106/41502786_0.shtml.

600 "智能硬件机器人 Nao" [Intelligent Hardware Robot Nao], Xiaoi Robot 小 i 机器人, accessed July 8, 2016, http://www.xiaoi.com/entity/hardware/nao.html.

601 "公司概况" [Company Summary], Horizon Robotics, accessed July 8, 2016, http://www.horizon-robotics.com/company_cn.html; "Chinese Start-Up on Track to Deliver Artificial Intelligence-on-a-Chip" *South China Morning Post*, March 6, 2016, accessed July 8, 2016, http://www.scmp.com/tech/article/1921396/chinese-start-track-deliver-artificial-intelligence-chip.

602 "Company Overview," iFLYTEK, accessed July 8, 2016, http://www.iflytek.com/en/about/index.html.

603 Ibid.

	• Boasts development of the world’s first cloud voice platform over mobile Internet.[604]
Megvii 北京旷视科技有限公司	• Company working with Alibaba’s Alipay that has developed intelligent facial recognition software Face++ that has application for banking and public security[605]
HIT Robot Group, Intelligent Cloud Robot Business Unit 哈工大机器人集团，智能云机器人事业部	• Focuses on use of the cloud in networking, Internet services, big data, cloud computing, AI, pattern recognition, and electromechanical integration, embedded data and information, physics fusion, service oriented computing, robot motion control, power control, machine vision, location services, algorithm, data collection and analysis, and the identification and treatment of core control platforms.[606] • Primary products are an Internet + product quality remote detection system, an intelligent flying robot for high-risk environments, and an intelligent cloud-based robot remote fault diagnosis system.[607]
Alibaba 阿里巴巴集团	• E-commerce provider Alibaba developed cloud platform Aliyun (阿里云) to support AI systems[608] • “DTPAI” platform released in 2015 was announced as the first intelligent AI platform in China.[609] • “Ai” AI system (小 Ai) used to predict Chinese reality show winners.[610]
Tencent 腾讯公司	• Internet service company that owns QQ chat and WeChat[611] • AI laboratory focuses on machine learning, computer vision, translation, intelligent chat, and speech recognition.[612]

[604] Ibid.

[605] “Alibaba Arm Seeks to Use Police Face Scans for Banking” Bloomberg News, January 28, 2015, accessed July 8, 2016, http://www.bloomberg.com/news/articles/2015-01-28/alibaba-arm-seeks-to-use-police-face-scans-for-banking; “About Us” FACE++, accessed July 8, 2016, http://www.faceplusplus.com/about/; Juro Osawa, "Alibaba’s Alipay Turns to Faces, Fingerprints for Security" The Wall Street Journal, October 16, 2014, accessed July 8, 2016, http://blogs.wsj.com/digits/2014/10/16/alibabas-alipay-turns-to-faces-fingerprints-for-security/.

[606] “智能云机器人事业部” [Intelligent Cloud Business Unit], HIT Robot Group 哈工大机器人集团, accessed July 8, 2016, http://www.hitrobotgroup.com/product/pro_list/6.

[607] “Intelligent Cloud Business Unit” HIT Robot Group 哈工大机器人集团, accessed July 8, 2016, http://www.hitrobotgroup.com/en/product/product_show/11.

[608] Alyssa Abkowitz, Lilian Lin, “Alibaba’s ‘Ai’ Predicts Winners of China’s Hit TV Show ‘I Am a Singer’” The Wall Street Journal, April 11, 2016, accessed July 8, 2016, http://blogs.wsj.com/chinarealtime/2016/04/11/alibabas-ai-predicts-winners-of-chinas-hit-tv-show-i-am-a-singer/.

[609] Catherine Shu, “Alibaba’s Cloud Computing Group Says Its New Artificial Intelligence Platform Is China’s First” *TechCrunch*, August 25, 2015, accessed July 8, 2016, https://techcrunch.com/2015/08/25/aliyun-ai/; “阿里云发布国内首个人工智能平台 深化大数据分析技术” [Alibaba Cloud Issues First Domestic Artificial Intelligence Platform, Deepens Big Data Analysis Technology], 电子信息产业网, August 18, 2015, accessed July 8, 2016, http://www.cena.com.cn/2015-08/18/content_289216.htm.

[610] Alyssa Abkowitz, Lilian Lin, “Alibaba’s ‘Ai’ Predicts Winners of China’s Hit TV Show ‘I Am a Singer’” The Wall Street Journal, April 11, 2016, accessed July 8, 2016, http://blogs.wsj.com/chinarealtime/2016/04/11/alibabas-ai-predicts-winners-of-chinas-hit-tv-show-i-am-a-singer/; “小 Ai-阿里云人工智能” [XiaoAi-Alibaba Cloud Artificial Intelligence], Alibaba Cloud 阿里巴巴集团, accessed July 8, 2016, https://ai.aliyun.com/xiaoai.

[611] “About Tencent” Tencent 腾讯, accessed July 8, 2016, http://www.tencent.com/en-us/at/abouttencent.shtml.

[612] “腾讯 AI Lab，力邀国内外大牛加盟” [Tencent AI Lab, Strongly Invite Domestic and International Experts to Join], Tencent 腾讯, accessed July 8, 2016, http://hr.tencent.com/news_detail.php?id=224.

	• Invested 10 million USD in Silicon Valley AI company Diffbot in 2015[613] • Sells Q robot (小小 Q 智能机器人) consumer product[614] • Developed "Betae" AI system[615]
Baidu Deep Learning Laboratory 百度深度学习实验室	• Established by CEO Li Yanhong (李彦宏) in 2013,[616] Baidu's Deep Learning Laboratory in Beijing works on developments related to image recognition, robotics, 3D vision, machine learning, and human-computer interaction.[617] • Baidu has worked on the development of UAVs, translation tools, voice assistants, web searching tools, and driverless cars, and advertises products such as the BaiduEye and BaiduLight personal electronic devices.[618]
Baidu Silicon Valley AI Laboratory (SVAIL) 百度美国硅谷研发中心	• One of three research laboratories under Baidu Research, along with the Beijing Deep Learning Laboratory (百度深度学习实验室), formerly known as the Institute of Deep Learning, and the Beijing-based Baidu Big Data Laboratory (百度大数据实验室).[619] • Focused on building the next generation infrastructure that will help AI researchers productively express their networks in computer code, and then efficiently train them on clusters of GPU's. • Purpose is to focus on fundamental research, while the Deep Learning Laboratory will continue to target applications of deep learning to new and existing Baidu products.[620] • Baidu announced in May 2014 that it will invest USD 300 million in the Silicon Valley laboratory over five years, and the staff has grown to 100 personnel as of 2015.[621]

[613] Kevin McSpadden, "Tencent leads US$10M Series A funding in AI startup Diffbot" *YAHOO! News*, February 12, 2016, accessed July 8, 2016, https://sg.news.yahoo.com/tencent-leads-us-10m-series-funding-ai-startup-051318017.html.

[614] Qrobot, accessed July 8, 2016, http://www.qrobot.com/.

[615] "腾讯人工智能系统 Betae 与谷歌 AlphaGo 麻将大战！" [Tencent Artificial Intelligence System Betae and Google AlphaGo Majiang War!], Toutiao 今日头条, April 3, 2016, accessed July 8, 2016, http://toutiao.com/i6269283260069577218.

[616] "IDL 介绍" [IDL Introduction], Baidu Institute of Deep Learning 百度深度学习实验室, accessed July 8, 2016, http://idl.baidu.com/IDL-about.html.

[617] "Institute of Deep Learning" Baidu Research, accessed July 8, 2016, http://research.baidu.com/institute-of-deep-learning/.

[618] "IDL 研究方向" [IDL Research Direction], Baidu Institute of Deep Learning 百度深度学习实验室, accessed July 8, 2016, http://idl.baidu.com/IDL-direction.html.

[619] Baidu, Inc., "Baidu Opens Silicon Valley Lab, Appoints Andrew Ng as Head of Baidu Research," PR Newswire, May 16, 2014, accessed June 24, 2016, http://www.prnewswire.com/news-releases/baidu-opens-silicon-valley-lab-appoints-andrew-ng-as-head-of-baidu-research-259539471.html; Di Wenting 翟文婷, "起底百度美国研发中心" [Breaking Ground on the Baidu-U.S. R&D Center], *Sina S&T* 新浪科技, February 3, 2015, accessed June 24, 2016, http://tech.sina.com.cn/i/2015-02-03/doc-iawzunex9713856.shtml.

[620] Tammy Parker, "Baidu's Silicon Valley R&D center targets deep learning", *FierceWirelessTec*h, May 18, 2014, accessed June 24, 2016, http://www.fiercewireless.com/tech/story/baidus-silicon-valley-rd-center-targets-deep-learning/2014-05-18.

[621] Paul Mozur and Rolfe Winkler, "Baidu to Open Artificial-Intelligence Center in Silicon Valley: Former Stanford, Google Researcher Will Lead Efforts at $300 Million Facility," *The Wall Street Journal*, May 16. 2014, accessed June 24, 2016, http://www.wsj.com/articles/SB10001424052702304908304579565950123054242;
Di Wenting 翟文婷, "起底百度美国研发中心" [Breaking Ground on the Baidu-U.S. R&D Center], *Sina S&T* 新浪科技, February 3, 2015, accessed June 24, 2016, http://tech.sina.com.cn/i/2015-02-03/doc-iawzunex9713856.shtml;

Professional and Research Associations	
Chinese Association for Artificial Intelligence (CAAI) 中国人工智能学会	• Established in 1981, CAAI is the only national-level professional society focused on scientific fields of research relating to AI in China.[622] • Promotes academic exchange, publication, education, and research exhibition for the purpose of AI development in China.[623] Has 40 subcommittees focused on different fields within AI. • CAAI is led by automation and AI expert Li Deyi (李德毅), a Major General in the PLA and doctoral advisor at the GSD 61st Research Institute (总参第六十一研究所). • Affiliated with Beijing University of Posts and Telecommunications. • Leadership consists of experts from Chinese and foreign institutions, including companies and military organizations.
China Computer Federation (CCF) Artificial Intelligence and Pattern Recognition Committee (TCAIPR) 中国计算机学会人工智能与模式识别专业委员会	• Established in November 1986 at Taiyuan Shanxi University (太原山西大学). Its predecessor organization was the Artificial Intelligence Study Group (人工智能学组), founded by Jilin University CAS Scholar Wang Xianghao (王湘浩). • Focuses on AI basic theory, intelligent expression and reasoning, machine learning, intelligent engineering, intelligent programming, heuristic searches, data mining, computational intelligence, neural networks, evolving computation, distributed AI, pattern recognition, natural language processing, information retrieval and extraction, and intelligent systems application.[624] • Led by five professors, all from different universities. Including its leadership, CCF TCAIPR consists of 112 members, affiliated with numerous universities and educational institutions.[625]
China Robot Industry Alliance (CRIA) 中国机器人产业联盟	• Founded on April 21, 2013, CRIA is a non-profit organization consisting of 104 members that include companies, manufacturers, universities, research institutes, robotic associations, and government-sponsored organizations. • Headquartered at the China Machinery Industry Federation (CMIF; 中国机械工业联合会). The goal of CRIA is to serve as a cooperation platform for the industry, and thereby strengthen members' R&D capabilities, organize exhibitions and conferences, and generally expand robot applications in China.[626] • Siasun (沈阳新松机器人自动化股份有限公司) and CMIF lead CRIA, followed by 20 tech and robotics companies.

Tammy Parker, "Baidu's Silicon Valley R&D center targets deep learning," *FierceWirelessTech*, May 18, 2014. http://www.fiercewireless.com/tech/story/baidus-silicon-valley-rd-center-targets-deep-learning/2014-05-18.

[622] "中国人工智能学会简介" [Chinese Association for Artificial Intelligence Introduction] Chinese Association for Artificial Intelligence 中国人工智能学会, accessed June 9, 2016, http://new.caai.cn/index.php?s=/Home/Article/index/id/2.html.

[623] Ibid.

[624] "人工智能与模式识别专业委员会" [Artificial Intelligence & Pattern Recognition Experts Committee] China Computer Federation 中国计算机学会, accessed July 8, 2016, http://www.ccf.org.cn/sites/ccf/rgznzw.jsp.

[625] Ibid.

[626] "Introduction" China Robot Industry Alliance, accessed July 8, 2016, http://cria.mei.net.cn/English/introduction.asp.

Chinese Association of Automation (CAA) 中国自动化学会	• CAA is a professional society that promotes education, business, research, and development in the Chinese automation industry.[627] • Has subcommittees on a range of automation-related subjects.
Government, Military, and Academic Research Institutes	
Chinese Academy of Sciences (CAS) Institute of Intelligent Machines (IIM) 中国科学院合肥智能机械研究所	• Founded October 8, 1979. • Employs 213 personnel,[628] 24 research fellows,[629] focuses on artificial intelligence and sensor technology, and consists of four research branches: Research Center for Biomimetic Sensing and Control, Research Center for Biomimetic Functional Materials and Sensing Devices, Research Center for Intelligent Information Systems and Research Center for Information Technology of Sports and Health.[630] • Collaborates with the University of Science and Technology of China, the Hefei Institute of Physical Science, and Anhui University, in its current support of 200 students pursuing graduate degrees in Pattern Recognition and Intelligent Systems, Instrumentation Technology and Automatic Devices, Precision Instrument and Machine and Information Acquisition and Control.[631] • IIM states that it "attaches great importance to high-technology transfer, which is the center source of the transformation and industrialization of the research products."[632]
National University of Defense Technology (NUDT) 国防科学技术大学	• As a military university, NUDT pioneered robotics development in China by developing China's first two-legged robot, humanoid robot, and ground patrol robot.[633] The university has made significant accomplishments in AI research at the Robotics and Ocean Technologies Interdisciplinary Research Center (国防科大机器人与海洋技术交叉研究中心).[634] • Announced the development of the "AnBot" intelligent security robot in April 2016,[635] designed for security surveillance and threat detection, and designed for connection to the NUDT-constructed

627 "我国自动控制学术团体——中国自动化学会" [Our Country's Automation Control Study Group--Chinese Association of Automation], Chinese Association of Automation 中国自动化学会, accessed June 9, 2016, http://www.caa.org.cn/index.php?me_id=2.
628 "Faculty and Staff" Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://english.iim.cas.cn/pe/fs/.
629 "Research Fellow," Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://english.iim.cas.cn/pe/as/.
630 "Brief Introduction," Institute of Intelligent Machines Chinese Academy of Sciences, accessed July 8, 2016, http://english.iim.cas.cn/au/bi/.
631 Ibid.
632 Ibid.
633 Wang Wowen 王握文, Li Zhi 李治, Jia Min 贾敏 (Ed.), "国防科大推出我国首款智能安保机器人 与'天河'联机" [NUDT Launched China's First Intelligent Security Robot and 'Tianhe' Joins], *PLA Daily* 解放军报, April 22, 2016, accessed July 8, 2016, http://youth.chinamil.com.cn/view/2016-04/22/content_7030386.htm.
634 Ibid.
635 Kuang Chunlin 匡春林, "国防科大成功研制我国首款智能安保服务机器人" [NUDT Succeeds in Developing China's First Intelligent Security Service Robot], People's Daily Online 人民网, April 22, 2016, accessed July 8, 2016, http://it.people.com.cn/n1/2016/0422/c1009-28298304.html.

	Tianhe Supercomputer Robotic Cloud Service Center (天河超级计算机机器人云服务中心).[636]
Dell-Chinese Academy of Sciences (CAS) Artificial Intelligence and Advanced Computing Joint Laboratory 人工智能与先进计算联合实验室	• Established in November 2015. • Focuses on developing advanced technologies relating to cognitive systems and deep learning.[637]

[636] Wang Wowen 王握文, Li Zhi 李治, Jia Min 贾敏 (Ed.), "国防科大推出我国首款智能安保机器人 与 '天河'联机" [NUDT Launched China's First Intelligent Security Robot and 'Tianhe' Joins], Jiefangjun Bao 中国军网-解放军报, April 22, 2016, accessed July 8, 2016, http://youth.chinamil.com.cn/view/2016-04/22/content_7030386.htm.
[637] Jack Clark, "Dell Expands in China With Venture Group, Creates AI Lab" Bloomberg Technology, September 9, 2015, accessed July 8, 2016, http://www.bloomberg.com/news/articles/2015-09-10/dell-expands-in-china-with-venture-group-creation-of-ai-lab; Mark Hanrahan, "Dell Inc Announces $125B Investment In China, Including Artificial Intelligence Lab" International Business Times, September 10, 2015, accessed July 8, 2016, http://www.ibtimes.com/dell-inc-announces-125b-investment-china-including-artificial-intelligence-lab-2090481.

Appendix IV: Leading Chinese Nanorobotics Institutions

Org. Name (EN/CN)	Summary
Professional Associations	
Chinese Society of Micro-Nano Technology Micro-Nano Robot Subcommittee 中国微米纳米技术学会微纳机器人分会	• Academic committee to focus on academic exchanges as well as technological development.[638] • Chairman Sun Lining (孙立宁) is a national 863 expert in robotics, MEMS, advanced manufacturing technology, and micro/nano manufacturing technology from Soochow University.[639]
Companies	
HIT Robot Group (HRG) 哈工大机器人集团	• HRG works on the development of service, military-use, and industrial robots. • In late 2015, HRG announced the development of a nanorobotic manipulation system while working with scientists from the University of Toronto.[640] In the announcement, HRG acknowledges the technology "came from returning overseas talent," and that the device was presented at the 2015 World Robot Conference (2015 世界机器人大会) in Beijing.[641]
Academic Research Institutes	
Tsinghua University 清华大学	• Tsinghua University has put much research into robotics development in recent years. Collaborating with University of Lincoln, Tsinghua researchers designed a swarm robotic system in 2014.[642]
Nanjing University 南京大学	• In 2010, Nanjing University researchers collaborated with researchers from NYU to construct a nanorobot assembly line, which successfully put together DNA component nanodevices.[643] These devices were assembled with programmable DNA devices that could function through switches.

[638] "中国微米纳米技术学会" [Chinese Society of Micro-Nano Technology], Chinese Society of Micro-Nano Technology 中国微米纳米技术学会 (Google Cache), July 10, 2016, accessed July 12, 2016, https://webcache.googleusercontent.com/search?q=cache:62vuenOG6HMJ:www.csmnt.org.cn; "中国微米纳米技术学会微纳机器人分会成立" [Chinese Society of Micro-Nano Technology Establishes Micro-Nano Robotics Subcommittee], Chinese Association for Science and Technology 中国科学技术协会, May 16, 2016, accessed July 12, 2016, http://www.cast.org.cn/n17040442/n17045712/n17059079/17192447.html.

[639] "现任领导简介——院长孙立宁" [Current Leader Introduction—Director Sun Lining], Soochow University School of Mechanical and Electric Engineering 苏州大学机电工程学院, November 25, 2015, accessed July 12, 2016, http://jdxy.suda.edu.cn/ShowPage.aspx?type=6741; "中国微米纳米技术学会微纳机器人分会成立" [Chinese Society of Micro-Nano Technology Establishes Micro-Nano Robotics Subcommittee], May 16, 2016, accessed July 12, 2016, http://www.cast.org.cn/n17040442/n17045712/n17059079/17192447.html.

[640] "哈工大机器人集团（HRG）：工业机器人让劳动更高效" [HIT Robot Group (HRG): Industrial Robots Allow Labor Force to be More Efficient], HIT Robot Group 哈工大机器人集团, November 18, 2015, accessed July 12, 2016, http://www.hitrobotgroup.com/news/news_show/115; "港媒:中外科学家成功研发可拿起纳米物体机器人" [Hong Kong Media: Chinese and Foreign Scientists Successfully Develop Robot That Can Handle Nano Objects], November 30, 2015, accessed July 12, 2016, http://news.163.com/15/1130/11/B9LSHA4Q00014AEE.html; "2015 世界机器人大会圆满落幕" [2015 World Robot Conference Comes to an End], HIT Robot Group 哈工大机器人集团, November 28, 2015, accessed July 12, 2016, http://www.hitrobotgroup.com/news/news_show/104.

[641] Ibid.

[642] "'Honeybee' Robots Replicate Swarm Behavior," September 18, 2014, *Nanowerk News*, accessed July 12, 2016, http://www.nanowerk.com/news2/robotics/newsid=37414.php.

[643] "Nature: 分子纳米机器人新突破" [Nature: Molecular Nanorobot New Breakthrough], Bioon.com, May 14, 2010, accessed July 12, 2016, http://www.bioon.com/biology/nanometer/442876.shtml; "Nanorobot Can Manipulate Molecules within a DNA Device," *Nanowerk News*, February 15, 2009, accessed July 12, 2016, http://www.nanowerk.com/news/newsid=9280.php.

	• Nanjing University scientists have published research on nanomotors.[644]
Beijing Institute of Technology (BIT) 北京理工大学	• In 2008, Thousand Talent micro- and nanomanipulation and nanorobotics expert Toshio Fukuda (福田敏男)[645] came to BIT after collaborating with researchers there.[646] Fukuda became an IEEE fellow in 2015 and is currently on the founding editorial board of AAAS *Science Robotics*.[647]
CAS Beijing Institute of Nanoenergy and Nanosystems (BINN) 中国科学院北京纳米能源与系统研究所	• In 2016, a team led by BINN director Wang Zhonglin (王中林) developed a triboelectric nanogenerator sized one billionth of a meter that could generate electrical energy through frictional forces.[648] • Wang has published widely in top journals on nanotechnology and is internationally recognized as a top researcher in the field.[649]
Harbin Institute of Technology (HIT) State Key Laboratory of Robotics and System	• In 2002, HIT researchers had begun constructing nanorobots to aid with gene manipulation with applications for medicine and agriculture.[650] • In late 2012, HIT announced that researchers were able to construct "nanorocket" (纳米火箭) nanomotors that were able to move at 74 micrometers per second.[651] These autonomous nanobots were made out of

[644] Yu Xiaoping, Wu Jie, Ju Huangxian, "The Application of Micro/Nanomotor in Biosensing" [微/纳米马达在生物传感中的应用], *Progress in Chemistry* 化学进展, 2014:10.

[645] "[讲座]Toshio Fukuda 教授讲座" [[Lecture] Professor Toshio Fukuda Lecture], Northwestern Polytechnical University 西北工业大学, April 2, 2015, accessed June 6, 2016, http://www.nwpu.edu.cn/info/1007/14666.htm.

[646] "Professor Toshio Fukuda wins Chinese Government Friendship Award" Beijing Institute of Technology 北京理工大学, October 21, 2014, accessed June 6, 2016, http://english.bit.edu.cn/NewsEvents/BITNews/106550.htm.

[647] "Professor Toshio Fukuda elected to IEEE Fellow," Beijing Institute of Technology 北京理工大学, December 16, 2015, accessed June 6, 2016, http://english.bit.edu.cn/NewsEvents/BITNews/120092.htm; "Editorial and Advisory Boards Founding Editorial Board Members," *ScienceRobotics*, accessed June 6, 2016, http://www.sciencemag.org/journals/robotics/editorial-board-members.

[648] "纳米发电机：摩擦也能带来'正能量'--石油百科" [Nanogenerator: Friction Can Also Bring 'Positive Energy' – CNPC Encyclopedia], China National Petroleum Corporation, accessed June 6, 2016, http://center.cnpc.com.cn/bk/system/2016/02/23/001580896.shtml.

[649] Katherine Bourzac, "Nanogenerator Powers Up" *MIT Technology Review*, November 8, 2010, accessed June 6, 2016, https://www.technologyreview.com/s/421577/nanogenerator-powers-up/; "Zhong Lin Wang," Professor Zhong Lin Wang's Nanoscience Research Group, accessed June 6, 2016, http://www.nanoscience.gatech.edu/group/Current%20Members/Group%20Leader/Zhong%20Lin%20Wang.php; "Triboelectric Nanogenerator – a New Energy Technology," Shanghai Jiaotong University Nano Science Technology Research Academy 上海交通大学微纳科学技术研究院, May 11, 2015, accessed June 6, 2016, http://tfmlab.sjtu.edu.cn/index.aspx?menuid=4&type=articleinfo&lanmuid=7&infoid=221&language=cn.

[650] "中国研制出纳米级的高精度微动机器人" [China Developed a Nanometer High Precision Micro Motor Robot], *Xinhua* 新华社, May 24, 2002, accessed June 6, 2016, http://www.people.com.cn/GB/junshi/60/20020524/736240.html; "哈工大为我国研制出可操作细胞的纳米级高精度微动机器人" [HIT Developed a Nanometer High Precision Micro Motor Robot that Can Be Manipulated at the Cell for China], Harbin Institute of Technology, May 25, 2002, accessed June 6, 2016, http://todayhistory.hit.edu.cn/54/2002/540525070916/.

[651] "科研信息" [Scientific Research News], *Today HIT* 今日哈工大, May 24, 2013, accessed June 6, 2016, https://webcache.googleusercontent.com/search?q=cache:CZpq3_t5ZdUJ:http://today.hit.edu.cn/news/2013/05-24/8241105150RL0.htm; Wu Yingjie, Wu Zhiguang, Lin Xiankun, He Qiang, Li Junbai, "Autonomous Movement of Controllable Assembled Janus Capsule Motors" *ACS NANO*, vol. 12, no. 6 (2012): 10910–10916, accessed June 6, 2016, http://pubs.acs.org/doi/abs/10.1021/nn304335xs; Yao Wen 耀文, "哈工大人工合成自驱动纳米机器取得新进展" [HIT Created Self-Propelling Nano Robot Achieves New Progress], *CENA* 电子信息产业网, July 18, 2014, accessed June 6, 2016, http://cyyw.cena.com.cn/2014-07/18/content_233533.htm; "近红外光驱动聚合物多层纳米火箭" [Near Infrared Light Propelled Polymer Multi-layered Nano Rocket], *Materials Views*, March 1, 2016, accessed June 6, 2016, http://www.materialsviewschina.com/2016/03/near-infrared-light-driven-multi-layer-nanometer-polymer-rocket/.

哈尔滨工业大学机器人技术与系统国家重点实验室 and Micro/Nanotechnology Research Center 微纳米技术研究中心	platinum-coated nanoparticles that composed Janus particle motors, enabling the nanoparticles to utilize hydrogen peroxide as fuel to move.[652] • In late 2015, lead author He Qiang (贺强)[653] with researchers from HIT Micro/Nanotechnology Research Center (微纳米技术研究中心) built a microrobot that was able to manipulate nanoscale objects.[654] • The Micro/Nanotechnology Research Center conducts research on nanotechnology and nanodevices and at least since 2007 has received state and provincial-level awards for nanorobotics and nanomanipulation research, including small nanorobots for MEMS operations and nano-precision positioning technology for object manipulation.[655]
CAS Institute of Automation 中国科学院自动化所	• Researchers at the CAS Institute of Automation have published research on nanorobotics and nanomainpulation of DNA.[656]
CAS Shenyang Institute of Automation (SIA) 中国科学院沈阳自动化研究所	• SIA along with researchers at its Micro and Nano Robotics Group under the State Key Laboratory of Robotics are conducting China's most cutting-edge nanorobotics and nanomanipulation research since 2009. • SIA researchers have been publishing this work in top international journals. • SIA has collaborated with Chinese military hospitals for nanorobotics application research.[657]

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Nankai University Center for Nanoscale Science and Technology **南开大学纳米科学与技术研究中心**	• In 2016, researchers constructed an intelligent swimming nanobot out of polyvinylidene fluoride (PVDF) and graphene that was able to "swim" at a speed of 5.02 millimeter per second.[658]
Soochow University Robot and Microsystem Research Center **苏州大学机器人与微系统研究中心** **and Jiangsu Key Laboratory for Advanced Robotics Technologies** **江苏省先进机器人技术重点实验室**	• One of the center's focuses of nanotechnology and advanced manufacturing research is micro and nanorobotics equipment and research.[659] • Researchers from the center have published articles in Chinese journals on piezoelectrics in nanoscale nano-manipulation.[660]
CAS Institute of Intelligent Machines (IIM) **中国科学院合肥智能机械研究所**	• Conducts research on intelligent nanodevices and nanomaterials as well as sensors and actuators.[661] • Has published research on "robotic skin" and nanoscale sensors.[662]

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