Testimony before the U.S.-China Economic and Security Review Commission:[1]
Hearing on China's Pursuit of Next Frontier Tech

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Introduction

China's commercial and military robotics industries are growing rapidly as the country upgrades its manufacturing sector and military capabilities. In a 2014 speech on the importance of science and innovation to the "great rejuvenation of the Chinese nation," Chinese President Xi Jinping stated that around the world industrial robots are considered the "jewel in the crown of manufacturing."[i] China's military planners believe unmanned systems and other technologies are transforming warfare and giving it "unmanned, intangible, and silent" characteristics." [ii] Consequently the People's Liberation Army (PLA) is developing and deploying increasingly capable unmanned systems as well as countermeasures to the U.S. military's unmanned systems.

These developments pose serious challenges for U.S economic and strategic interests. China's policies and investments in industrial robotics could erode U.S. advantages in robotics and manufacturing. Unmanned systems will increase the PLA's intelligence, surveillance, and reconnaissance (ISR), long-range strike, and anti-submarine warfare (ASW) capabilities, challenging U.S. power projection in the Asia-Pacific region. To address these issues more fully, this testimony is organized as follows:

I. China's industrial and service robotics industries
II. The PLA's military robotics and unmanned systems
III. China's acquisition of foreign robotics technology
IV. Recommendations to maintain U.S. economic and strategic advantages.

[1] This testimony largely draws from a report on China's robotics development that this author and others at DGI prepared for the Commission and was published in October 2016. For the full report, see Jonathan Ray, Katie Atha, Edward Francis, Caleb Depedahl, Dr. James Mulvenon, Daniel Alderman, and Leigh Ann Ragland-Luce, *China's Industrial and Military Robotics Development*.
http://origin.www.uscc.gov/sites/default/files/Research/DGI_China's%20Industrial%20and%20Military%20Robotics%20Development.pdf.

I. China's Industrial and Service Robotics Industries

China boasts the world's largest market for industrial robots and has ambitious plans to become the leading supplier of them. While China's industrial robotics market is growing rapidly, it is still underdeveloped as China's automation rates remain well below the averages of other leading manufacturing countries. The industry has also faced chronic challenges with components requiring precision engineering that are essential to industrial robots. China's policies for its industrial robotics industry threaten to skew the market and block international competitors. State plans, most notably Made in China 2025, provide generous subsidies to Chinese industrial robotics firms that are beginning to oversaturate the market. The same plans strongly encourage Chinese companies to choose domestic brands of industrial robots, boxing out international competitors.

China's service robotics industry has also quickly matured as robots for professional service and domestic use have proliferated. Chinese startups such as DJI have successfully expanded and marketed their products abroad to capture international market share. Factors such as China's growing middle class and aging demographics will likely continue to drive this market.

As China focuses more on quantity of robots and catching up in component technologies, the United States should focus on its advantages in quality and innovation. U.S. universities, start-ups, branches of multinational corporations, and domestic companies have innovated in the past and are doing so today. Support mechanisms such as the National Robotics Initiative will be instrumental for future breakthroughs in areas such as human-machine collaboration.

The Rapid Growth of China's Industrial Robotics Market

In 2015, China commanded 27% of the world's industrial robotics market, and the International Federation of Robotics (IFR) predicts that number will increase to 40% by 2019. For perspective, consider that in 2015, sales of industrial robots in China surpassed the total sales volume of industrial robots for all of Europe. Sales in China increased 20% from 2014 to reach 68,600, surpassing Europe's total sales volume of 50,100 units. Chinese suppliers saw increases of 29% in sales to their domestic market, while foreign suppliers enjoyed 17% increases.[iii]

Despite its rapid growth and high volume, China's industrial robotics market is still underdeveloped compared to other countries. One useful measurement from the IFR is China's average robot density, measured as the number of industrial robots in operation per 10,000 employees. At 69 units, China is well behind the United States (fifth highest density with 176 units) and the global leader Republic of Korea (531 units). This data strongly suggests ample room for growth in this market as more Chinese industries automate.[iv]

Table 1: Number of industrial robots installed per 10,000 employees in the manufacturing industry as of 2015. Source: International Federation of Robotics.[v]

Country	Robot Density
Republic of Korea	531
Singapore	398
Japan	305
Germany	301
United States	176
China	49
Global average	69

Trends in China's Adoption of Industrial Robots

Chinese and international experts highlight the following trends for China's industrial robotics industry:

1. The automobile industry has driven much of the market to date. – Since 2000, China's automobile industry has been a primary driver for the country's industrial robotics market, which is common for other countries.[vi] It is telling that Miao Wei (苗圩), a leading voice for the Made in China 2025 initiative (discussed below), was an automobile executive before becoming the Minister of Industry and Information Technology.[vii] The IFR assesses that ongoing modernization for China's automobile industry will continue to boost robot installations.[viii]
2. Other industries are increasingly adopting industrial robots. – In line with international trends, other industries such as the "3c" industries (computers, communications, and consumer electronics) machinery, electrical and electronics industries, rubbers and plastics, food industries, logistics, and manufacturing are demanding more automation.[ixx]
3. Traditionally, wholly owned foreign-owned enterprises and foreign joint venture enterprises have been the primary customers for industrial robots. Foreign enterprises and joint ventures in China have traditionally been more adept at adopting robots compared to their domestic competitors, who have had inflexible production models.[xi] This trend may be changing as labor costs and state plans push greater automation across more industries.
4. Rising labor costs are a major reason for China's adoption of industrial robots in various industries. As in other countries (including the United States), China's labor costs are rising and encouraging industries, especially labor-intensive ones, to adopt industrial robots.[xii]
5. The world's leading robot manufacturers are very active in China through sales and production in country, including Germany's KUKA, Japan's Yaskawa, and Swedish-Swiss multinational corporation ABB.

National Plans and Support Mechanisms for China's Industrial Robotics Industry

The Chinese government's support for its robotics industry is massive, and risks both overcapacity in China's domestic industry and boxing out international competition. From 2006 to 2012, China included robotics as part of broader science and technology, manufacturing, and state level Five-

Year Plans (FYPs) and guidelines.[2] By 2013, as China became the world's largest market for industrial robots, the state plans became more specific in their goals.

- 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 (including its dependence on foreign suppliers for high-precision components), to promote the adoption of industrial robots, and to develop national champions to manufacture these systems.[xiii]
- The 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) calls for numerous developments related to robotics, and includes "robotics equipment" (机器人装备). It was the first FYP to include the term artificial intelligence (AI).[xivxv]
- 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 reiterates the same goals of breaking China's dependence on foreign suppliers for advanced components, increasing the adoption of industrial robots across industries, and increasing the production and sales of China's domestic models.[xvi]

Made in China 2025 (中国制造 2025) is one of China's most ambitious programs to date. Instead of targeting a specific industry, this program aims to improve the entire Chinese manufacturing sector's competitiveness, innovation, technology, quality, reliability, and "green-ness."[xvii] While these goals have merit, the European Union Chamber of Commerce in China describes the policy tools for its implementation as "highly problematic." According to the Chamber, this support from central and local governments constitutes "hundreds of billions of euros of funding in the form of subsidies, funds, and other channels of support." This support is "contributing to overcapacity in the low- and mid-tiers of China's market." Furthermore, international firms are facing pressure to hand over advanced technologies for market access. In the long term, the program "amounts, in large part, to an import substitution plan."[xviii] In addition to skewing the playing field against international competition, this program is arguably a "shopping list" for China's foreign investment targets to acquire key technologies and licenses, as discussed in the technology transfer section below.[xix]

Challenges to China's Industrial Robotics Industry and Reliance on Imports

While China's industrial robotics industry is growing rapidly, problems persist that hamper the development of Chinese manufacturers and leave them dependent upon foreign suppliers for key technologies. At a broader level, some analysts worry that Chinese companies are struggling to find niches, and that overinvestment is leading to blind competition. At a more technical level,

[2] National plans that included robotics from 2006 to 2012 include the 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)) and the Twelfth Five Year Plan for Intelligent Manufacturing (智能制造科技发展"十二五"专项规划).

while China is proficient in the general construction and design of robotics systems, it lags behind on complicated components and controls, as well as parts requiring precision engineering.

Xin Guobin, Vice Minister of the MIIT, commented 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."[xx] Chinese industry analysts agree, stating that Chinese manufacturers tend to imitate leading brands rather than innovate, have trouble converting prototypes into marketplace products, and lack qualified personnel.[xxi] Additionally some commentators consider China to be overinvesting in its robotics companies. According to the CRIA, China has built or started construction on 40 new robot industrial parks since 2014.[xxii] For some Chinese observers, the problem with too much competition too quickly is that companies do not define a niche in the market and blindly compete.[xxiii] The EU Chamber of Commerce in Beijing, as noted above, considers this overinvestment to be oversaturating the market.

At a more granular level, China is proficient at general robotics, but continues to struggle with advanced components, complicated controls, and integration of data and sensors. It continues to struggle with high-precision reduction drives, servo (small electric motor) electrical machinery, controllers, and other components that require precision engineering. Additionally, China remains behind international standards in programmable logic controller (PLC) and changing frequency controls products, multiple sensor information fusion control technology, remote control plus local autonomous system remote control robots, and intelligent assembly robots. [xxiv]

As China grapples with problems of quality and defining competition, international brands have reputations for quality, defined market niches, and declining prices (at least over the past decade). As of 2012, Chinese analysts wrote that automobile industry executives preferred foreign brands for these very reasons.[xxv] As Made in China 2025 progresses, a key indicator of progress will whether these attitudes change and Chinese robotics manufacturers come mature and offer better quality products, defined niches, and competitive prices.

Opportunities and Implications for the U.S. Industrial Robotics Industry

The U.S. industrial and service robotics industries have tremendous potential to compete and innovate. The key for stakeholders is to recognize the structure of the U.S. industry and define realistic goals for success. The majority of leading industrial robotics firms are based in Japan and Europe and have operations here in the United States. 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. Instead of completed robots, half of the value of U.S. industrial robotics exports and a quarter of U.S. imports of industrial robots are parts.[xxvi] In short, the U.S. and Chinese industrial robotics industries are very different.

While China rapidly expands production numbers and catches up on component technologies, the guiding principles for the U.S. robotics industry should be quality and innovation. The United States have advantages to leverage in the robotics industry, including highly trained personnel, leading R&D institutions, and dynamic companies that innovate robotics technologies. For personnel, Chinese experts are openly envious of U.S. universities and the quality of their programs. Continuing to support university research and attracting leading students from around

the world ensures this advantage. For R&D, the United States should continue to support universities and companies with grants and R&D tax incentives that help fund research into new applications and enabling technologies. The National Robotics Initiative (NRI, now NRI 2.0) is an excellent model of making funding available to research that fundamentally changes robotics, in this case by focusing on human-machine collaboration.

U.S. companies are already leaders in innovation for industrial and service robots. For example, SoftWear Automation Inc., an Atlanta-based robotics startup, has developed robots that can sew garments, the first of their kind.[xxvii] 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.[xxviii] 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 addition to supporting U.S. robotics R&D and manufacturing, the U.S. Government should voice the same concerns over Made in China 2025 raised by the European Union Chamber of Commerce in China. Barriers to market access, pressure on companies for intellectual property in exchange for market access, generous subsidies to Chinese companies, and import substitution policies skew the playing field against U.S. companies.

Service Robotics Industry

China's service robotics industry has grown rapidly over the past decade, and Chinese official expect the industry to become more prominent within the overall robotics industry in the future. Service robots are partially- or wholly-autonomous robotic devices that assist people with tasks other than production and manufacturing, and are generally divided further into professional service and domestic use categories.[3] Professional service robots include nuclear power plant inspection robots, unmanned aerial vehicles (UAVs) for agriculture or infrastructure maintenance, deep sea and space exploration robots, 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.[xxix]

A number of factors drive demand for service robots in China, including:

- Rising living standards are increasing demand for service robots, which offer comparatively inexpensive domestic services and serve as a status symbol for members of the growing middle class.[xxx] Higher 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.[xxxi]
- China's aging population encourages the domestic service robot industry today, and can drive strong growth for the future. The CRIA notes that as of 2016 China has over 221.82

[3] In most taxonomies, military robots and unmanned autonomous vehicles are considered a subset of service robots, given they engage in activities other than manufacturing.

million citizens aged 60 years old or older, amounting to 16.15 percent of the total population.[xxxii]

- As of 2016, China has approximately 60 million handicapped citizens who are limited in their capabilities or require nursing care, affecting almost one in ten Chinese households.[xxxiii]
- 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.

China's government has provided industry guidance to the service robotics industry. Services robots were the focus of a special development program by China's Ministry of Science and Technology (MOST) during the Twelfth FYP period (2011 through 2015). The program built off previous Chinese advancements in service robots related to public security robots, bio-mimetic robots, and medical and rehabilitation robots.[xxxiv] In December 2015, 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.[xxxv]

Chinese manufacturers are at or near international standards for industrial, commercial, and recreational consumer UAV systems. Dai-Jiang Innovation Technology Company (DJI) was a startup in 2011, and today corners 70% of the market for commercial and recreational UAVs. The leading U.S. competitor was 3D Robotics, until missteps with its flagship UAV and ill-advised market projections led to its collapse. DJI outmaneuvered the company with consistent performance from basic models, introduction of newer models more quickly, and price cuts.[xxxvi] It appears difficult U.S. newcomers to compete in this industry, though newer companies like XCraft are innovating designs to break through the market.[xxxvii]

One advantage that U.S. firms have in the services robotics industry, including in China, 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.[xxxviii]

II. The PLA's Military Robotics and Unmanned Systems

China's leaders and military strategists believe the nature of warfare is changing and increasingly relies on unmanned and robotic systems. These weapons are appearing in the air, land, and sea domains, and necessitate that China develop its own systems and countermeasures. Consequently China is providing generous support to the R&D and production of unmanned systems, and is

fielding increasingly capable systems. These unmanned systems and countermeasures against unmanned systems present challenges to the U.S. military operating in the Asia-Pacific region, particularly as U.S. defense planners implement the Third Offset strategy.

The Changing Nature of Warfare Necessitates Unmanned Systems

China's defense planners consider many new technologies such as unmanned systems to be maturing rapidly and changing the nature of warfare. For example, the most recent edition of *Science of Military Strategy*,[4] an authoritative Chinese text on military affairs, states 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."[xxxix] In 2015, senior analysts at China's National University of Defense Technology (NUDT) wrote that unmanned systems are as revolutionary as steam engines, tanks, airplanes, missiles, and the Internet.[xl] China's 2015 Defense White Paper on the "National Security Situation" endorses these views, claiming that 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."[xli]

Chinese defense analysts consider these trends to be global and necessitate the PLA's own development of such systems and countermeasures. An article from the *PLA Daily* estimates that 70 countries have military robotics plans, and over 4,000 types of UAVs are available on the global market.[xlii] In addition to the United States, analysts follow developments in unmanned systems, particularly UAVs, in Russia, Israel, the United Kingdom, India, and others. Among these countries, unmanned systems are increasingly able to operate autonomously, fuse different intelligence and data, participate in joint manned and unmanned operations, and conduct operations with multiple unmanned systems.[xliii]

Trends in PLA's Development and Deployment of Unmanned Systems

China is investing heavily in unmanned systems that improve key capabilities and can carry out an increasing variety of missions at land, air, and sea. Among these domains, China's UAVs are the most mature, and contribute to the PLA's long-range ISR and strike operations that could pose challenges to the U.S. military. While UUV capabilities appear to be more nascent, their development could advance China's anti-submarine warfare (ASW) capabilities and erode long-held U.S. advantages. To date, Chinese media has covered PLA drills or deployments of unmanned systems for various missions including counterterrorism,[xliv] ISR (including in the South China Sea),[xlv] various military exercises,[xlvi] border patrol,[xlvii] [xlviii] explosive ordnance disposal,[xlix] humanitarian assistance/disaster relief,[l] and combat support[li] (such as smaller UAVs for special forces).

A direct comparison between Chinese and U.S. unmanned systems is difficult, as both countries closely guard technical and performance parameters, but two trends are noteworthy. First, Chinese UAV manufacturers and their customers (both domestic and abroad) appear to emphasize lower

[4] The *Science of Military Strategy* is produced by the staff of the Academy of Military Science, the PLA's highest-level research and education institute. It represents officially endorsed (or at least sanctioned) views of military affairs, other national security topics, and developments in sciences and technologies with defense applications.

price points and quantity over increased capabilities. Second, Chinese scientists and Department of Justice (DOJ) reporting on espionage cases strongly suggest that China lags behind the United States on technologies for propulsion, autonomous operation, advanced sensors, and data links.

Unmanned Aerial Vehicles (UAVs)

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 report 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.[lii] The PLA's demand for UAVs stems from their ability to enhance numerous capabilities and support a wide range of missions.

According to the 2013 *SMS*, both the PLA Air Force (PLAAF) and PLA Navy (PLAN) should prioritize improving surveillance, early warning, and command and control capabilities.[liii] Additionally, the PLAAF should prioritize medium and long-range precision strike systems that extend PLA strike capabilities to the second island chain.[liv] UAVs are ideal for all these missions. Russian media and at least one Chinese commercial analyst believe the "Soar Dragon" High Altitude Long Endurance (HALE) UAV could be used for guidance for the DF-21D anti-ship ballistic missile (ASBM), a threat to U.S. aircraft carriers operating in the region.[lv]

Looking ahead, Chinese defense companies have demonstrated 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.[lvi]

Unmanned Underwater Vehicles (UUVs)

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.[lvii] UUVs, deep sea submergence vehicles (DSVs), and other underwater robotics systems are useful for commercial activities such as laying and repairing undersea cables and exploring natural resources. In 2016, Chinese UUVs carried out exploration missions in the southwest Indian Ocean searching for sulfide deposits and precious metals.[lviii] These vehicles can also, however, wiretap, disrupt, or sever undersea cables, as well as support ASW operations.

The Zhishui series of autonomous underwater vehicles (AUVs) may currently be in service with the PLA Navy.[5] 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.[lix] According to authors with Harbin Engineering University (HEU), in 2003 the

[5] Zhishui is likely a shortened version of 智慧 (*zhihui*, intelligent) and 水下机器人 (*shuixia jiqiren*, underwater robot).

university's Underwater Intelligence Robot Technology Laboratory (水下智能机器人技术实验室) 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.[lx]

China is actively exploring newer concepts for UUV designs and technologies. In 2014, Tianjin University 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.[lxi] 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.

Unmanned Surface Vehicles (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).[lxii] These activities included the following:[lxiii]

- 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.
- In 2014 the Jinghai-2 accompanied the "Snow Dragon" (雪龙) on China's 31st expedition to the South Pole, conducting topography surveys.
- The Jinghai-3 uses a highly modularized design and the most advanced "intelligent obstacle avoidance guidance systems."

Unmanned Ground Vehicles (UGVs)

China's deployment of unmanned ground systems (UGVs) 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."[lxiv]

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 received support from China's 973 and 863 programs for high-technology development, as well as the Twelfth FYP of the former General Armament Department (GAD).[lxv]

To spur these systems' development, in September 2016 the PLA hosted the "2016 Leap Over Treacherous Paths" (跨越险阻 2016) contest. The contest featured five competitions to simulate battle operations including 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.[lxvi]

"Military-Civilian Fusion" in China's Robotics Industries

Across many industries, China is pursuing its strategy of "military-civilian fusion" (军民融合), in which military, commercial, and academic entities are encouraged to jointly develop and share breakthroughs in technologies.[6] Robotics and related technologies such as artificial intelligence are ideal for this "fusion" as commercial companies outpace their military counterparts. This close integration of military and civilian institutes poses diversion risks for U.S. entities as cooperation agreements, academic exchanges, and investments can inadvertently support PLA end-users. One example is the Chinese Association for Artificial Intelligence (CAAI), which leads international academic exchanges for AI, but also has leaders and member institutions with military affiliations. Another potential example is Chinese investment in Neurala, a Boston-based company for AI software for UAVs and other unmanned systems that has potential military applications. These cases and other technology transfer risks are discussed in more detail in the section below on China's acquisition of foreign robotics technology.

Challenges for China's Unmanned Systems

China is proficient in unmanned system designs and manufacturing, but lags behind the United States on advanced components. In a 2013 interview with a Chinese UAV designer, challenges included capabilities, engines, data links, and airborne electronics as challenges for China's systems.[lxvii] According to the designer, China's data links and airborne electronics in particular lag behind U.S. standards, making systems such as the RQ-4 Global Hawk and the X-47B the global standard. China also has traditionally struggled with advanced materials such as high-grade carbon fiber, and acquired it through illicit means.[lxviii][lxix]

For UUVs, China has sought advanced components from the United States. The technology transfer discussion below includes the case of Yu Amin, AKA Amy Yu. In June 2016 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.[lxx]

The PLA Seeks to Exploit the U.S. Military's Dependence on Unmanned Systems

The PLA considers the U.S. military to be increasingly dependent upon unmanned systems, and actively researches countermeasures to such systems. The Third Offset strategy's emphasis on unmanned systems and human-machine collaboration confirmed what China perceived to be the growing importance of unmanned systems in the U.S. military. One analyst writes that robots and unmanned systems will outnumber people in the U.S. military by 2040.[lxxi] With this assessment

[6] For more on "military-civilian fusion" and China's civil-military integration 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.

that the U.S. military is heavily invested in unmanned systems, the PLA has demonstrated and funded research into soft- and hard-kill countermeasures.

Chinese analysts consider the United States to be a pioneer in the development of unmanned systems, and have closely followed their deployment. Writing on the history of military UAVs, a PLAAF senior colonel follows the U.S. deployment of UAVs from the first Gulf War to the War on Terrorism.[lxxii] The 2013 *SMS* discusses the U.S. military's use of UAVs for precision strikes in Afghanistan, Pakistan, and Libya.[lxxiii] Analysts also consider the United States to be a leader in the development and application of UGVs, citing systems such as the Scorpion Small UGV, SWORDS armed system, Packbot, and Big Dog.[lxxiv]

Among the military services, Chinese analysts consider the U.S. Navy to be the most dependent upon unmanned systems. They are following the Navy's plans to develop large-scale long-deployment autonomous unmanned submersibles, the X-47B, and ship-launched unmanned aerial surveillance and attack systems, and estimate the Navy will have a fleet of 1,000 unmanned submersibles by 2020.[lxxv] One program receiving special interest is the ASW Continuous Trail Unmanned Vessel (ACTUV) program funded by the U.S. Defense Advanced Research Projects Agency (DARPA),[7] which is a "vessel optimized to robustly track quiet diesel electric submarines."[lxxvi] Chinese research and military institutes track the system and assume it is targeting China's diesel attack submarines.[lxxvii]

Chinese analysts perceive the United States to be dependent on unmanned systems for financial and technological reasons, a view confirmed by the Third Offset. Following the U.S. budget debates in 2012 and sequestration cuts of 2013, Chinese analyst concluded that financial constraints will make the U.S. military even more dependent upon technological advantages like unmanned systems.[lxxviii] The Third Offset strategy's objective to leverage technological advantages such as human-machine collaboration confirms these analysts' views, and convinces them that the strategy and emphasis on unmanned systems are aimed at China.

With this in mind, it is not surprise that China is investing heavily in countermeasures against unmanned systems. The 2013 *SMS* calls for innovating countermeasures against UAVs in particular, and military research institutes routinely use U.S. systems as examples and targets in their research.[lxxix] The most illustrative example of such research is an article titled "Analysis of X-47B UCAS and Electronic Counter Measures" that appeared in *Aerospace Electronic Warfare*, China's leading journal on electronic warfare.[lxxx] The authors assess that this system has advantages in stealth, flexibility for different operations, and the ability to carry out long-range precision strikes. In the authors' assessment, the critical weakness of the X-47B is that if it loses contact with controllers or is confused, the system defaults to returning to base. Hence they propose countermeasures such as electronic interference to negate information collection capabilities and better camouflage for targets to force the system to return to base. Kinetic countermeasures include

[7] 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.

air-based intercepts, obstacles (such as balloons), early warning fighter intercepts, and even preemptive strikes on the launch platform (such as an aircraft carrier).[lxxxi]

Some of these non-kinetic countermeasures appear to already be in operation. In 2015 a U.S. press report claimed the PLA attempted to jam a Global Hawk UAV operating over the South China Sea, and Chinese authors followed Iran's downing of the RQ-170 UAV in 2011 by interfering with its navigation system.[lxxxii] These non-kinetic countermeasures likely are attractive to the PLA because they can be used for interference in peacetime, and in a crisis are less escalatory than a kinetic kill. These options pose challenges for the U.S. military power projection in the Asia-Pacific region as unmanned systems become increasingly integral to ISR and other capabilities.

III. China's Acquisition of Foreign Robotics Technology

China actively acquires components, technologies, and materials from abroad for its robotics industry and military unmanned systems. From a commercial standpoint, technology transfers can greatly improve the quality of Chinese robotics systems, particularly for higher end components that have been a chronic weakness of the industry. From a security standpoint, intelligence on U.S. unmanned systems can improve China's own military assets and provide insights into countermeasures. This section breaks down China's acquisition and technology transfer efforts by the following categories:

- **Illicit technology acquisitions** include the illegal means through which China acquires key technologies from abroad, such as cyber intrusions and export control violations.
- **Informal knowledge and technology transfers** refer to China's acquisition of foreign technologies via open source collection, talent recruitment, and academic exchanges.
- **Formal technology acquisitions and investments** involve Chinese companies acquiring or investing in foreign robotics companies or other entities to acquire targeted technologies.

Illicit Technology Acquisition

China actively seeks U.S. technologies for unmanned systems through illicit means including cyber intrusions into sensitive U.S. defense contractors and state entity-directed efforts to circumvent U.S. export controls.

China's vast cyber espionage campaign has directly contributed to its unmanned systems, including UAVs and UGVs. 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.[lxxxiii] Of the 261 attacks uncovered, 123 of them are reported to have targeted U.S. UAV companies.[lxxxiv] According to a manager of the investigation, "We believe the attack was largely successful."[lxxxv] Other cyber targets include companies such as QinetiQ North America, a major supplier of UAVs, satellites, helicopters, military robotics, and other systems for the U.S. military.[lxxxvi] According to news reports, the hackers first targeted QinetiQ's UAV and robotics technologies. Then in April 2012, the PLA displayed a bomb disposal robot similar to QinetiQ's Dragon Runner, likely reflecting the use of this stolen data.[lxxxvii]

According to the 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. Since 2010, DOJ reporting includes six cases in which China has sought to acquire U.S. unmanned systems and their technologies.[lxxxviii] BIS reports that between 2007 and 2008, a couple in the United States illegally exported miniature UAV autopilots to Xi'an Xiangyu Aviation Technical Group in China.[lxxxix]

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.[xc] According to the plea agreement, Yu obtained systems and components from U.S. companies for marine submersible vehicles (such as UUVs).[8] She then illegally exported the components to the PRC. She acted at the direction of co-conspirators working for Harbin Engineering University, a leading Chinese institute for commercial and military UUV research.[xci]

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."[xcii]

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.[xciii] This system features institutions that monitor foreign technical developments, disseminate information to relevant Chinese institutions, and model foreign R&D for domestic programs. In the field of UAVs, a leading collection institute is the 310th research institute (RI) under the China Aerospace Science and Industry Corporation (CASIC). The 310th RI closely follows UAVs, aircraft, and missiles of foreign countries, and publishes the *Aerodynamic Missile Journal* (飞航导弹), which "introduces intelligence on relevant foreign flying missiles, and advances the rapid development of China's flying missile industry."[xciv]

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,[xcv] discussed the designs in context of decreased infrared signatures,[xcvi] and simulated configurations and drag effects of what appears to be the X-45A's weapons bays.[xcvii] For the X-47B system that will enter deployment, in 2013

[8] According to the indictment, Yu exported the following components: 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; and control sticks and button strips.

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.[xcviii]

The Chinese government actively recruits Chinese and foreign experts living abroad to work in China and boost domestic R&D in critical technologies. The central government organizes and guides this effort with active participation at lower levels. The leading program is the Thousand Talents Program (千人计划).[xcix] 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.

Chinese research institutes and universities actively participate in and host international conferences on 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, Chinese Association for Artificial Intelligence (CAAI) is China's leader in promoting academic exchange, publication, education, and research exhibition for artificial intelligence.[c] CAAI participants, however, include the PLA General Staff Department, National University of Defense Technology, and National Defense University. [ci] 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.[cii] 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 served as a member of the former General Armament Department's Science and Technology Committee (总装备部科技委).[ciii]

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.,"[civ] 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, however, these investments appear more targeted. One observer 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.[cv]

Recent AI and robotics deals since 2015 include the following:

- Haiyin Capital's investment in Boston-based Neurala - 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.[cvi] 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 had 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.[cvii] In October 2015, NASA awarded Neurala a $250,000 grant to commercialize autonomous navigation, object recognition, and obstacle avoidance technology in UGVs and UAVs.[cviii] Chinese investment in Neurala potentially poses at least two risks for the United States. One is that Chinese access to source code and underlying technologies behind Neurala software 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 previous U.S. contracts and grant money.

- Midea Group's investment in KUKA – 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.[cix] KUKA has been a leading supplier of industrial robotics for Chinese companies for a long time.[cx] According to one analysis, this acquisition raises questions on technology transfers, because KUKA is a supplier for the European defense industry, including robots used in the construction of the Eurofighter.[cxi] 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.[cxii] KUKA also maintains U.S. operations, leading to a review of the Midea deal by the Committee on Foreign Investment in the United States (CFIUS) and the Directorate of Defense Trade Controls (DDTC). To comply with the security-relevant requirements, in December 2016 KUKA sold KUKA Systems Aerospace North America to the U.S. company Advanced Integration Technology Inc.[cxiii]
- 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.[cxiv] 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.[cxv] The deal is reported to be worth USD 113 million.[cxvi] These tools are ideal for industrial robots in the automotive, plastics, electronics, food, and pharmaceuticals industries, among others.

IV. Recommendations to Maintain U.S. Economic and Strategic Advantages

As China surges ahead with production and deployment of industrial, service, and military robotics systems, it is essential for the United States to define and protect its advantages and interests. For industrial and service robots, the United States should focus on the advantages of quality and innovation, and support both U.S. entities developing new technologies for robotics and U.S. businesses trying to compete in the Chinese market. For military systems, the United States holds

technological advantages that must be protected from cyber intrusions and other illicit activities, and take into account China's rapid development of countermeasures against these systems.

Below are more detailed recommendations for Congressional and Executive action to maintain and increase U.S. economic and strategic advantages.

1. The Congress should continue to support initiatives that advance U.S. manufacturing and innovation in the industrial and service robotics industries, such as Manufacturing USA and the National Robotics Initiative, and monitor Chinese plans like Made in China 2025 to ensure it does not exclude U.S. companies from Chinese markets.

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.

3. 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.

4. 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.

5. 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.

6. 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 companies, and consider the security implications of transactions and acquisitions involving emerging technologies such as artificial intelligence and nanorobotics.

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