CHINA’S REMOTE SENSING

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OTH Intelligence Group LLC

Tate Nurkin, Christian Le Miere, Chris Eusebi, Stephen Rodriguez, Hassan Almaala, Andrew Gonzales

Reviewed by Becca Wasser

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About the OTH Intelligence Group Team

The coauthors of this paper represent three organizations focused on Indo-Pacific security, U.S.-China strategic competition, and emerging defense technologies.

OTH Intelligence Group LLC is a sole proprietorship LLC established in March 2018 by lead author Tate Nurkin to provide objective customized research and analysis to the U.S. and allied and partner defense and security communities as well as private sector companies. OTH's analysis focuses on emerging technologies and their impact on the future of conflict and military capabilities and Indo-Pacific security. OTH also specializes in the design, facilitation, and execution of wargames and tabletop exercises for private sector, government, and nongovernmental organizations.

One Defense is a strategic advisory firm that specializes in technology horizon scanning and competitive assessments. It works closely with both government organizations and high-tech companies seeking to work more closely with the U.S. national security community. Coauthors Chris Eusebi, Stephen Rodriguez, Hassan Almaala, and Andrew Gonzalez worked with One Defense during this effort.

Arcipel and Associates is an international strategic and defense consultancy based in London, UK that specializes in technology assessments and geopolitical risk, especially related to the Indo-Pacific region. Coauthor Christian Le Miere is the founder of Arcipel and Associates.

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Contents

Executive Summary and Introduction

Over the past two decades, China has rapidly improved its remote sensing capabilities. While the United States remains the overall leader in currently developed and deployed remote sensing with military, commercial, civil government, and research applications, this continued leadership in remote sensing is in doubt over the long term. China's prioritization of and investments in remote sensing are driving rapid maturation of China's commercial, civil government, and military remote sensing capabilities.

When coupled with continued investment by Chinese government entities, universities, and venture capital, China is positioned to further advance commercial and applied research in both state-of-the-art and emerging remote sensing technologies. China's emergent remote sensing capabilities have led it to become a leader in aspects of research and development (R&D) as it seeks to leverage these remote sensing capabilities to support its military, economic, geopolitical, and societal development objectives. Over time, China's development and application of these capabilities may weaken U.S. leadership in remote sensing capabilities and has already created or enhanced national security risks as well as economic and market challenges, especially in the automotive, small drone, and—over a longer time horizon—commercial remote sensing markets.

This paper provides a high-level overview of China's efforts to develop, deploy, and leverage advanced remote sensing capabilities in pursuit of economic and societal development, national security and geopolitical interests, and military modernization. It analyzes the key objectives, priorities, actors, technologies, and investments that are animating the steep growth of China's remote sensing capabilities. The paper further assesses the extant and potential future risks for U.S. economic and national security associated with the continuing growth of China's advancing remote sensing sector.

The OTH team engaged a diverse set of open and publicly available research sources, including scientific journal articles published in both English and Chinese; English-language Chinese media sources; Chinese company and state-owned enterprise websites; official State Council and government publications; independent think tank publications; industry consultant publications on specific markets of interest; U.S./Western media reporting; China space-focused blogs and substacks; and U.S. government sources. This secondary-source research was augmented with background interviews with eight additional individuals with industry-specific knowledge or expertise in China's technology acquisition efforts.

The analysis yielded several key findings about China's remote sensing development that can inform U.S. efforts to retain global leadership in this capability area and to mitigate the strategic, economic, and national security implications of China's remote sensing development:

China prioritizes remote sensing research in support of national objectives: China's government has prioritized remote sensing capability development and commercial industry support to further several critical national objectives: 1) to increase competitiveness and secure market position in select strategic industries; 2) to promote national development, to include the digitalization of the economy and society and provision of public goods and services; 3) to encourage and reinforce broader geopolitical engagement; and 4) to support People's Liberation Army (PLA) modernization efforts.

China's approach to remote sensing R&D reflects its national objectives and centralized structure: China's approach to remote sensing R&D consists of five main pillars: 1) central government policy guidance and prioritization of technologies and sectors/industries for investment; 2) subsidies and incentives to industry, research institutes, and researchers from provincial and city governments; 3) leverage of China's large and adaptive domestic markets to create consistent and scalable demand; 4) reinvestment in R&D and manufacturing; and 5) technology acquisition through talent recruitment, investment, mergers and acquisition, and surreptitious means such as espionage.

China has narrowed the technological gap in remote sensing: While the United States is viewed as the global leader in currently deployed remote sensing technologies, China has closed the gap in technological development in most applications and sectors. China is currently leading the world in research impact in several remote sensing technology areas, including applications of multispectral and hyperspectral imaging sensors, radar, and satellite positioning and navigation. China is also seeking to invest in and acquire capabilities in enabling technologies critical to remote sensing, such as semiconductors, Field Programmable Gate Array (FPGA) chips, analog chips, artificial intelligence (AI), and novel remote sensing platforms such as small satellites and uncrewed aerial systems (UASs).

Advancement in China's remote sensing poses challenges and risks for U.S. economic and national security: China's development of advanced remote sensing poses current and long-term risks to U.S. security, including: 1) continued advancement of PLA military modernization by strengthening its abilities to observe, detect, track, and target U.S. and allied assets and personnel through both dedicated military sensing and dual-purpose civil government and commercial remote sensing capabilities; 2) the potential for China to gain an entrenched advantage in remote sensing platform and technology areas vital to the growth of emerging market areas, such as electric and autonomous vehicles, commercial satellite remote sensing and the space economy, and small UASs; 3) the potential for the exploitation of strong market positions in light detection and ranging (LiDAR) remote sensing and small drones to create difficult-to-overcome competitive advantages in fast-growing industries, market dependencies on Chinese sensors, and several national and infrastructure security challenges.

China leverages investments in U.S. advanced remote sensor companies to gain remote sensing knowhow: China is using multiple methods, both licit and surreptitious, to gain knowhow, expertise, and access to mature remote sensing technologies. Acquisition through investment in automotive LiDAR firms and technology has been particularly successful, and Chinese investment groups have participated in deals to acquire space-based remote sensing companies.

China is a near peer or peer in military remote sensing, creating new and enhanced operational planning dilemmas: The PLA's improving remote sensing capabilities and ability to access the growing number of Chinese commercial remote sensing satellite constellations are likely to allow the PLA to more successfully: 1) locate U.S. and allied mobile assets; 2) track U.S. and allied deployments; 3) develop and deploy new autonomous capabilities; 4) improve situational awareness and understand topographical, marine, and atmospheric conditions in operating environments; and 5) strike U.S. and allied assets with greater range and precision. These risks will only grow over time as improved fidelity of remote sensors will allow the PLA to access more precise observational data over greater distances. Remote sensing data will then be processed with AI algorithms to rapidly detect objects, patterns, and anomalies. This will complicate U.S. and allied operational planning as they are likely to face a PLA with improved intelligence, tracking, and targeting capabilities, making efforts to deter or conduct military operations within the second island chain in the Indo-Pacific more difficult.

Based on these findings, we have developed 12 recommendations—grouped into five categories in Table 1 below—for mitigating the risks of the growth, technological development, and use of China's remote sensing capabilities. Overall, these recommendations reflect an approach that balances the "defensive" use and expansion of export controls with more constructive and proactive risk reduction measures.

Promote U.S. Remote Sensing Development and Investment
Recommendation 1: Congress should consider regulatory and financial measures to support the domestic remote sensing industry and incentivize investment in areas such as small drones and LiDAR for autonomous systems and higher-risk next-generation remote sensing technologies such as quantum sensing. Recommend expanding targeted funding for the National Science Foundation, Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and Office of Strategic Capital (OSC) as well as investment credits.
Recommendation 2: Congress should consider regulatory and financial incentives (tax incentives) to support the United States' ability to accelerate development and scaling of a domestic workforce with expertise on critical components of advanced remote sensing and to attract and retain talent from abroad to work in the U.S. remote sensing and connected industries, such as space.
Ensure Data Security
Recommendation 3: Congress should mandate a focused and technical study on the nature of the data security and Department of Defense (DoD) supply chain risks associated with use of Chinese-made LiDAR in cars operating in the United States. The House Select Committee on Strategic Competition between the United States and China should also consider holding hearings on the topic.
Recommendation 4: Congress can encourage government entities, industry, and external experts to facilitate the development of training for business and academic leaders of the risks of engagement with China and implications of China's National Intelligence Law. Congress should actively encourage the development of internal corporate resources to mitigate the risks of business ventures with Chinese companies and implications of China's National Intelligence Law.
Recommendation 5: Congress should consider standardizing regulations of the access, collection, and storage of data related to roads, terrain, and infrastructure.
Engage Allies and Partners
Recommendation 6: Congress should encourage DoD to increase research collaboration with its European and Pacific allies—many of whom are global leaders in remote sensing technology development—and establish a framework to safeguard defense-critical technology and knowhow from surreptitious acquisition by China.
Recommendation 7: Congress should encourage DoD to work closely with allies and partners in the Indo-Pacific and Europe to better understand how China's remote sensing capability might be employed in a crisis or security contingency and what capabilities or operational concepts might help reduce allied vulnerability. Congress should further encourage DoD to use wargames to iteratively and collectively create a shared understanding of the problem and potential solutions. Additionally, Congress should support DoD efforts to accelerate the procurement of commercial remote sensing from both the United States and allied nations.
Recommendation 8: Congress should consider ways in which the United States can expand cooperation with allies and partners in countering or dampening the soft-power impact of China's sale of or collaboration in remote sensing diplomacy, particularly in Latin America, Africa, and the Middle East.
Expand Export and Investment Controls
Recommendation 9: Congress should revisit the Foreign Investment Risk Review Modernization Act (FIRRMA) and apply it to other critical technologies such as those associated with remote sensing. It should also look to empower the Committee on Foreign Investment in the United States (CFIUS) to address legal loopholes that allow People's Republic of China (PRC) shell companies to operate in legal gray zones and still invest in or acquire U.S. technology.
Recommendation 10: Congress should consider updating the 2003 U.S. Commercial Remote Sensing Space Policy (CRSSP). While the presidential directive is the baseline for U.S. commercial activity, the global remote sensing market has undergone significant changes since it was enacted. Congress should engage with industry to revise the directive and codify into law an update to the policy as it relates to competition with the PRC.
Mitigate Risks to U.S. and Allied Militaries
Recommendation 11: Congress should press the armed forces for greater clarity on how the U.S. military will meet the challenge from a more situationally aware PLA and how improved remote sensing will affect deployments in the Indo-Pacific region.
Recommendation 12: Congress should consider including funding in future defense appropriation bills for measures that would mitigate the effects of improved Chinese remote sensing, such as counter-intelligence, surveillance, and reconnaissance (ISR) systems, electronic attack and cyber capabilities, antiradiation ordnance, base hardening, close-in weapons systems, and air defense capabilities.

Table 1: The 12 recommendations for mitigating risks associated with China's remote sensing capability development.

The report that follows is divided into seven chapters:

Chapter 1—Introduction on Remote Sensing—provides an overview of the key concepts, components, values, and applications of remote sensing capabilities.

Chapter 2—China's Remote Sensing Progress, Priorities, and Objectives—offers an assessment of China's remote sensing capabilities in relation to those of the United States and also assesses the main priorities and objectives of China's remote sensing development.

Chapter 3—Key Guidance, Entities, and Actors Shaping China's Remote Sensing Development— lays out several overarching policy statements and strategies that are informing China's remote sensing development across industries. It also provides profiles of many of the government, commercial, academic, and financial organizations involved in China's diverse and growing remote sensing activities.

Chapter 4—China's Acquisition of Overseas Remote Sensing Capabilities—provides insight into the techniques China uses to acquire remote sensing capabilities, technologies, and knowhow, using several specific examples of how both licit and illicit methods of technology acquisition have been employed to acquire remote sensing capabilities.

Chapter 5—Case Studies—examines three case studies that demonstrate the progress and challenges associated with China's remote sensing development and deployment across three different contexts: the LiDAR and the autonomous vehicle markets, the small drone market and remote sensing, and commercial space remote sensing.

Chapter 6—The PLA and Remote Sensing—documents PLA remote sensing activities and capabilities across several platform types, provides a high-level comparison of these capabilities to those of the U.S. military, and assesses the implications for the United States of China's advancing military remote sensing capabilities.

Chapter 7—Recommendations—includes a more complete articulation of the 12 recommendations across five categories provided in Table 1 above.

Chapter 1: Introduction on Remote Sensing

Remote Sensing Components and Concepts

Remote sensing is the process of detecting and monitoring the physical characteristics of an object or area by measuring its reflected and emitted radiation at a distance.[1] Remote sensing capabilities are transforming a wide range of industries and markets as well as scientific research, civil-government, and defense and security activities by providing a systematic means of collecting and processing data, frequently from a bird's eye view, which enhances operator and decision-maker understanding of what is happening on Earth.

At a minimum, remote sensing systems involve three interlinked components: 1) platforms; 2) sensors; and 3) data processing, fusion, and transmission.

Platforms carry different types of remote sensors. These sensors collect distinct types of spectral data, which are sent to a ground station or to a secure cloud environment where they are processed and analyzed. This analysis process increasingly uses AI algorithms to identify objects, patterns, trends, and anomalies and to make data-driven recommendations. Processed data and recommendations are then delivered to operators or users to inform research and decision-making. Some AI-enabled platforms can process data on board, precluding the need to send data to a processing center and further reducing the amount of time between collection and transmission of processed data to users that can exploit these remote sensing data.

Regardless of platform or sensor type, the utility of a given remote sensing capability is linked to four primary attributes and metrics.

- **Resolution/precision:** Higher-resolution data can be interpreted more accurately and more quickly, providing more reliable inputs into data-driven decision-making. Resolution for optical satellite imagery is classified into four categories: low resolution (> 20 meters [m]), medium resolution (> 2 m to ≤ 20 m), high resolution (> 50 cm to ≤ 2 m), and very high resolution (≤ 50 centimeters [cm]).[2] Higher-resolution imagery is typically more expensive to provide and acquire.
- **Revisit time/responsiveness:** Remote sensing data are more valuable the more recently they have been collected. As a result, there is heightened demand for responsiveness to tasking from users, shortened intervals between the times a sensor or remote sensing constellation is able to revisit a specific site, or endurance of platforms to observe a specific site for extended periods of time.
- **Data processing and transmission speeds:** The value of remote sensing is also tied to the quality of the assessment of the data and the speed at which collected data can be processed, analyzed, and then securely transmitted to stakeholders and decision-makers.
- **Resilience to weather and environment:** Some types of high-resolution sensors cannot be used at night or in cloudy conditions. While these types of sensors can provide considerable value in daylight and clear conditions, many remote sensing operators seek to develop layered systems that incorporate several types of sensors to allow for collection of a range of data in all weather conditions.

Platforms

Remote sensors are placed on platforms, such as satellites, crewed and uncrewed aircraft, vessels, and vehicles. Unattended ground-based sensors also can be used to covertly or unobtrusively monitor ground-based activity. Ground-based remote sensors can also be fixed to towers or hand held.

Remote sensing satellites are launched into one of several types of orbit, each of which offers specific advantages and tradeoffs. Of particular importance to the discussion of space-based remote sensing are low Earth orbit (LEO), which runs from 160 kilometers (km) to 2,000 km above Earth's surface, and geostationary orbit (GEO), which is at 35,786 km. LEO satellites are typically smaller and cheaper to make. They operate in constellations of a handful to several dozen or even hundreds of satellites to increase redundancy and the rate at which at least one satellite in the constellation revisits a specific site. Because these satellites operate closer to Earth, collection and transmission of data to ground stations on Earth is faster than at higher orbits. In contrast, satellites operating in GEO can maintain their position over the same place on Earth's surface, ensuring more persistent monitoring of a specific location or area.

Sensors can also be placed on aircraft, vessels, and vehicles—which can be crewed or uncrewed—to collect data about specific locations from a distance. These platforms offer increased flexibility in monitoring specific sites, as they can be easily navigated over sites of concern multiple times and capture data from different angles—unlike satellites, which typically follow specific orbits. They also allow for sensor flexibility, as many crewed and uncrewed aircraft are designed to be able to carry multiple sensor types and even "plug and play" different sensors for different sorties over a specific site. An emerging trend in remote sensing operations is the growing use of uncrewed systems, particularly UASs, as they increase flexibility at a lower cost than high-end aircraft or satellites.[3]

Sensors

Remote sensing technologies are separated into two broad categories of capability based on the mechanisms through which they collect data: passive and active. Below is a discussion of the differences between passive and active sensors as well as descriptions of sensor types that constitute the current state-of-the-art technologies in use today.

Passive Sensors

Passive sensors measure light emitted or reflected naturally from objects, relying on the sun's energy and light to illuminate these objects. Passive sensors use optical sensors such as cameras to collect data in the visible spectrum as well as other spectral bands, including visible, near-infrared, mid-infrared, and thermal infrared.[4] However, because they rely on natural light to collect data, passive sensors do not operate as effectively at night and can also be disrupted by clouds and other environmental conditions. Current state-of-the-art passive sensors include:

- **Panchromatic imagers:** Panchromatic imagers are the workhorses of satellite imaging, providing crisp and clear high-resolution images of the Earth in black and white. Panchromatic imagers can help pinpoint objects easily, making them especially capable for mapping out urban developments or assessing damage after an event such as an earthquake or hurricane.
- **Multispectral cameras:** Multispectral imagers capture light within multiple discrete bands of the electromagnetic spectrum, including the visible, near-infrared, mid-infrared, and thermal infrared bands. This enables analysts to discern information that might not be visible to the naked eye, such as the health of vegetation, the presence of certain minerals, or the clarity of water.
- **Hyperspectral cameras:** Hyperspectral imagers are more capable than multispectral imagers and collect information across a broader range of the electromagnetic spectrum and with finer wavelength resolution. Hyperspectral sensors are considered the most accurate type of passive remote sensor, capable of differentiating hundreds of spectral bands within visible, near-infrared, and mid-infrared bands.[5]
- **Short-wave infrared (SWIR) cameras:** SWIR cameras operate in a part of the light spectrum invisible to humans but which can reveal hidden details of the Earth's surface. This technology can

distinguish between materials based on how they reflect this special light. For instance, using SWIR, healthy plants can be told apart from distressed ones, aiding in agriculture and environmental monitoring. SWIR is particularly useful because it can make water vapor, fog, and certain materials such as silicon transparent, enabling monitoring when it would not be possible with standard cameras. Additionally, colors that appear almost identical in the visible spectrum may be easily differentiated using SWIR.[6]

While passive sensors do have some limitations related to the conditions in which they can be effectively deployed, they also provide an important and frequently lower-cost remote sensing capability that—because it does not actively emit energy—uses less power, produces easy-to-interpret images, is more difficult for competitors or adversaries to detect, and does not impact the environment it is observing.

Active sensors

Active sensors differ from passive sensors in that they have their own source of emission, typically microwaves or light/lasers. Active sensors direct this energy at target objects or locations, collecting the data that reflects off that object to determine measurements such as height or distance or atmospheric conditions. Active sensors do not require sunlight to operate, and they are able to operate any time of day and in most atmospheric conditions.[7] A key trend in remote sensing is the use of the two advanced active sensor technology areas that provide high-resolution three-dimensional (3D) images of target areas.

Synthetic aperture radar (SAR): Synthetic aperture radar (SAR) actively sends microwave signals to the Earth’s surface and records the reflected signals. SAR can penetrate through cloud cover and provide high-resolution 3D images irrespective of weather conditions, making it an indispensable tool for year-round monitoring activities. SAR systems are placed on crewed and uncrewed aircraft as well as on government and commercial remote sensing satellites, though the use of SAR on commercial satellites is a recent development. Only in 2018 did a U.S. company launch a commercial SAR satellite when Capella launched its Denali satellite.[8] Chinese commercial remote sensing companies Beijing Smart Satellite, PieSat, and Spacety are all developing commercial SAR satellite constellations,[9] while China’s military has deployed the first, and currently only, SAR satellite in GEO.[10]

LiDAR: LiDAR is a sophisticated tool that measures distances by shining a laser on a target and then analyzing the reflected light that bounces back. This technology rapidly allows operators to create a 3D map of physical features on a surface or in immediate surroundings (depending on range).

LiDAR is applied for military and civilian use in three main ways. First, LiDAR installed in a crewed or uncrewed aircraft can map topographical features of an object or location with increased precision. This application can support the detection of changes in an environment, which can support improved planning. Second, LiDAR sensors installed on vehicles or aircraft provide a detailed picture of the platform’s surroundings. This application is currently seen as crucial to scaling increased levels of autonomy in automobiles and is discussed in more depth as one of the Chapter 5 case studies. Third, bathymetric LiDAR, also known as blue-green LiDAR, is fixed to an aircraft (or crewed or uncrewed vessel) and used to penetrate water. While the traditional LiDAR laser—the “blue” in blue-green LiDAR—is reflected back to the aircraft from the land and water surface while the additional green laser travels through the water column to capture sub-surface data.[11] This technology holds some promise for future use in anti-submarine warfare (ASW) missions. A team from the Shanghai Institute of Optics and Fine Mechanics successfully tested an airborne bathymetric LiDAR sensor that can reach 160 meters below the surface of the sea as part of an effort to develop new means of detecting submarines.[12]

Together, these methods of active sensing provide the ability to obtain remote measurements at any time of the day or year and can better control the way a target is illuminated since they are not dependent on sunlight to capture measurements. They can also examine wavelengths such as microwaves that are invisible to passive radars because they are not sufficiently illuminated by the sun.

Emerging and next-generation technologies: Quantum sensing

In addition to these current state-of-the-art techniques, there are emerging and next-generation technologies currently at a low level of technology readiness but that could have a profound impact on the future of remote sensing. Of greatest interest are quantum sensing technologies that could deliver more accurate and secure sensing with less chance of signal jamming or electromagnetic interference.

Quantum sensing applies the principles of quantum mechanics to enhance the precision of measurements. Quantum sensors leverage quantum states such as superposition and entanglement to detect minute changes in physical quantities, including magnetic fields, temperature, and gravitational forces, with remarkable sensitivity and accuracy.[13] In the context of remote sensing, quantum sensing's high sensitivity and resolution enable the detection of subtle signals that are otherwise undetectable with conventional sensors.

There is significant value in military applications of quantum sensing. Quantum sensors can provide enhanced capabilities for positioning, navigation, and timing (PNT) in environments where Global Navigation Satellite Systems (GNSS) such as the U.S. Global Positioning Systems (GPS) signals are degraded or denied by electronic warfare measures such as jamming. These emerging sensors are anticipated to play a vital role in ISR by detecting underground structures, nuclear materials, and even concealed adversary forces through their extreme sensitivity to environmental disturbances.[14] For example, quantum magnetometers can detect weak magnetic fields for submarine detection, and quantum gravimeters can map gravitational anomalies to locate underground bunkers or tunnels.[15]

Despite its potential, the advancement of quantum sensing technology faces several technology development challenges. Key hurdles include the need for highly controlled environments to maintain quantum coherence—the complexity of scaling up quantum devices for practical use—and the integration of quantum sensors with existing technologies.[16] Moreover, there are significant costs and technical requirements associated with developing and fabricating quantum materials and devices. While substantial progress has been made, the widespread adoption of quantum sensing in commercial and industrial applications is likely to be a gradual process, with timelines varying across different sectors and technologies. Significant advancements in materials science, quantum computing, and cryogenic technology will be required before quantum sensing capabilities can be rapidly scaled and adopted.[17]

While quantum sensing is not yet mature, the technology holds promise for both commercial and military remote sensing by improving PNT, increasing sensitivity of detection and resilience of operations against jamming and electronic warfare threats. As a result, quantum sensing is likely to be a key component of U.S.-China competition in quantum technologies, a broader category of technology in which China currently outspends the United States by $13.4 billion.[18]

AI and Remote Sensing

Developments in platform and sensor technologies are increasing the amount and quality of remote sensing data available to analysts and decision-makers, frequently overwhelming their capacity to process, analyze, and exploit these data in a timely manner. AI and machine learning (ML) algorithms provide a means to better manage data processing and analysis in support of timely and more informed decision-making.[19] Specifically, AI/ML can improve and greatly accelerate identification and classification of objects and extract insights from remote sensing data, such as finding patterns, identifying trends, detecting anomalies, and making predictions that can inform, improve, and accelerate human decision-making.

DoD's Scarlet Dragon exercise—an iterative exercise for the U.S. 18th Airborne Corps—is a useful example of the benefits of applying AI algorithms to process complex and large remote sensing data sets in the defense and national security sector. Reporting on the 2021 exercise shows the value AI can provide in speeding up target detection and identification. Multinational military analysts and operators applied AI algorithms to interrogate different remote sensing data to recommend geographic areas to search for potential targets. Participants reported significant increases in both speed and precision, reducing the amount of time it took to locate targets in the exercise from 320 minutes to around 60 with nearly complete accuracy in target recognition.[20]

AI/ML use is no longer limited to military training exercises. It is now being incorporated in real-world combat operations to help support human targeting and intelligence efforts both in the United States and elsewhere. In February 2024, the U.S. Central Command (CENTCOM) confirmed that AI/ML algorithms were used to interrogate remote sensing data and narrow down targets for human decision-makers for more than 85 U.S. air strikes in Iraq and Syria.[21]

China has used AI to enhance its ability to identify and track U.S. and allied assets and bases. In June 2021, the PLA reported using a remote sensing satellite "powered by the latest artificial intelligence" to automatically detect and track the USS *Harry Truman* aircraft carrier in real time as it and other U.S. Navy ships transited to an exercise off the coast of Long Island, NY.[22]

Additionally, reporting from April 2024 revealed that China's Taijing-4 03 satellite, which is equipped with AI processors for rapid detection and identification of targets at sea, captured detailed images of three U.S. aircraft carriers, two Arleigh Burke-class warships, and four other vessels at U.S. Naval Station Norfolk. Taijing-4 03 is part of a five-satellite constellation operated by Chinese commercial remote sensing company MinoSpace, reflecting the connections between the PLA and China's emerging commercial remote sensing industry, which will be explored in Chapter 5's discussion of case studies.[23]

The relationship between AI and remote sensing data is multidimensional and goes beyond AI algorithms analyzing remote sensing data. Remote sensing data are also being used to train AI models to accurately discern and differentiate between objects that may have similar characteristics. One recent example: In March 2024, the U.S. Air Force Research Lab, working through prime contractor Axient, awarded U.S. commercial space-based remote sensing company BlackSky a $2 million contract to provide thousands of satellite images to train AI models to improve and more swiftly refine algorithms that can accurately identify moving objects from space and recognize patterns of life.[24]

AI—in combination with powerful computer chips—is also being leveraged to reduce dependencies on ground stations and reduce the cost associated with monitoring and controlling remote sensing operations, especially in space. In 2020, the European Space Agency (ESA) and Intel became the first to publicly acknowledge sending an AI-enabled satellite into space. PhiSat-1 carried Intel's Movidius Myrian 2 vision processing unit chip, which uses AI to assess images and sort out unclear images. Intel's data processor then sends only the useful images to human operators, improving bandwidth utilization and saving time for researchers and analysts on the ground.[25]

Remote Sensing Market, Value, and Applications

The emergence of AI as an enabler of remote sensing data alongside advancements in sensor technologies and platforms such as small satellites and uncrewed systems are together driving increased demand for remote sensing products and services among commercial, civil government, scientific and research, and defense and security organizations.

Estimates of the size of the global remote sensing market vary based on what capabilities and technologies are included. Publicly available estimates tend to center on a global remote sensing market worth between $16.5 billion and $18.5 billion in 2023. Anticipated double-digit growth rates over the next decade could bring the total size of the market to between $55 billion and $68 billion, reflecting the increasing value of remote sensing data to a broad range of industries.[26]

In the commercial sector, industries use remote sensing to identify operating efficiencies, mapping locations, tracking changes in activity over time, and tracking environmental and human conditions and activity. Remote sensing helps companies get ahead of risks and opportunities as well as to create new products, especially those that support the digitalization of economies and societies. Industries employing remote sensing include agriculture, forestry, mining, energy, retail, maritime shipping, logistics and transportation, fishing, e-commerce, insurance, resource planning and management, and autonomous vehicle and system development.

Civil government agencies and scientific organizations also use remote sensing for tasks including environmental or coastal/ecosystem monitoring, resource planning and management, disaster detection and response, search and rescue, law enforcement, infrastructure monitoring, and smart city development. It is also being used to explore new or remote locations, such as remote islands, mountainous areas, undersea environments, or dense jungles.

For defense and security communities, remote sensing has become a crucial part of ISR infrastructure, allowing military and intelligence organizations to see, find, and track adversary activities more easily, for longer periods of time, and over longer distances. These capabilities allow militaries to hold adversaries at risk at more distant, stand-off ranges. Remote sensing data are also helpful in the development of autonomous systems, assured PNT, and military planning.

Across these applications and regions, remote sensing provides five main types of value to support data-driven decision-making and planning; diagnose, anticipate, or respond to changes or anomalies; and create new products.

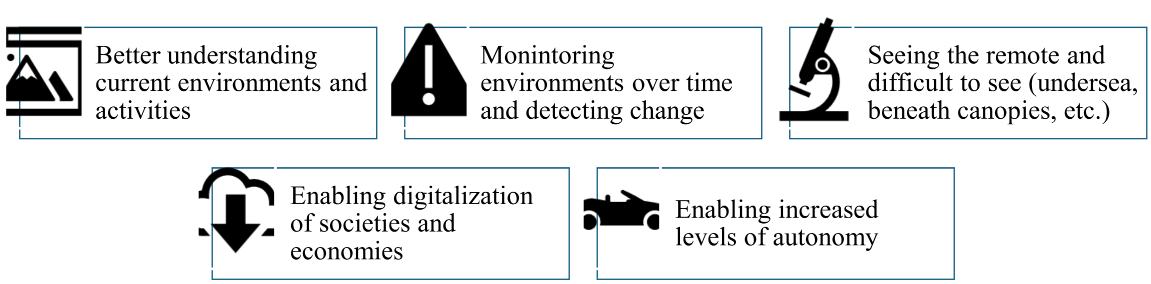

Figure 1: Five types of value remote sensing capabilities provide to commercial, civil government, scientific and research, and defense and security organizations. Source: Nurkin and Microsoft Office Icons.

Dual-Use Applications of Remote Sensing

The relevance and utility of remote sensing depends on the target of observation, how it is targeted, which purposes are behind data collection, and the end use of collected data. Nevertheless, remote sensing data collected for one purpose may be useful for another. As a result, many commercial, civil government, or scientific applications are inherently dual-use and can also be used to support defense and national security organizations. The following selected dual-use applications demonstrate the complicated and overlapping nature of remote sensing applications in support of commercial, civil government, scientific, and defense and national security objectives.

Remote sensing as a service: U.S. and European companies such as Planet, BlackSky, Maxar (all U.S.-based), and ICEYE (Finnish), among others, have proven the viability of a business model in which providers operate satellites and deliver processed remote sensing and imagery intelligence to governments, companies, and even individuals. These data can include information that is materially useful for defense and national security communities, even for those that have access to high-resolution military surveillance. In January 2022, for instance, the U.S. National Reconnaissance Organization (NRO) issued contracts to five commercial suppliers to provide SAR imaging.[27]

The abundance of commercially available high-resolution remote sensing data creates opportunities for the United States and its allies as well as for U.S. competitors. For example, Chinese commercial remote sensing companies have sold remote sensing data to entities sanctioned by the U.S. government. Indeed, in 2023 the U.S. Department of the Treasury sanctioned Chinese commercial remote sensing companies Changguang Satellite Technology Laboratory Corporation (CGSTL) and Spacety for providing remote sensing data through partners to the Russian Wagner Group in support of the group's operations in Ukraine and Africa.[28]

Environmental monitoring and management and crisis response: Remote sensing data can help detect ecological or environmental changes or new patterns of activity, information that can help researchers and policymakers better understand and monitor environments and get ahead of environmental or ecological crises. Remote sensing data can also be useful for tracking natural disasters, such as floods or earthquakes. Constellations of LEO satellites and crewed or uncrewed aircraft or vehicles can provide timely and potentially life-saving intelligence about fast-moving and dangerous situations.

These same data can be used to support a range of military activities. Environmental monitoring of island or maritime environments can also serve as an important input for planning military or national security-related activities or amphibious operations. For example, China has developed a "maritime dynamics and surveillance system" that maps and surveils islands in the South and East China Seas, including the contested islands and features of Scarborough Shoal, Senkaku Islands, Paracel Islands, Macclesfield Bank, and Spratley Islands. Data from the remote sensing system monitoring maritime conditions around these islands could be repurposed to support security crisis response, military planning, or military operations.[29]

Another example is seen in the July 2023 announcement by Chinese state-owned enterprise (SOE) China Aerospace Science and Industry Corporation (CASIC), which is developing a 300-satellite constellation in very low Earth orbit (VLEO)—typically 250 to 350 km above Earth[30]—to support resource and emergency management entities. According to CASIC subsidiary Space Engineering Development, the constellation will be used to carry out real-time, high-resolution observation of designated areas and specific targets in accordance with users' requests and will be able to map or survey any place in the world within 15 minutes of receiving a user request.[31] This ability to collect remote sensing data about any spot on Earth in a matter of minutes could deliver a crucial situational awareness advantage in an unfolding crisis or military contingency.

Oceanographic mapping: Oceans cover over 70 percent of the Earth's surface, yet only 19 percent of the ocean floor has been spatially mapped. According to the General Bathymetric Chart of the Ocean (GEBCO) organization, "knowing the depth and shape of the seafloor is fundamental for understanding ocean circulation, tides, tsunami forecasting, fishing resources, sediment transport, environmental change, underwater geo-hazards, infrastructure construction and maintenance, cable and pipeline routing and much more."[32]

Remote sensing data of the sea floor and of the undersea environment more broadly can also be used by military and security forces to both support their own undersea operations and potentially detect those of other nations. A January 2024 Center for Strategic and International Studies (CSIS) report detailed PLA suspected collaboration with linked SOEs and scientific/research organizations such as the China Academy of Sciences (CAS) to map large areas of the Indian Ocean. As China develops its power projection capabilities—particularly in the maritime domain—this information would enable the People's Liberation Army Navy (PLAN) to operate more safely and more actively in the distant and unfamiliar waters of the Indian Ocean. Accurate civilian remote sensing data about undersea features would also be an important input for the PLAN to track and target undersea capabilities more accurately, which would be critical to its efforts to redress perceived military imbalances between itself and the United States in the undersea domain.[33]

Chapter 2: China's Remote Sensing Progress, Priorities, and Objectives

Assessing China's Progress in Remote Sensing Technologies

China's remote sensing industry and capabilities have experienced a "massive tailwind"[34] in the last decade. China has rapidly advanced the technical sophistication of remote sensing capabilities, the diversity of applications of these capabilities, and the scale of investment in, manufacturing of, and revenue derived from the country's commercial remote sensing industry.[35] This advancement has generated opportunities to leverage remote sensing for economic, geopolitical, and military gain. The breadth and pace of this development naturally raises the question of whether China has caught or surpassed the United States in remote sensing capabilities.

The prevailing qualitative and open-source assessment is that China has closed the gap with the United States and other advanced remote sensing development countries such as France, Germany, India, Canada, Spain, the Republic of Korea, and Australia, among others.

This narrative is especially prevalent in space-based remote sensing. A 2024 academic paper from researchers at Wuhan University—a leading Chinese university for remote sensing—captures this perspective, stating that "through collaborative efforts between the government and enterprises, China has made remarkable strides in narrowing the technological gap with foreign countries" in Earth observation.[36]

General David Thompson, U.S. Space Force vice chief of operations, made a similar assessment about China's military and dual-use space-based remote sensing in October 2022. General Thompson commented that China is "building and fielding space capabilities at an incredible pace. Their space capabilities are still not quite as good as ours, but they are really, really good."[37] He also included some insight into implications for how the U.S. military at least views China's remote sensing development, saying the United States has "to assume that they are a peer competitor in that regard."[38]

Another anecdotal but still valuable indicator of China's space-based competitiveness in remote sensing technology is seen in the results of a 2021 National Geospatial-Intelligence Agency (NGA) study that evaluates commercial Earth observation solutions across nine categories. Chinese providers topped three of the nine categories: best electro-optical persistence, best video, and best hyperspectral imaging across 20 or more bands.[39] U.S. providers also won three categories: best panchromatic resolution, best shortwave infrared, and best SAR resolution.[40] Results of a similar competition published in October 2024 show Chinese companies winning five categories (of 11) and the United States winning four.[41]

More detailed and comprehensive one-to-one comparisons of the relative balance between the United States and China in remote sensing are complicated by at least three factors.

First, the diversity of the remote sensing landscape means there are pockets of national advantage and disadvantage across platforms, sensors, markets, and applications. The United States retains a lead in space-based remote sensing, an assessment that reflects U.S. industry's history of innovation in the field, the maturity and sophistication of existing technologies and capabilities, extant data processing capability, and capacity to integrate these components. The industrial scale of the U.S. commercial space industry is also a current advantage for the United States. In 2023, 2,870 satellites were launched globally; approximately 78 percent were launched from the United States.[42] According to the U.S. National Space Intelligence Center and the National Air and Space Intelligence Center, there were 7,096 commercial and military satellites in space in 2022; 4,723 satellites are from the United States, while 647 are from China.[43] While not all of these satellites are remote sensing satellites, these numbers demonstrate that the U.S. capacity to build and launch satellites is currently unmatched.

Still, China is demonstrating growing capability in space-based remote sensing. China is deploying novel capabilities, such as the Ludi Tance-4, the only SAR satellite in GEO,[44] and the impressive capabilities of the Jilin-1 commercial remote sensing constellation discussed later in this paper. There are also other areas and applications where China demonstrates significant advantages. China retains a strong market position in LiDAR for autonomous vehicles and in small drone remote sensing. Together, these examples provide insight into how both China and the United States possess areas of advantage and disadvantage and how current advantages are not assured and may be contested by continued advancement.

Second, China is investing heavily in R&D in key remote sensing technologies. The Australian Strategic Policy Institute's (ASPI) Critical Technology Tracker uses a combination of metrics related to publications in high-profile journals and citations to assess China's technology development relative to the United States and the rest of the world in dozens of technology areas. For "advanced sensing" technologies, ASPI's research found that China's research impact is world leading in seven of ten technology areas. China held the highest percentage of papers in the top 10 percent of highly cited publications in multispectral and hyperspectral imaging sensors (48.9 percent), radar (40 percent), photonic sensors, (43.7 percent), and satellite positioning and navigation (36.3 percent).[45] The United States led in atomic clocks, gravitational force sensors, and quantum sensors.[46]

Leading in citations and publications does not necessarily guarantee future leadership in the development of novel technologies. More importantly, the focus on academic and basic research excludes much of the innovation taking place in the U.S. commercial sector. Nonetheless, the extent of China's lead in academic research does ensure that its remote sensing development at the very least is on a "strong future trajectory."[47]

Third, evaluations of remote sensing capabilities must also take into consideration the remote sensing value chain (see Figure 2) and the potential for a country or company to develop a chokehold on strategic technologies or capabilities.

Figure 2: One conception of the value chain for remote sensing capabilities. Source: Nurkin/Eusebi.

Both the United States and China hold advantages in technology development or demonstrated capability in specific areas of the remote sensing value chain, including divergent advantages within each of these categories based on the industry or application.

Consider manufacturing. As referenced above, the United States holds "a substantial advantage in satellite manufacturing and launch capacity and a robust and competitive commercial space ecosystem."[48] However, China holds the advantage in manufacturing scale for the production of LiDAR sensors for the automotive industry or the production of small drones for remote sensing applications in the commercial, civil government, scientific, and law enforcement sectors. In these areas, Chinese LiDAR companies Hesai, Robosense, and Seyond and small drone company DJI have been able to scale manufacturing in ways that have made it difficult for U.S. companies to compete globally and even increase market share in the U.S. domestic market, as discussed in more detail in Chapter 5.

Both the United States and China also possess advantages in "chokehold" technologies across this value chain. China dominates the rare earth materials market and the processing of these materials. As of late 2022, China accounts for 63 percent of the world's rare earth mining, 85 percent of the global total, and 92 percent of rare earth magnet production.[49] The rare earth elements (REE) and rare earth oxide (REO) materials are critical throughout the remote sensing value chain. While the specific rare earth materials needed and their supply chains may vary, China controls the mining sources and refining of many—if not most—of these materials.[50]

For the United States, advantages in FPGA and analog chips have meant that China's LiDAR providers are mostly reliant on the United States for these technologies. One in-depth assessment of China's surge in LiDAR production over the last three years argues that China's dependence on foreign suppliers, particularly the United States, for "crucial analogue chips" and FPGA chips is a challenge and vulnerability for China's burgeoning LiDAR industry.[51]

While side-by-side comparisons are important and useful and do reveal areas of advantage for and continued areas of competition between the United States and China, the overall assessment of the impact of China's remote sensing development is more nuanced than "one and zero" evaluations. Even in areas in which China may trail the United States or other countries, China's rapid advancement and improving capabilities are creating economic and national security challenges that Congress and policymakers across the U.S. government should acknowledge and address.

China's Motivations and Priorities for Remote Sensing Development

The development of China's remote sensing industry is in service of four main motivations and objectives:

1. To catalyze and support China's competitiveness and market position in key strategic emerging industries that prominently incorporate or support remote sensing activities and are likely to experience steep market growth.
2. To accelerate national development and societal resilience, improve civil governmental capacity to provide public services and goods, and facilitate the broader digitalization of China's economy and society.
3. To build and deepen geopolitical relationships and economic dependencies—remote sensing capabilities have opened up new opportunities for soft power engagement, especially in Belt and Road Initiative (BRI) countries—that can deliver geopolitical and economic benefits.
4. To support modernization of PLA ISR capabilities, allowing the PLA to collect more and better data and observe U.S. and allied activities more persistently and accurately at greater ranges.

This chapter focuses on the first three priorities and motivations. Chapter 6 provides a thorough assessment of PLA remote sensing development and its implications for U.S. and allied military planners.

Increasing Competitiveness and Ensuring Market Position in Strategic Emerging Industries

The combination of improved remote sensing capabilities, new platform types and operational concepts, and AI processing efficiencies has increased the utility of remote sensing for a broad range of commercial industries. These developments have also introduced new opportunities and disruptive dynamics in industries such as space and automotive. China's development of advanced remote sensing technologies is in part motivated by a desire to capitalize on these disruptions and achieve advantage in strategically important and growing global markets.

Remote sensing as a component of building a comprehensive domestic space capability

Prioritization of China's remote sensing industry should be viewed at least in part as an element of a wider effort to build a comprehensive domestic space industry capable of delivering all aspects of the space value chain: increased launch capacity, satellite manufacturing, satellite applications (remote sensing and communications), and space exploration.

Establishing China as a leading—and, eventually, the leading—and self-sufficient actor across all space activities brings international prestige as well as geopolitical and national security advantages. By investing in remote sensing capabilities, China can not only strengthen its position in the global space race but also ensure it has the necessary infrastructure and industrial base to support other economic, national development, and national security objectives.

The economic benefits of becoming a global leader in space are also significant. The Satellite Industry Association (SIA) and Bryce Tech estimated in June 2024 that the global space economy reached $400 billion in 2023.[52] Of this total, $285 billion was related to the global satellite industry, including satellite manufacturing, launch, ground equipment, and satellite services.[53] Space-based commercial remote sensing services constitute only $3.2 billion of this estimate, though satellite manufacturing reached $17.2 billion.[54] McKinsey and Company and World Economic Forum data place the 2023 global space economy at $330 billion and the commercial Earth observation market at $3 billion. The Earth observation market is projected to grow to $8 billion by 2030 and $18 billion by 2035.[55] McKinsey's forecast places the total value of the space industry in 2035 at $775 billion.[56]

Several high-level government policy and guidance documents have articulated this objective and described the activities China has taken to achieve it. Most notably, the *State Council White Papers on Space Activity* published in 2000, 2006, 2011, 2016, and January 2022 (this paper is referred to as the *2021 White Paper* despite being published in 2022) offer a review of important space accomplishments and a list of prioritized activities for the next five-year period. The *2021White Paper* repeatedly emphasizes the importance of remote sensing for broader space ambitions, positioning it as a crucial component of building out China's space infrastructure and creating "a variety of products and services such as high-accuracy maps using remote sensing data [and] full dimensional images."[57]

China's focus on remote sensing as a key component of its efforts to take advantage of the growing space market, both at home and in the international market, is creating potentially significant economic opportunities that also intersect with geopolitical and national development objectives discussed below.

Gaining leadership in emerging automobile markets

The global automotive market is experiencing a transition driven by a shift in global demand toward electric vehicles, enhanced autonomous features, and, over time, the staged introduction of autonomous vehicles.

China's ability to adapt to this shift has allowed it to become the global leader in automotive exports in 2023, a year in which Chinese companies sold more than five million vehicles abroad. Chinese company BYD Co. became the global leader in electric vehicles sales in 2023, in part on the back of $4.3 billion in state subsidies and financial support from 2015 to 2020.[58]

Electric vehicles, referred to as new energy vehicles (NEVs) in China policy documents, were included as one of ten industries prioritized for indigenous development in 2015's Made in China 2025 policy guidance.[59] More recently, smart vehicles, or intelligent connected vehicles (ICVs), have also been named a long-term strategic focus as China seeks to become the leading global player in the emerging autonomous vehicle markets.[60] There are intersections between the NEV and ICV markets, as NEVs can more easily accommodate autonomous functionalities than traditional internal-combustion-engine (ICE) vehicles.[61]

In January 2024, McKinsey and Company estimated that the market for both advanced driver assistance services (ADAS)—which allow algorithms to carry out more vehicle functions while keeping humans in control of the vehicle—and fully autonomous vehicles will reach \$300 billion–\$400 billion annually by 2035.[62] This is a significant jump from the \$40 billion–\$55 billion estimated value of the market in 2022.[63]

Taking advantage of China's position in the global electric vehicle/NEV market and creating opportunities for leadership in the ADAS and autonomous vehicle market is a priority for China, given the potential financial gains. As a result, it is a motivation for China's investment in and development of its domestic LiDAR industry.

While there are other technologies such as radar and vision/cameras that can enable levels of autonomy in vehicles, the most popular means to enhance levels of autonomy in vehicles currently is by incorporating LiDAR sensors on the vehicles. Higher-end LiDAR solutions serve as the eyes of the vehicle to provide a high-definition 3D map of the surroundings and assist in detecting obstacles and discerning an autonomous vehicle's larger environment. To date, China's remote sensing industry is leading in the development of automotive LiDAR for electric and autonomous vehicles in terms of market share.

China's recent dominance of the LiDAR market has also created data and national security risks for the United States. Many lawmakers in the United States have expressed concern that use of Chinese-made LiDAR in vehicles operating in the United States could collect data about U.S. infrastructure or sensitive locations that could subsequently be accessed by Chinese government agencies.

A July 2024 analysis of California Department of Motor Vehicles data shows that since 2017, "self-driving cars owned by Chinese companies have traversed 1.8 million miles of California alone," collecting precise mapping data of the roads and surroundings. The cars are part of a state program that allows companies developing self-driving technologies to test autonomous vehicles on public roads. Seven of the 35 companies participating in the program are wholly or partly China-based. Some Chinese companies are approved to test in Arizona and Texas as well.[64] The economic and national security risks associated with LiDAR are discussed in more detail in Chapter 5.

National Development, Digitalization, and Provision of Public Goods

The Digital China plan was codified as a national strategy in 2017, making it the first national-level digital modernization strategy in the world.[65] The March 2023 Plan for the Overall Layout of Building a Digital China explains that the Chinese Communist Party (CCP) and State Council view a future Digital China as "an important engine for the advancement of Chinese-style modernization in the digital era."[66]

China's 14th Five-Year Plan for National Informatization, released in 2021 and covering the period from 2021 to 2025, also underscores the need for the digitalization of China's economy and society, observing that China "must accelerate the building of a Digital China, forcefully develop the digital economy, [and] promote the upgrading of the industrial base and modernization of industry chains."[67]

Remote sensing data are foundational to achieving Digital China objectives. The 2023 Digital China paper and other policy documents also advocate for use of remote sensing data in support of urban planning, the energy industry, smart city development, rural revitalization, and natural resource management, given China's population, resource, and environmental pressures.[68] Moreover, according to the *2021 White Paper on Space Activity*, remote sensing data in conjunction with AI-enabled processing can drive “more advanced economical, high-quality products and convenient services for all industries and sectors for mass consumption.”[69] Remote sensing data can also support new opportunities in activities, such as “transport, e-commerce, trading of agriculture products, assessment of disaster losses and insurance claims, and the registration of real-estate.”[70]

More specifically, data from remote sensing can help create precise digital twins, which are virtual representations of real-world objects or systems. The creation of digital twins in a shared digital environment allows designers across sectors (such as smart cities, resource management systems, shipyards, stores, etc.) and operators to visualize networks and systems. According to a special issue of the journal *Remote Sensing*, the increasingly precise data collected by remote sensors helps to build digital twins that can be applied in “agriculture, climate, sustainable development, ecosystems, urban areas, waste management, oceans, [and] water management.”[71] Digital twinning also enables engineers to quickly run thousands (or potentially millions) of digital simulations of how various objects or systems might function under different conditions, configurations, or scenarios. Lessons from these digital experiments can improve efficiency in planning and design. Additionally, digital twins can help monitor the functioning of these systems by representing data collected from sensors in or on the object and using algorithms to analyze these data, thus providing insights into the health of these systems as they operate.

Public services: Disaster prevention and response and ecological monitoring

Throughout China’s government policy documents related to remote sensing, there is a consistent emphasis on the need to build resilience in the face of climate change and related ecological and natural disaster-related challenges. The importance of science and technology development for ensuring environmental development is one of the central themes of the 14th Five-Year Plan for Informatization. The document calls for the strengthening of “remote sensing monitoring and emergency response and protection service capabilities in critical ecological sections such as deserts, grasslands, wetlands, lakes and rivers, forests, arable land, etc.”[72] This strategic emphasis not only supports China’s environmental and sustainability goals but also positions the country at the forefront of innovation in ecological management at a time when such capabilities are increasingly in demand.

Remote Sensing as a Mechanism for Geopolitical Engagement

China’s remote sensing capabilities are intrinsically linked to continued engagement on space infrastructure and services with countries in Africa, Latin America, the Middle East, and Southeast Asia as well as partnerships with European nations and the ESA. Thus, remote sensing capabilities serve a broader purpose of deepening China’s geopolitical engagement with key actors and potential allies and partners around the globe, especially countries participating in BRI. Specific motivations and benefits associated with this activity are included in the text box on the next page.

China’s international collaboration on space-based remote sensing and other related space topics and capabilities is not new. The China National Space Agency (CNSA) has cooperated with Brazil since 1988 on the China Brazil Earth Resources Satellite (CBERS) to develop satellites for meteorological and Earth observation purposes. The CBERS program launched satellites in 1999, 2003, 2007, 2013, 2014, and 2019 and has become a centerpiece and “strategic pillar” of the countries’ bilateral relationship.[73]

However, China’s international engagement on space generally and remote sensing more specifically has intensified in the last decade as countries participating in BRI seek to expand their presence in space and build domestic space capabilities to sustain and grow their space programs. For countries in the Middle

East, building a domestic space industry offers international prestige as well as an attractive avenue for diversification of national economies that have long been dependent on oil and gas revenues.

For all BRI nations, China's appeal is heightened by the country's willingness to sell and transfer technology and knowhow and its ability to do this in a way that is affordable for the customer and offers long-term revenue opportunities for China. Much of China's remote sensing and space-related engagement in the Middle East, Africa, and Latin America is managed through BRI's Space Information Corridor program. The initiative was established to facilitate China's ability to develop, deploy, and operate communications, remote sensing, and navigation satellites for BRI partners. According to a 2019 CNSA briefing, the program can "provide 'four-in-one' space information service for countries along the Belt and Road," integrating "sense, transmission, knowledge, and use."[74]

China's motivations for international remote sensing/space engagement:

China realizes several types of benefits from its collaboration and engagement with foreign partners both in BRI and in Europe:

- **Geopolitical influence** that can be leveraged during a crisis to support China's aims, to garner support Chinese efforts to establish global standards, or to increase trade.
- **Long-term economic opportunities** to support countries as they expand their space industries and capabilities and diversify their economies.
- **Winning financial contracts** with national space agencies in BRI countries for satellite development, manufacture, and operation.
- **Expanding opportunities for a dynamic and growing domestic commercial space industry** that may not be sustained by domestic demand.
- **Ability to leverage joint remote sensing capabilities and ground stations for national security or military purposes.**
- **Acquiring technology or knowhow** that can further develop China's remote sensing and space industries.

China's engagement with Egypt offers an indicative case study of an expansive collaboration effort that revolves around remote sensing. Engagement on remote sensing satellite development and production started in 2016 and has included at least $92 million in grants[1] from China to Egypt as part of efforts to co-develop remote sensing satellites and build an Assembly, Integration, and Testing Center (AITC) in New Cairo.[75]

The collaboration between CNSA and the Egyptian Space Agency (EgSA) on remote sensing satellites began to deliver results in February and March 2023 when China launched the Horus-1 and Horus-2 remote sensing satellites for Egypt. The satellites were co-developed by the two nations. Little information has been revealed about the Horus-1 satellite's mission, though at least one China space observer has cited a Chinese source as saying the satellite is "most likely" an Egyptian military remote sensing satellite.[76] Egyptian government sources have stated that Horus-2 will be used to reach sustainable development goals.[77]

In December 2023, China launched the EgyptSat-2 remote sensing satellite to support resource management and environmental monitoring objectives. The satellite was jointly developed by China and Egypt and was tested at the AITC. CNSA formally turned over control of the AITC to Egypt's Ministry of International Cooperation in March 2024, providing a mechanism for Egypt to begin building and

[1] The exact amounts of grants cited in open-source reporting vary. The most commonly cited number is $92 million, including $72 million for the development of the EgyptSat-2 remote sensing satellite and ~$20 million to build the AITC. Other sources tracking space activity and investment in Africa and China cite the AITC as being $45 million, while China Space Monitor also references a $21 million dollar grant to Egypt related to satellite development and manufacturing in 2016. We have chosen to use the more frequently cited number of $92 million in grants from China to Egypt to support the AITC and EgyptSat-2.

exporting satellites to the rest of Africa.[78] For its part, China deepened its geopolitical relationship with Egypt but may also gain longer-term economic opportunities to continue to sell sustainment and maintenance services and equipment to Egypt's AITC.[79]

China's space engagement with Argentina also demonstrates how it has leveraged technical collaboration for multifaceted political, economic, and security gains. China and Argentina began collaborating on an observational station in the 1980s, resulting in the building of the Felix Aguilar Astronomical Observatory and a memorandum of understanding (MOU) signed by both countries in 2004.[80] In 2012, China concluded a $300 million agreement with Argentina to independently construct and operate the Espacio Lejanio station in Neuquén, Argentina. A May 2024 report authored by Evan Ellis, a noted expert on China-Latin America relations, assesses that the effort was partly driven by Argentina's desire to maintain positive relations with the PRC and to attract Chinese investment.[81] Between 2002 and 2022, Argentine exports to China increased from $1.09 billion to $7.93 billion; while Argentine imports from China surged to $17.5 billion in the same time frame.[82]

In March 2024, concern over China's use of its global remote sensing capability led U.S. Ambassador to Argentina Marc Stanley to raise questions about the activities of the Espacio Lejanio remote sensing ground station. The station is operated by the PLA with few constraints on or transparency about its activities.[83] A recent report from CSIS suggests the proximity of the station as well as other Chinese ground stations in Latin America "has heightened fears that they can be used to spy on U.S. assets and intercept sensitive information."[84] As demonstrated by China's space-related engagement with Argentina, such collaborations are dual-purpose and may provide China with critical access and infrastructure needed to leverage remote sensing capabilities against U.S. national security interests.

In addition to engagement with BRI countries, China is also collaborating with parts of the European space community on remote sensing initiatives. These structures serve as a means for knowledge and technology exchange and to increase China's prominence as a leader in space power.

In 2018, China and France launched the China-France Oceanography Satellite (CFOST).[85] Data from the satellite are shared with scientists around the world to make better predictions about ocean conditions. France and China are also currently pursuing the Space-Based Multi-Band Astronomical Variable Objects Monitor (SVOM), a joint project to detect gamma rays in distant space.[86]

China has multiple additional collaboration programs with the European Union, including the China-EU-ESA Dialogue on Space Technology Cooperation, which provides a forum for dialogues and exchanges in the fields of satellite navigation, Earth observation, and space exploration. The Dragon program with the ESA involves several elements of collaboration on Earth observation, including thematic training courses for young European and Chinese scientists on Earth observation data processing and algorithm and product development for geospatial science applications. Over 1,100 Chinese scientists have participated in the Dragon program since 2004.[87] These relationships offer a pathway for training, collaborative research, and technology transfers that could support the further development of China's expertise in remote sensing capabilities, including data processing.

Chapter 3: Key Guidance, Entities, and Actors Shaping China’s Remote Sensing Development

China’s efforts to pursue the objectives identified in Chapter 2 are shaped by consistent high-level policy guidance. However, given the diversity of applications and industries associated with remote sensing capabilities, this framing guidance is implemented by a patchwork of government entities, SOEs, commercial companies, and academic and financial institutions. This chapter describes the strategic guidance directing China’s remote sensing activities and provides high-level profiles of key government organizations and other organizations across China’s remote sensing ecosystem.

High-Level Policy Guidance

High-level policy guidance, often found in the form of format strategies, white papers, and established initiatives, help prioritize technologies, industries, objectives, and outcomes for the central government as well as provincial and city governments, industry, and China’s financial sector.

While the development of remote sensing capabilities to support national priorities also draws on sector-specific policy guidance and strategies, there are a few broader strategies and plans that have been and continue to be critical to shaping China’s remote sensing development across various sectors. These strategies and initiatives contribute to amplifying the economic and security challenges for the United States and its allies posed by China’s remote sensing capabilities. Below is a description of four examples of broad policy guidance, strategies, and initiatives most relevant to this paper:

Made in China 2025: Made in China 2025, announced in 2015, articulates a ten-year whole-of-society effort to invest in ten key industries, including aerospace/space and electric vehicles, two industries with direct relevance to China’s remote sensing development. The industrial policy seeks to boost China’s economic competitiveness in these industries and to build a more robust domestic industrial base.[88] Made in China 2025 uses subsidies, tax incentives, and acquisition of foreign companies and technologies to position its companies for global leadership.[89] Chinese drone company DJI and LiDAR company Hesai have used Made in China 2025 levers to gain dominant positions in different elements of the remote sensing market.

Military-Civil Fusion (MCF) Strategy: China’s longstanding MCF strategy stresses the need to increase the integration of China’s commercial and research sectors with its defense and law enforcement. The national strategy seeks to leverage China’s commercial technology development and innovation to support PLA military modernization efforts with the goal of turning the PLA into a world-class military by 2049. The initiative was elevated to a national strategy in 2014. Key technology focus areas include aerospace/space, AI, semiconductors, and other dual-use technologies that have become relevant to military operations. Military-civil fusion has become a personal priority for General Secretary of the CCP Xi Jinping, who established and chairs the Military-Civil Fusion Development Committee (MCFDC).[90]

2017 National Intelligence Law: The State Council’s National Intelligence Law requires individuals and companies to share data collected through commercial and research activities with the Chinese government and military when requested. The law and its implications for data collected in the United States by Chinese companies are increasing concerns among many U.S. lawmakers and national security leaders that sensitive data about U.S. infrastructure and citizens collected by remote sensing satellites, UASs, and smart vehicles will be shared with China’s government, potentially compromising U.S. national security.[91]

BRI: BRI, initiated in 2013, is a massive project through which China builds several types of infrastructure in participating states, most of which are located in Southeast Asia, the Middle East, Africa, and Latin America. The program provides a mechanism for China to develop and realize new commercial and geopolitical opportunities. Through BRI, China can also develop leverage with specific countries or in sectors that can subsequently be used to garner support for China's aims or to help diminish support for U.S. or allied geopolitical activities and objectives.

Administration of China's Remote Sensing Industry and Research

China's remote sensing industry is not a single, self-contained ecosystem, and there is not one set of government documents or a single government organization that oversees it, given its connections to the space and automotive industries, Digital China strategy, the military, and other strategic industries and objectives. As a result, the administration of the industry is dispersed across multiple ministerial organizations and their components and elements of the Central Military Committee (CMC), including those listed below:

The Ministry of Industry and Information Technology (MIIT) is a ministerial-level agency that is tasked to oversee the development of China's telecommunications industry and holds administrative control over space activities related to the telecommunications sector. This includes allocation of telecommunications resources such as satellite orbit positions.[92] Two organizations that fall under the MIIT also play a role in overseeing elements of China's remote sensing industry:

- **State Administration of Science Technology and Industry for National Defense (SASTIND):** SASTIND issues and monitors the implementation of regulation and standards associated with China's defense and space industries and is responsible for regulating procurement and supply of the defense and aerospace sectors.[93] On May 19, 2021, SASTIND issued the "notice on promoting the orderly development of small satellites," which includes guidance on frequency, use, production, and on-orbit safety of small satellites.[94]
- **CNSA** is the only institution within China's central government to have an explicit administrative mandate on China's space industry. However, in contrast to the other institutions, CNSA plays only an advisory role in the development of China's space industry and has been described as "a figurehead organization."[95]

The Ministry of Science and Technology (MOST) is responsible for formulating guidelines and related policies for science and technology development in China. The **National Remote Sensing Center of China (NRSCC)** is a quasi-governmental organization under MOST that serves as "the main body"[96] for China's international cooperation projects in the aerospace remote sensing field, including the China-Europe Cooperation on Space Science and Technology and the Dragon program with the ESA referenced in Chapter 2.

In March 2023, the Central Committee of the CCP and the State Council jointly announced that MOST would be reformed and that a new **Central Science and Technology Commission (CSTC)** would be formed to take over the strategic planning and policy setting for China's science and technology development with potential implications for the administration of the remote sensing industry. MOST will transition to function as the administrative body supporting the CSTC.[97]

The Ministry of Natural Resources is responsible for the management of China's natural resources, including land, minerals, forests, grasslands, wetlands, and water. Given the utility of remote sensing for ecological conservation and monitoring, land and water management, smart city development, and other environmental applications, the Ministry of Natural Resources is playing a role in the promotion, administration, and regulation of remote sensing activities. For example, in 2019 it released policy guidance, the Technical Outline for the Construction of Smart City Spatiotemporal Big Data Platforms, which helped set remote sensing priorities.[98]

The State-Owned Assets Supervision and Administration Commission (SASAC) is a ministerial agency that oversees the operations of China's SOEs and their subsidiaries. China Aerospace Science and Technology Corporation (CASC) and CASIC are the leading SOEs with remote sensing portfolios in the space sector, while the Aviation Industry Corporation of China (AVIC) and China Electronic Technology Group Corporation (CETC) are also involved in the development of remote sensing capabilities, as described in more detail below.[99]

The Chinese Investment Corporation (CIC) is a sovereign wealth fund established in 2007 to manage part of China's foreign exchange reserves. While the CIC does not specifically focus on remote sensing, its investments indirectly support key industries that are pivotal for technological development. As a major domestic investor, the CIC regularly injects funds into start-ups, fosters global partnerships between Chinese companies, and facilitates technology transfer through strategic acquisitions.[100]

The National Development and Reform Commission (NDRC) is a ministerial-level department of the State Council. It is tasked to oversee the development and modernization of China's industries and as such plays a regulatory role in several aspects of China's remote sensing industry, including space. For example, Geespace, the space systems division of automotive company Geely Technology Holding Group, received its license to begin manufacturing its remote sensing satellites from the NDRC.[101]

CAS is the national academic institution for natural sciences and the world's largest scientific research institute.[102] It plays a pivotal role in China's remote sensing industry, functioning as both a research incubator and policy influencer. CAS oversees a broad spectrum of research areas, including key remote sensing enabling technologies such as satellite development. CAS has been instrumental in the success of spin-off companies in the remote sensing and commercial space sectors, providing training, education, and technical support.

The Equipment Development Department (EDD), a department of the CMC, is responsible for "the planning, R&D, testing and authentication, procurement management and information system construction for the equipment of the armed forces."[103] Together with SASTIND, the EDD serves as a main administrative institution in charge of governing China's space development efforts through drafting laws and regulations concerning the development of China's space industry.[104]

Provincial governments also are part of the system of authorities that play a role in administering and guiding China's remote sensing industry. Many provincial and city governments have developed strategies to recruit companies and talent working in industries prioritized by central government policies, including remote sensing satellites, uncrewed systems, and other technologies relevant to delivering remote sensing capabilities. These strategies include subsidies and investments as well as tax and other incentives. One example of provincial priority-setting is seen in the September 2023 issuance by the General Office of the Beijing municipal government of a notice entitled Implementation Plan of Beijing Municipality for Promoting the Innovative Development of Future Industries. The notice specifies information, manufacturing, health, energy, materials, and space as the leading priorities for industry development in the municipality and lists the construction of high-resolution, rapid revisit, full-coverage optical and radar sensing constellations as an objective for Beijing's approach for continuing to build its already robust space industry.[105]

Key Players in China's Remote Sensing Industry

China's remote sensing industry is large, expanding, and diverse. Below are general descriptions of key SOEs and commercial players in this industry. Also included below are representative lists of universities/research centers and holding companies and investment houses that are active in China's remote sensing industry. Given the scale and scope of China's remote sensing industry, these lists are not exhaustive but rather focused on the companies and organizations that are most frequently referenced in open-source research efforts. Additional information about some listed companies and their activities are included in the Chapter 5 case studies.

State-Owned Enterprises

The Chinese government controls many SOEs—firms that play a key role across most strategic industries, including aerospace and defense. Until policy guidance emerged in 2014 that helped catalyze the formation of a private space industry, China's aerospace firms were almost exclusively responsible for the development and deployment of China's space-based remote sensing capabilities. Even as the commercial sector has become more engaged in space activities, the following SOEs remain central to the development of civil government and military remote sensing activities.

CASC: CASC is the leading SOE for space and has led the design and manufacture of many of China's military and government remote sensing satellites. It has several subsidiaries that support remote sensing, including Shanghai Academy of Spaceflight Technology (SAST), China Academy of Space Technology (CAST), Institute of Remote Sensing Satellites (IRSS), Beijing SpaceView, and Siwei WorldView Technology.[106]

CASIC: CASIC is another SOE involved in the space remote sensing industry in China, though to a lesser degree than CASC. In July 2023, CASIC announced plans to build a 300-satellite remote sensing constellation in VLEO by 2030.[107]

AVIC: AVIC manufacturers planes, helicopters, and UASs for remote sensing missions,[108] including the Morning Star high-altitude pseudo satellite (HAPS) and WZ-8 supersonic UAS.

CETC: CETC has worked with private company Spacety (discussed below) since 2021 to build the 96-satellite X- and C-band SAR remote sensing constellation named Tianxian. Spacety and CETC'S 38th Institute also combined to develop the satellite platform and SAR payload for the C-band Hisea-1 satellite, China's first commercial SAR satellite.[109]

Private Companies and State Spin-Offs

Since 2014, dozens of commercial space companies have entered China's remote sensing industry. Some are spin-offs of state-owned research entities such as CAS, or SOEs. They also include start-ups. The list below includes space remote sensing companies involved in the manufacture, deployment, and operation of remote sensing satellites and the processing and use of remote sensing data. It also includes several automotive LiDAR companies that are leaders in the market.

CGSTL: China's first commercial remote sensing company and the most prominently placed in the global market, CGSTL is a spin-off of CAS and operates the Jilin-1 remote sensing constellation. CGSTL data were sold to the Wagner Group in 2023, indicating military use cases for the constellation.[110]

Spacety: A leader in commercial SAR constellations, Spacety is also a spin-off of CAS. It has previously been sanctioned by the U.S. Department of the Treasury for selling remote sensing data to front companies for the Wagner Group.[111]

Geespace: A wholly owned subsidiary of automotive company Geely Technological Holdings, Geespace is building two remote sensing constellations. The Future Mobility Constellation will provide services for autonomous driving, logistics, drone navigation, mapping, and other fields. It will consist of 240 satellites, with the first phase of 72 satellites expected to be placed in orbit by 2025.[112] The company's Blue Guardian remote sensing network will be used for the monitoring of ocean debris.[113]

PieSAT: A publicly traded company listed on the Shanghai Stock Exchange, PieSat began by developing tools for extracting insight from remote sensing data sets. It has recently transitioned into the manufacture, deployment, and operation of remote sensing satellites and uncrewed vehicles to create an end-to-end remote sensing offering through which the company builds the platforms from which data are collected; collects its own proprietary data; and uses its own tools to assess this data for its customers. In 2023, PieSAT began to launch its new SAR constellation and its revenues hit $345 million as it achieved a market capitalization of $2.5 billion.[114]

Hesai: Hesai is the global market leader in autonomous vehicle LiDAR remote sensing. The U.S. government has alleged Hesai is cooperating with the PLA on the development of autonomous military vehicles. The company is under investigation by the U.S. International Trade Commission[115] and was placed on DoD's 1260H list of companies affiliated with the Chinese military in January.[116] Hesai has denied that any "Chinese governmental or military entity has sought to exert influence" over the company," though it also admitted in a 2023 filing to the U.S. Securities and Exchange Commission that "the PRC government has significant authority in regulating our operations and may influence or intervene in our operations at any time."[117] In May 2024, Hesai sued DoD to be removed from the list, and in August 2024 DoD acceded, reportedly after U.S. government lawyers expressed concern that the justification for Hesai's original inclusion may not have been upheld in a legal proceeding.[118] More detail on Hesai's market position and U.S. government concern over Hesai's activities in the United States are included in Chapter 5.

Robosense: Robosense is another leading autonomous vehicle LiDAR remote sensing company, claiming approximately 15 percent of the global LiDAR market. A November 2023 letter to U.S. Secretary of Commerce Gina Raimondo, U.S. Secretary of the Treasury Janet Yellen, and U.S. Secretary of Defense Lloyd Austin from the members of the House Select Committee on Strategic Competition between the United States and China noted that "Robosense has ties to the Harbin Institute of Technology, a PRC military university."[119] Other Chinese commercial remote sensing firms identified through OTH's research include:[120]

- GEOVis
- Beijing SpaceView
- JiaheInfo
- Galaxy Space
- ADASpace
- MinoSpace
- NavTech
- Obita
- 21AT
- Livox
- LiangDao
- Huawei

Academic Institutions[121]

The following academic and research institutions emerged as involved in China's advanced remote sensing industry over the course of OTH's research into patents and remote sensing R&D.

A number of universities have dedicated remote sensing departments or institutes, including Peking University (Institute of Remote Sensing and Geographic Information Systems), Wuhan University (School of Remote Sensing Information Engineering), Xidian University (Department of Remote Sensing Science and Technology), and Guangzhou University's School of Geography and Remote Sensing. Other universities have developed departments with broader space science studies and dedicated remote sensing courses and research, such as Beihang University's Regional Center for Space Science and Technology Education, which is closely affiliated with the MIIT and the China National Space Administration.[122]

The Academic Ranking of World Universities (commonly known as the Shanghai rankings) is an annual survey of global universities' research capabilities. It includes subject-specific rankings, with remote sensing as one of the options. Although the rankings are produced by a China-based consultancy and therefore might be seen to have an innate bias toward Chinese universities, it is nonetheless instructive to analyze the assessment of such an organization. According to the Academic Ranking of World Universities 2023 edition, the top ten universities worldwide and within China for remote sensing research are:[123]

Rank	Top Ten Universities Worldwide	Top Ten Universities in China
1	Wuhan University (China)	Wuhan University
2	Xidian University (China)	Xidian University
3	University of Maryland, College Park (USA)	Beijing Normal University
4	California Institute of Technology (USA)	University of Electronic Science and Technology of China
5	Beijing Normal University (China)	Northwestern Polytechnic University
6	Technical University of Munich (Germany)	Sun Yat-sen University
7	University of Electronic Science and Technology of China (China)	China University of Geosciences
8	Universite Grenoble Alpes (France)	Tsinghua University
9	Northwestern Polytechnic University (China)	Hunan University
10	Mississippi State University (USA)	Nanjing University of Information Science and Technology

Table 2: A comparative list of the top ten universities in remote sensing globally and in China according to the Academic Ranking of World Universities 2023 edition

Other institutions also have close relationships with the PLA and active remote sensing research programs. The Harbin Institute of Technology (HIT), for instance, hosts five national defense laboratories focused on space or satellite research.[124] HIT is one of the "seven sons of national defense" military-affiliated universities directed by the MIIT.

Holding Companies and Investment Firms

Investment from private, state-run, and provincial venture capital funds and investors has been a prominent feature of the growth of China's remote sensing industry in space, uncrewed systems, and radar technologies. Dozens of firms have been involved in these funding rounds over the past several years. The list below is obviously not exhaustive, but it does include names of companies and state and provincial investment funds that have been referenced in open-source reporting as participating in significant funding rounds or as leaders in investing in relevant companies.[125]

Entity Name	Investment Activity and Focus Areas
Baidu[126]	$182 million joint investment with SoftBank into drone manufacturer XAG.
CDH Investment[127]	$47 million joint investment into Chinese remote sensing company MinoSpace.
China Investment Corporation[128]	CIC regularly injects funds into start-ups, fosters global partnerships between Chinese companies, and facilitates technology transfer through strategic acquisitions.
Changguang Group (a holding company for CAS)	CAS has been instrumental in the success of spin-off companies in the remote sensing and commercial space sectors, providing training, education, and technical support.
Dongguan Financial Holdings[129]	$55 million joint investment into ADA Space with Hengjiang Holding, Shenzhen Oriental Future Capital, and Qingchuang Bole.
Donghao Lansheng[130]	Participated in MinoSpace's series B and B+ funding rounds in 2022.
Geely Holding Company[131]	Geely Holding is directly involved in funding Geespace satellite launches.
Gopher Asset Management (GAM)[132]	A key investor in a $175 million funding round for Chinese launch provider LandSpace in 2020.
Guangdong-based Shenzhen Oriental Fortune Capital[133]	Participated in ADA Space's $55 million funding round in 2021.
Guokai National Manufacturing Transformation and Upgrade Fund[134]	Backed by the Ministry of Finance. The Guokai National Manufacturing Transformation and Upgrade Fund invests in industrial technologies and has made investments in firms specializing in industrial robots and the autonomous vehicle market.
Guotai Jinan Securities[135]	In September 2024, Guotai Jinan Securities acquired Haitong Securities, which had previously invested in China's remote sensing sector. The merger forms a mega-brokerage with $236.9 billion in combined assets.
Hengjiang Holding	An investment vehicle of the Guangdong Provincial People's government.
Lightspeed China Partners[136]	Participated in Hesai's $300 million funding round in 2021 with Hillhouse, Xiaomi, and Meituan. Also invested in MinoSpace in 2022.
Nio Capital[137]	Led a $30 million series A investment into Innovusion/Seyond in 2018.
Plum Ventures[138]	Participated in MinoSpace's series B and B+ funding rounds in 2022.
Power Capital	Participated in MinoSpace's series B and B+ funding rounds in 2022.
Qingchuang Bole	Participated in ADA Space's $55 million funding round in 2021.
Tencent Holdings[139]	Reportedly participated in World View Enterprises' $15 million series B funding round, and separately invested in the firm between 2013 and 2016.
Yuexiu Industrial Investment Fund Management[140]	Led a 2023 series C funding round for CAS Space, securing $86.8 million.
Zero2IPO Group's fund	Participated in MinoSpace's series B and B+ funding rounds in 2022.
IDG Capital[141]	Identified by PitchBook as the leader among Chinese investment firms in investing in the autonomous car industry, followed closely by HongShan.

Table 3: A partial list of holding companies and investment firms in China that are investing in the remote sensing industry

In addition, our team reviewed PitchBook data showing the last four years of capital transactions of U.S. investors into China-located companies. When calibrating a search for companies specializing at the intersection of LIDAR, SAR, and uncrewed systems, there are approximately 74 companies demonstrating significant capability, all located in China. The investors in these companies all either include investment funds domiciled in the United States or are foreign/Chinese funds with Americans directly affiliated with the foreign firm. When viewed in the aggregate, the results are interesting; despite major economic and geopolitical headwinds, ~$2.8 billion was invested into these leading Chinese technology companies.[142] This fresh, private capital bolstered their valuations by a cumulative ~$13.3 billion, which is even more significant when considering the doldrums of the global venture capital market since Q4 2021.[143]

Chapter 4: China's Acquisition of Overseas Remote Sensing Capabilities

As with other areas of defense or strategic technology, China has sought to acquire overseas technologies and knowhow to advance, accelerate, or reinforce its own domestic remote sensing development. Specifically, China's technology acquisition through both licit and surreptitious means has focused on several technology areas in which China is perceived as either trailing in its development or in which China either has an advantage and is reinforcing its strength or is developing R&D momentum.

China's strategic acquisition of remote sensing technology from the United States and other leaders in the global remote sensing market does not significantly deviate from the model of technology acquisition deployed in other sectors, all of which are prioritized by the Chinese government to extend its control of key technologies. Although financial investments are overt and arguably have the most significant and short-term effect on remote sensing capabilities and R&D, a range of measures is utilized to attempt to indigenize or gain control of key technologies and expertise, including:[144]

- Increasing levels of Chinese investment in U.S. firms developing remote sensing technology areas in which China maintains advantage or is seeking to address a perceived disadvantage or vulnerability.
- Academic partnerships with both U.S.-based institutions as well as academic and professional organizations based in Europe.
- Cyber theft and espionage.
- Use of open-source information and analysis.

These strategies are aligned with China's broader approach to technological development and industrial strategy, emphasizing the importance of integration into global innovation ecosystems while pursuing domestic advancements.[145] While no overt policies or legislation that supports the procurement of U.S. remote sensing firms in particular have been identified, the government has long developed industrial and regulatory policies to encourage outward investment into overseas technologies. The Going Out strategy of 2000, which encouraged Chinese companies and SOEs to invest overseas, BRI, and Made in China 2025 have historically and actively encouraged outward investment in overseas technology to leapfrog China's development.

OTH research has identified over $3.7 billion of Chinese investments into U.S. remote sensing firms, the majority in the emerging LiDAR sector. This investment has come from commercial entities and state-owned funds directly under the purview of the Chinese government through the State Council. These investments reflect transactions documented in open sources and likely do not represent all of China's efforts to gain access to U.S. remote sensing technology. Overall, the processes through which financial investments, mergers, and acquisitions occur are often opaque and can be conducted clandestinely. China's economic and industrial espionage tactics are widely acknowledged to operate at every level of advanced technology development and function in tandem with legal mechanisms for technology transfer. Whether it is talent recruitment or direct acquisition of key components, China has an array of tools at its disposal to evaluate, invest in, and acquire remote sensing technologies and human capital from the United States and its allies and partners.

Acquisition of Talent and Knowhow

As noted earlier in this paper, China has a diverse range of entities engaged in remote sensing research. Military and governmental research institutes such as CAS are complemented by state-run aerospace companies, private commercial entities, and a robust academic sector. While nominally separate, these entities often work together in China's Party-state apparatus. As an example, CGSTL was spun out of CAS's Changchun Institute of Optics and Precision Mechanics as a joint venture between the academy and the Jilin provincial government. Since then, CGSTL has worked with provincial, central governmental, and military entities.[146] These entities are geographically dispersed, particularly in the university sector, with leading research institutes related to remote sensing in a range of locations across the country.

Nevertheless, China has been eager to recruit overseas talent to further bolster R&D in its remote sensing industry. One method China has used for attracting overseas technological knowhow is through academic exchanges and trainings from the United States and other leaders in the global remote sensing market. It is difficult to uncover every instance of this type of knowledge transfer. However, below are three indicative examples that emphasize separate mechanisms through which China has pursued remote sensing knowhow and expertise.

Recruitment and retention: The annual Overseas Chinese Entrepreneurship and Development Fair—a United Front project administered by the Overseas Chinese Affairs Office of the State Council—exemplifies the PRC's strategy by incentivizing overseas Chinese talent and innovation through cash prizes and business opportunities.[147] The fair is hosted each year by multiple provincial governments in Hunan, Fujian, Guangdong, Hubei, Zhejiang, Shandong, and Henan. While these fairs have not specifically emphasized remote sensing business opportunities or contests—as they typically focus on broader themes of innovation, entrepreneurship, and technological collaboration across various industries—it is important to note that the purposes of these fairs can change and adapt over time. Recent conferences have focused on biomedicine, manufacturing, optoelectronic information, new energy, and other emerging and critical technologies. Since 2001, the conference has supported over 2,800 projects, according to the United Front Work Department of the Hubei Provincial Committee of the Communist Party of China.[148]

The 2023 Hubei fair held in Wuhan was attended by over 1,000 entrepreneurs, businesspeople, and researchers representing 37 countries. The organizing committee awarded its top prizes to remote sensing projects in integrated marine equipment, autonomous driving radar, and far infrared sensing.[149] The first-place winner, Zhu Tiefeng, revealed in post-event comments that he returned to China after a 14-year stay in the United States to further China's global ocean strategy (although it was not a condition of the prize that researchers must relocate permanently to China).[150]

A leading government-sponsored academic recruitment policy is known as Qiming (more commonly known as the Thousand Talents Program), a recruitment program from overseas (often Chinese) researchers and academics in the field of science and technology. Qiming is administered by the MIIT and the United Front Work Department and aims to either permanently recruit researchers into Chinese academia or provide short-term appointments for international experts in China, often with generous signing bonuses of up to ¥5 million ($700,000).[151] There is also a program called the Young Thousand Talents, which targets early career doctorate students.[152] The Thousand Talents Program has been successful in recruiting high-level overseas remote sensing academics, such as Taiwan's Chen Kun-shan, a professor at National Central University who received his doctorate from the University of Texas at Arlington and transitioned his career to China in 2014.[153]

Significantly, in 2012, Natarajan Ishwaran, formerly the director of the Division of Ecological and Earth Sciences at the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and secretary of the Man and Biosphere Program, was selected by the Thousand Talents Program to join the Center for Earth Observation and Digital Earth (CEODE) of CAS in Beijing.[154] More than a decade later, Dr. Ishwaran remains employed by the CEODE, focusing on remote sensing technologies and the application of space and data science technologies for ecosystem management and conservation. While there is no specific focus on remote sensing within the program's publicly available documentation and objectives, Qiming seeks to attract industry experts across a wide range of fields, including remote sensing.

Academic exchanges: China's ability to leverage academic collaborations with lucrative incentives also plays a crucial role in developing the PRC's domestic high-tech and remote sensing programs.

The Tsinghua Berkeley Shenzhen Institute's (TBSI) focus on LiDAR underpins this approach to cultivate a domestic knowledge base that supports its technological ambitions. The University of California, Berkeley (UC Berkeley) is a leading research institute within the U.S. academic sector, ranked fourth globally among all research universities by the 2024 Times Higher Education university rankings.[155] It has a dedicated Geospatial Innovation Facility with remote sensing research capabilities, and it separately conducts ground-breaking LiDAR research.[156] Established in 2014, the TBSI is a joint academic venture between Tsinghua University and UC Berkeley with the support of the Shenzhen Municipal Government.[157] Academic partnerships like TBSI provide the PRC with access to leading academics in advanced technology departments, including remote sensing.

The transition of key academics to significant roles in China's tech industry or academia further illustrates the PRC's commitment to harnessing global talent and expertise in remote sensing technologies.[158] The case of Li Rongxing is instructive. Dr. Li was the chair of Ohio State University's mapping and geographic information system laboratory and one of five fellows for the American Society for Photogrammetry and Remote Sensing. Dr. Li spent much of 2012 in Shanghai on sabbatical at Tongji University. An Ohio State University internal investigation determined that he maintained positions at Tongji University and worked on Chinese government research programs but failed to disclose this information to U.S. authorities despite working on a NASA project. Dr. Li subsequently resigned his position at Ohio State and moved to China to work at Tongji as director of the Center for Spatial Information Science.[159]

In September 2023, the United Kingdom's (UK) Cambridge University Center for Advanced Photonics and Electronics (CAPE) ended a ten-year partnership with the Beijing Institute of Aerospace Control Devices (BIACD). CAPE is a world-leading research center for photonic sensors, including LiDAR, and BIACD is a subsidiary of CASC, a leading aerospace, space, and military-focused SOE.[160]

The collaboration involved dual-use technology projects like fiber optic sensing technology, digital antenna systems, and opto-electronic oscillators, representing the intersection of academia and technology with aerospace applications. Cambridge University returned £1.2 million ($1.5 million) in funding, reflecting the increasing scrutiny of Chinese research collaborations, especially with entities like CASC.

Despite the intended civilian application and civilian nature of the projects, the military connections of BIACD and CASC raised concerns, promoting the decision to end the collaboration by September 2023.[161]

U.S. academic institutions have also partnered with Chinese commercial entities in a bid to gain access to funding or state-of-the-art technology to support ongoing research. For example, in January 2024, Mcity, a University of Michigan-led public-private research center focused on the future of mobility and transportation, welcomed Robosense to its list of partners, which also includes Toyota, Ford, Honda, Japanese auto parts supplier Denso—which also makes LiDAR systems—and the U.S. Department of Transportation (DoT). Mcity will utilize Robosense' s vehicle-mounted LiDAR technology in its research to enhance data collection both inside Mcity's test facility and on the streets of Ann Arbor.[162] While there is no indication of illicit technology transfer to China associated with this project, the partnership does provide an indicative example of the interconnectedness between China's leading technology development companies and the U.S. research ecosystem, especially in emerging market areas such as autonomous vehicles.

A more troubling example of the efforts of Chinese companies to engage with U.S. academics was revealed in a May 2024 *Bloomberg* report detailing that Huawei secretly funded a U.S. academic research competition, exploiting a loophole in technology transfer export controls against Chinese companies. Huawei was the sole funder of a competition administered by the Washington, DC-based Optica Foundation, a nonprofit that supports development of advanced applications of light.[163] The Optica Foundation Challenge focuses on applications of light research for the environmental, health, and information technology sectors, including remote sensing. For example, one topic area of interest to the challenge listed on Optica's website is "improving environmental monitoring capabilities using satellite, airborne imaging and measurement sensors, as well as ground-based measurement technologies (e.g., distributed optical fiber sensing, multispectral, thermal, and hyperspectral imaging, etc.)."[164]

Huawei's funding was disguised as anonymous donations and Huawei's arrangement with the foundation included nondisclosure language to obfuscate its involvement. Multiple institutions involved in Optica's research competition, including Texas A&M and Harvard University, were unaware of the funding source and acknowledged the clandestine nature of Huawei's participation. Optica cut ties with Huawei in June 2024,[165] but the case underscores the breadth of technology acquisition methods Chinese authorities are capable of pursuing outside of standard financial processes.

Partnerships and Investment

Parallel to these talent attraction and collaboration initiatives, Chinese investment in and partnerships with U.S. firms can facilitate the transfer of remote sensing technologies. Drawing upon open-source research, financial sector databases, and interviews with industry experts, OTH research suggests these governmental and private sector engagements have prioritized LiDAR technologies. However, there is also activity related to commercial space-based remote sensing, drones, AI, and critical remote sensing components. These activities involve utilizing joint ventures, mergers and acquisitions, and venture capital investments to develop linkages and transfers between China and U.S. remote sensing companies. Among the examples below are also multiple instances of U.S. sensor makers partnering with Chinese automakers to break into the large autonomous vehicle market in China. While some of these examples do not involve direct technology transfer, we have included them to highlight the efforts of U.S. LiDAR makers to expand their business into China and deepening relationships between U.S. and Chinese automakers and sensor developers.

Significantly, the specific technologies acquired by Chinese firms are opaque to outside observers and only revealed through open-source investigation. Relevant transactions in LiDAR and space-based remote sensing are listed in greater detail below, but capability acquisitions include antennae, gyroscopes, lasers, or underlying designs.

LiDAR-related transactions and partnerships

- Chinese auto manufacturer Baidu made a $75 million investment in Velodyne, a Silicon Valley-based LiDAR company (matched by a $75 million investment by Ford), to enable the company to commercialize its LiDAR sensors.[166] This investment was followed by a three-year sales agreement in 2020 for LiDAR sensors.[167] Although Baidu has concentrated its autonomous vehicle research on commercial robo-taxis, the company has also been forced to confront allegations that its AI technology has been used by the PLA, raising the question of whether technology such as LiDAR might also be utilized by the Chinese military to develop autonomous vehicles that could be used in a range of support and combat missions.[168] Velodyne's products have been used by the U.S. military, with its HDL-46E sensor equipping the Common Uncrewed Surface Vessel of the U.S. Navy.[169]

- U.S.-based Luminar Technologies, an autonomous vehicle sensor and software company, is making a large push to break into the Chinese autonomous vehicle market and has partnered with Chinese automotive firms such as SAIC Motor and Geely to sell its solutions in the China market.[170] It has established an office in Shanghai to work closely with Chinese car manufacturer SAIC in incorporating its technology in the car company's "R" brand vehicles.[171] Of the more than 20 production vehicle models Luminar systems are designed into, the majority are slated for the Chinese market. Luminar is partnering with Taiwan's TPK, a touchscreen supplier to Apple and Tesla, to build a manufacturing plant in Xiamen.[172]

- In May 2022, Luminar also made a $15 million strategic investment through U.S.-based COVA Acquisitions as part of Geely-backed ECARX Holdings' initial public offering in the United States. ECARX has facilities in China and Gothenburg, Sweden, and was founded by Eric Li, also the founder of Geely automotive.[173] According to Austin Russell, CEO of Luminar, "As things are successful, I do not think it would be surprising if we ultimately collaborate even more, invest even more, as this partnership scales."[174]

- Quanergy Systems, a U.S.-based LiDAR start-up, underwent a $1.4 billion reverse merger with CITIC Capital Acquisition Corp, an arm of China's state-owned investment company. The company entered bankruptcy just a year later.[175] The company's assets were later auctioned off, with the winning bid coming from a group of investors that includes former Quanergy board member Tamer Hassanein.

- OmniVision Technologies, a manufacturer of sensor chips for smart phones and cameras with applications in autonomous vehicles, was originally bought by a Chinese private equity consortium in 2015 for $1.9 billion before being sold again in 2019 to Chinese firm Will Semiconductor in 2019.[176]

- In October 2018, Silicon Valley-based Innovusion (now known as Seyond) secured $30 million in Series A funding led by Nio Capital, a China-based investment firm that focuses on investments in energy, automobiles, and deep technology (that is, technology that seeks to move beyond current boundaries). Innovusion/Seyond is the LiDAR supplier to the automobile manufacturing company Nio and has additional facilities in Suzhou and Shanghai with manufacturing facilities in Ningo and Suzhou. Innovusion had previously received $64 million in Series B funding, the second round of funding after the initial start-up stages, and $56.6 million in Series B+ funding. Nio Capital has been involved in both rounds. As of August 2023, Innovusion/Seyond is planning to make a U.S. initial public offering of up to over 21 million ordinary shares on the Nasdaq exchange.[177]

Space-based remote sensing and the supply chain

Technology acquisition through investment has not been limited to LiDAR. Other sectors such as space remote sensing and the technological supply chain related to remote sensing have also seen considerable interest from China's venture capital firms and remote sensing companies. Notably, in 2015, Chinese remote sensing and navigation company NavTech bought Swedish company Silex Microsystems through a chain of investment companies using state-controlled funds, acquiring the Swedish company's expertise in micro-electro-mechanical systems (MEMS), which can enable miniaturization of satellite-based modules and systems, reducing launch costs and power usage.[178]

Estimating the total level of Chinese investment in the U.S. remote sensing industry is a challenging task, but the above examples give an idea of the amounts involved. According to this partial list, at least $3.7 billion has been invested through acquisitions, and given that this is not an exhaustive list, the total value is likely to be higher. More than 90 percent of this sum has been in LiDAR firms, reflecting China's current policy focus on becoming a global leader in electric and autonomous vehicles.

The various investments have come from either state-owned financial entities or large private companies. In the case of the former, the motivations for these investments will not be purely financial, as they are owned and managed by the state to further China's national interests. CITIC Group, for instance, is wholly owned by the Ministry of Finance on behalf of the State Council and is thus acting as an arm of the state rather than a profit-motivated investment vehicle. China Orient Asset Management Co. similarly is wholly owned by the Ministry of Finance and the National Social Security Fund, while CIC reports directly to the State Council, which selects the board.

For privately owned entities, the motivations are primarily commercial, though their technology acquisition efforts also contribute to Chinese government efforts to indigenize remote sensing capabilities through various means to underline and achieve broader strategic objectives. According to the *New York Times*, a DoD report from early 2017 underlines how Beijing "is encouraging its companies to invest for the purpose of pushing the country ahead in its strategic competition with the United States," particularly in high-tech areas such as LiDAR.[179]

NavTech is a useful example for demonstrating the threat posed by Chinese companies whose tactics are sanctioned by the CCP. NavTech's founder, Yang Yunchun, obtained his doctorate in the United States in 2001 before returning to China and founding the company in 2007. During this time, Mr. Yang was selected as a leader in China's Thousand Talents Program, discussed above. After successfully launching NavTech, Mr. Yang was recruited to participate in China's 863 Program to develop cutting-edge technologies with state funds. Less than a decade after its founding, NavTech secured lucrative contracts for significant projects like the Beidou satellite navigation system and the JF-17 Xiaolong fighter jet.[180]

Yet, the NavTech acquisition of Silex highlights weaknesses in China's semiconductor supply chain that it is aggressively seeking to address and reinforce. The gap between China's stated policy goals under the Made in China 2025 initiative and its technological reality illustrates the semiconductor predicament in which it sees itself mired. China's foreign acquisitions in the semiconductor industry reflect a general failure to acquire major manufacturers in the United States and Taiwan and greater success in acquiring smaller European integrated circuit producers.[181]

Indeed, Chinese attempts to secure U.S. semiconductor technology continue, as seen in the indictment of two Chinese nationals in April 2024. Han Li and Lin Chen were charged with conspiracy to smuggle semiconductor fabricators out of the United States and to restricted Chinese companies between 2015 and 2018.[182] Using an intermediary company called Jiangsu Hantang International, the defendants portrayed their proxy firm as the end user and sought to conceal the real recipient, Chengdu GaStone Technology Company. Proxy and shell companies are widely known tools for export control evaders but carry significant risk for the individuals involved in the illicit activity, which explains China's efforts to covertly, but legally, acquire semiconductor manufacturing technology.

The NavTech acquisition of Silex exemplifies how Chinese firms can successfully indigenize foreign MEMS technology to attempt to mitigate risks to supply chains or bottlenecks. However, it is unclear if all Chinese investments in U.S. firms have been as successful in developing or indigenizing technology. The reverse merger of the now defunct Quanergy, for instance, appeared to be a risky bet on an unproven start-up that eventually led to bankruptcy and loss of funds. Nevertheless, investment has proven to be a key element of China's attempts to acquire overseas technology and expertise.

Acquisition through Espionage

China's use of cyber espionage to steal data and technology is well documented. An estimated one in five U.S. corporations has had their intellectual property (IP) stolen, according to a survey of chief financial officers.[183]

This cyber espionage has extended into the remote sensing sector. The Dutch Military Intelligence and Security Service (MIVD) claims in its annual report released in April 2023 that China had attempted to gain military-relevant space technology "outside the export restrictions" and that China was specifically seeking "ISR and communications satellites."[184] According to the U.S. Department of Justice (DoJ), two Chinese individuals were charged with alleged hacks of 45 companies in 2018, including seven companies in aviation, space, and satellites, in a campaign sponsored by the Chinese government.[185]

Although the information released by DoJ did not specify remote sensing targets, aerospace and satellite technology more broadly can also be used to improve China's dual-use space platforms. DoJ deemed two individuals to be part of a group it termed Advanced Persistent Threat (APT) 10, linked to the Ministry of State Security.[186] Other Chinese APT groups have also been identified by cyber security companies as targeting satellite and remote sensing companies, with Mandiant claiming that APT14 was focused on cyber theft of military and maritime equipment, including encryption and satellite communication equipment specifications.[187]

Espionage is not limited to the virtual world. In 2022, Chinese national Xiang Haitiao, who was working for a subsidiary of Monsanto, was sentenced to 29 months in prison for conspiring to commit economic espionage. Mr. Xiang worked on remote sensing to estimate soil properties using satellite imagery and had applied to China's Thousand Talents Program to work at the CAS Nanjing Institute of Soil Science. Xiang duplicated Monsanto IP and delivered it to contacts in China to support his application for the talent program. The case underlines the overlapping methods of recruitment and espionage that are sponsored by the Chinese government.[188]

While not rising to the level of espionage, IP theft by Chinese companies is also an oft-cited concern in the remote sensing industry. A Congressional Research Service report from August 2023 noted that Chinese "policies incentivize aggressive tactics to obtain foreign IP, which may distort the common use of trade tools and involve questionable practices or illicit activity."[189] It cites the case of Hesai, which was charged by U.S. firm Velodyne in 2019 with IP infringement for illegally acquiring Velodyne IP while discussing production of its products in China. The two firms settled in 2020, but in 2023, U.S. firm Ouster again charged Hesai with IP infringement on five of its patents. That case is pending arbitration.[190] Velodyne and Ouster completed a "merger of equals" in February 2023 to create increased scale to better compete in the delivery of LiDAR solutions in the global automotive, industrial, robotics, and smart infrastructure markets.[191]

These various targeted cyber operations, human espionage, and alleged IP theft encompassing remote sensing technologies suggest that Chinese firms and governmental entities are willing to use a range of tactics and strategies, often working in lockstep, to further China's own domestic industries and military capabilities in the sector.

Chapter 5: Case Studies

This chapter examines three case studies that demonstrate the progress and challenges associated with China's remote sensing development and deployment across three different contexts:

- **Case Study One:** LiDAR and the Autonomous Vehicle Market
- **Case Study Two:** The Small Drone Market and Remote Sensing
- **Case Study Three:** Commercial Space Remote Sensing and the Jilin-1 Satellite Constellation

These three case studies have been chosen for four reasons.

First, individually and collectively, the case studies reinforce the breadth of applications of remote sensing capabilities and their relevance to the geopolitical, technological, economic, and national security components of U.S.-China strategic competition.

Second, they provide insight into emerging industries or markets at the start of transitions that are likely to lead to steep growth in demand for remote sensing platforms, sensors, and underlying chokehold technologies over the next decade. These are industries and markets in which the U.S. government has a growing interest in maintaining current advantage (commercial satellite remote sensing) or enhancing the competitiveness of U.S. commercial providers (commercial and hobbyist drones) to mitigate risks of dependency on Chinese suppliers and avoid losing market share in both the U.S. domestic and international markets.

Third, each case study describes current and potential defense and national security challenges. Specifically, the case studies examine the risks associated with the dual-use nature of remote sensing platforms and collection and use of sensitive data, the reportedly close relationships between featured companies and the PLA, and the potential misuse of sensitive data collected on U.S. soil through commercial Chinese remote sensing capabilities.

Fourth, the case studies reveal key elements of the approach China has used to build its remote sensing capabilities across industries and applications. Steered by high-level policy guidance, China's approach includes some combination of the following:

- Venture capital funding
- Using funding to lower costs and invest in R&D and manufacturing
- Leverage a large and adaptive market to scale sales

A final and frequently referenced component of China's approach is the use of central, provincial, and city government support through subsidies and other financial assistance, such as tax breaks. Research from 2022 shows that benefits in the form of direct subsidies, below-market-rate loans and land sales, tax breaks, and capital provided by state-run investment funds in 2019 were worth between $248 billion and $407 billion. Our research was unable to locate independently verifiable data on the scale of subsidies committed to companies in the remote-sensing industry, but many sources state that companies in the sector, including those mentioned in the case studies below, benefited from central and government support.[192]

For example, CGSTL, the developer and operator of the Jilin-1 satellite constellation, was originally established as a spin-off of CAS with support from the Jilin provincial government. CAS and the Jilin government remain its largest shareholders, and the company continues to receive "support" from central and provincial government entities, though the nature and dimensions of that support are not explicitly stated.[193] Two other companies profiled below—Hesai and DJI—have denied receiving subsidies, though as mentioned in Case Study Two, the *Washington Post* has reported that DJI received subsidies from four banks with government affiliations. Our assessment is that subsidies and various forms of government support are a frequently used tool for China to support companies operating in strategically important industries. It is likely that remote sensing leaders have benefited from various forms of central and provincial government support, even if our research was not able to fully document the scale and nature of this support.

Case Study One: LiDAR and the Autonomous Vehicle Market

Summary

China's commercial LiDAR industry is the global market leader for the autonomous vehicle market. China's current dominance poses risks for U.S. companies seeking to compete in this market. LiDAR is not the only means of enabling vehicle autonomy, and many concepts of ensuring safe autonomous services and driving involve the use of multiple systems, though it remains the predominant mechanism for much of the market, including when used alongside other technologies. One key supply chain challenge for China's LiDAR development is reliance on foreign suppliers, including the United States, for analog and FPGA chips. In addition, use of Chinese-made LiDAR in U.S.-operated vehicles has caused concern within Congress and among many in the national security community about the security of the data collected by these systems and the potential for the data to be accessed by the CCP.

China and the global LiDAR market

LiDAR sensors provide a high-definition 3D map of the vehicle's surroundings and help identify objects and obstacles.[194] It is currently viewed as a leading technology for scaling the ADAS and vehicle full autonomy markets discussed in Chapter 2.[195] Chinese LiDAR manufacturers Hesai, Seyond, Robosense, Livox, LiangDao, and NavTech are among the global leaders and dominate the market. The top three Chinese LiDAR companies—Hesai, Seyond, and Robosense—accounted for over 80 percent of LiDAR market share in 2023, according to data from Gasgoo Automotive Research Institute, a China-based automotive industry observer.[196] French market research firm Yole Group estimates that Hesai held 47 percent of the total global LiDAR market in 2022, to include both the autonomous vehicle and robot market.[197]

Founded in 2014, Hesai recorded $174 million in revenues in 2022 and was publicly listed on Nasdaq in February 2023 after raising $190 million in an initial public offering. Chinese LiDAR companies, including Hesai, partner with both Chinese and international automotive original equipment manufacturers (OEMs) and technology companies as well as research institutes. These include partnerships with companies based in the United States. For example, in August 2023, Hesai announced a partnership with U.S.-based chip maker Nvidia to integrate Hesai's LiDAR technology with Nvidia's autonomous driving system.[198]

While Chinese firms dominate the LiDAR market, they are not the only companies with significant market share. Non-Chinese competitors include Valeo (France), Innoviz Technologies (Israel), Ouster (United States)—which, as discussed above, merged with former market leader Velodyne in February 2023—Luminar (United States), Neuviton (United States), Denso (Japan), and Continental (Germany).[199]

LiDAR is currently the leading solution for enabling various levels of autonomous driving. The Level 1–3 autonomy market revolves around ADAS-related capabilities that increase autonomy of the vehicle while humans still retain control of the vehicle. Level 4 and Level 5 autonomy constitute full autonomy. In January 2023, McKinsey and Company estimated that the combined ADAS and fully automated vehicle market may reach $150 billion–$225 billion by the end of the decade and $300 billion–$400 billion by 2035.[200]

A rapid and steep rise: China's market dynamics

China's ascendance in the global LiDAR market for autonomous vehicles in particular is a recent phenomenon. U.S. and European firms held dominant positions in the market until 2020. However, within just three years, Chinese firms have become global leaders in revenue and volume of system installations.[201] This growth is driven by several factors, including the size and characteristics of the Chinese market, which offers opportunities for large domestic revenues. These revenues, in turn, can further support product development and improved manufacturing. One estimate of China's total LiDAR market (which includes multiple applications of LiDAR other than automotive, such as in industrial robots) places it at $366 million in 2022, $1 billion in 2023, and $1.94 billion in 2024.[202]

This growth rests on what many observers view as an increased willingness of Chinese consumers to accept new technologies such as autonomous vehicles. Stephen Dyer, co-leader of the Greater China practice at consulting firm AlixPartners, observes that "Chinese consumers are much more open and willing to try new technology, whether it be levels of autonomous driving, as well as what we call intelligent cockpit technology."[203] A 2022 Global Automotive Executive Survey from KPMG echoes this assessment, finding that "early customer acceptance of autonomous driving functionality is higher in China than in most other countries."[204] The robust demand for ADAS features in vehicles enables advantages in economies of scale for Chinese LiDAR producers who can outprice overseas competitors.

Drivers of growth

Policy guidance has also played a role in the sharp increase in the revenues and presence of Chinese LiDAR companies. In 2016, China's central government began prioritizing LiDAR in automotive electronics policies and pushed for its use in smart vehicles and autonomous driving in 2019.[205] In 2020, several ministries, including the NDRC and MOST, identified LiDAR as a "strategic emerging industry" as part of a government effort to prioritize the acceleration of "the establishment of basic support capacity for the intelligent and new energy vehicle industry" as well as smart cities and smart manufacturing.[206]

These measures to prioritize remote sensing applications coincide with the conspicuous growth in the revenues of Chinese LiDAR companies and a broader shift in the LiDAR market. In 2019 and 2020, U.S.-based former market leader Velodyne accrued roughly $100 million in revenue, while Hesai accumulated $50 million–$60 million.[207] In 2021, these totals flipped: Velodyne claimed $60 million while Hesai took in $100 million.[208]

The sudden growth of both Hesai's revenues and the prominence of Chinese companies in the market is also attributed in part to China's industrial policies, such as Made in China 2025, and the subsidies and other incentives and protections afforded by these policies. OTH research has been unable to uncover data revealing the amount of subsidies injected into China's LiDAR market, though a common theme of open-source research on all three case studies is that, according to a Congressional Research Service report on LiDAR, "China's LiDAR firms benefit from PRC industrial policies and related subsidies, market protections, preferences (e.g., procurement), and other practices widely seen as unfair."[209]

Momentum in China's NEV and ICV markets has led to increased investment from both domestic and international venture capital. According to PitchBook, China accounted for about 60 percent of investment globally in autonomous vehicles from the start of 2022 to late 2023.[210] U.S. companies took more than half of global investment in the sector in 2021 but accounted for only around 15 percent in investment in 2023.[211]

While some of this shift is due to growing momentum in China's market, there is also a corresponding downturn in enthusiasm for autonomous vehicles in the United States in response to concerns over safety and the decision of GM's Cruise to leave the market. Still, "Chinese driverless carmakers have been raising vast amounts of capital, backed by state-owned entities and VC firms," according to a November 2023 PitchBook analysis of autonomous vehicle market investment.[212]

An important outcome of subsidies and private investment is that there has been a sharp drop in prices of Chinese companies to increase competitiveness and gain more customers. Hesai Technology's LiDAR price dropped from around $17,400 in 2019 to between $500 and $1,000 per unit today. Robosense's LiDAR price dropped from over $2,500 in 2020 to $970 in 2022.[213]

Chinese LiDAR firms are investing heavily in R&D despite the companies not being especially profitable. Approximately 40 percent of Hesai's expenses in 2022 were for R&D, including in manufacturing, an area considered to be an advantage for the company.[214] In December 2023, Hesai reportedly became the first company in the automotive LiDAR industry to exceed a monthly delivery volume of 50,000 units.[215] The combined effect of continued product development, the scale of production and market penetration, the relative robustness of the Chinese market, and the ability to undercut other competitors on cost has put Hesai and other Chinese companies in a strong market position both at home and in the U.S. autonomous vehicle market and hampered the ability of American companies to compete effectively.

Alternatives to LiDAR and the supply chain

LiDAR solutions for autonomous vehicles have gained traction in the market due to their high degree of precision and the fact that they see the world in 3D, unlike other competing solutions. Still, LiDAR does have drawbacks that have opened up market opportunities for other technologies. LiDAR's performance in poor or cloudy weather can be inconsistent. In addition, while costs have come down for LiDAR, especially for Chinese LiDAR, they are likely to settle between $500 and $1,000 per sensor, more expensive than other potential autonomy-enabling solutions such as radar and vision. Most autonomous cars will require more than one sensor and may include as many as eight, driving up the overall cost of autonomous vehicles and amplifying the cost difference between LiDAR and other solutions.[216]

Data from Guotai Junan Securities, a large Chinese securities trading firm, provides costs estimates for four types of automotive sensors in China: an ultrasonic radar costs between ¥90 and ¥120 ($13–$30); a vision camera costs between ¥200 and ¥400 ($30–$57); a mmWave radar costs between ¥300 and ¥1,500 ($43–$215); and a single LiDAR system costs between ¥5,000 and ¥80,00 ($710–$1,140).[217]

As a result, other solutions are being developed and employed both independently and in conjunction with one another and with LiDAR. For example, Tesla CEO Elon Musk has spoken out against LiDAR and has instead opted for a combination of external cameras and computer vision software to deliver the Autopilot solution on Tesla's cars.[218]

In mid-2023, German technology company Bosch, which previously was the global leader in patents in LiDAR, announced that it was no longer pursuing the technology, instead opting to perform research on radar technologies, which are less expensive to develop and adopt. Bosch was dissuaded by the expense of LiDAR development as well as market challenges, including continued uncertainty about autonomous vehicle regulation.[219]

Radar technologies are not new to the autonomous vehicles market. They have been used in a supporting role due to challenges with resolution, especially the capability of technologies such as 3D mmWave radar to accurately measure height, opening the possibility that objects will be mischaracterized and leading to false breaking or worse.[220]

One radar technology that is gaining traction as both a competitive and complementary lower-cost remote sensing solution for autonomous vehicles is 4D mmWave radar. This technology reportedly fixes the problems 3D mmWave radar had with measuring object height and is now able to see the world in 3D, though some observers argue LiDAR retains an advantage in precision imaging.[221] Regardless, advances in semiconductors, system design, and technology evolutions have enabled significant performance gains, offering a solution that balances performance and cost in a more compelling way than in the past.[222]

Despite these improvements and cost advantages, radar, including 4D mmWave, still faces technical challenges to adoption and still may not be viewed as an independent or primary solution for enabling autonomy. Most analyses consulted for this report view radar as an increasingly capable but also complementary solution to vision, LiDAR, or both in an effort to establish "heterogeneous redundancy."[223] For example, Tesla, which moved away from the use of radar in conjunction with vision in 2021 due to performance concerns, has incorporated radar into its HW4 package alongside vision.[224]

Nonetheless, while LiDAR is likely to remain a preferred solution for many automotive OEMs, the continued development of radar and vision technologies could create new opportunities for incorporation as part of a broader ADAS-enabling solution.

Supply chain issues are also shaping the discussion of China's LiDAR market dominance. Chinese LiDAR companies are reliant on the United States for semiconductor chips. However, American companies Xilinx (now part of AMD) and Altera (a subsidiary of Intel), in particular—but also Lattice Semiconductor—are the leading FPGA suppliers globally.[225] These suppliers, particularly Xilinx and Altera, produce the vast majority of FPGAs for LiDAR systems in the world, raising the likelihood that U.S. technology is supporting the development of Chinese LiDAR remote sensing capabilities.[226] U.S. companies are also global leaders in other critical LiDAR supply chains, such as analog chips.[227] OTH research did not uncover any specific information that leading U.S. or European companies are selling directly to Chinese companies, but given the importance of these companies in market share, the potential for the sale of additional U.S. chips to Chinese suppliers is possible.

Economic and national security risks

As Chinese LiDAR firms continue to grow and dominate the industry, their products will increasingly become the go-to for automotive manufacturers globally. This portends a growing dependence on LiDAR products developed and manufactured in China. Indeed, the threat posed by this excessive dependence has already started to manifest. LiDAR systems have been listed on a 2023 draft of the "Catalogue of Technologies Prohibited and Restricted from Export" in China. The move restricts the transfer of LiDAR technologies, but not end products, from China to other nations, including the United States. This means Chinese companies can continue to export finished products but are prohibited from entering agreements that transfer the underlying technology—at least for now. These export controls hint at the risks associated with Chinese LiDAR being withheld from the U.S. market and the potential perils of being dependent on China for technologies supporting key industries such as the autonomous vehicle and future mobility markets.[228]

Moreover, discussion of Chinese LiDAR in the U.S. policy community has raised potential national security risks, particularly related to data security.

U.S.-based LiDAR companies and members of Congress have understandably focused on the potential for Chinese-made LiDAR on vehicles operating in the United States to collect sensitive data about U.S. infrastructure, sensitive sites, or military bases. Variations in state laws that allow Chinese-made vehicles to train autonomous vehicle solutions on public roads, as discussed in Chapter 2, have also contributed to the concern over the potential for sensitive data to be transmitted back to China based on China's National Intelligence Law and the overall control the central government can exert over commercial activities.

DoD has also demonstrated concern over Chinese LiDAR companies' ties to the PLA and their ability to collect data on the U.S. military. As a result, in February 2024, DoD placed Hesai on the 1260H list of Chinese military companies operating in the United States due to the company's reported ties with the PLA.[229] The move barred DoD from doing business with Hesai, though Hesai has denied the claims and sued the U.S. government in response.[230] In August 2024, DoD removed Hesai from the 1260H list, reportedly due to concerns that the justifications for removing the company in February would not stand up to legal scrutiny.[231] However, in October 2024, DoD announced its intention to return the company to the 1260H based on new information.[232]

The U.S. government should take this data security risk seriously. However, it also needs to better understand the nature and dimensions of the data security challenge. Multiple individuals working in the autonomous vehicle industry interviewed for this effort expressed doubt that Chinese LiDAR could store any data on servers outside the automobile on which it was operating. In addition, two German companies tested Hesai's technology and determined that Hesai's sensors can neither store data nor transmit it outside the vehicle.[233]

Nonetheless, even if these assessments are true, they cover only part of the risks associated with the collection and storage of LiDAR data, or any sensitive data. Storing data in on-board computers in the United States does not inoculate the risk of an untoward actor hacking into the vehicle's operating system to collect and aggregate data. Moreover, the rapid development cycle of Chinese LiDAR firms described above may enable data exfiltration capabilities from LiDAR systems in the future.

The combination of the uncertainty about the nature scale of the data security threat coupled with the certainty of the assumptions about the data security risk suggest a broader need for Congress to mandate an independent technical assessment to provide a baseline for understanding of this risk. Congress should also consider an effort to first review any previous efforts to understand penetration of the DoD supply chain by Chinese LiDAR firms and then fill gaps in our visibility into this related challenge.

Case Study Two: The Small Drone Market and Remote Sensing

Summary

The growing trend toward increased use of UASs in remote sensing referenced in Chapter 1 of this paper has created opportunities for China to export both military UASs and commercial small drones. According to the London School of Economics, at least 14 countries, most involved in China's BRI, have imported Chinese military drones, while Chinese companies, especially DaJiang Innovation Technology Co. (DJI), have become global leaders in the development and delivery of commercial and hobbyist drones. Small remote sensing drones are an important and increasingly prevalent tool in industries such as agriculture, energy, power, law enforcement, and film.[234]

Over the past nearly two decades, China has nurtured a dominant position in the commercial small drone market revolving around Shenzhen-based DJI and including other firms such as Autel Robotics. In achieving this position, DJI and other Chinese small drone manufacturers have benefited from innovation and reinvestment in supply chain and manufacturing capabilities as well as government prioritization of the small drone industry and the associated aggressive state policies this prioritization has delivered. These measures have provided distinct and now entrenched competitive advantages that are creating dependencies as well as economic and national security risks for the United States.

Economically, DJI and other Chinese small drone brands are reducing market access both domestically and internationally for U.S.-based providers unable to match DJI's market and pricing advantages. The layered national security implications include concerns over data security as well as potential dependence on China for scaled use of small drones, a capability that has become central to the future of military conflict. Russian and Ukrainian forces have used DJI Mavic 3, DJI Matrice, and Autel EVO II quadcopters in combat in Ukraine.[235]

China and the global commercial drone market

DJI reportedly holds 90 percent of the global consumer drone market and 70 percent of the enterprise/industrial market globally.[236] A 2020 report from the Center for the Study of the Drone at Bard College reveals that DJI also holds 77 percent of the U.S. hobby drone market and 90 percent of the commercial drone service provider market.[237] While not all DJI drones are remote sensing, many will be used in the capacity to monitor infrastructure, agriculture, maritime features, and sensitive sites.

DJI's market position is due to several factors. Notably, the company has demonstrated a capacity for innovation and has developed leading technologies in the small drone remote sensing field. Similar to Chinese LiDAR companies, DJI has invested heavily in R&D and manufacturing to support continued refinement of products. Of its 14,000 employees, 25 percent are dedicated to R&D.[238]

Technological innovations incorporated into DJI drones revolve around advanced AI and sensors that allow more precise and autonomous operations at greater distances. AI-powered drones are enabling emerging swarm capabilities in which hundreds of drones operate simultaneously without human operators. These nascent drone abilities possess commercial and military use cases, offering Chinese-made drones a dual-innovation advantage.[239]

Additionally, DJI also regularly emphasizes the automation of its manufacturing processes, scaled operations, and integration of its supply chain as competitive discriminators and key elements of its success in gaining the market position it holds today.[240]

But DJI and other Chinese small drone companies have also gained a dominant market position through government policies, such as Made in China 2025*,* and subsidies and funding that have allowed them to develop novel solutions at much lower costs than other providers that do not have these protections and benefits.

These measures have catalyzed several trade practices that advantage Chinese providers in the global market,[241] such as the provision of low-interest loans to industry participants. Other measures related to Made in China 2025 require companies to build Chinese domestic supply chains, buy domestically, spend a high percentage of their revenue on R&D, and partner with high-tech industry to ensure an end market. It also directs state-owned companies to acquire and transfer Western technology and, notably, pushes investment firms to invest heavily in drones and component parts.[242]

Reporting from the *Washington Post* in 2022 states that DJI has received backing from four state-run and -owned banks and investment funds. The four banks named were: China Chengong Holdings Group, which is administered by Beijing's SASAC; Shanghai Venture Capital Guidance Fund, which is administered by the Shanghai Municipal Government; Guangdong Hengjian Investment Holdings; and SDIC Unity Capital, a fund administered by the State Development and Investment Corporation (SDIC)—a state-owned investment holding company approved by China's State Council.[243] OTH could not confirm values of these investments nor could we validate the involvement of the four entities named in funding DJI through other sources. DJI has denied receiving subsidies from the Chinese government and has stated that investment from any banks associated with the Chinese government are "the same as any institutional investor that purchases stock in a private company, regardless of where that company is headquartered."[244]

Furthermore, regulatory agencies in China are further embedding demand for small drones within China's domestic market to the benefit of Chinese drone providers. The Civil Aviation Administration of China (CAAC) established clear guidelines in January 2019 governing drone airworthiness standards for manufacturers and signaling a prioritization of the low-altitude economy.[245] Months later, the CAAC announced a 30-year development strategy for China's uncrewed civilian aircraft industry, enshrining UASs and the low-altitude economy as a future pillar of the Chinese economy.[246]

Economic and national security risks

The effect of DJI's market dominance, based both in technological development and China's industrial policies, has been significant for U.S. providers and for the U.S. government. In 2019, U.S. Undersecretary of Defense for Acquisition and Sustainment Ellen Lord specifically cited DJI's ability to overwhelm the U.S. market with "so many low-price quadcopters" and the associated dependence on DJI drones as a national security challenge that needed to be addressed.[247]

Dependency on and overall market dominance of Chinese providers raises cascading economic and national security risks. First, it creates an environment in which U.S. suppliers' ability to compete effectively in the U.S. and global markets has been diminished. The global small drone market is set to grow from $30.6 billion in 2022 to $55.8 billion by 2030, according to an open-source market analyst resource.[248]

The dominance of Chinese firms may create a dependence on them for small drones. This dependence, in turn, creates vulnerabilities in which critical industries in the United States that rely on drone remote sensing are tied to supply chains managed by U.S. competitors. These supply chains can be turned off or dialed back in times of crisis or intensified competition to exert leverage and pressure on the U.S. economy to achieve economic, geopolitical, or military objectives.

In July 2023, China announced it would restrict export of commercial small drones and components that could be used for military purposes. The 2023 export controls did not target any specific country, but the emphasis on restricting drones at risk of "being converted for military use" suggests Russia and Ukraine were the primary targets,[249] though it is not clear that the flow of small drones was effectively halted to either country. The restrictions also applied to some drone engines, lasers, communication equipment, and anti-drone systems.[250]

These restrictions have not had a large effect on the U.S. market but do hint at a potential future vulnerability. Small drones and first-person view (FPV) drones have become high-value weapons in war as they act as ISR platforms, substitute for more traditional and expensive munitions, and serve as a critical node in communications, targeting, strike, and battle damage assessment. The ability of DJI or other Chinese companies to control or restrict sales of these systems could create gaps in supply that—with few scaled competitors to fill the market gap—could undermine U.S. national security interests.

But breaking away from a dependency on Chinese small drone companies is difficult without a scaled and robust domestic drone industry with reliable revenue streams and demand signals from the market. For example, DJI holds 92 percent of the first responder market in the United States, and government efforts to ban or heavily tax law enforcement and security agencies' use of DJI drones have had mixed results. Law enforcement officers interviewed by *Nikkei Asia Review* cited both the high quality and ease of use of DJI remote sensing drones as well as their low cost as a reason why they are still purchasing DJI drones despite tariffs and restrictions on using federal funds to purchase them.[251]

In addition to the economic and national security risks, dependency on DJI and Chinese small remote sensing drones raises a further connected risk around data security—especially, but not exclusively, when small drones are used to monitor critical infrastructure or activities that require flying drones near to military bases. In May 2024, a senior U.S. defense official acknowledged that there two to three incidents a week in which small drones flew near military bases in the United States. While the official cautioned that there is no evidence indicating the activity is nefarious, the incidents are of concern to DoD, and he stated that DoD needs to "treat them all as if it's nefarious until we hear otherwise."[252]

Concerns revolve around the possibility of sensitive geographic and operational data being transmitted to servers under Chinese jurisdiction, potentially leading to unauthorized data access by Chinese authorities.[253] Such risks are compounded by intelligence and data security laws in China that compel companies to cooperate with intelligence operations if requested, posing a direct threat to the security of data collected via drones.

Recent research found that DJI drones can transmit their GPS location to DJI servers, as well as the coordinates of their operators, and DJI is increasingly offering the company's drone operators the ability to livestream through DJI's cloud where that information would become available for further dissemination if the CCP requested it.[254]

Early in the war with Russia, Ukraine utilized Chinese commercial drones produced by DJI for surveillance and targeting. Within months, Ukraine's military encountered issues stemming from suspected data leakages purportedly from DJI to Russia, including GPS data of Ukrainian military positions. DJI rejected the allegations but also continued its commercial support to Russia.[255]

As with the LiDAR case study, the U.S. government has taken measures to address some of the current and potential future economic and national security risks, including:[256]

- In August 2017, an Intelligence Bulletin from a U.S. Department of Homeland Security Field Office stated DJI is providing sensitive U.S. data to the Chinese government.[257]
- In the National Defense Authorization Act for Fiscal Year 2020, Congress banned DoD from purchasing and using drones and components manufactured in China.
- In December 2020, the U.S. Department of Commerce added DJI to its "Entity List" for its role in enabling China's wide-scale human rights abuses.[258]
- In October 2022, DJI was added DoD's 1260H Chinese Military Company list because of its role in advancing the PLA's modernization efforts.
- In December 2023, President Joe Biden signed the National Defense Authorization Act for Fiscal Year 2024, which included language of the American Security Drone Act and prohibits federal agencies and federally funded programs from purchasing or using drones manufactured in countries deemed threats to U.S. national security.
- In January 2024, the Cybersecurity and Infrastructure Security Agency and the Federal Bureau of Investigation released cybersecurity guidance that states that Chinese-manufactured drones pose a significant risk to critical infrastructure and U.S. national security.[259]

These measures are all reasonable efforts to mitigate extant and potential economic and national security risks and should be accompanied by additional measures to reinforce the domestic small drone industry in the United States, as discussed in Chapter 7's recommendations.

Case Study Three: Commercial Space Remote Sensing

Summary

Since 2014, China has built a robust commercial space industry, which has collectively developed and is continuing to develop over a dozen remote sensing constellations, including CGSTL's Jilin-1, which will become the largest commercial remote sensing constellation in the world in 2025, with a total of 300 satellites. While the U.S. commercial space industry retains overall market leadership, the continued growth and development of and investment in China's commercial remote sensing industry is creating competitive tensions and could pose challenges in emerging markets in which demand for Earth observation data is likely to increase. Additionally, the continued growth of China's commercial remote sensing capabilities and presence will create or amplify challenges to U.S. and allied national security, given documented relationships between several of China's commercial remote sensing companies and the PLA as well as other actors whose objectives do not align with those of the United States.

C*hina and the commercial space and remote sensing industry and market*

Among the most significant developments in China's efforts to become a global leader in space has been the rapid ascent of its commercial space and remote sensing industry. Prior to 2014, China's space industry was dominated by a small number of SOEs, mainly CASC. The release in 2014 of Document 60, formally called the Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment, for the first time established China's intent to allow private capital participation "to be used to develop, launch, and operate commercial remote sensing satellites," "provide for market-oriented and professional services," and "construct satellite navigation ground application systems."[260]

The effort to establish a commercial remote sensing and space industry was an acknowledgement of the need to build a more innovative and flexible capability to capitalize on the economic potential of the space industry and as an appreciation of the value the U.S. commercial space industry had created. The effects were not necessarily immediate, as investors and potential start-ups and spin-offs waited to better understand how Document 60 would be interpreted and implemented, though some firms were established in 2014, including CGSTL, China's first and likely most well-known and prominent remote sensing company.

By 2018, China's commercial space industry had experienced considerable growth in the number of commercial companies—including spin-offs from CAS or SOEs—and the amount of funding being invested in these new enterprises.[261] Estimates of the number of private space companies that have come into being since 2015 differ based, at least in part, on the definition of a private company and the timeline being discussed. These estimates range from the formation of 78 new companies in 2018[262] to 300-plus in 2022[263] to over 400 in 2023.[264] Regardless of the exact number, the data show a steady and impressive—if leveling out—increase in commercial space industry activity from a nearly nonexistent base in 2014.

Similarly, estimates of total funding from private capital and the central government for China's commercial space sector also vary, but they also tell a story of steep growth, especially after 2018. A 2023 analysis from China Space Monitor shows between $6 billion and $7 billion in funding for the industry from 2014 to 2022, including an average of $1.2 billion per year from 2018 to 2021.[265]

The growth in China's space and remote sensing industry continues, and China's commercial companies are increasing their market prevalence. November 2023 data from space research firm Euroconsult and reviews of company websites show that 12 Chinese commercial remote sensing companies are currently developing or have begun deploying a total of 14 new commercial Earth observation satellite constellations ranging in size from four to 300.[266]

At the high end of commercial satellite constellations is the planned 300-satellite Jilin-1 constellation, developed and operated by CGSTL. The constellation currently has over 100 satellites on orbit. CGSTL announced in late 2023 it would expand the constellation to 300 by 2025,[267] making it the largest remote sensing satellite constellation in the world. In comparison, U.S.-based Planet's largest constellation is made up of "roughly 200" optical multispectral imaging satellites.[268]

In terms of capability, the Jilin-1 satellites provide the user community with very high resolution (VHR) multispectral and panchromatic Earth observation images. The company's website claims that the current constellation can visit anywhere in the world 23 to 25 times a day.[269]

Assessments of Jilin-1's overall capability are favorable. One U.S.-based aerospace researcher referred to Jilin-1's resolution capabilities as "spectacular" in 2023.[270] EOPortal, an online Earth observation resource, assesses that the expanded Jilin-1 could deliver "round-the-clock, all-weather, full-spectrum data acquisition, capable of providing geospatial information products and services of the highest temporal and spatial resolution globally."[271] A June 2022 ESA technical assessment of Jilin's GF-03A and GF-03B satellites is less positive, although it does give the satellites an "intermediate" or "good" rating in several performance categories, suggesting that at least some satellites in the constellation provide adequate but not necessarily exceptional capability.[272]

In addition to these independent assessments of existing capabilities, Jilin-1 is expanding its capability and has incorporated emerging capabilities to improve its resolution and capacity to track small moving objects on Earth. Researchers from the PLA's Space Engineering University in Beijing published a paper in March 2022 that detailed how AI-enabled Jilin-1 satellites were able to successfully detect small objects such as planes in the air and cars on the street in videos with 95 percent accuracy, a nearly seven-fold increase in precision from the then state-of-the-art.[273]

To date, most of CGSTL's clients are Chinese provincial or city governments seeking to better understand environmental or resource issues. While it is unclear if Chinese provinces or cities contract with non-Chinese providers, several provinces in China are investing heavily in the domestic space sector, including remote sensing capabilities, indicating an increasing preference for domestic capabilities.

There are additional indications of the improving—and in some cases, leading—quality of China's commercial remote sensing capabilities. In October 2024, four organizations—CSIS, Taylor Geospatial Institute, Taylor Geospatial Engine, and the United States Geospatial Intelligence Foundation—ran an "Olympic Games for commercial remote sensing" that evaluated the best-in-class commercial remote sensing capabilities across 11 categories, similar to the 2021 NGA survey referenced at the beginning of Chapter 2. Chinese companies won "gold" in five categories, while the United States won in four. Finland's SAR specialist company ICEYE and South Korea's KARI KOMPSAT SA won the other two gold medals. Overall, China won 14 medals and the United States won 12. The United States led in SAR and hyperspectral while China held advantages in multispectral and other Earth observation categories.[274]

Economic and national security challenges

Such comparisons are valuable and offer important data points for making qualitative comparisons between growing and diverse industries in both the United States and China. However, they should also be viewed as informative and representative rather than as fully authoritative statements of China's ascendancy in remote sensing. The results reinforce the assessment that China's commercial remote sensing capabilities have improved across many technology categories and are globally competitive, even if China's remote sensing industry lacks the scale and depth or current market share of the U.S. industry.

From an economic and market perspective, China's recently invigorated private sector remote sensing industry is unlikely to imminently supplant U.S. companies or leading European, Japanese, Korean, and Indian commercial space-based remote sensing providers in their domestic markets. The U.S. remote sensing industry is robust and growing, with global leaders in the provision of commercial remote sensing such as Planet, Maxar, Black Sky, Capella, and HySpecIQ as well as a burgeoning set of small and innovative commercial space companies. Finnish ICEYE is also a global leader in SAR sensing, and several European and Asian allied and partner nations are building commercial remote sensing industries, including Japan, South Korea, India, France, Germany, Canada, and the United Kingdom.[275]

Still, there will be opportunities for the most capable and well-supported Chinese companies to establish or expand their share in growing markets in countries that are already engaged with China through BRI, especially as these companies demonstrate their ability to compete in resolution, revisit time, and data processing speed and accuracy. As noted earlier in this paper, while estimates of the future size of the commercial satellite remote sensing market vary, most place the market at between \$3.0 billion and \$3.5 billion today, with the chance to grow to between \$5.0 billion and \$8.0 billion by the start of the next decade with significant opportunities in emerging markets. Many of these countries are already engaging with CNSA, Chinese SOEs, or Chinese commercial space companies in other aspects of the space industry through the Digital Silk Road initiative.

In testimony to Congress in February 2023, Kari A. Bingen, director of the Aerospace Security Project and senior fellow with CSIS, highlighted the market risk for U.S. companies of the entrance of Chinese commercial remote sensing satellite providers, saying, "The advantages in space technology and dominant market share that the United States has long enjoyed is eroding as China's space capabilities rapidly grow in quantity and quality, accelerated by clear political will, government prioritization, and large state and private investments."[276]

In addition to these market and economic challenges, the development of the Jilin-1 constellation—as well as other commercial Chinese remote sensing constellations—also indicates multiple defense and national security risks given the increased utility of commercial remote sensing for military applications. A March 2024 China Aerospace Studies Institute (CASI) profile of CGSTL assesses that the Jilin-1 constellation is intended for civil government uses "as well as in providing remote sensing capabilities to" the PLA.[277]

In addition, at the end of 2023, CCP-run news outlet the *Global Times* reported that Jilin-1 offers "high quality remote sensing information and products for various sectors, including national security" as well as other development and scientific tasks.[278] The combination of such reporting, the emphasis placed on military-civilian fusion in aerospace and space activities, and ties to the PLA indicate that Jilin-1 could serve a secondary, but still important, role in augmenting PLA remote sensing efforts and supporting PLA operational planning and execution.

The Jilin-1 constellation has also been used to support foreign actors pursuing national security interests that contravene those of the United States. In October 2023, Agence France-Presse[279] reported that CGSTL sold access to remote sensing data from two on-orbit Jilin-1 constellation satellites to a fruit-trading subsidiary of the Wagner Group for $31 million to include information on several countries in Africa—where Wagner Group has a strong presence—as well as information likely used to support the Wagner Group coup attempt against President Vladimir Putin in May 2023.[280] The U.S. government also sanctioned the Luxembourg subsidiary of Chinese remote sensing company Spacety in January 2023 for selling SAR satellite imagery of locations in Ukraine to Terra Tech, a Russia-based technology firm.[281]

The concern is that these will not be isolated incidents and that more countries or actors will draw upon China's commercial remote sensing firms. Yasuhito Fukushima, a senior research fellow specializing in space security at Japan's Ministry of Defense's National Institute for Defense Studies, captured the broader concern, noting that "it's vital to recognize that more and more countries and organizations will draw upon China's commercial space services for military purposes, as Wagner did. [Allies and partners] must carefully monitor the extent to which the Chinese military utilizes private-sector space technology and services."[282]

Chapter 6: The PLA and Remote Sensing

China's PLA has successfully developed a robust remote sensing architecture in the Indo-Pacific over the last several years. The applications of this architecture have created several linked and increasingly urgent operational challenges for U.S. and allied military planners.

Remote sensing equipment is now utilized across multiple services and in various domains to enable advanced capabilities such as all-weather remote sensing to support a range of ISR activities; dedicated maritime awareness; a global navigation satellite system for positioning, navigation, and timing (PNT); and improved location services and navigation for targeting at longer ranges. In addition, the PLA and research institutes and commercial companies associated with the PLA continue to develop advanced remote sensing technologies that could be deployed to further disrupt areas of U.S. military advantage, including in undersea warfare.

An analysis of quantitative data and qualitative assessments suggest the United States retains an edge in military remote sensing. However, comparative assessments of U.S. military and PLA remote sensing capability are complicated by the availability of open-source technical information. Scale also complicates comparative assessments, as the U.S. military possesses a global remit while the PLA is primarily regionally focused.

Most critically, the PLA need not have technical or numerical superiority over the United States and its allies in remote sensing capabilities to create persistent dilemmas for them. As a December 2023 joint report from the National Space Intelligence Center and the National Air and Space Intelligence Center observes, China's growing remote sensing capability in space is "improving the Chinese military's ability to observe U.S. aircraft carriers, expeditionary strike groups, and deployed air wings" in the Indo-Pacific.[283] The presence and movement of U.S. and allied forces in the Indo-Pacific will be under more regular monitoring and surveillance, leaving few places for U.S. forces to go undetected in the region—even as it shifts to a more distributed posture to improve force resilience.

The PLA's increased investment in and deployment of advanced remote sensing capabilities—as well as the potential to leverage constellations with purportedly commercial, civil, or scientific purposes—is also improving its ability to carry out longer-range precision strikes more effectively; to detect U.S. or allied missile launches in a time of conflict, and to secure communications and command and control. According to Deputy Chief of Space Operations for Intelligence Major General Greg Gagnon, "[The PLA] has rapidly advanced in space in a way that few people can appreciate," with the overall effect of holding U.S. forces at risk over longer distances than the PLA has been capable of in the past.[284]

Examining the PLA's growing remote sensing capabilities is essential to understand how these capabilities may complicate or disrupt U.S. and allied military operations. This chapter uses a platform-based approach to review current and under-development PLA remote sensing capabilities in five categories: satellites, high-altitude systems, aircraft, ground vehicles, and maritime assets.

Satellites

China has invested heavily in the development and deployment of military satellites over the last decade. A July 2024 Space Force Threat Fact Sheet assesses that China's on-orbit presence has grown by approximately 560 percent (+820 satellites) and that as of June 2024, China had more than 970 satellites in orbit, second only to the United States.[285]

The primary series of remote sensing satellites with military applications utilized by the PLA is the Yaogan series, with 144 satellites placed into orbit since the program began in 2006.[286]

Although Chinese state-run media usually refers to Yaogan satellites being utilized for tasks such as "scientific experiments, land resource surveys, crop yield estimation, and disaster prevention and relief," the classified nature of the program and launches suggests a military utility.[287] The Yaogan series includes a diverse range of classes of satellites, with the first Yaogan classification being the Jianbing-5 series in 2006. In late 2023, China launched several sets of Yaogan-39 "triplets" into LEO,[288] an orbit the PLA has used heavily in the last decade.

The PLA has also used GEO, notably launching the Yaogan-41 satellite into GEO on December 15, 2023.[289] Satellites in GEO orbit at the same rate as the Earth, meaning they can stay over the same location on Earth delivering persistent surveillance of that area. Additionally, GEO satellites can see nearly half the Earth's surface from its orbit approximately 36,000 km in altitude.[290]

The Yaogan high-resolution optical satellite is one of five optical GEO satellites operated by China. The CHEOS system includes three Gaofen optical surveillance/Earth observation satellites, while the Ludi Tance-4, launched in August 2023, is the world's first and only GEO satellite that carries a SAR payload. China claims the mission of all these satellites is non-military. However, CSIS assesses that the combination of Yaogan-41's data and data from other Chinese surveillance assets could "provide China an unprecedented ability to identify and track car-sized objects throughout the entire Indo-Pacific region and put at risk numerous U.S. and allied naval and air assets operating in the region."[291]

The Yaogan are not the only military remote sensing satellites in operation. The PLA also reportedly utilizes the Yunhai meteorological series of satellites, Tianhui Earth observation satellites, Gaofen series (part of the civilian China High-Resolution Earth Observation System, or CHEOS), and Tongxin Jishu Shiyan series. Other series of satellites that are more commercial or civilian in nature still have dual-use applications and retain increasingly sophisticated remote sensing capabilities, including the Haiyang ocean satellites, Huanjing disaster and environmental monitoring satellites, Jilin-1 series, and the China-Brazil CBERS program.[292]

Remote sensing satellites with military or dual-use applications can be categorized by three functions:

- **Early warning/ISR:** The majority of China's remote sensing satellites are utilized for early warning and/or ISR missions. The July 2024 Space Threat Fact Sheet indicates that "the PLA benefits from 490+ ISR-capable satellites with optical, multispectral, radar, and radio-frequency sensors, increasing its ability to detect U.S. aircraft carriers, expeditionary forces, and air wings."[293] The table below describes the remote sensing capabilities on these satellites in more detail:

Sensor type	Description
Electro-optical	Electro-optical satellites form the bedrock of China's space-based ISR sensor network. Some of the earliest Yaogan satellites housed electro-optical sensors, such as the Yaogan-2 (JB-6) family—first launched in 2007—which captured Earth imagery with a resolution of around 1.5 meters (m). The Yaogan-5 (JB-10) family improved this resolution to 0.77 m. The Yaogan-41 was launched on December 15, 2023, and is also described as an optical remote sensing satellite, though few specific details are available.[294]
Multispectral/ hyperspectral	An increasing share of China's electro-optical sensors include multispectral or hyperspectral capabilities. The Gaofen-5 series carries both multispectral and hyperspectral imagery sensors, while the commercial Jilin series combines multispectral imaging with video imaging satellites to improve accuracy and discrimination of its imagery.[295]
SAR	The first synthetic aperture radar series satellite developed by China was the Jianbing-5 (Yaogan-1), launched in 2006. Since then, simultaneous launches have placed tri-satellite constellations into orbit, from the Yaogan-98 launches onward, into A, B, and C groupings. These satellites fly in triangular formation in similar orbits at identical inclination with an electro-optical satellite, a SAR satellite, and an electronic intelligence satellite. The groupings enable all-weather monitoring and tracking of fixed locations and mobile assets, such as naval vessels.[296]
LiDAR	There has not yet been any confirmed information about the development of a military LiDAR satellite by China. The commercial Daqi-1 atmospheric environment monitoring satellite, launched in 2022, features an atmospheric detection LiDAR.[297] Unverified reports in 2018 claimed China was developing a space-based anti-submarine warfare LiDAR capability named Guanlan, but few details have been published since.[298]

Table 1: Descriptions of capabilities by sensor type for China's ISR aircraft.

- **Electronic intelligence (ELINT):** ELINT is intelligence gathered from electronic signals without speech or text, such as emissions from radars and communication systems. ELINT is often gathered by remote sensing equipment analyzing factors such as direction, modulation, power, and frequency of these electronic signals. China's first experimental ELINT satellite, Shijian-1, was launched in March 1971, with three further experimental ELINT satellites launched in 1975–1976. A tri-satellite launch followed in 1981, but little else occurred until the 1990s, when the Shijian series was resurrected. The first ELINT Yaogan satellites were launched in 2010 with the Yaogan-9 (JB-8) series. There are now more than 80 Yaogan and Shijian SIGINT or ELINT satellites in orbit, including the JB-8 and CX-5 series of triplet satellites, providing broad ocean surveillance.[299]
- **PNT:** Remote sensing capabilities can collect electromagnetic signals for a range of uses, including the ability to pinpoint an object's location with great accuracy. This PNT capability, most commonly understood through GPS, enables vessels and vehicles to navigate even in remote areas. China now has a global radio satellite navigation system through its Beidou constellation, with the final satellite launched in June 2020. The Beidou series included 60 launches in three series: Beidou 1 was just four satellites with limited coverage; Beidou 2 involved 20 launches and became operational in 2011; and Beidou 3 included 36 launches from 2015, thus providing full global PNT functionality able to determine location, speed, direction, routes, and duration of travel of vessels and vehicles.[300] According to the Pentagon's annual report on Chinese military capabilities, Beidou provides a global positional accuracy standard of 10 meters, which reduces to five meters in the Indo-Pacific region. The PLA uses Beidou for force movement and precision-guided munitions delivery.[301]

These satellites sit across different orbits. The Beidou system has GEO and inclined geosynchronous orbit (IGSO) satellites.[302] The PLA's ELINT satellites have largely been launched into LEO, while almost all of the more recent Yaogan launches, such as Yaogan-36, -37, -39, and -40, have also been into LEO.[303] LEO satellites ensure high bandwidth and low communication latency, enabling reliable and near-real-time monitoring of the Earth if enough satellites are used.

High-Altitude Systems

In near space, China is also developing a range of high-altitude systems that can provide ISR over extended periods of time with minimal guidance and without the expense of orbiting a satellite. High-altitude balloons are one such example, although the dual-use aspect of such balloons that can also be used for meteorological purposes makes it challenging to outline the PLA's current fleet of high-altitude balloons. In the wake of the passage of a Chinese high-altitude balloon across U.S. airspace in early 2023, the Biden Administration briefed reporters on China's previous use of high-altitude balloons on four occasions over the United States and across 40 other countries on five continents.[304]

Single high-altitude balloons can provide China with valuable intelligence, but a chain of multiple balloons would be able to provide broader-area surveillance and can transmit communications in a near-orbit trajectory. Yet, balloons are just one component of a broader attempt to utilize high-altitude or near-space aircraft with remote sensing capabilities. China has developed HAPS in the guise of solar-powered UAS that can fly at altitudes above 18 km with an endurance lasting weeks. These UASs not only have a large operational radius but also are more operationally flexible than satellites, as they do not follow a set orbital trajectory. HAPS flexibility means it can be specifically tasked with ad hoc surveillance missions. High-altitude balloons and HAPS can typically carry payloads, including SAR and electro-optical sensors for all-weather monitoring.

China SOE AVIC is leading research into these aircraft. AVIC has developed a Morning Star 50 HAPS platform, which made its maiden flight in September 2022. The system is able to fly in near space for periods lasting months.[305] If multiple HAPS are operating in concert, this network provides a persistent, wide-area, and flexible remote sensing capability for ISR missions. HAPS could also act as backups for satellites in conflict, as anti-satellite weapons might threaten space-based assets while HAPS would be harder to easily track and target.

Additionally, AVIC has also developed a high-altitude, high-speed UAS, the WZ-8, which can fly at supersonic speeds in near space, making it more difficult to track and intercept and allowing it to utilize its SAR and electro-optical payload for surveillance over targets. The WZ-8 has been seen at a PLAAF air base in satellite images, indicating operational testing.[306]

Aircraft

The PLA Air Force (PLAAF) was for some time a limited service and, like the other PLA services, had few remote sensing capabilities beyond airborne radar. The PLA transitioned away from a land-centric "people's war doctrine" in the 1990s and invested fast-growing budgets into a wider range of aerial and naval capabilities. During this period, the PLAAF began to develop special mission aircraft that utilize remote sensing capabilities for ISR missions. Most of these aircraft have been modified from the Y-8 transport aircraft or, for second-generation models, the more modern Y-9. They are also often designated with a Gaoxin (literally "high new") or GX designation.

- **Airborne early warning and control (AEW&C):** The PLA's indigenous AEW&C program began in earnest in the mid-1990s as China sought to develop the capability to detect aircraft, vessels, and missiles at longer ranges to better defend its military assets. The first maritime airborne early warning aircraft, the Y-8J, was introduced to the PLA Naval Air Force (PLANAF) in the late 1990s, with a Skymaster radar in a nose radome. The first-generation AEW&C aircraft, the KJ-2000, was equipped with a phased array radar within its dorsal radome atop an Il-76 transport fuselage and first deployed in the early 2000s. As issues with the supplies of the Il-76 mounted, China also developed the KJ-200 (GX-5), which features a large SAR "balance beam" radar on the body of a Y-8 transport aircraft. Subsequently, China developed the KJ-500 (GX-10), based on the larger Y-9 transport aircraft with an active electronically scanned array housed in its dorsal radome and a surface search radar in its nose cone. These AEW&C aircraft, although limited in number, provide the PLA with an ability to detect U.S. vessels and aircraft from up to 400 km.

A carrier-based AEW&C aircraft, the KJ-600 (GX-15), outfitted with an active electronically scanned array (AESA) radar, will be the next evolution of China's airborne early warning fleet. The KJ-600 is expected to enter service from 2024 or 2025 and is planned to be deployed on China's new Type 003 aircraft carrier.[307] Once deployed, the KJ-600 will increase the flexibility and range of the PLA's AEW&C capabilities into the western Pacific.

- **Anti-submarine warfare (ASW):** The PLA has also developed maritime patrol/ASW aircraft based on the same Y-8 airframes as early AEW&C aircraft. The Y-8X was an early maritime patrol aircraft (MPA) that was deployed in the mid-1980s with optical and infrared cameras. A more modern aircraft, the KQ-200 (Y-8Q/GX-6), entered service in 2015 with the PLANAF. The KQ-200 hosts a magnetic anomaly detector, an electro-optical turret underneath housing a forward-looking infrared (FLIR) camera, a charge-coupled device (CCD) camera and laser rangefinder, and a chin radome with a surface search radar. Although not yet deployed in a military context, Chinese universities are experimenting with airborne LIDAR capabilities for monitoring and assessment of vegetative or marine environments, with the Shanghai Institute of Optics and Fine Mechanics claiming in 2019 to have tested a laser capable of penetrating 160 m below the surface of the sea.[308] Both capabilities have clear applications in ASW. The Y-9Q (GX-154) is the latest ASW aircraft to enter service. It possesses a larger redesigned nose radome with a possible SAR and a shorter magnetic anemology detector (MAD) than the KQ-200, providing all-weather surveillance and more sophisticated submarine detection.

- **EW/ELINT:** ELINT aircraft use remote sensing to detect and/or disrupt the use of the electromagnetic spectrum in rival assets. It thus enables the user to detect and locate an aircraft, vessel, or vehicle as well as to prevent the effective use of enemy sensors such as radar. For the PLA, the ELINT-capable Y-8CB, first seen in 2005, was the first special mission ELINT aircraft developed by China within the Gaoxin family. The Y-8CB has a large ventral canoe, which houses a KZ800 ELINT antenna that can detect, record, locate, and analyze radar, EW, and communications signals. The second aircraft in the Gaoxin series, the Y-8JB, features a large chin radome with surface search radar and also a KZ800 ELINT antenna. The Y-9JB is the eighth aircraft in the Gaoxin series and the third with an ELINT mission. It is based on the newer Y-9 airframe and features ELINT arrays and an electro-optic/infrared (EO/IR) turret, with a potential SAR in the nose cone.[309] The Y-9G (GX-11) is the newest ELINT aircraft in service, equipped with a new generation of electronic jammers and ELINT sensors, while the Y-9DZ (GX-12) is a modern communications intelligence aircraft with SAR and ELINT systems able to fulfill a wider range of ELINT missions.

- **Uncrewed systems**: The PLAAF and PLANAF now boast a range of strike and ISR uncrewed systems that can be fitted with multiple remote sensing capabilities, particularly FLIRs and SARs. The BZK-005 Chang Ying (Long Eagle) UAS has been in service since 2010 and can carry a combination of EO/IR cameras, a SAR, and an ELINT array. The GJ-1/2 Wing Loong also carries a FLIR and SAR alongside its air-to-surface weapons, as can many variants of the CH (Caihong, or Rainbow) series. The more recent Xianglong ISR and TB-001 strike UASs are also equipped with EO/IR sensors and SAR, while the next-generation JY-300 features an unusual fuselage conformal SAR along with other electro-optical sensors, underlining the ubiquity of these remote sensing capabilities on China's uncrewed systems.[310]

Of all of China's remote sensing military capabilities, UASs have proven the most successful export. The Wing Loong and Caihong series, for example, have been exported to 14 countries.[311] The fact that these users of Chinese UASs are all members of BRI underlines how remote sensing capabilities are part of the strategic and diplomatic benefit of defense exports.

- **Airborne radar and sensors:** Data on China's AESA and other airborne radars are scant in open sources. Defense intelligence firm Janes claims that the KJ-200 (GX-5) AEW&C aircraft has an E-band AESA radar that has a coverage of 240 degrees, while the newer KJ-500 (GX-10) aircraft has a 3.2 GHz AESA radar with 360-degree coverage.[312] AESA radars are now fitted into China's most modern fighter aircraft, including the J-15, J-16, and stealth J-20 and J-31. The latter two aircraft are equipped with the Type 14789 (export version: KLJ-7A), an X-band fire control radar. The KLJ-7A is in use with Pakistan's JF-17 aircraft and uses multiple arrays to provide 300-degree coverage and can simultaneously track ten targets and engage two up to a range of 105 km for objects with a radar cross-section of 5 sq m. Other sensors have also been developed for the PLA, such as infrared search and tracking systems (IRSTs), which do not emit radio waves and thus are less likely to alert enemy forces of an aircraft's location. IRSTs have been deployed on China's J-15 carrier-borne fighter aircraft and the J-16 twin-seat fighter aircraft, the latter using long-wave infrared sensors to increase range by up to 100 percent.[313]

  As a result, the PLA's aircraft are increasingly able to detect and track enemy aircraft, including stealth aircraft, while using AESA technology to maintain lower observability themselves. This makes PLA aircraft a more formidable opponent in air-to-air combat. Although open-source data do not exist on whether current Chinese radars would be able to detect advanced U.S. fighter aircraft such as the F-22 or F-35, the continued development of AESA and IRST technology makes it more feasible that China's fleet would be able to detect and track U.S. fighter jets.

Ground Vehicles

- **Autonomous vehicles:** As with other advanced militaries, the PLA is increasingly interested in the development of autonomous ground vehicles for a range of roles, including combat and reconnaissance.[314] Often utilizing electro-optical sensors, CCD cameras, and thermal imaging, vehicles such as the Sharp Claw series, Pathbreaker reconnaissance/fire support uncrewed ground vehicle (UGV), and the amphibious uncrewed combat vehicle offer remotely piloted options for a range of missions. Although these are nascent or in development, as China's uncrewed systems become more complex and increasingly autonomous, other remote sensing capabilities, such as LiDAR, will need to be integrated.[315]
- **Ground-based radar:** As with airborne radar, China has been developing increasingly complex ground-based radars in recent years, utilizing X-band, VHF, UHF, and AESA technology. This mix of radars allows the PLA to maintain broad situational awareness with air surveillance out to 500 km and over-the-horizon maritime surveillance.[316] This has particularly been the case in the South China

Sea, where the deployment of newer ground-based radars has been particularly noticeable and means Chinese-occupied features now host tens of radar stations.

In just one Chinese-occupied feature, Fiery Cross Reef, there are now 23 radomes housing various forms of ground-based radar. In total, the Spratly and Paracel islands host more than 80 radomes of many sizes, including long-range air surveillance radars, air traffic control radars, and surface movement radars. The multi-radar systems likely incorporate a mix of JY-27A VHF-band, YLC-8B UHF-band and SLC-7 L-band anti-stealth AESA radars as well as over-the-horizon 3D phased-array radars. These radars provide China with real-time, all-weather, persistent monitoring throughout the South China Sea, allegedly including the ability to detect stealth aircraft. In effect, it allows China to maintain situational awareness of the positioning of military vessels and aircraft in the South China Sea.[317]

Maritime Assets

- **Ship-based radar:** The PLAN has been indigenizing and improving the sophistication of its ship-based radars, an area previously reliant on Russian technology. The Type 366 radar is currently the most advanced surface search radar in use, providing detection ranges of up to 450 km in active mode. Development of fire control radars and air search radars are also improving China's targeting, close-in weapons systems, and ability to track multiple targets, such as aircraft and incoming missiles, at longer ranges.[318]

Comparison with U.S. Remote Sensing Capabilities

China's remote sensing capabilities have grown across all domains—space, air, maritime, and land—however, available data indicate they have not yet matched those of the United States. The U.S. military has launched and operates more military-grade remote sensing satellites and possesses far more remote sensing aircraft than the PLA. These assets have been in service for decades longer than China's capabilities and possess greater accuracy and resolution, suggesting a more sophisticated and diverse range of remote sensing capabilities.

The number of military satellites operated by the United States is classified. Nevertheless, the United States has been the leading developer and operator of space-based assets since the early years of the Cold War. As the Heritage Foundation notes, despite the classified nature of the information, open-source information on the number and sophistication of U.S. remote sensing satellites suggests that "the [Space Force's] position, navigation and timing (PNT); command and control (C2); communications (Comm); weather satellites; and intelligence, reconnaissance and surveillance satellites (ISR) are unrivaled by our peer adversaries and provide extraordinary capabilities."[319]

Various military agencies also rely on commercial satellite providers to develop and launch satellites and provide exclusive data from in-orbit satellites. The U.S. commercial satellite industry is dominant worldwide; the Satellite Industry Association estimates the United States accounts for 73 percent of the world's space business.[320] Nonetheless, China's commercial and military space-based remote sensing and communications infrastructure has grown dramatically over the last decade, with a particular focus on building out ISR capabilities. Again, according to the July 2024 Space Force Space Threat Fact Sheet, China launched 217 satellite payloads into space in 2023, 114 of which were ISR-capable satellites.[321]

The United States also boasts a much more extensive aerial ISR capability in terms of overall numbers. As an example, the *Military Balance 2023* lists more than 100 AEW&C airframes across the U.S. Navy and Air Force, compared to just over 50 for the PLA.[322] Similarly, the United States is operating over 130 ASW fixed-wing aircraft, in comparison to the PLA's 20.[323]

While this does not offer a comprehensive assessment of U.S. versus Chinese remote sensing capabilities overall, the United States has been operating more assets over a longer timeframe with new technologies fielded earlier than the PLA. These bilateral comparisons also do not consider allied assets the United States could draw upon, whether from NATO allies or allies in the Indo-Pacific.

Implications of the PLA's Remote Sensing for the United States

Since the first Gulf War in the early 1990s, China has attempted to replicate and compete with U.S. remote sensing capabilities to improve its precision-strike capabilities. The ability of the United States to launch joint force operations with extensive stand-off strikes against the Iraqi military was a wake-up call for the PLA, which perceived U.S. capabilities as a direct threat to its own defenses. Therefore, the PLA has spent 30 years investing significantly in its own remote sensing capabilities.[324]

While they do not yet exceed U.S. capabilities, side-by-side comparisons only offer part of the picture of the current and emerging challenges presented by China's advancing military and dual-use remote sensing capabilities. China's remote sensing capabilities are already sufficient to create a number of problems for U.S. forces in the Indo-Pacific, reflecting two primary reasons why the PLA does not need to have superior capabilities to create a significantly more contested environment.

First, U.S. assets are stretched across multiple theaters of operations and combatant commands. Two of these commands are currently involved in conflicts in Ukraine (U.S. European Command EUCOM and the Middle East CENTCOM) while the U.S. Indo-Pacific Command is actively engaged in efforts to deter China. RAND's August 2024 "Commission on the National Defense Strategy" report emphasizes how fighting—or even preparing to fight—across multiple theaters will stress the readiness of the U.S. force structure. The report recommends a "multi-theater force structure" but also acknowledges that this model does not meet "the dimensions of today's threat or the wide variety of ways in which and places where conflict could erupt, grow, and evolve."[325] While the PLA has taken on a more global role and vision for its operations in recent years, its most immediate military concern is in the Indo-Pacific.

Second, the PLA does not need to achieve parity or superiority in remote sensing capabilities to have increased its ability to pose challenges and dilemmas for U.S. and allied forces operating in the Indo-Pacific. China has achieved a sufficiency of capability that has improved its situational awareness and combat effectiveness and enabled a constant, all-weather ISR capability while ensuring more secure and robust command, control, and communications between its leadership and units and improving its target acquisition and engagement in a way that lessens risk to its own warfighters.

China's increased ability to monitor and surveil extends to the sub-sea environment, the most challenging domain for reconnaissance. China's ASW capabilities have historically lagged behind its broader ISR, with the 2022 DoD report on China stating that the PLA's ASW capabilities are "improving … through the development of its surface combatants and special mission aircraft, but it continues to lack a robust deep-water ASW capability."[326]

Modern and emerging technologies such as space-based or airborne LiDAR and quantum sensing could provide Beijing with such a capability, improving its ASW monitoring and tracking. When taken alongside other developments such as the fitting of towed-array sonars on surface and sub-surface vessels, it suggests the PLA is becoming more capable of deploying ASW assets to track rival submarines. This has potentially significant consequences for the United States' submarine presence in the South China Sea and Western Pacific, making it harder to conceal submarine movements.

Overall, China's improving remote sensing capabilities are likely to have several implications for U.S. national security, including**:**

- **Locating U.S. and allied mobile assets:** With a large network of satellites, improving airborne ISR, and greater ground-based and maritime radars, the PLA is now better able to locate, track, and target U.S. assets, including mobile platforms such as naval vessels. This is true both of U.S. combat capabilities as well as combat support capabilities, such as resupply and logistics chains that will be a key aspect of any protracted potential conflict in a geographically sprawling region lacking easy or uncontested supply routes. The resulting threat to U.S. and allied naval, air, and ground assets will be amplified by advancements in China's missile targeting systems and increased range and precision of its missile force.
- **Tracking U.S. and allied deployments:** With all-weather satellite capabilities and near-constant monitoring through a web of early warning and ISR assets in space, in near space, in the air, on the ground, and at sea, it will be more challenging for the United States to hide, move, or deploy equipment without detection. This should provide the PLA with greater awareness of U.S. force posture and logistics plans and activities, which may affect the United States and allies' ability to deter China in an emerging military or national security crisis or territorial dispute. China's improved ability to track U.S. and allied forces is especially worrisome for the United States and its allies, as it could offer a counter to recent DoD efforts to disperse forces in the region to make them more difficult to locate, track, and target.
- **Developing new autonomous capabilities:** Wider use of remote sensing in Chinese uncrewed systems will remove the human operators from platforms, reducing risk to human operators that cannot easily be replaced. Removing these risks can increase the willingness to use uncrewed assets in dangerous or escalatory situations, such as cross-border uncrewed strikes. Further, the development of autonomous vehicles and vessels, supported by remote sensing, will provide China with new capabilities such as loyal wingmen and swarming systems that provide mass and can operate in ways that may complicate U.S. operational concepts, force protection measures, and strike capabilities.
- **Knowing the environment:** China's increasingly accurate remote sensing should translate into improved spatial intelligence and mapping. These data should improve the PLA's ability to operate safely, en masse and at speed, even in difficult terrain and environments.[327]
- **Striking U.S. and allied assets with greater range and precision:** China's satellite network is now able to provide more accurate space-based positioning, navigation, and location information to assist precision fires, particularly long-range precision-guided missiles. In addition, the growing range of Chinese radars is enabling a greater over-the-horizon capability to detect and track targets. In direct combat, therefore, U.S. forces may now face a greater challenge in being able to approach and engage Chinese forces. Moreover, increased PLA strike range will pose additional challenges to U.S. force survivability and may lead the United States to operate at greater stand-off range.
- **Blinding U.S. and allied forces:** China's growing space capabilities, remote sensing assets, and EW capabilities can combine to disrupt and undermine U.S. command and control during conflict. Space-based and airborne ISR and ELINT capabilities could identify and monitor U.S. radar, communications, and command systems, using EW aircraft to disrupt their operations or precision strike to destroy them. The effect would be to make U.S. forces "fight blind" and remove key enablers that support U.S. operations.

The consequences of this improved Chinese capability for U.S. deployment and posture were highlighted by comments from Chief of Space Operations General B. Chance Saltzman in March 2024 when he stated that China "has more than 470 ISR satellites that are feeding a robust sensor-shooter kill web … this new sensor-shooter kill web created unacceptable risk to our forward-deployed force."[328] Major General Greg Gagnon, deputy chief of Space Operations for Intelligence, echoed this assessment at the Air and Space Force Association's annual Air, Space, and Cyber Conference in September 2023. General Gagnon observed that China's rapid development of sensing technologies and deployment of remote sensing satellites has allowed the PLA "to see much further with greater precision at day and at night and through all weather" leading to Chinese forces "extending their weapons engagement zone" and creating "a profound shift in the operational problem [the United States faces] in the Western Pacific"[329]

Currently, the PLA retains the capability to monitor the western Pacific with persistent, all-weather ISR, providing the ability to track objects the size of a car across much of its near-abroad. Its PNT satellite network has improved its ability to target U.S. assets with precision munitions across the region. In the short term, China's continued aggressive launch schedule and increasing numbers of SAR, hyper/multispectral, and other ISR satellites mean it can track not only slow-moving and large naval vessels but also faster-moving and smaller aircraft, while investment in next-generation technology such as LiDAR may see the PLA surpass the United States in certain uses in the near term. Over the longer term, China's investment in next-generation technologies and expansion of its special-mission aircraft program may provide the ability to monitor the sub-sea environment more effectively, meaning even U.S. submarines will be more vulnerable to monitoring. Other remote sensing capabilities such as ELINT/EW aircraft could disrupt the U.S. ISR network, which when combined with anti-satellite weapons could effectively "blind" U.S. forces.

Thus, while PLA capabilities in many of these areas currently lag behind those of the United States, development has been rapid in China and continues apace. This means that in the short to medium term, China may move from being a near-peer competitor in remote sensing to becoming a rival and even overtaking the United States as the leader in select remote sensing capabilities.

Chapter 7: Recommendations

Based on our research findings, our team has built five categories of recommendations for mitigating the risks associated with the technological development, market positioning, military relevance, and use of China's remote sensing capabilities. Overall, these recommendations endorse the need to balance the use and expansion of export controls with constructive and proactive approaches designed to incentivize and catalyze investment in market-competitive U.S. remote sensing solutions.[330]

Promote U.S. remote sensing development and investment: One key area for policy correction is to create conditions in which the United States can compete more effectively with China, especially in emerging technologies such as LiDAR or quantum sensing, markets, and military applications of remote sensing. Enhancing security of domestic supply of key remote sensing technologies reduces the vulnerability of the United States to economic and supply chain coercion and, potentially, other more explicit defense and national security risks.

- **Recommendation 1:** Congress should consider regulatory and financial measures to support the domestic remote sensing and drone industry, incentivize investment in areas such as LiDAR remote sensing for autonomous systems and higher-risk next-generation remote sensing technologies such as quantum sensing. This could include expanding targeted funding for the National Science Foundation, Small Business Innovation Research (SBIR), Small Business Technology Transfer (STTR), and Office of Strategic Capital (OSC) as well as using investment credits and creating or sustaining scaled government procurement opportunities for small drones.
- **Recommendation 2:** Congress should consider legal and financial incentives (tax incentives) to support the United States' ability to accelerate development and scaling of a domestic workforce with expertise on critical components of advanced remote sensing *and* to attract and retain talent from abroad to work in the U.S. remote sensing and connected industries, such as space.

Ensure data security: There is a need for more clarity about the dimensions of the risks to U.S. economic and national security at two levels. First, while our research indicates Congress should continue to take seriously and address the data security risks associated with the use of Chinese LiDAR on autonomous vehicles and Chinese drones in a range of function , it also uncovered multiple and even conflicting perspectives on the scale and dimensions of these risks. Technical resolution from a trusted third party about the scale and mechanisms of this risk is required. So, too, is more transparency into the risks associated with DoD's use or potential use of Chinese LiDAR systems in order to ensure that policy prescriptions address the correct problems in the most efficient ways. Second, while U.S. corporate awareness of the risks of joint ventures in China has increased in recent years, it is still insufficient, in many cases increasing the vectors through which China can target U.S. technology and IP.

- **Recommendation 3:** Congress should mandate a focused and technical study on the nature of the data security and DoD supply chain risks associated with use of Chinese-made LiDAR in vehicles operating in the United States. The House Select Committee on Strategic Competition between the United States and China should also consider holding hearings on the topic.
- **Recommendation 4:** Congress can encourage government entities, industry, and external experts to facilitate the development of training for business and academic leaders of the risks of engagement with China and implications of the National Intelligence Law. Congress should actively encourage the development of internal corporate resources to mitigate the risks of business ventures with Chinese companies and implications of China's National Intelligence Law. In addition, Congress

could make it a requirement for companies to divulge the full terms of a venture to CFIUS to determine if they grant Chinese firms access to critical data or IP. Congress should also hold hearings on this topic to include representatives of government entities, industry, and national security experts to better articulate risks associated with U.S. businesses engagement in China and possible mitigation strategies.

- **Recommendation 5:** Congress should consider standardizing regulations on the access, collection, and storage of infrastructure data related to roads, terrain, and infrastructure.

Engage allies and partners: U.S. responses to China's remote sensing development and the economic, national security, and military risks this development could entail will be significantly more effective if they incorporate allies and partners. As imperfect as CFIUS regulations are, they are stronger than the export control and investment approaches of many close U.S. allies, potentially offering Chinese investment and technology firms a way to acquire advanced remote sensing technology without having to deal with CFIUS. Allies and partners can also play a crucial role by coordinating efforts to counter the impacts of the PLA's improved remote sensing and terrestrial and undersea mapping through joint military planning and deployments as well as countering the growing reliance on China in some countries and regions for remote sensing capabilities and the influence that garners for Beijing.

- **Recommendation 6:** Congress should encourage DoD to increase research collaboration with its European and Pacific allies—many of whom are global leaders in remote sensing technology development—and establish a framework to safeguard defense-critical technology and knowhow from being illicitly or surreptitiously acquired by China.
- **Recommendation 7:** Congress should encourage DoD to work closely with allies and partners in the Indo-Pacific and Europe to better understand how China's remote sensing capability might be employed in a crisis or security contingency and what capabilities or operational concepts might help reduce allied vulnerability. Congress should further encourage DoD to use wargames and futures-focused exercises to iteratively and collectively create a shared understanding of the problem and of potential solutions. Additionally, Congress should support DoD efforts to accelerate the procurement of commercial remote sensing and supporting data process software from both the United States and, where applicable, allied nations.
- **Recommendation 8:** Congress should consider ways in which the United States can expand cooperation with allies and partners in countering or dampening the soft-power impact of China's sale of or collaboration in remote sensing capabilities, particularly in Latin America, Africa, and the Middle East.

Expand export and investment controls: Reliance on CFIUS by the U.S. government to reduce risks of Chinese technology acquisition and other national and economic security vulnerabilities is not sufficient. However, it can be a useful tool, especially if it is updated to focus on technologies of interest to this study more explicitly.

- **Recommendation 9:** Congress should revisit the Foreign Investment Risk Review Modernization Act (FIRRMA) and apply it to other critical technologies associated with remote sensing. It should also look to empower CFIUS to address legal loopholes that allow PRC shell companies to operate in legal gray zones and still invest in or acquire U.S. technology.
- **Recommendation 10:** Congress should consider updating the 2003 U.S. Commercial Remote Sensing Space Policy (CRSSP). While the 2003 presidential directive is the starting point for U.S.

regulation of commercial activity, the global remote sensing market has undergone significant changes since it was enacted. Congress should engage with industry to revise the directive and codify into law an update to the policy as it relates to competition with the PRC.

Mitigate risks to the U.S. military: Remote sensing is improving the Chinese military's ISR capabilities and the effectiveness of its precision-guided munitions, undermining the ability of U.S. forces to deploy without detection and threatening those deployments in conflict. This raises the question of whether U.S. and allied forces in the Indo-Pacific are sufficiently prepared with base hardening, counter-UAS capabilities, counter-ASW capabilities, air defense, stealth, and various other requirements needed to evade or defeat China's improving remote sensing capabilities.

- **Recommendation 11:** Congress should press the armed forces for greater clarity on how the U.S. military will meet the challenge from a more situationally aware PLA and how improved remote sensing will affect deployments in the Indo-Pacific region. Congress should also consider requiring DoD to provide a closed-door update on the Joint Warfighting Concept (JWC) and how this concept is addressing concerns over the advancement of China's military and commercial remote sensing capabilities.
- **Recommendation 12:** Congress should consider including funding in future defense appropriation bills for measures that would mitigate the effects of improved Chinese remote sensing such as counter-ISR systems, electronic attack and cyber capabilities, anti-radiation ordnance, base hardening, close-in weapons systems, and air defense capabilities.

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