Connection of Private Remote Sensing Market with Military Contracts – the Case of Ukraine

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Kostenko, Inesa and Anna Hurova (2024) Connection of Private Remote Sensing Market with Military Contracts – the Case of Ukraine. *Advanced Space Law*, Volume 13, 4-20. https://doi.org/10.29202/asl/13/1

The Russian invasion of Ukraine has underscored the strategic importance of advanced space technologies in modern warfare. This paper examines the pivotal role of the private remote sensing market in supporting military operations, particularly through satellite imagery and synthetic aperture radar (SAR) technology. By leveraging high-resolution commercial satellite data, Ukraine has significantly enhanced its situational awareness and operational effectiveness despite lacking sovereign space capabilities. The study explores the integration of private remote sensing services into military contracts, their benefits, and the implications for future conflicts and space policy. It also addresses the challenges of data sovereignty, transparency, accountability, and the ethical use of satellite imagery. This research employs a multi-faceted approach, including a comprehensive literature review, case study analysis, and qualitative assessments of current remote sensing technologies and their applications in military and humanitarian contexts. Key sources include peer-reviewed articles, government reports, and accounts from industry experts. The study also examines the regulatory frameworks governing remote sensing data and the evolving relationship between private companies and governmental agencies.

Keywords: remote sensing, satellite imagery, synthetic aperture radar (SAR), military operations, data sovereignty, ethical guidelines, space policy, commercial satellite technology.

Received: 20 April 2024 / Accepted: 12 May 2024 / Published: 1 July 2024

Introduction

On 24 February 2022, Russia's invasion of Ukraine marked a significant escalation in the ongoing conflict, underscoring the strategic importance of integrating advanced technologies into military operations (Höyhtyä & Uusipaavalniemi, 2023). This conflict has highlighted the crucial role of outer space in modern warfare. Although the use of space technology in military operations dates back to the 1991 Persian Gulf War (often referred to as the "first space war" due to the use of global positioning systems and other space-based technologies), the Russo-Ukrainian war represents a new dimension as both sides leverage space-based resources (Burbach, 2022). The Russian aggression against Ukraine has brought significant attention to the role of satellite imagery in armed conflicts. Satellite images, once primarily used for military and intelligence purposes, now permeate all aspects of armed conflict. Their importance in influencing the course of conflicts will continue to grow as advancements in deep learning make automated analysis increasingly feasible (Sticher et al., 2023). Emerging technologies have already played a crucial role in this conflict, including arms control monitoring and the use of satellite imagery. Satellite images have provided critical information on urban changes and damage assessments, as evidenced by studies of the Mariupol conflict (Huang et al., 2023). These technologies have enabled enhanced real-time monitoring and assessment of battlefield conditions and infrastructure damage, facilitating both military and humanitarian responses. Even longtime industry veterans like Stephen Wood, an imagery analyst who has spent the last 22 years with Maxar, are awestruck – and often horrified – by what they are seeing. Wood, currently the senior director of the Maxar News Bureau, which provides satellite imagery and analytics to news organisations to inform news coverage, notes, "We have been doing this since the beginning of the launch of our satellites, from September 11 with the first overhead images of the World Trade Centre towers to the conflicts in the Middle East to the aftermath of the Japanese tsunami," he tells Via Satellite. "The war in Ukraine has elevated satellite imagery, particularly the data we've been providing, to a level never seen before. I'd even say that this war is probably the most documented in history. I've been looking at a lot of these types of conflicts for many, many years, and I've never seen the avalanche of data we have today" (Torrieri, 2022). Wood is not alone in his view that the role of high-resolution commercial satellite imagery in the Ukraine conflict is unprecedented. The extensive use of satellite imagery has not only provided real-time battlefield intelligence but also fostered a level of public transparency and awareness unprecedented in modern conflicts (Albon, 2022). This transparency has influenced global public opinion and policy decisions, further illustrating the power of satellite technology in contemporary warfare. An important aspect of this conflict is the commercialization of space technology in military contracts, exemplified by the deployment of Starlink terminals to support communication capabilities in the early days of the Russian invasion of Ukraine.

This development highlights the growing importance of commercial space technologies in modern warfare and their potential implications for future conflicts. The integration of these technologies has raised new questions and challenges regarding the regulation of satellite data, information privacy, and the potential for espionage abuses (Vaynman, 2021). Understanding these dynamics is crucial to developing effective space policies and strategies. The war against Ukraine has shown the vital importance of SATCOM, PNT, and EO/ISR services to situational awareness and command and control (C2) on the modern battlefield. It has also demonstrated the convergence of competition in space with the contest to achieve information and decision advantage. Russian attempts at jamming, spoofing, or hacking satellite networks supporting the

Ukrainian Armed Forces have been a feature of the war since its outset. In February 2022, for example, only an hour before the invasion, Russia launched a cyberattack on the ground-based infrastructure of ViaSat's KA-SAT network, causing thousands of European users, including the Ukrainian government and military, to experience widespread disruption. Though the Ukrainians were able to adapt quickly to this attack, with Western help, the ViaSat incident presaged the central role that commercial space systems would come to play in supporting the early Ukrainian war effort.

Even 15-20 years ago, access to space capabilities was limited to only the most powerful states, primarily the US, China, and Russia, with even major economies and global players such as the UK, France, Germany, or Japan having only a handful of military satellites. Since the invasion in February 2022, however, Ukraine has been able to offset its lack of sovereign space capabilities by buying in commercial data and services from a fast-burgeoning market, primarily from private US companies (Ogden et al., 2024). The proliferation and sophistication of such commercial space services provide huge opportunities for Ukraine, enabling it to compete in and through the space domain. Even for better-funded militaries with their own ISR constellations, commercial EO satellites can provide more coverage, added redundancy, and improved revisit rates compared to high-demand, low-density government-owned satellites. Such commercial assets supplement the sensing capabilities of government systems, reducing costs and offering capabilities such as electro-optical sensors, synthetic aperture radar (SAR), and AI-assisted data analytics and mapping (Ogden et al., 2024). This paper aims to examine the relationship between the private remote sensing market and military operations, using Ukraine as a focal point. It investigates the impact of new technologies, particularly satellite imagery, on arms control monitoring. High-resolution optical and synthetic aperture radar (SAR) satellites have significantly improved the ability to accurately monitor urban change in conflict zones (Vaynman, 2021). For instance, satellite data from Mariupol revealed significant urban damage, providing critical information for humanitarian and military assessments (Huang et al., 2023). This progress has enabled rapid and accurate damage assessments even in the absence of ground surveys (Huang et al., 2023). Thus, there is the critical intersection between the private remote sensing market and military operations. The use of satellite imagery to monitor urban changes and assess damage in conflict zones exemplifies the significant role of new technologies in modern warfare (Huang et al., 2023). As the commercial space sector continues to grow, its relationship with military contracts is likely to deepen, raising important considerations for future space policies and strategies.

The benefits of private remote sensing services

Private suppliers of remote sensing data offer significant advantages that enhance military operations, especially in conflict zones like Ukraine. These benefits include high-resolution imagery, synthetic aperture radar (SAR) capabilities, 24/7 surveillance, and automated, customer-focused processes. This section discusses these benefits in detail.

High-resolution imagery

One of the primary advantages of private remote sensing services is their ability to capture high-resolution imagery. Commercial satellites can achieve resolutions as fine as thirty centimeters, and with advanced processing, some can even reach ten centimeters. According to Wood (2022), this level of detail is indispensable for reconnaissance, surveillance, and

monitoring activities during conflicts. High-resolution images enable decision-makers to track the movement of materials across land, sea, and air, from military assets to humanitarian supplies, thereby providing actionable insights for strategic planning and real-time responses (Torrieri, 2022). These precise imaging capabilities have proven invaluable in various sectors, including environmental monitoring and mining, where satellite data are crucial for mapping and tracking changes over time (Borotkanych, 2022). In addition to their military applications, high-resolution images are essential in civilian contexts. For instance, optical images from the Sentinel-2 satellite have been instrumental in damage assessment following natural disasters. These images facilitate the detection of changes in urban areas, such as the extent of fires and damaged buildings, thus aiding rapid response and recovery efforts (Aimaiti et al., 2022). Furthermore, remote sensing data have been pivotal in monitoring environmental impacts, such as the increased air pollution caused by fires in Ukraine (Shevchuk et al., 2022).

Synthetic Aperture Radar (SAR)

SAR technology marks a significant advancement in remote sensing. Unlike optical sensors, SAR can penetrate cloud cover and operate effectively in darkness, making it particularly useful for monitoring the movement of people, tanks, and other materials under diverse weather conditions. This capability is critical for continuous surveillance and reconnaissance, providing vital data that optical sensors might miss. SAR data enable the detection of missile movements and GPS jamming, offering comprehensive situational awareness (Torrieri, 2022). The mining industry employs SAR technology to monitor slope stability and detect terrain changes, thereby ensuring operational safety and efficiency (Borotkanych, 2022). The utility of SAR extends to urban conflict zones, where it can accurately assess building damage. For example, SAR imagery was effectively used to map damage in Kyiv, Ukraine, highlighting its potential in war-related damage assessment (Aimaiti et al., 2022). By combining SAR and optical data from Sentinel-1 and Sentinel-2, limitations posed by adverse weather conditions can be overcome, providing a comprehensive picture of affected areas. Additionally, SAR's ability to detect environmental impacts, such as water pollution from destroyed hydraulic structures, underscores its versatility in both military and environmental monitoring contexts (Shevchuk et al., 2022). Highlighting the practical applications and importance of SAR technology, Payam Banazadeh, CEO of Capella Space, explains: "We have been super active in Ukraine, for example. When the invasion started, it was cloudy over Ukraine a lot, so optical sensors were not usable a large portion of the time. As a result, SAR became one of the most important tools for monitoring the situation in real time" (Gangware & Swartz, 2023). This example underscores SAR's critical role in providing reliable, real-time data under challenging conditions, further cementing its value in various high-stakes scenarios.

24/7 surveillance

The integration of SAR and electro-optical remote sensing satellites ensures round-the-clock monitoring of the Earth. This 24/7 surveillance capability is akin to having "body cameras for our planet," as described by Rafal Modrzewski, CEO of Iceye, a Finnish SAR company (Torrieri, 2022). The ability to continuously observe and record ground activities enhances situational awareness and the operational effectiveness of military forces. This continuous monitoring proved particularly beneficial during the initial stages of the Russian invasion of

Ukraine, where Maxar's satellite imagery provided critical information about the infamous 40-mile convoy approaching Kyiv (Torrieri, 2022). In other contexts, such as environmental monitoring, continuous surveillance allows timely detection and assessment of natural disasters, facilitating rapid response and mitigation efforts (Sergieieva, 2024). Continuous surveillance is also essential for tracking the environmental impact of military conflicts. For example, ongoing monitoring of fires and smoke plumes in Ukraine has provided valuable data on air quality and environmental damage (Shevchuk et al., 2022). This capability supports natural resource management and disaster response by enabling prompt and informed decision-making.

Automated customer-oriented processes

Another benefit of private remote sensing services is their emphasis on customer-oriented, automated processes, from the initial request to the delivery of interpreted products. Services like Spymesat.com exemplify this approach, ensuring that users can efficiently obtain the necessary data tailored to their specific needs. This streamlined process enhances the utility of satellite imagery, making it more accessible and actionable for various stakeholders, including military planners and humanitarian organizations. In the mining sector, automated processes facilitate rapid analysis and distribution of data, enabling companies to make informed decisions quickly and effectively (Borotkanych, 2022). Automated processes also enhance the effectiveness of environmental monitoring. Automated data analysis has been crucial in assessing the environmental consequences of the Russia-Ukraine war, allowing for the rapid detection and evaluation of pollution events and habitat destruction (Shevchuk et al., 2022). This approach guarantees the swift processing and dissemination of pertinent data, thereby facilitating timely interventions and policy responses.

Case studies and impacts

The practical applications of these advantages are evident in several case studies full-scale Russian invasion in Ukraine. For instance, the high-resolution imagery provided by Maxar played a crucial role in documenting and verifying the massacre in Bucha. As Russian forces occupied and then withdrew from Bucha, videos surfaced showing Ukrainian civilians lying dead in the streets. Maxar's satellite imagery verified the date, time, and location of these bodies, corroborating the authenticity of the footage and aiding in refuting Russian authorities' claims of staged videos (Torrieri, 2022).

Similarly, SAR technology has been instrumental in tracking the movement of Russian forces and materials, offering a continuous stream of data even under adverse weather conditions. This capability has been essential for both military strategy and humanitarian efforts, ensuring that accurate and timely information is available for decision-making. In the realm of environmental monitoring, the use of satellite imagery has been critical in assessing the impact of mining activities and ensuring compliance with environmental regulations (Borotkanych, 2022).

The impact of remote sensing extends to broader environmental monitoring efforts. For instance, the war against Ukraine has largely relied on the analysis of remote sensing data to identify and quantify environmental damage, such as water body pollution and fire spread (Shevchuk et al., 2022). These case studies highlight the transformative potential of remote sensing technologies in various applications beyond military operations.

Comprehensive benefits beyond military applications

The advantages of private remote sensing services extend well beyond military applications. Environmental monitoring uses high-resolution imagery and SAR capabilities to track deforestation, monitor wildlife habitats, and assess coral reef health. Continuous surveillance enables early detection of illegal activities such as poaching and logging, allowing for timely interventions. Automated processes expedite the analysis and dissemination of environmental data to pertinent authorities and organisations, thereby bolstering conservation efforts (Sergieieva, 2024).

In disaster response, the ability to obtain real-time, high-resolution images is crucial for assessing damage and planning rescue operations. After natural disasters such as earthquakes, floods, and hurricanes, remote sensing data can provide detailed maps of affected areas, guiding emergency responders to the most impacted zones. The integration of SAR technology allows for effective monitoring even during adverse weather conditions, ensuring that critical information is available when it is most needed (Sergieieva, 2024).

The advantages of private remote sensing services, including high-resolution imagery, SAR capabilities, 24/7 surveillance, and automated processes, have significantly enhanced the ability to monitor and respond to dynamic situations in conflict zones and other critical areas. The ongoing Russian invasion in Ukraine has underscored the importance of these technologies, highlighting their potential to transform military operations and other applications such as environmental monitoring and disaster response.

In summary, the integration of high-resolution imagery and SAR technology provides unparalleled situational awareness, essential for modern military operations. Continuous surveillance and automated, customer-oriented processes ensure that data is both timely and actionable, enhancing decision-making in critical situations. The demonstrated impact of these technologies in Ukraine and other areas underscores their transformative potential.

Government as a priority customer

The expanding role of private remote sensing services underscores the significance of government contracts. Governments have emerged as the primary customers for private remote sensing companies due to their urgent and large-scale needs, driven by geopolitical tensions and the existential nature of the problems they face. This chapter explores why government markets are prioritised, how they influence the growth of the remote sensing industry and the potential future trajectory of this relationship. One of the primary reasons private remote sensing companies focus on government contracts is the maturity and scale of these markets. Government agencies, particularly those involved in defense and intelligence, have well-established infrastructures and substantial budgets dedicated to acquiring high-resolution satellite imagery and other remote sensing data. As noted by Payam Banazadeh, CEO of Capella Space, "Today we're primarily focused on government markets because they're mature, they are supply constrained, and they face problems that are often existential, which creates an urgency to move fast on products that can help solve them. They are also massive markets growing at a pretty high rate because of geopolitical tensions" (Gangware & Swartz, 2023). The urgency associated with government needs arises from the critical nature of national security and defense operations. For example, during the Russian invasion of Ukraine, the immediate deployment of Starlink terminals for communication support highlighted the necessity for rapid technological integration in military contexts (Torrieri, 2022). This urgency drives governments to invest heavily in advanced remote

sensing capabilities to gain real-time intelligence and maintain strategic advantages (Höyhtyä & Uusipaavalniemi, 2023). Geopolitical tensions significantly boost the demand for advanced remote sensing technologies. The ongoing Russian aggression against Ukraine exemplifies how such tensions can escalate the need for continuous monitoring and assessment of battlefield conditions. High-resolution imagery and synthetic aperture radar (SAR) capabilities provided by private companies have proven invaluable for military intelligence, urban damage assessments, and humanitarian responses (Vaynman, 2021; Huang et al., 2023). Banazadeh's assertion that government spending on remote sensing is increasing despite global economic challenges further underscores this point. "Despite the global macroeconomic situation, government spending is not decreasing. The demand has gone up significantly across the board for our SAR capabilities, in part because of what is happening in Ukraine" (Gangware & Swartz, 2023). This consistent and growing demand ensures that government contracts remain a stable and lucrative market for remote sensing companies. The integration of high-resolution optical and SAR technologies into governmental frameworks addresses significant supply constraints. Government agencies often require large volumes of data to monitor and respond to dynamic situations, such as military conflicts, natural disasters, and environmental changes. The ability of private remote sensing companies to meet these demands through advanced satellite constellations and continuous surveillance capabilities is crucial (Gangware & Swartz, 2023). Furthermore, these technologies' scalability to meet large-scale government needs is evident. For instance, the significant increase in satellite imagery collection and the expansion of satellite constellations by companies like Capella Space demonstrate their capacity to manage extensive government contracts (Gangware & Swartz, 2023). This scalability is vital for maintaining operational effectiveness in diverse and high-stakes scenarios.

Engagement of private remote sensing data suppliers with governmental and intergovernmental projects

The integration of private remote sensing data suppliers into governmental and intergovernmental projects has significantly expanded in recent years. This section explores various examples of such engagements, highlighting the strategic benefits and implications for military and non-military applications.

National reconnaissance office

The National Reconnaissance Office (NRO) has been pivotal in leveraging commercial remote sensing capabilities. In January 2022, the NRO awarded contracts to five companies – Airbus U.S., Capella Space, ICEYE U.S., PredaSAR, and Umbra – to provide synthetic aperture radar (SAR) imagery. These contracts aim to validate commercial SAR capabilities and integrate them into national geospatial intelligence missions (Strout, 2022). The focus on SAR technology is particularly notable because it can operate in all weather conditions and provide critical data on material properties and precise movements, which is invaluable for intelligence missions.

These initial six-month contracts, with options to extend up to 30 months, emphasise the NRO's commitment to quickly scale up based on operational needs and the performance of the providers. The ability to rapidly procure and validate commercial SAR data enhances the NRO's flexibility and capacity to respond to dynamic global situations (Strout, 2022).

In May 2022, the NRO further expanded its engagement with commercial remote sensing companies by awarding 10-year contracts to BlackSky, Maxar, and Planet. This substantial

investment is part of the NRO's largest commercial contracting effort to date. These contracts are designed to secure a steady supply of high-resolution satellite imagery to support a wide range of intelligence and reconnaissance operations (Erwin, 2022).

Maxar has been a significant contributor to U.S. government projects. The company was awarded a renewal of its Global Enhanced GEOINT Delivery (G-EGD) contract in September 2022, ensuring continued access to mission-ready satellite imagery for various U.S. government agencies (Maxar, 2022). Maxar's high-resolution imagery has been instrumental in monitoring geopolitical developments and environmental changes, showcasing the critical role of commercial providers in enhancing national security and operational effectiveness.

NATO's Alliance Persistent Surveillance from Space (APSS)

The North Atlantic Treaty Organisation (NATO) has also engaged with commercial remote sensing data suppliers through its Alliance Persistent Surveillance from Space (APSS) initiative. This program aims to integrate commercial satellite capabilities into NATO's surveillance and reconnaissance operations, providing member states with enhanced situational awareness and operational readiness (NATO, 2023). The APSS leverages high-resolution imagery and SAR data from commercial providers to monitor global hotspots, detect potential threats and support humanitarian missions.

Broader implications and future directions

The involvement of private remote sensing data suppliers in government and intergovernmental projects highlights a significant shift towards leveraging commercial space capabilities for strategic advantages. These collaborations offer several benefits:

- Enhanced flexibility and capacity: government agencies can rapidly procure high-resolution imagery and SAR data to address urgent needs and dynamic situations.
- Innovation and resilience: leveraging commercial technologies drives innovation and ensures that the best available capabilities are integrated into national and international security frameworks.
- Operational efficiency: automated, customer-oriented processes streamline the acquisition and dissemination of critical data, supporting timely decision-making and effective responses.

Collaborations between commercial satellite imagery providers and governmental organisations are not limited to the NRO and NATO. The broader scope includes partnerships with various international bodies and other national governments. For example, in December 2023, the NRO signed agreements with five commercial suppliers of electro-optical imagery – Airbus U.S., Albedo Space, Hydrosat, Muon Space, and Turion Space. These agreements allow the NRO to assess and potentially integrate these companies' products into their operations, further diversifying the range of available satellite data (Erwin, 2023).

As geopolitical tensions and global challenges continue to evolve, the reliance on commercial remote-sensing data suppliers is expected to grow. Future space policies and strategies will likely emphasise further integration of commercial capabilities, ensuring that government agencies can maintain a strategic edge in intelligence, surveillance, and reconnaissance operations (Strout, 2022; Erwin, 2022).

In summary, the engagement of private remote sensing data suppliers with governmental and intergovernmental projects has proven to be a transformative approach to enhancing situational

awareness, operational effectiveness, and strategic readiness. The ongoing collaborations with the NRO and NATO exemplify the significant potential of commercial satellite technologies in addressing both military and non-military challenges.

Future trajectory and dual-use growth

While government markets are the current priority for private remote sensing companies, the commercial market is rapidly emerging as a significant growth driver. Banazadeh highlights the dual-use growth roadmap, indicating that while the focus remains on government customers, the commercial market is expected to eventually match or exceed government demand. "We see government being a key customer for a very long time – in fact, forever – but the commercial market is picking up quickly and will be a significant growth driver in the coming years" (Gangware & Swartz, 2023).

This dual-use approach ensures that private remote sensing companies can diversify their revenue streams and mitigate risks associated with reliance on a single market segment. As the commercial market for remote sensing technologies continues to grow, driven by applications in agriculture, environmental monitoring, urban planning, and disaster response, the interplay between government and commercial markets will shape the future landscape of the industry (Huang et al., 2023; Shevchuk et al., 2022).

Investment and technological advancements

Significant investments in technology and infrastructure are essential to meet the growing demands of government customers. Private remote sensing companies have leveraged substantial capital to expand their satellite constellations and enhance their data processing capabilities. The investment in technology not only supports the current operational needs but also paves the way for future advancements, such as the fusion of multiple sensor types and the development of new analytics capabilities (Gangware & Swartz, 2023).

The integration of different sensor technologies, including optical, SAR, and other emerging modalities, will enhance the versatility and applicability of remote sensing data. This technological fusion will address the diverse needs of government customers, providing comprehensive and actionable intelligence across various domains (Gangware & Swartz, 2023).

The relationship between the private remote sensing market and government contracts is pivotal for the ongoing development and application of advanced satellite technologies. Governments, with their mature, urgent, and large-scale needs, provide a stable and significant market for remote sensing companies. The current geopolitical landscape, exemplified by the war against Ukraine, further amplifies the demand for real-time and high-resolution data, underscoring the importance of government customers in this sector (Höyhtyä & Uusipaavalniemi, 2023; Burbach, 2022).

As private remote sensing companies continue to innovate and expand their capabilities, the dual-use growth strategy will ensure that both government and commercial markets benefit from these advancements. The future trajectory of the industry will be shaped by the integration of diverse sensor technologies, increased investment in infrastructure, and the evolving needs of government and commercial customers alike (Gangware & Swartz, 2023).

Ukraine's current capabilities and challenges in space

Ukraine's space capabilities are deeply rooted in its significant technological heritage, which traces back to its Soviet-era achievements. During this period, the Ukrainian SSR played a crucial role in the development and construction of satellites, with key contributions from the Kharkiv Kommunar and Monolit plants, Kyiv's Arsenal factory, and the Evpatoria Space Center. These institutions were instrumental in launching the first satellite into orbit in 1957. Notably, the OKB-586 workshops, now known as the Pivdenne Design Bureau, established the production line for Dnipro a satellites, also known as Cosmos and Intercosmos (Polyakov, 2023).

Following its independence, Ukraine aspired to develop its satellites. However, the country faced significant challenges, including a lack of orders and an outdated industrial and technical base, remnants of its Soviet legacy. Despite these hurdles, recent advancements in the private aerospace sector have shown promise. Both state and private firms have successfully launched Ukrainian-developed satellites, marking a positive turn in the country's space endeavors (Polyakov, 2023).

A notable achievement in Ukraine's independent satellite history is the Sich series. Following the dissolution of the USSR, Ukraine leveraged its agricultural prowess by utilizing satellite technology to monitor farmland conditions. This initiative led to the creation of the Sich satellites, beginning with Sich-1 in 1995. Developed by the A.M. Makarov Pivdenne Machine Building Plant, Sich-1 provided valuable data on vegetation, soil, water bodies, and other physical and geological structures. Its success extended until 2001, surpassing its planned operational life (Polyakov, 2023).

Building on the success of Sich-1, Ukraine launched Sich-1M in 2004, featuring improved optical capabilities. This was followed by Sich-2 in 2011, which was equipped with advanced scientific equipment for studying space plasma and the Earth's upper atmosphere. Unfortunately, Sich-2's mission was cut short due to a power supply anomaly in 2012. The latest satellite, Sich-2-30, launched in 2022, faced communication challenges that limited its operational capabilities. Despite these setbacks, the Sich series exemplifies Ukraine's persistent efforts in space technology (Polyakov, 2023).

Ukraine had ambitious plans to launch seven satellites between 2021 and 2025. However, the full-scale Russian invasion significantly disrupted these plans. The war has necessitated reliance on active satellites from other countries, such as the Finnish SAR satellite ICEYE, which Ukraine rented to maintain its orbital monitoring capabilities. Consequently, the war's impact has paused many of Ukraine's satellite initiatives, shifting hopes for the space sector's revival to the private aerospace industry (Polyakov, 2023).

In this context, the private sector has played a pivotal role in enhancing Ukraine's satellite capabilities. The Serhiy Prytula Charity Foundation's acquisition of a satellite from ICEYE marked a significant milestone. This satellite, known as the "People's Satellite," provided the Ministry of Defence of Ukraine with vital intelligence, leading to the destruction of substantial Russian military assets. The satellite's SAR technology, capable of capturing high-resolution images regardless of weather conditions or time of day, proved invaluable in military operations and environmental monitoring (Defence Express, 2022; Prytula, 2023).

The Defense Intelligence of Ukraine reported that the ICEYE satellite had helped in their activity. This cooperation between private enterprises and the Ukrainian government underscores the critical role of private sector innovation in national defense and space technology (Defense Intelligence, 2023).

Ukraine's journey in space technology is marked by significant historical achievements, persistent efforts despite challenges, and a promising future driven by private sector innovation. While geopolitical challenges have impacted the country's space ambitions, the synergy between state initiatives and private enterprises holds potential for Ukraine's re-emergence as a significant player in space technology.

To support these initiatives, the Situational Centre of the General Staff of the Armed Forces of Ukraine plays a crucial role. This structural unit contains the specialists responsible for conducting space activities in the field of defense and national security. Its tasks include planning, organizing, and implementing space support for the Armed Forces of Ukraine and other defense components. The primary responsibilities are:

- Conducting space activities in the field of defense and national security of Ukraine.
- Organizing and implementing space information and analytical support in the Armed Forces of Ukraine.
- Organizing the deployment, maintenance, and development of the space support system for the Armed Forces of Ukraine.
- Organizing and implementing space support for the strategic planning and use of the Armed Forces of Ukraine and other defense components (Ministry, 2023).

Following the Draft of the Act on the State Regulation in the Field of Remote Sensing of the Earth from Space, the National Space Facilities Control and Test Center serves as the operator of national space remote sensing systems. According to the Draft of the Act on the State Regulation in the Field of Remote Sensing of the Earth from Space, state users are entitled to receive remote sensing data free of charge from national space remote sensing systems or foreign (commercial) space remote sensing systems if the data is purchased at the state's expense or obtained through other legal means. The operator provides remote sensing data to users on a contractual basis. Information on customers of ultra-high spatial resolution remote sensing data on the territory of Ukraine is submitted by the operator of national space remote sensing systems and official distributors to the Security Service of Ukraine (On the approval, 2013).

From a broader legal perspective, international principles also govern the use and sharing of remote sensing data. Specifically, GA Resolution 41/65 "Principles Relating to Remote Sensing of the Earth from Outer Space" states: "As soon as the primary data and the processed data concerning the territory under its jurisdiction are produced, the sensed State shall have access to them on a non-discriminatory basis and on reasonable cost terms. The sensed State shall also have access to the available analysed information concerning the territory under its jurisdiction in the possession of any State participating in remote sensing activities on the same basis and terms, taking particularly into account the needs and interests of the developing countries" (UN, 1986).

Challenges

On the international front, the landscape of remote sensing data security has become increasingly complex, as illustrated by recent geopolitical tensions. For instance, the U.S. Treasury Department imposed sanctions on Spacety, a Chinese operator of commercial synthetic aperture radar (SAR) satellites, for allegedly providing imagery to Russia's Wagner Group through a shell company (Jones, 2023). These sanctions underscore the global dimension of

remote sensing data security and highlight the necessity for robust regulatory frameworks to prevent misuse.

Adding to these complexities, the U.S. Department of Commerce's Office of Commercial Remote Sensing Regulatory Affairs (CRSRA) enforces stringent conditions on American companies with advanced satellites. During periods of heightened national security concerns or foreign policy interests, these companies may be required to limit data collection and dissemination. The CRSRA categorizes each private space-based remote sensing system it licenses based on whether the system produces or can produce unenhanced data already available from other entities. For example, in July 2023, NOAA modified the licenses of its Tier 3 licensees, removing 39 individual temporary conditions (Jones, 2023).

Operational security remains a significant concern for Ukraine. ICEYE CEO Rafal Modrzewski emphasized the company's policy of not releasing imagery of conflict zones or politically sensitive areas to media outlets, recognizing the potential misuse of such data (ICEYE, 2022). This caution is echoed by Kateryna Chernohorenko, Ukraine's Deputy Minister of Defense, who noted that Russia might be acquiring satellite imagery through third-party companies, potentially using it in armed aggression against Ukraine (Wood, 2024).

A notable example of this risk occurred on May 18, 2022, when a request was made to Maxar to capture imagery of a large square in the town of Lubny. Two days later, a missile strike targeted that location, and another request soon followed to capture post-strike imagery (Wood, 2024). This pattern raised alarms within the Ukrainian military about the potential misuse of commercial satellite imagery in planning and executing attacks.

As noted by Harrison and Strohmeyer (2022), space remote sensing has been a critical component of U.S. intelligence collection and power projection capabilities for over six decades. Traditional paradigms, such as government-developed satellites, human processing, and siloed data, served the nation well throughout the Cold War. However, advances in commercial space remote sensing offer the potential to alter these paradigms, providing new advantages. The commercial space remote sensing industry is rapidly advancing in satellite technology, sensors, sensing methods, large constellations, and high revisit rates. Furthermore, the industry leverages AI systems to quickly process raw sensing data into actionable products for human analysts and uses secure cloud-based systems for storage and dissemination, eliminating data silos. Despite these advances, commercial systems cannot entirely replace government-owned and operated space remote sensing capabilities.

Some missions may not be suitable for commercial sensing capabilities. However, as recognized by Congress and the National Space Council, commercial space remote sensing should be a significant component of the overall ISR architecture for the Department of Defense (DoD) and the Intelligence Community (IC) (Harrison & Strohmeyer, 2022).

One of the main obstacles to effectively leveraging commercial capabilities is the acquisition and contracting system within the U.S. government. The traditional approach of purchasing space remote sensing capabilities as a product rather than a service is incompatible with the business model of many commercially oriented firms. Moreover, the multiyear requirements development and funding process typically used by the DoD and IC for acquisition programs is too slow to keep pace with the innovation cycle of commercial space companies and the capabilities of U.S. allies and adversaries. To fully leverage the innovation, capabilities, and additional capacity offered by commercial space remote sensing companies, the U.S. government must adjust its acquisition approaches to focus on purchasing services rather than products and creating contract on-ramp opportunities on a more frequent basis (Harrison & Strohmeyer, 2022).

The term "space data" encompasses information collected from various sources in outer space, such as satellites, telescopes, space probes, and other instruments. This includes satellite imagery, remote-sensing data, astronomical data, space weather data, space-based navigation and communications data, planetary exploration data, and more. Applications for space data are extensive and include scientific knowledge, environmental monitoring, agriculture, disaster response, mapping, urban planning, military planning, and more (National, 2023). States could, for example, claim national security interests by demanding the deletion of satellite images over their military installations or the deletion of location data about their sensitive space assets. However, given customary international norms and laws around ISR and espionage, these demands may lack significant legal or moral force. Furthermore, such national security demands conflict with the pressing need for better space situational awareness (SSA), which requires more awareness of where space assets are to avoid collisions and other interference, regardless of ownership or purpose. Domestic privacy laws can also create tensions, as stakeholders like Native American tribal nations and farmers may lack the same access or ability to understand EO data as their competitors or negotiating parties. Balancing privacy and commercial interests with the public good in domestically sharing EO and other space data presents another challenge (National, 2023).

In summary, the international and domestic landscapes of remote sensing data security and operational security present significant challenges that require robust regulatory frameworks and innovative acquisition strategies. The evolving nature of geopolitical tensions, the rapid advancement of commercial remote sensing technologies, and the need for comprehensive space situational awareness underscore the complexity and urgency of these issues. Addressing these challenges will be critical for maximizing the strategic benefits of remote sensing data while ensuring its secure and ethical use.

Conclusions

The rapid deployment of advanced technologies for Ukraine, such as synthetic aperture radar (SAR) and high-resolution imagery, underscores the urgent need for scalable solutions to address supply constraints. Investments in expanding satellite constellations and enhancing data processing capabilities are essential to meet the growing demands of government customers. Integrating diverse sensor technologies and leveraging artificial intelligence (AI) for data analytics can provide comprehensive and actionable intelligence, thereby enhancing operational effectiveness across various domains.

The Ukrainian case vividly illustrates the transformative impact of commercial remote sensing technologies on modern military operations. The integration of private satellite imagery and advanced data analytics into Ukraine's defense strategy has significantly enhanced situational awareness and operational effectiveness. This example underscores the broader potential of these technologies in other sectors, including environmental monitoring and disaster response.

This paper highlights the substantial benefits of private remote sensing services, such as high-resolution imagery, SAR capabilities, continuous surveillance, and automated processes. However, it also identifies critical challenges that must be addressed to optimise the use of these technologies while aligning with ethical standards, data sovereignty, and security concerns.

Data Sovereignty

Strategic partnerships between private remote sensing companies and government agencies are pivotal in enhancing data sovereignty. These collaborations should be governed by strict due diligence processes to vet customers and their intended use of imagery, ensuring compliance with ethical standards, and preventing misuse for hostile purposes. Contracts must include clauses prohibiting the resale of imagery to unauthorised entities, particularly those from sanctioned countries or with malicious intentions. Additionally, implementing advanced technology controls and tracking mechanisms will monitor the end-use of satellite imagery and ensure compliance with usage agreements.

To foster these partnerships, governments should establish clear frameworks that encourage private companies to share data responsibly while maintaining control over sensitive information. Regular audits and compliance checks will ensure adherence to data sovereignty principles. By leveraging commercial capabilities through strategic partnerships, governments can enhance situational awareness and operational readiness while maintaining strict control over the dissemination and use of critical satellite data.

Transparency and Accountability

Transparency and accountability in the remote sensing industry are paramount for maintaining public trust and ensuring the ethical use of satellite imagery. Enhancing private companies' liability in contracts for the misuse of their imagery, including imposing penalties and obligations, is critical. Liability should be shared between the state and private companies based on the company's level of due diligence and control over the end-use of their data.

Government regulation should be strengthened to ensure that private companies adhere to ethical and legal standards. This includes mandatory reporting of data usage and regular audits to verify compliance. Encouraging collaboration between the state and private companies will enable better monitoring and control of satellite imagery distribution and usage.

By focusing on buying services rather than products, governments can more effectively integrate commercial capabilities into their national security frameworks. This approach allows for more frequent contract opportunities, keeping pace with the innovation cycle of commercial space companies. Such partnerships should emphasise the role of commercial providers in supporting both military and humanitarian missions, leveraging their advanced technologies, large satellite constellations, and rapid data processing capabilities to enhance transparency and accountability in the use of remote sensing data.

Privacy and human rights

Developing and enforcing ethical guidelines for the sale and use of satellite imagery is crucial to protecting privacy and upholding human rights, particularly in conflict zones. The Recommendation on Space Data Ethics (2023) underscores the necessity of managing such imagery with care to prevent further trauma and exploitation of vulnerable populations. The misuse of satellite imagery for propaganda, as seen in Bucha and Mariupol, demonstrates the severe psychological impact and manipulation of public perception that can result from unethical practices. Strengthening legal frameworks to regulate the dissemination and use of satellite imagery is imperative to prevent misinformation and conflict escalation.

Transparency in data collection, processing, and sharing, coupled with consultation with local communities, ensures that the use of imagery aligns with ethical standards and mitigates psychological harm. By mandating the careful depiction of war impacts and applying strict standards to minimise distress, robust ethical guidelines can safeguard against harmful purposes. Integrating these considerations into legal frameworks will harness the benefits of satellite data while protecting against its potential harms, enhancing global security and humanitarian efforts.

The evolving relationship between the private remote sensing market and military contracts, particularly in the context of Russian aggression against Ukraine, highlights the transformative potential of commercial satellite technologies. While these technologies offer significant benefits in enhancing situational awareness and operational effectiveness, it is crucial to address the challenges of data sovereignty, ethical usage, and regulatory compliance. By implementing stringent vetting processes, enhancing liability clauses, and fostering international cooperation, we can ensure that the use of satellite imagery aligns with ethical standards and contributes positively to global security and humanitarian efforts.

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