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A REVIEW OF LEGAL REGULATION REGARDING THE USE OF UNMANNED AERIAL VEHICLES FOR BORDER SECURITY AND THE IMPACT OF GLOBAL TECHNOLOGIES

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Abstract. In the modern world, Unmanned Aerial Vehicles (UAVs) are becoming increasingly powerful tools for ensuring security and protecting national borders. Their monitoring and reconnaissance capabilities make them valuable assets for border services seeking to counteract smuggling, illegal migration, and other transborder crimes. However, the rapid development of UAV technologies also poses new challenges to the legal system, which require careful analysis and the adaptation of existing regulatory frameworks. This scientific article is dedicated to a comprehensive study of the legal aspects of using UAVs to ensure security and protect national borders. The research covers a wide range of issues, including: the legitimacy and ethical aspects of using UAVs for monitoring and protecting national borders; the right to privacy; freedom of movement; ethical principles of the use of force; and potential abuses of UAVs. The article also thoroughly examines international, intergovernmental, and national legal acts regulating the use of UAVs in the security sphere. An analysis of the conformity of modern technological achievements to existing norms is conducted, and areas requiring improvement are identified. In addition, practical aspects of implementing unmanned technology in border security systems are considered. Potential risks and benefits of using UAVs are identified, along with recommendations for minimizing risks and maximizing benefits. Geopolitical consequences of the rapid development of UAV technologies are explored, with attention paid to the influence of semiconductor geopolitics and technological progress in the field of UAVs through the lens of contemporary trends in global relations. The article concludes that UAVs have significant potential for ensuring security and protecting national borders. However, to fully realize this potential, it is necessary to improve the legal regulation of UAV usage. Alongside this, there is a need to develop effective strategies for utilizing UAVs in border security and enhance legislation in this regard. The scientific novelty of this study lies in its comprehensive analysis of the legal aspects of using UAVs for security and border protection, and in identifying and analyzing new challenges posed by modern technological advancements in the UAV field to the legal system. The research findings can be utilized to improve legislation regulating the use of UAVs in border security. General recommendations outlined in the conclusion, developed within the study, will assist border services worldwide in enhancing the use of UAVs for border protection. This research could contribute to the development of international cooperation in the legal regulation of UAV usage.

Keywords: Unmanned Aerial Vehicles, legal regulation, state borders, national security, international relations.

Introduction

This study aims to explore the legal aspects associated with the use of UAVs in border security. The main objective of the research is to conduct a review of the regulatory environment governing the use of these technological tools, taking into account their significant impact on global security and national sovereignty. The progress of modern technologies, especially in the field of UAVs, creates both new opportunities and challenges in border security. The use of UAVs for monitoring and ensuring security in border regions has become a pressing issue (State Border Guard Service of Ukraine, 2023), requiring deep understanding and legal regulation. The study aims to analyze and examine specific aspects of the legal regulation of UAV usage for border security, taking into account the latest advancements in this field (Militarnyi, 2021).

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In the context of ensuring security and border control, the use of UAVs can be an effective mechanism for detecting potential threats and supporting the surveillance of border territories (Klein, 2021). However, the implementation of such technology is associated with numerous challenges regarding the protection of the constitutional rights and freedoms of citizens, which requires the careful consideration and adaptation of existing regulatory frameworks (Lee et al., 2022).

Discussions regarding the observance of the constitutional rights and freedoms of citizens when using UAVs for border security often overlook the legal principle of necessity, which is key to ensuring security and preventing crime. Critics and scholars point out that UAV technology affects rights in various ways. In this context, the scope of analysis expands to indicate that UAVs can serve as tools for law enforcement agencies in combating crime, but at the same time, they can have military applications. Likely, there is a synthesis of both law enforcement and military aspects (Tyshchuk, 2023) in the use of UAVs for border security. Such an approach opens up a wide range of possibilities and risks associated with the application of these technologies, ensuring the necessary balance between security and the protection of fundamental human rights.

In the realm of military application, the use of UAVs is necessarily linked to international humanitarian law, which establishes rules for armed conflicts and the use of weapons, including UAVs. Countries have the right to self-defence, and may use UAVs as part of their strategy to ensure national security. However, they are also bound by international treaties and agreements regulating the use of weapons and military technologies. The use of UAVs is reflected in the strategic plans of the Armed Forces and is subject to control and authorization by military command, which includes mission management and coordination with other military assets (Haider, 2021).

The legal aspects of UAV usage demand careful study and regulation at both the international and national levels. International norms should address issues of classification and regulation of UAV usage, particularly in maritime border zones. National legislative acts should establish rules ensuring the protection of personal information, define responsibilities for rule violations, and regulate the use of UAVs for border security purposes.

The technological aspects of UAV usage require continuous improvement and the integration of advanced technologies to enhance their effectiveness and ensure security. This includes the application of advanced data processing algorithms, artificial intelligence (AI) systems, and information security measures. Such an approach will help ensure the efficient and secure use of UAVs in various fields.

The first section of this article provides an overview of the legal regulation regarding the use of UAVs at the international, intergovernmental, and national levels. Attention is paid to the correlation between the goal of ensuring public safety and the necessity of preserving fundamental human rights. Section 2 focuses on specific aspects of using UAVs for border security. Section 3 explores the application of AI for unmanned systems using the example of Australia as one of the main hubs of new technologies. Section 4 examines the relationship between semiconductor geopolitics and UAV technology progress, highlighting significant aspects of how these factors influence the geopolitical strategies of countries and the dynamics of global technological relations.

The aim of the article is to analyze various types of UAVs used for border security in selected countries, evaluate their effectiveness in performing border security tasks, identify challenges faced by border services when using UAVs, and develop recommendations for improving the use of these devices in ensuring border security.

The article has the following objectives: conduct a literature review on the use of UAVs for border security; provide a comparative analysis of different types of UAVs used for border security; analyze the effectiveness of UAVs in performing various border tasks, such as patrolling, surveillance, and the detection of violators; identify challenges faced by border services when using UAVs, including legal constraints, technical issues, and human factors; and develop recommendations for improving the use of UAVs in border operations, such as legislative enhancements, technical equipment upgrades, and personnel training.

The methodological approach to this article is based on collecting and analyzing data from various sources, including scientific publications, official reports from government agencies, informational resources, as well as electronic databases and websites. Various methods were used during the data collection process, such as content

analysis, the systematic evaluation of textual information, and the identification of key themes and issues. Adhering to ethical principles in the data collection process was an important component of the methodology. The results of the analysis were structured and classified using text editors and electronic spreadsheets. One of the challenges encountered during the research was the limited availability of information from some sources, which could affect the completeness and objectivity of the analysis.

The main approach involved systematic analysis and the identification of key aspects of UAV usage in the context of border security. This methodological approach was chosen based on its ability to provide a comprehensive analysis of information from various sources, taking into account the geographical location and the political and socio-economic situation in the selected countries – Australia, Brazil, China, European Union (EU) countries, Japan, Ukraine, and the United States (USA) – to ensure the objectivity and reliability of the research results. Other aspects – such as the fact that certain countries are essentially island nations (Australia, Japan), others occupy a significant portion of a continent (Brazil, China, EU, USA) or even constitute an entire continent (Australia), and some have practical experience in using UAVs in combat conditions (Ukraine, USA) – were also taken into consideration. Furthermore, the unique geography of Australia prompted the author to direct the most attention towards it. This approach allowed for a differentiated investigation using the abovementioned countries as examples. The conclusions drawn from applying this methodology will contribute to further research development in this area and the creation of effective regulatory mechanisms for the use of unmanned technologies in border security.

1. A general overview of international legal norms regulating the use of UAVs

1.1. Issues of international legal regulation of the use of UAVs

UAVs are rapidly being integrated into various aspects of life, from military and law enforcement activities to civilian applications such as goods delivery, agriculture, and mapping. However, the rapid advancement of UAV technology outpaces the development of a legal framework to regulate their use. This poses a range of challenges related to flight safety, the protection of confidentiality, and the potential for UAVs to be used for illicit purposes.

Given the rapid advancement of UAV technology, it is critically important to assess the current state of their legal regulation, especially in the context of their use for border security. Thanks to their capabilities, UAVs provide high-precision monitoring and rapid response to potential threats. Their usage includes tasks such as detecting illegal border crossings, monitoring the movement of vehicles and individuals, and gathering information for situational analysis (JOUAV, 2024).

Considering the above, the contradictions in legislation that arise during the legal regulation of the use of UAVs for border security pose a significant challenge for the legal system. Some of the main aspects of these contradictions are discussed below.

The use of UAVs for monitoring state borders raises serious concerns regarding the confidentiality and privacy of citizens. This creates a contradiction between the need for security and the risk of violating individual rights. Additional contradictions arise regarding the processing and storage of the large amount of data collected from UAVs, including issues of access, retention periods, and liability for use. International law questions the legislative regulation of the use of UAVs for border monitoring, especially considering potential deliberate or unconscious border crossings and violations of sovereignty. Additional uncertainties arise due to significant differences in the tasks performed by UAVs for law enforcement agencies and armed forces, leading to ambiguity regarding the legal status of such technological applications. Finally, questions of liability for potential events, such as accidents or breaches of confidentiality, remain unresolved, complicating the situation and highlighting the need for careful examination of the ethical and legal aspects of using UAVs for border monitoring.

Another key issue is adherence to the principle of non-refoulement, which is a cornerstone of international law concerning refugees and human rights. The use of UAVs in border control is defined by efficiency, technological innovations, and high productivity. However, some functions introduced or enhanced through UAVs do not exclude aspects of refugee rights and human rights in many maritime rescue operations. There is a real risk that

during the apprehension of illegal migrants, search and rescue operations may be perceived as unrelated to human rights and tragedies. Therefore, the use of advanced technology in border control should not overshadow the moral and legal consciousness of professionals (Garijo, 2020).

To address these contradictions, there is a need to develop clear, adaptive, and compromise-based legislation that balances the need for security with respect for human rights.

The international legal regulation of UAV usage is based on a combination of approaches from a number of documents, including:

- The Chicago Convention on International Civil Aviation (1944). This foundational document establishes general principles for international civil aviation, including airspace rules, flight safety, and licensing. UAVs used for civilian purposes must adhere to these rules just like manned aircraft. It is important to note that the Chicago Convention is not exhaustive and is supplemented over time with annexes and protocols reflecting new technologies and challenges. This document plays a crucial role in ensuring the safe, orderly, and efficient development of international civil aviation.
- The Rules of the Air (Annex 2 to the Chicago Convention; ICAO, 2013). This document establishes clear rules for UAV flights, ensuring their safety and integration into international airspace. This document also covers both general rules and visual and instrument flight rules, thus making UAVs accountable to the same standards as manned aircraft.
- Technical Instructions for the Operation of Unmanned Aircraft Systems (UAS). This ICAO (2015) document contains recommendations for the safe operation of UAVs, covering flight planning, pilot training, maintenance, and repair.

Although these documents contain recommendations for the safe operation of UAVs, they are not legally binding in Member States. Intergovernmental agreements, whether bilateral or multilateral, regulate the use of UAVs in the airspace of participating countries, establishing more detailed rules than ICAO regulations. National laws, varying from country to country, may be more or less stringent than ICAO rules or intergovernmental agreements. The fragmented nature of these international legal norms can create difficulties for UAV operators seeking to operate lawfully in different countries.

The general shortcomings of international UAV legal regulation are presented in Table 1, alongside brief descriptions, examples, consequences and possible solutions.

Table 1. The drawbacks of UAV regulation

Shortcoming	Description and Examples	Consequences and Possible Solutions
Fragmentation	Description: Inconsistency of sources leads to contradictions and ambiguity in interpreting rules	Consequences: Legal disputes, incidents, lack of clear understanding of rights and obligations
	Example: Differences in regulations complicate international flights	Solution: Standardization of international law norms, adoption of a framework convention regulating key aspects of UAV usage
Incompleteness	Description: Unaddressed aspects of liability for damages or the use of UAVs in armed conflicts	Consequences: Legal uncertainty, risk of abuse, lack of compensation mechanisms
	Example: Abuse due to impunity	Solution: Development of new norms of international law addressing gaps regarding the use of UAVs
Lag	Description: The pace of technological advancement outpaces attempts at legal regulation of UAV usage	Consequences: Lack of effective control over the use of UAVs, risk of new problems not addressed by international law emerging
	Example: Abuse due to impunity	Solution: Continuous updating of international law, adoption of flexible norms allowing regulation of new technologies

Inefficiency of control mechanisms	Description: Lack of effective mechanisms for monitoring compliance with the rules of UAV usage, which can lead to their violation	Consequences: Non-compliance with international norms, risk of conflicts arising, lack of accountability for violations
	Example: Countries may ignore international norms if they do not face sanctions	Solution: Establishing effective control mechanisms, such as monitoring systems and sanctions, involving international organizations in enforcing compliance
Insufficient international cooperation	Description: Countries are not always willing to cooperate with each other on regulating the use of UAVs, which can lead to the duplication of efforts	Consequences: Inability to address common issues, such as cross-border UAV flights. Risk of conflicts arising
	Example: The lack of a unified approach to regulating UAVs can complicate international cooperation in this area	Solution: Strengthening international cooperation, establishing joint regulatory and control mechanisms, exchanging information and experiences

1.2. Inter-governmental agreements and standards for the classification of UAVs

The growing popularity of UAVs in various fields such as border security, environmental monitoring, mapping, and delivery requires the clear regulation of their use at the international level. Inter-governmental agreements play an important role in this regard, establishing framework rules and principles for cooperation between countries regarding UAV operations. Examples of such agreements include: the Agreement on Joint Use of Airspace between Ukraine and Romania (2022), allowing the use of UAVs for joint monitoring and border protection; the Memorandum of Understanding between the United States and Canada on cooperation in the field of unmanned systems (2019), promoting cooperation in the research, development, and operation of UAVs; and the Cooperation Agreement between the European Aviation Safety Agency (EASA) and the International Civil Aviation Organization (ICAO) (2018), aimed at harmonizing UAV operation rules in Europe and worldwide.

Another, more recent example is the agreement signed between the United Kingdom and Northern Ireland and Frontex (Frontex and Home Office, 2024) regarding the deployment of border force officers and UAVs to help stem the flow of illegal migration. The uniqueness of this agreement lies in the fact that it cannot be fully characterized as intergovernmental, as it was signed on one side by a government (UK) and on the other by an intergovernmental special-focus organization (Frontex).

Intergovernmental agreements contribute to standardizing the rules for UAV operations across different countries, facilitating cross-border flights and collaboration. This opens the door to information exchange and joint projects, fostering innovation and the development of new technologies. Additionally, intergovernmental agreements allow for the establishment of stringent safety standards for UAV operation, significantly reducing the risk of accidents and incidents. This ensures the protection of people and property on the ground and enhances trust in UAVs overall. Moreover, intergovernmental agreements can substantially stimulate economic growth in various sectors, helping to safeguard the environment.

Thus, intergovernmental agreements regarding UAVs play a crucial role in creating a favourable environment for responsible and efficient UAV utilization. Their benefits encompass areas such as safety, innovation, economic growth, and UAV classification. As the popularity of UAVs continues to grow, the importance of intergovernmental agreements will only increase.

The general classification of UAVs is based on their functional characteristics, such as flight principles, mission, weight, thrust, control, altitude range, configuration, launch method, payload, size, flight duration, autonomy level, operational radius, ability to perform tasks in various weather conditions, and considering the specific requirements of each application field (target) (Telli et al., 2023).

NATO standards regulate the classification of military UAVs based on their maximum take-off weight. According to these standards, UAVs are divided into three classes: Class I, with a maximum take-off weight of up to 150 kg; Class II, with a maximum take-off weight of up to 600 kg; and Class III, with a maximum take-off weight of over 600 kg. Class I is further subdivided into the micro (up to 2 kg), mini (up to 15 kg), and small (over 15 kg) categories. According to the STANAG 4670 standard (NATO Standardization Office, 2019), UAV classification involves defining categories based on the level of military operations, operational altitude, operational radius, and other parameters. For example, Class III includes tactical and strategic strike UAVs such as Reaper and Global Hawk, while Class I encompasses small tactical units represented by platforms with compact sizes and limited operational radius, such as Scan Eagle and PD-2.

In the law enforcement sector, the classification of UAVs is also based on various criteria, taking into account the specific needs and tasks of law enforcement agencies. First and foremost, significant attention is given to the functional characteristics of UAVs, such as video surveillance capabilities, object detection and tracking abilities, as well as the capability to capture and store video material for further analysis. The level of autonomy is also an important criterion, as law enforcement agencies may use UAVs to carry out missions without constant operator intervention. The operational radius of UAVs in law enforcement agencies may be limited or expanded depending on the requirements of a specific operation, and the ability to operate in various weather conditions may be crucial for the successful completion of tasks. Additionally, it is important to consider specific requirements and limitations established by legal norms regarding the protection of personal information and ensuring human rights and fundamental freedoms in the process of using UAVs by law enforcement agencies. Such an approach allows for the effective and ethical use of UAVs in law enforcement activities (Haider, 2021).

The main functional characteristics of UAVs in the civil sector include their capabilities for aerial photography, geodetic surveys, the monitoring of transportation, control of agricultural lands, as well as for search and rescue operations. The level of autonomy of UAVs in the civil sector can be high, as this allows for the automation of processes and increases productivity. The operational radius of UAVs can vary depending on specific tasks, but is often limited to relatively short distances from the control point. It is also important for UAVs to be able to operate in various weather conditions, as many civil UAV applications require work even in inclement weather. In the civil sector, particular attention is paid to complying with flight safety requirements, protecting personal information, and adhering to legislation regarding the use of airspace. This approach ensures the effective and safe use of UAVs in the civil sector for various tasks and activities.

According to the classification system of the European Union Aviation Safety Agency (EASA), based on Regulations (EU) 2019/947 and 2019/945, there are three categories of civil UAVs: open (low risk, no pre-flight authorization required); specific (higher risk, pre-flight authorization required); and certified (significantly higher risk, certification and licensing required) (European Union Aviation Safety Agency, n.d.).

Dasom et al. (2022) propose a comprehensive set of recommendations to ensure the safety and confidentiality of civil UAVs. Their suggestions include user training, mandatory incident reporting, unique UAV identifiers, detailed rules, user control over data, transparency of data management methods, data transmission limitations, penalties for violations, the monitoring and certification of confidentiality practices, as well as the harmonization and standardization of the classification, registration, and certification of UAV usage cases. Implementing these recommendations can help minimize risks associated with UAV use and foster trust in this technology.

Therefore, the recommendations suggest that the classification of UAVs is a critical step in standardizing their use and establishing appropriate rules. Clear definitions based on functional characteristics, mission, weight, thrust, and range will allow the diversity of unmanned systems to be harmonized and their optimal sphere of application to be determined. This provides a foundation for setting standards and rules, promoting their effective use, and reducing potential conflicts.

1.3. Features of the national legislation of individual countries in the field of UAV use, with a focus on Ukraine

First and foremost, the use of UAVs is subject to legislation and standards established by national aviation authorities, such as those listed in Table 2 below.

Table 2. The national aviation authorities of selected countries

Country	National Aviation Authority	Website Link
Australia	Civil Aviation Safety Authority (CASA)	https://www.casa.gov.au/
Brazil	Agência Nacional de Aviação Civil (ANAC)	https://www.gov.br/anac/en
China	Civil Aviation Administration of China (CAAC)	http://www.caac.gov.cn/English/
EU countries	European Union Aviation Safety Agency (EASA)	https://www.easa.europa.eu/en
Japan	Civil Aviation Bureau (CAB)	https://www.mlit.go.jp/en/koku/index.html
Ukraine	State Aviation Administration of Ukraine (SAAU)	https://avia.gov.ua/
United States	Federal Aviation Administration (FAA)	https://www.faa.gov/

These authorities establish rules and restrictions for the safe operation of UAVs, covering aspects such as maximum flight altitude, distance from airports, no-fly zones, and other safety issues (Table 3). According to these rules, UAV operators, including border service personnel, must adhere to the established requirements to prevent accidents, ensure airspace safety, and protect confidentiality.

Table 3. The specifics of licensing and flight regulations

Countries	Licensing and permits	Main flight rules	Special features
Australia	Operator Category 1: Up to 250 g – registration, 0.25–2 kg – license, >2kg –license and certificate	Visual line of sight (VLOS), 120 m, restricted areas, confidentiality, no alcohol/drugs, no hazardous cargo	Registration for UAVs <250 g, categorization, extended certificate for >2 kg
Brazil	Class A1: Up to 250 g – no license, 0.25–2 kg – license, >2 kg – license and permit	VLOS, 400 m, restricted areas, confidentiality, no alcohol/drugs, no hazardous cargo	Classification, permit, no registration required for UAVs <250 g
China	Class C0: Up to 250 g – no license, 0.25–4kg – license, >4kg – license and permit	VLOS, 120 m, restricted areas, confidentiality, no alcohol/drugs, no hazardous cargo	Classification, permit, registration required for all UAVs
EU countries	EASA Drone Rule: Open (up to 250 g), Specific (0.25–2 kg), Certified (>2kg); requirements depend on category/operation	VLOS, altitude restrictions (depending on category), restricted areas, confidentiality, no alcohol/drugs, no hazardous cargo	Categorization and requirements of EASA Drone Rule, altitude limitations depending on category
Japan	Class 1: Up to 200 g – no license, 0.2–6kg – license, >6kg – license and permit	VLOS, 150 m, restricted areas, confidentiality, no alcohol/drugs, no hazardous cargo	Registration for all UAVs, license for commercial use, restrictions on flights over residential areas
Ukraine	Resolution No. 1389: Up to 250 g – no registration, 0.25–	VLOS, 400 m, restricted areas, confidentiality, no	Registration for UAVs >250 g, no categorization

	2 kg – registration, >2kg – registration and permit	alcohol/drugs, no hazardous cargo	
USA	FAA Part 107: Registration, UAV pilot license for commercial use	VLOS, 400 ft, restricted areas, confidentiality, no alcohol/drugs, no hazardous cargo	Registration for all UAVs, license for commercial use, altitude limitations in feet

In Ukraine, Khalymon et al. (2021) identified gaps in legislation and proposed amendments to law enforcement legislation regarding: additions to Article 20 of the Law of Ukraine 'On the State Border Guard Service of Ukraine' regarding the use of UAV flight monitoring results to ensure border security and security in the maritime economic zone; the recognition of information obtained through UAVs as official documents admissible as evidence in criminal, administrative, and civil cases; the confirmation of the legality of actions by the State Border Guard Service of Ukraine in border monitoring using UAVs, establishing flight conditions that do not violate human rights; the classification of UAVs by categories and restrictions on the use of Class I (micro and mini) UAVs for border monitoring without crossing borders; and the regulation of compensation issues for damage caused by UAVs, including accidents and collisions with other vehicles. These provisions are aimed at improving the legislative framework for the use of UAVs in border control, ensuring effective use and the protection of human rights.

Currently, Ukraine is in the process of developing rules regulating UAV operations. These draft rules adhere to relevant EU principles, ensuring aviation safety and development. It is important to note that the legislative regulation of UAV use is not unique to Ukraine. In most EU countries, UAV operation procedures are not yet fully defined. The USA is the most advanced in this regard, allowing small UAVs to fly freely up to 400 meters. However, even in the USA, questions remain about the safe use of UAVs, especially in densely populated areas and over urban territories. Legal uncertainties slow down the development of the UAV market, which is technically ready to launch many new services such as goods delivery, urgent aerial photography, and large-scale monitoring (Ivannikova & Ayrapetyan, 2021). Ultimately, similar rules which entered into force in the EU in 2023 (Regulations (EU) 2019/947 and 2019/945) will significantly simplify access to unmanned operations, regardless of the European country in which one plans to operate.

In many other countries, the use of UAVs sparks active debates among lawyers, focusing on potential privacy and security breaches (Bentley, 2019). It is important to emphasize the conflict between the task of ensuring public safety and the need to preserve fundamental human rights (Fox, 2022). Technological innovations in the field of UAVs open up new opportunities for information gathering (Lundgaard, 2023), with particular attention paid to remote control capabilities (Yaacoub et al., 2020). The legality of UAV use must be regulated within existing legal norms (Chen et al., 2024), except for the use of AI-based software, which introduces additional complexities (Kaplina et al., 2023).

Research by Tan et al. (2021) on the impact of UAVs on public opinion in Southeast Asia revealed that societal attitudes toward this technology vary depending on the context of use. Using the Knowledge, Attitude, and Practice model, the researchers identified differences in perception by zones: industrial zones had the highest level of acceptance, followed by recreational and commercial zones, while residential areas showed the lowest level. Important factors such as fear and concern influenced public perception differently in various contexts.

The use of UAVs by armed forces poses complex challenges for international law. Conducting strikes using UAVs requires the consideration of several legal frameworks, such as international humanitarian law and the law of war. A key aspect is not only compliance with individual norms, but also adherence to all relevant rules. Even a single violation can render an action illegal, regardless of compliance with other rules. It is important to understand that UAVs, as instruments of war, do not inherently violate international law; they can be used lawfully if they comply with applicable regulations. However, their use may increase legal disputes, especially in the realm of human rights and liability for civilian casualties. Additionally, extraterritorial use of UAVs may serve as a basis for expanding the interpretation of the law, which can impact international norms. Such expansion arises from a broad interpretation of the law that supports military actions using UAVs (Brookman-Byrne, 2018).

2. Specific aspects of using UAVs to ensure border security

2.1. The role of UAVs in ensuring border security

The border services of many countries recognize the relevance and potential of using UAVs to ensure security along national borders (the main advantages are summarized in Table 4). This initiative is considered necessary given rapid technological advancements and increasing security challenges. The active integration of these technologies becomes a crucial step in enhancing border security and the efficiency of border control, as well as improving the overall security systems of the country (Shah, 2023).

UAVs are utilized in border security to provide continuous surveillance and monitoring of territory. They enable the rapid detection of illegal border crossings, smuggling, and other breaches. Moreover, UAVs are employed for patrolling inaccessible areas, ensuring efficient control at minimal costs, and allowing rapid responses to events by providing crucial real-time information to operational services for decision-making. The use of AI technologies for image processing allows for the automatic detection of suspicious activity at the border, contributing to the more effective combatting of illegal crossings and other infringements. The advantages of using UAVs lie in their effectiveness, cost-efficiency, and ability to ensure personnel safety. Additionally, UAVs demonstrate flexibility and manoeuvrability in various conditions. Examples of successful implementation include programs in the USA (U.S. Customs and Border Protection, 2023; Davis, 2020; Sweet, 2023), Israel (Israel Economic Mission to South Africa, 2022), the EU (Frontex, 2023), and other countries or state associations utilizing UAVs to effectively monitor and ensure security along national borders.

Table 4. Key advantages of UAVs for border security

Advantage	Description
Comprehensive overview	UAVs cover significant areas in a short period of time, providing a wider picture of border activity compared to ground patrols
Increased precision	UAVs are equipped with high-resolution cameras and sensors, allowing them to capture details that may be missed by ground patrols
Risk reduction	UAVs can perform dangerous or complex tasks, such as flights over remote areas or in adverse weather conditions, without risking human lives
Cost reduction	Typically, UAVs are cheaper to operate than aeroplanes or helicopters, making them an economically advantageous solution for long-term surveillance
Flexibility	UAVs are quickly deployable in any terrain, even in hard-to-reach areas
Ability for 24/7 surveillance	UAVs can operate day and night, providing continuous border surveillance
Data collection	UAVs can collect various data types, such as photos, videos, thermal images, and sensor data, which can be used for analysis and reconnaissance
Support for ground patrols	UAVs can provide ground patrols with real-time information, coordination, and aerial assistance

2.2. Using UAVs for border security in selected countries

2.2.1. The experience of Australia

UAVs are actively utilized in Australia across various sectors including agriculture, healthcare, emergency response, arts, goods delivery, scientific research, environmental protection, and education. They contribute to increased efficiency, provide economic benefits, and improve quality of life for Australians. The Australian government and stakeholders seek public feedback for the further development and implementation of UAV technology (Department of Infrastructure, n.d.).

The Australian technology industry is filled with newcomers who emphasize the importance of their products in changing the world and their global significance. However, many of them encounter a less exciting reality. In

the case of Sypaq Systems (https://www.sypaq.com.au), an engineering and technology company from Melbourne, the development of the Precision Payload Delivery System (PPDS) has become a key component of Ukraine' s efforts in effectively countering the Russian army (Smith, 2023).

The uniqueness of the PPDS lies in its portability and ease of assembly. Thanks to its integrated design and independently developed mechanisms, the UAV can be assembled in field conditions with a minimal set of tools. This makes it an ideal choice for use in extreme scenarios where availability and mobilization speed are critically important factors (Nichigo Press, 2023).

Representatives from industry and the Ministry of Defence of the Commonwealth of Australia participate in congresses and conferences to discuss the role of UAVs and robotics in defence. This collaboration underscores the current partnership between government and industry aimed at developing innovative technologies in the field of UAVs. Additionally, this partnership is crucial for future defence capabilities and protecting the national interests of Australia across various security domains (Australian Government, 2023).

The Australian Army utilizes UAVs for reconnaissance, surveillance, target acquisition, and ground operations support. The primary UAV in the army's inventory is the RQ-7B Shadow 200, which features high-resolution capability and long-endurance flight capability. Australia also plans to introduce Small Unmanned Aerial Systems (SUAS) to enhance reconnaissance and surveillance capabilities at the tactical level (Australian Army, n.d.).

In addition, Australia has actively utilized UAVs over the past decade to enhance border security. UAVs offer flexibility, accessibility, and observational capabilities that cannot be achieved through traditional patrol methods.

With the increasing prevalence of UAV technology, there is growing potential for their use in all maritime fleets. UAVs such as the MQ-4C Triton (Royal Australian Air Force, n.d.) have become particularly popular for maritime surveillance to combat illegal, unreported, and unregulated fishing. However, it is important to note that international law does not contain clear classifications and conditions for the use of UAVs along maritime borders in pursuit of border violators. This could lead to increased UAV usage, significantly complicating law enforcement activities in the maritime domain. The shortcomings of existing legislation may be exploited by states employing UAVs to advance their use in the maritime environment within the grey zone of military operations, undermining existing international maritime law and order (McLoughlin, 2022).

To prevent the emergence of grey zones, Australia is establishing partnerships with island nations in the region. For example, the Sri Lanka Coast Guard (SLCG) utilizes UAVs and other equipment provided by the Australian Border Force (ABF). This significant enhancement improves surveillance and response capabilities in the coastal zone. The SLCG serves as a crucial partner to the ABF in combating human trafficking and other transnational crimes in the maritime waters of Sri Lanka (Sri Lanka Coast Guard, 2023).

Additionally, Australia offers the use of UAVs to enhance border security in the Philippines. As a strategic ally of the Philippines alongside the USA, Australia increases military and defence cooperation, aiding in countering China's influence in the Indian and Pacific Ocean regions. The use of UAVs underscores the strategic support of Australia and the importance of modern technologies for effective border control amidst growing security and defence challenges (Cepeda, 2023).

2.2.2. The use of UAVs in Brazil

In Brazil, a country with continental dimensions, detecting and monitoring various illegal activities poses a growing challenge for government agencies. Therefore, the Brazilian government actively utilizes UAVs to enhance the security of its land and maritime borders, which extend over 23,000 kilometres. UAVs offer flexibility, accessibility, and observational capabilities that are impossible to achieve using traditional patrolling methods (Silva, 2013). Table 5 highlights the uses of UAVs in Brazil.

Table 5. The use of UAVs in Brazil

Criteria for UAVs	Description
Potential	This is a promising solution for monitoring remote and hard-to-reach areas, capable of collecting high-resolution data in real-time at a lower cost
Challenges	Fighting illegal activities in the Amazon is challenging due to the large scale of the region and the complexity of access
Applications	Monitoring illegal deforestation, identifying airstrips, locating mines, and intercepting vessels
Examples (Types)	HERON 1, FALCAO, HERMES 450
Regulation	UAV operations in Brazil are regulated by ANAC and DECEA
Processing Systems	Data obtained from UAVs is processed using geographic information systems (GIS) for spatial analysis

The use of UAVs in combating illegal activities in the Amazon is a promising tool. However, for the successful large-scale implementation of this technology, careful consideration of regulation, privacy and data protection, and security issues is necessary. Moreover, the successful implementation of this technology requires wide cooperation among government agencies, the private sector, and international partners, as well as adherence to the highest standards of safety and ethical practice to ensure a balanced approach that achieves security goals and protects the rights and freedoms of citizens.

2.2.3. Chinese issues and prospects regarding the use of UAVs

Issues related to the use of UAVs by the National Border and Immigration Service (NBIS) of China include the complexity of models and their insufficient functionality. The variety of UAV models contributes to these challenges, including those related to servicing. Most used models have limited functionality, which reduces their effectiveness. There is also an issue around the lack of clear operational standards, leading to risks and the inefficient use of UAVs (Zhang, 2017).

In the future, the Chinese government plans to develop clear standards for the use of UAVs by the NBIS, which will contribute to improving their effectiveness and safety. Integrating UAVs with other systems, such as radars and sensors, will help enhance situational awareness and coordination. Additionally, the development of UAVs with expanded functional capabilities, such as surveillance, reconnaissance, and attack, will make them more versatile and useful for border security operations.

Thus, UAVs have the potential to significantly enhance border security in China, but addressing the challenges of their use is necessary. The development of standards, integration with other systems, and the expansion of functionality are identified by the Chinese government as key directions that will contribute to increasing the value of UAVs as tools for the NBIS.

2.2.4. European practice

The increasing use of UAVs in the EU opens up wide opportunities for various sectors, including agriculture, environmental monitoring, delivery, search and rescue operations, and law enforcement. However, this development is accompanied by challenges in the areas of legal regulation, safety, confidentiality, and ethics. At present, the use of UAVs in the EU is regulated unevenly, with different rules in each Member State, leading to legal uncertainty and complicating their cross-border use. The lack of a clear European legal framework in this area necessitates further implementation and supplementation at the national level to ensure the effective functioning of this technology in the EU.

The European Union has had positive experiences when conducting Maritime Air Surveillance (MAS), which is an essential component of their activities and a permanent Frontex service that is provided to national authorities. MAS utilizes surveillance aircraft and UAVs that transmit video and other data from the external borders of the EU and the Schengen area directly to headquarters in Warsaw and to national and European authorities. This enables real-time monitoring and timely responses to potential threats and events at borders (FRONTEX, n.d.).

The Eurosur information exchange system effectively complements maritime air surveillance by enhancing the management of Europe's external borders. It aims to support Member States by improving their situational awareness and ability to respond to transnational crime and illegal migration, and thus prevent loss of life at sea (Frontex, n.d.).

Eurosur is based on a network of National Coordination Centres (NCCs). Each Member State establishes an NCC, which brings together the agencies responsible for border control within that Member State. The main role of the NCC is to coordinate border surveillance activities at the national level and serve as the focal point for information exchange.

NCCs gather local and national information about border activities, including illegal border crossings and criminal activities. The data processed by NCC staff creates a national situational picture. NCCs are also responsible for exchanging relevant information with other Member States and Frontex. Based on this input data and information from other sources, Frontex creates the European situational picture and the Joint Border Surveillance Picture (focused on areas outside the Schengen zone and EU borders).

In recent years, there has been an increase in the militarization of EU borders through the use of UAVs and databases. This has resulted in significant financial and human costs, sparking debates among politicians and experts regarding the effectiveness and social consequences of such measures. Policymakers are considering plans to further strengthen this process (Statewatch, 2022).

2.2.5. The early stages of using UAVs for border security in Japan

The use of UAVs in Japan is growing, but it still remains at a relatively early stage concerning border security, offering greater potential in other areas which traditionally include agriculture, infrastructure monitoring, delivery, search and rescue operations, and law enforcement. Currently, the use of UAVs in Japan is regulated by the Civil Aviation Law and other regulations that restrict their application in populated areas, over people, and in flight-restricted zones. In 2020, the Japanese government announced a plan to liberalize UAV usage rules to stimulate innovation and economic growth, which involves expanding the scope of applications, streamlining permit procedures, and developing new technologies. However, there are challenges such as strict regulations, the need for infrastructure, and societal acceptance that limit the full potential of UAVs in the country. Nevertheless, the use of UAVs in Japan is expected to continue growing, with the government planning to invest in research, development, and infrastructure.

Even in the early stages of UAV usage, the Japanese government is determined not to fall behind other countries and has announced plans for data sharing between the Japan Coast Guard and the Japan Maritime Self-Defense Force (JMSDF), obtained from MQ-9B UAVs operated by each of the government agencies. This data exchange could be a step towards enhancing coordination and cooperation between various military and law enforcement agencies in Japan, helping to improve overall effectiveness and security in the region. Such information sharing could aid in responding to security threats by facilitating the timely exchange of data and collaborative problem-solving (Unmanned Systems Technology, 2023).

2.2.6. Ukrainian experience in using UAVs in wartime conditions

After the start of full-scale aggression on February 24, 2022, UAVs became an integral tool for protecting the Ukrainian border, providing round-the-clock monitoring of the border zone and helping to detect enemy reconnaissance and sabotage groups, adjust artillery fire, and save lives. The advantages of using UAVs are obvious: wide coverage, round-the-clock monitoring, accuracy and detail, mobility, and reduced risks for border guards. Despite significant advantages, the use of UAVs also faces challenges such as cost, dependence on technology, and the need for qualified personnel. However, in the long term, the role of UAVs in border protection will grow as the Ukrainian government plans to increase procurement and develop its own production of UAVs and related systems, as well as train more border guards to use them, in order to enhance the effectiveness of protecting state borders.

In response to the demands and restrictions created by the conditions of war in Ukraine, the use of UAVs is subject to a series of regulations. Civilians must obtain permission for their use, and the country's airspace has been closed to civilian users since February 24, 2022, with additional restrictions that vary by region. Prior approval from law enforcement agencies is required before using UAVs. Legislation also provides for the neutralization of UAVs posing a threat. Considering the above, the use of UAVs requires careful preparation and compliance with all requirements and restrictions (Institute of Mass Information, 2023).

2.2.7. USA's practice in the field of UAVs

UAVs, also known as drones, are an important and widely used tool in the USA for various applications in the civilian, law enforcement, and military sectors. The government, law enforcement agencies, private companies, and research institutions actively use UAVs to perform diverse tasks. In the civilian sector, UAVs find wide applications in fields such as land surveying, land management, agronomy, and environmental monitoring. In the law enforcement sector, drones are used for surveillance, patrolling, and crime detection. In the military sector, UAVs are crucial for conducting reconnaissance operations, as well as providing fire support and carrying out precision strikes on enemy targets.

The military applications of UAVs encompass various functions. In the realm of reconnaissance, they are used to gather intelligence on enemy forces and terrain, providing crucial information to military decision-makers. The monitoring of combat actions and frontline observation also becomes feasible through the use of UAVs, aiding in military operations management and enhancing the safety of military units. Some UAVs are equipped with weaponry and employed for striking enemy targets, ensuring precision and efficiency in military operations. In the logistics sphere, UAVs are utilized for delivering goods to the frontlines and evacuating the wounded, contributing to the support of combat units and reducing risks for military personnel. Additionally, UAVs are employed in electronic warfare to disrupt enemy radar signals and communication, providing vital support in counterintelligence and protection against electronic threats.

Looking ahead, the innovative approach suggested by Ahmadian et al. (2022) could be an intriguing prospect for the USA-Mexico border. This approach proposes the use electric lines (E-lines) to recharge UAV batteries. Instead of manually patrolling safety and danger zones, patrols could utilize UAVs to detect potential threats, and E-lines would allow UAVs to operate for longer periods without the need to return for recharging. This approach simplifies and enhances the effectiveness of border patrol operations, ensuring the security of national borders and reducing risks for patrol officers.

Rapid and accurate vessel detection using UAVs is crucial for maritime surveillance by the U.S. Coast Guard. Potential applications of UAVs include accident prevention and combating illegal fishing and smuggling. Therefore, Cheng et al. (2023) highlight the challenges associated with vessel detection in photographs obtained from UAVs, such as complex backgrounds and the need for high, real-time performance. To address these tasks, the aforementioned researchers propose the YOLOv5-ODConvNeXt enhanced deep learning model, which improves the accuracy and speed of vessel detection.

Research by Kumar et al. (2023) points out the current technologies and challenges regarding the integration of Blockchain technology (Ravikiran, 2023) into real-world applications for UAVs. Scientists emphasize the importance of using Blockchain as an effective solution for ensuring data security and confidentiality by distributing data across multiple transactions (blocks) and recording information on various physical media.

Alongside this, due to the potential use of UAVs by adversaries or criminals, some companies are actively working on the development and implementation of advanced border security systems to counter UAV swarm intrusions. These systems, tested by the U.S. Department of Homeland Security (2024), provide control over national borders and help prevent various threats, including smuggling, reconnaissance, illegal crossings, and potentially dangerous attacks. Through analytical protocols and integrated counter-UAV solutions, an increase in border protection levels and border control effectiveness can be expected. This is critically important for maintaining territorial integrity and the inviolability of national borders (Sentrycs, n.d.).

Also critical is the strategy to combat military UAV swarms, which faces significant legal hurdles, especially on domestic soil. These restrictions complicate the ability of military agencies to defend infrastructure from UAV threats. For instance, the existing legislative framework in the USA does not allow for the timely detection of potential threats emerging outside military facilities. Additionally, distinguishing between hostile and friendly UAVs is challenging, and gathering information about them can pose legal difficulties. Even if a threat is identified, it is often challenging to implement effective measures due to legal constraints and complex inter-agency cooperation procedures. This may result in UAVs remaining undetected until the moment of attack. At the same time, private individuals and law enforcement agencies also encounter legal constraints and risks when attempting to employ countermeasures against UAVs (Bell, 2022).

3. AI in action: The Australian perspective

AI is a field of computer science concerned with creating systems equipped with analytical, recognition, and decision-making capabilities. It is defined as a process in which human intelligence is modelled in machines to mimic human action. From a scientific and technical standpoint, AI is an organized set of information technologies that utilize research methods and algorithms to perform complex tasks in the current era of the Fourth Industrial Revolution (Sarker, 2022). The legal definition of AI presents challenges, and regulation must constantly adapt to the rapid development of this field. Ukraine is already implementing legal frameworks, including the Concept of AI Development (The National Council, 2022), while the EU is developing the Artificial Intelligence Act, which contains detailed legal definitions and ethical principles for regulating the use of AI (European Parliament, 2023). A working group in Ukraine is analyzing legal issues and data protection in the context of AI.

AI, in the evolution of its algorithms, poses a potential threat to the protection of personal data and even global security, which has become a pressing issue for regulators in various countries (United Nations, 2023). Regulation (EU) 2016/679 – the General Data Protection Regulation (GDPR) – came into effect in 2018 and set standards for the collection, processing, and storage of personal information in the EU, playing a key role in ensuring confidentiality and user rights in the virtual environment. An example is Austria, which applies GDPR to AI systems such as Clearview AI, demonstrating that violations of personal data rules can lead to sanctions from regulators (European Data Protection Board, 2023). Another example is Italy, which restricted access to the ChatGPT system due to concerns about the processing of citizens' personal data (Rahman-Jones, 2024). The successful integration of AI and GDPR involves considering the principles of lawfulness, transparency, consent, and other GDPR requirements, ensuring a high level of protection of personal data when using AI (Think Tank, 2020).

As of 2024, Australia has joined international efforts in the field of AI by signing the Bletchley Declaration along with 28 other countries and the EU. This declaration, signed during the AI Security Summit in the UK, commits to the development of AI safely, ethically, and responsibly. Summit participants included governments, companies, NGOs, and researchers in the field of AI. The declaration underscores the potential of AI and the importance of governments working together to effectively manage risks, ensuring the safe use of this technology for the entire international community. The Bletchley Declaration also aligns with the current efforts of the Australian government to support the responsible implementation of AI (Department of Industry, Science, and Resources, 2023b).

As of 2024, the Australian government recognizes AI as a critical technology in serving national interests, and seeks to ensure comprehensive access for Australians to the benefits that AI can provide. This includes fostering economic growth, creating new jobs, and improving citizens' quality of life. AI technologies are utilized to support small businesses in understanding their customers, transforming local production into more competitive ventures, effectively managing the environment and resources, as well as addressing significant national issues such as forest fires and healthcare. The government places special emphasis on promoting and safeguarding AI technology, identifying it as part of a list of critical technologies that constitute national interests. Australia aims to become a global leader in the development and implementation of reliable, secure, and responsible AI, demonstrating its ambitions in this technological field (Department of Industry, Science, and Resources, n.d.).

Additionally, as part of the budget guidance for the 2023–2024 financial year, the Australian government plans significant investment in the development of quantum technologies and AI to support businesses and integrate these technologies into various sectors. Initiatives include the creation of programs and the provision of grants to support projects utilizing quantum computing, as well as measures for the responsible and safe implementation of AI. This investment will amount to $101.2 million USD in total, contributing to the development of critical technologies and fulfilling government commitments to create jobs and support small and medium-sized enterprises in these areas by 2030 (Department of Industry, Science, and Resources, 2023a).

Autonomous systems, robotics, positioning, synchronization, and sensors are key technological domains that unite robots and machines for autonomous task execution with minimal human intervention. These technologies encompass the development of various robots, ranging from UAVs and autonomous systems to advanced imaging and sensor technologies (Shakhatreh et al., 2019). Their applications span a wide spectrum and include mapping, navigation, security, manufacturing, and scientific research. Global research in these domains has surged in recent years, further increasing scientists' interest. China and the USA lead research efforts, while the Australian government (Department of Infrastructure, 2021) implements these technologies in agriculture, healthcare, and other sectors. Commercialization is gauged by patents, and the Australian government aims to establish international standards for these technologies. Significant challenges exist in the form of socio-legal barriers, which can be overcome through public education, effective governance, and legislation. Autonomous technologies are viewed as a promising avenue for productivity enhancement and the development of new economic sectors, and the Australian government sees them as an opportunity for economic growth.

In June 2023, the Australian government demonstrated the integration of various robotic and autonomous systems in a combat environment, organized by the Office of Robotics and Autonomous Systems Implementation and Coordination within the Army. This demonstration included the deployment of dozens of UAVs, providing real-time observation streams to commanders, supporting tank and mechanized platoons. Additionally, remotely controlled autonomous combat vehicles and unmanned transport vehicles were used to minimize risks to soldiers. This demonstration showcased the prospects and potential of merging humans and machines in combat conditions, as well as the opportunities for utilizing high-tech solutions to ensure the safety and effectiveness of military operations (Australian Government, 2023).

The use of a UAV swarm in military or law enforcement situations, including border control, is a highly effective and advanced approach to security. These UAVs interact as an organized team, collectively detecting potential threats and transmitting critical information to the command centre. Leveraging natural collective mechanisms in the operation of UAV swarms contributes to the development of cooperation theory and effective control methods. The intelligent swarm concept has been successfully implemented in the joint management of various types of UAV swarms, and interaction with human operators expands the functional capabilities of such systems (Duan et al., 2023). There is a trend towards the continuous development of intelligent swarm technology and corresponding systems, positioning them as promising directions for further scientific research in this field.

4. The interplay between the geopolitics of semiconductor technologies and advancements in drone technology

The interplay between the geopolitics of semiconductor technologies and progress in UAV technology defines modern trends in global politics and technological development. Semiconductor geopolitics, a key element in the production of modern electronic devices, including UAVs, influences countries' strategic decisions on the world stage (Sehgal, 2023).

In the context of semiconductor geopolitics, countries actively compete for access to advanced technologies, which affects their strategic position and economic potential. Ensuring access to modern semiconductor technologies allows countries to effectively develop and implement advanced UAV systems, thereby defining their power in the realm of security and military capabilities (Omelianenko, 2023).

Furthermore, the increasing importance of semiconductor technologies, which serve as the backbone of innovation, defines the competitiveness of nations in the key segment of the technological space. Of particular

significance is the impact of AI-based software, which acts as a catalyst for the development of unmanned systems (Inoshita, 2024).

The semiconductor industry, based on the unique properties of semiconductor materials, is a crucial component of the modern electronics sector, providing the foundation for the development and production of advanced electronic devices. Equipment and material suppliers play a vital role in this process by providing necessary resources and technologies. As chip components continue to decrease in size, the semiconductor industry evolves, contributing to the increased productivity and energy efficiency of electronic devices while opening up new prospects for their utilization. Thus, the semiconductor industry not only serves as a significant catalyst for technological progress, but also plays a strategic role in the modern electronics sector, fostering its growth and innovation, particularly in the development of AI (Inoshita, 2024).

The development and application of the abovementioned solutions for UAVs and AI are based on ASML (Advanced Semiconductor Materials Lithography) technologies – a Dutch company that manufactures high-precision lithographic equipment for semiconductor production. The impressive growth and innovation of this company in recent decades have transformed it from a competitive player into the world's sole producer of high-quality lithographic equipment for semiconductors. This successful transition from a competitive player to a monopolist reflects the high level of innovation and technical expertise of ASML in the field of lithography, which defines and shapes the modern semiconductor industry (Koc et al., 2023).

Thanks to the high-quality equipment produced by ASML, which manufactures microchips that can also be used in modern weapon systems and AI devices, the company is effectively considered critical infrastructure for U.S. national security and has become the target of industrial espionage from China. ASML, considered the most valuable tech firm in Europe, indeed finds itself at the centre of geopolitical and technological tension (Koc et al., 2023), especially considering competition between the U.S. and China in the use of UAV swarms, a technology that remains imperfect at present (U.S. Government Accountability Office, 2023).

One of the main challenges that urgently needs to be addressed to improve current UAV swarm technology is dynamic task allocation for ground targets, which plays a crucial role in ensuring the autonomy, efficiency, flexibility, and resilience of UAVs. The complexity of this process arises from high environmental demand, the resource constraints of UAVs, and the need for reliable communication. Challenges include algorithm development, processing large datasets, action coordination, and cybersecurity. Current research in this field focuses on the use of AI and machine learning methods, alongside the development of new UAV swarm control techniques. Prospects include a wide range of applications in various industries and enhanced collaboration with humans, opening up new opportunities to increase autonomy and efficiency. Overall, dynamic task allocation is an active research area with great potential for further development, although it is somewhat dependent on the computational capabilities of hardware (Peng, et al., 2021).

Quantum physics and advanced algorithm architectures for machine learning have the potential to redefine innovations in computer technology by reducing their reliance on hardware. However, the fact that China's computational capabilities rely on access to a single tool produced by one company (ASML) illustrates the central role that lithography plays in the global technology sector. This industry is highly complex and is the result of intensive research efforts by a global network of experts in optics and materials science, as well as billions of dollars in investment. Chinese domestic lithographic tools lag behind the leading edge by several generations, lacking many key components such as ultrathin mirrors, as well as experience in system integration (Miller, 2023).

In a few years, ASML (2024a) will release a new version of its extreme ultraviolet (EUV) technology with a high numerical aperture, allowing for even more precise lithography. Research is underway for future tools with even greater precision, although it is unclear whether this will ever be practically or commercially feasible due to physical limitations (with precision approaching the size of an atom). However, we should hope for this, as it is critical for the future of Moore's Law (ASML, 2024b) and the advancements in computational technology that it enables (Miller, 2023).

Conclusions

This research highlights a broad spectrum of current challenges and prospects for using UAVs to ensure border security, focusing on key aspects of their legal regulation. Technological innovations in the application of UAVs for border security significantly impact legal aspects. Algorithms used to predict the behaviour of individuals and border violators may create uncertainty and raise legal questions. Law enforcement agencies, including the border services of different countries, emphasize their high-tech capabilities, but insufficient transparency in their processes and the secrecy of surveillance programs may lead to abuses and may be used to justify human rights restrictions. The conditions of unmanned surveillance may lead to confusion, as this does not always accurately distinguish border violators from civilian populations. The use of UAVs entails constant monitoring and restriction at the border to prevent law violations and detain criminals.

Researchers view UAVs as observation systems that integrate technological and legal aspects and create new legal challenges as they differ from traditional means of information gathering. Thus, the analysis of the legal environment reveals significant challenges and gaps, especially in the areas of confidentiality, information processing, and liability. Emphasis is placed on the need to enhance the regulatory framework to ensure the effective and ethical use of UAVs. In particular, the importance of developing clear and adaptive rules aimed at balancing national security and human rights is underscored. The research findings indicate the relevance and importance of improving legal regulation for the implementation of unmanned technologies in the context of security and law enforcement.

Securing unmanned aerial vehicles (UAVs) against cyber threats is becoming increasingly crucial due to the rising prevalence of cyberattacks and their potential consequences. Malicious actors can gain unauthorized access to UAV systems, hijack control, alter flight paths, steal data, or even disable the aircraft altogether. Therefore, it is recommended to implement comprehensive cybersecurity measures, including: data encryption, authentication and authorization, regular software updates, system monitoring, and personnel training. This can help minimize financial losses, protect reputations, and prevent casualties, while also promoting trust in UAV use and regulatory compliance.

Regulating the use of UAVs requires a careful approach and clear rules. Developing international safety standards for unmanned systems, taking into account potential threats and risks to the public and infrastructure, is a step towards ensuring safety. However, it is also important to establish monitoring and control mechanisms for the use of unmanned systems, including restricting access to sensitive areas.

Another key aspect of successful UAV utilization is increasing public awareness. Public discussions and consultations with community representatives help identify the ethical, legal, and social aspects of UAV use, while also, creating favourable conditions for their responsible use.

The general recommendations of this paper are presented in Table 6, which includes various aspects of using UAVs for border security aimed at addressing complex issues and tackling challenges in this field.

Table 6. General recommendations of this paper

Directions	Recommendations
Legitimacy and Ethics	Develop transparent standards for the use of UAVs that ensure human rights and confidentiality
	Establish effective mechanisms for monitoring potential abuses and violations of rights
Legal Regulation	Adapt national and international regulatory frameworks to rapidly changing technological conditions
	Define clear procedures for the collection, storage, and processing of information, with attention paid to the protection of personal data
Cybersecurity	Conduct regular security audits and vulnerability assessments of UAV management systems
	Implement effective mechanisms for detecting and responding to cyberattacks to ensure reliability and continuity of operations

Monitoring and control	Develop monitoring and control systems for UAV activity to prevent unauthorized interventions and loss of control
	Establish mechanisms to restrict access to critical data and zones
Public awareness	Hold public discussions and consultations to engage the community in the decision-making process
	Develop educational programs and informational materials to raise public awareness about the ethical and legal aspects of UAV usage

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