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# Leveraging drone technology for advancements in photogrammetry, remote sensing, and military intelligence: a review

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## ABSTRACT
**Background**: In the modern technological era, drones have become one of the leading innovations in aviation. This study aims to present a comprehensive literature review on the development and application of drone technology in various contexts, including remote sensing, photogrammetry, military, and intelligence. **Methods**: A literature review was used to collect, evaluate, and analyse relevant literature from various sources, such as scientific journals, conferences, and reference books. This literature review identifies the development of drone technology from its initial form to their more sophisticated use in military and intelligence operations. **Results**: The review presents an overview of the role and contribution of drones in information gathering, earth surface mapping, surveillance, reconnaissance, as well as battlefield attacks. The implications of drone technology for future military operations are also discussed, including the integration of sensors, the development of communication systems, and improvements in the decision-making process. **Conclusion**: This research provides an in-depth understanding of the potential of drone technology and the challenges and opportunities associated with its application in various fields.

**KEYWORDS**: drone; intelligence; military; remote sensing.

## 1. Introduction

Drone technology, characterized by remote-controlled unmanned aerial vehicles (UAVs), is a significant technological breakthrough with broad potential applications in various fields. One such domain is the field of photogrammetry and remote sensing, which intersects with military, intelligence and civilian interests. Drones have attracted worldwide attention due to their technological implications, privacy concerns, regulatory frameworks, and even implications in warfare (Colomina I, 2013). For more than three decades, photogrammetry and remote sensing have been disciplines that have great potential in image formation. Recent advances in aviation technology have posed challenges to regulatory frameworks and conventional processing methods over the past five years. The ingenuity of researchers in integrating equipment with advanced computer vision, robotics and geomatics has resulted in products with high resolution and accuracy.

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The development of drone systems, or Unmanned Aerial Vehicles (UAVs), has also seen rapid growth in the military, serving as active combat weapons (drone bombers) and intelligence gathering platforms through aerial photography and data collection (Watts, 2012). The characteristics of drones, such as flexible flying capabilities, long flight duration with minimal operational costs, and improved control systems, have enabled them to rapidly replace manned aircraft in military and intelligence operations, thereby improving personnel safety. However, the advantages offered by drones are highly dependent on factors such as the type of drone, sensor capabilities, purpose, and applicable operational regulations. The advent of drone technology a few decades ago has ushered in a new era in photogrammetry, remote sensing, military, and intelligence, promising to be an enabling technology in these fields. The inherent potential of drones should be maximized to advance scientific knowledge and improve defense against military and intelligence threats.

## 2. Methods

The purpose of the review research is to evaluate and describe the development and application of drone technology, both in civilian and military contexts, and explore their role and contribution in the fields of remote sensing, photogrammetry, and intelligence. Data was collected from various sources such as books, journals and other relevant references. A literature evaluation and analysis was conducted to filter the information and identify patterns, key findings and contributions from the reference sources. The information extracted from the literature was then synthesized and interpreted to form a comprehensive picture of the development of drone technology, their role in remote sensing, photogrammetry, as well as their implications in the military and intelligence context. This also involved identifying remaining research gaps and potential areas for further research.

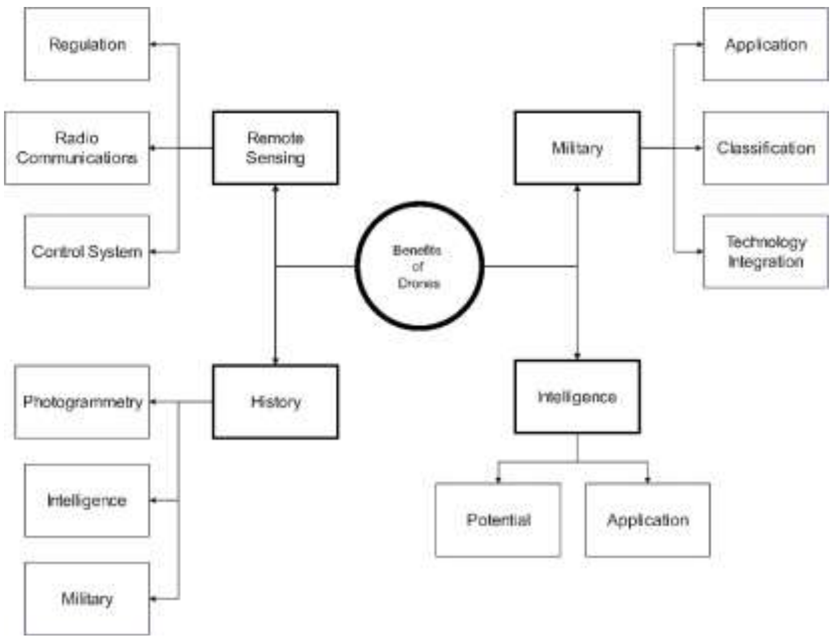


Fig. 1 Brainstroming

## 3. Results and Discussion

*3.1 Evolution of drone technology for remote sensing*

The early development of aerial reconnaissance can be traced back to 1858 when Gaspard-Félix Tournachon, a photographer and journalist from Paris, conducted aerial observations using a hot air balloon. This event marked the precursor to the birth of drones or Unmanned Aerial Vehicles (UAVs) for earth surface reconnaissance. Technological advancements subsequently led to the simplification of methods in aerial photography for cost-efficiency purposes. In 1882, an English meteorologist named E.D. Archibald utilized kites for aerial photography. Another notable event in the history of aerial photography occurred in 1903 when J. Neubronner attached a small camera to a pigeon from the Bavarian Pigeon Corps for aerial observation of the Earth. These pioneering events in aerial reconnaissance demonstrate that the oldest form of aerial reconnaissance was based on the ease of operating tools in line with technological advancements in each era.

This journal focuses on the use of drones or Unmanned Aerial Vehicles (UAVs) for remote sensing and aerial photography for civilian and intelligence purposes. UAVs are closely associated with integrated circuits and remote control systems based on radio signals. The 20th century marked the emergence of radio control technology for UAVs for remote sensing. Researchers such as Przybilla and Wester-Ebbinghaus developed a radio control system with a 3-meter wavelength to control fixed-wing UAVs equipped with optical cameras (Przybilla H, 1979). Testing of their radio control system continued in 1980, where it was used to control rotary-wing copters carrying Rolleiflex format cameras for aerial observation of construction and Earth surfaces (Wester-Ebbinghaus, 1980). The discovery by the Wester team in 1979, which was then developed in 1980, became the earliest experiment opening the development of radio control systems to control fixed-wing UAVs, rotary-wing UAVs for remote sensing, and aerial photography.

The evolution of drone technology for remote sensing and aerial photography has undergone significant advancements since its inception in the 19th century. From humble beginnings with hot air balloons and kites to sophisticated radio-controlled UAVs equipped with optical cameras, the capabilities of drones for aerial reconnaissance have expanded dramatically. Moving forward, further research and development are needed to enhance the efficiency, accuracy, and safety of drone-based remote sensing and aerial photography. Additionally, addressing regulatory frameworks and ethical considerations surrounding the use of drones in civilian and intelligence applications will be crucial for maximizing their potential benefits while mitigating risks.

*3.2 Categorization of unmanned aerial vehicles (uavs) for remote sensing*

Unmanned aerial vehicles (UAVs) represent a culmination of advancements in unmanned aircraft technology and optical cameras, facilitating their utilization for various purposes. Throughout history, the categorization of UAVs by different communities has encountered complexities (Everaerts, 2009). Classification of UAVs is based on various factors such as size and weight, endurance, aerodynamics, mission range, and altitude. To facilitate clear definition of each aspect related to UAVs, Everarts emphasizes the necessity of categorizing UAVs explicitly. In this article, we attempt to categorize UAVs clearly to enable readers to understand the various types of UAVs comprehensively.

Formally, in the context of remote sensing, a remote sensing mission to capture Earth images requires at least a fixed-wing or rotary-wing UAV with a maximum takeoff weight (MTOW) of less than 30 kg, capable of flying 10 km away and flying at an altitude above 300 m, equipped with a small or medium optical camera that can be remotely operated by humans or autonomously controlled based on the Global Navigation Satellite System

(GNSS) such as GPS. The specified standards above provide a representative overview of current UAVs for remote sensing purposes in capturing Earth images.

While the current ecosystem of remote sensing with UAVs aligns with the aforementioned paragraph, there have been deviations from formal developments in the field of remote sensing. The discovery of stratospheric UAVs capable of providing real-time aerial image resolution for large-scale mapping is one such deviation (Everaerts J, 2004). In light of this, a comparative analysis of various UAV technologies for remote sensing is necessary for precise categorization with the aim of identifying the most efficient UAV platform for remote sensing.

### *3.3 Remote control systems for unmanned aerial vehicles (UAVs)*

Control systems for unmanned aerial vehicles (UAVs) are integral components that cannot be separated when discussing drones. The control system for UAVs is arguably as important as the UAV itself, as it communicates with the UAV interface and regulates every flight route. The Ground Control Station (GCS) is a hardware/software device, either portable or fixed, designed to command UAVs. As the most fundamental part of UAV operations, the GCS has evolved alongside advancements in telecommunication technology and computer science.

Crucial requirements for controlling and communicating with UAVs include signal transmitter devices, multiple monitors, and a crew. Examples such as the Predator or Global Hawks GCS demonstrate simultaneous control of multiple platforms, requiring six crew members to operate UAVs. Conversely, there are smaller, portable PC-based GCSs like the UX5 and SwingletCAM. In general, an overview of various types of GCSs provides insight into the technology behind any commercial UAV, highlighting the indispensability of GCSs.

### *3.4 Communication systems for unmanned aerial vehicles (UAVs)*

The operational efficiency of a UAV system commanded from a Ground Control Station (GCS) heavily relies on communication between the UAV and the GCS. UAV communication plays a critical role in mission activities, controlling and issuing commands to the UAV, as well as ensuring flight safety in coordination with Air Traffic Control (ATC) within shared airspace. In February 2012, the World Radiocommunication Forum (WRC-12) convened in Geneva to address various communication-related issues among UAVs. Furthermore, the forum deliberated on spectrum requirements and regulatory actions, including global spectrum identification to harmonize UAV operations worldwide safely within non-segregated airspace alongside commercial flights. One outcome of the WRC-12 forum was the allocation plan for the Aeronautical Mobile Satellite (Route) Service (AMS). Subsequently, in 2015, the International Telecommunication Union's communication sector was tasked with developing technical regulations for WRC operationalization. According to agreements, the ITU and WRC will continue researching whether the Fixed Satellite Service (FSS) can still support UAV communication consistently with flight safety, while examining the necessity of flight regulations concerning other aviation interests.

Currently, the most prevalent communication method between control devices and commercial UAVs is through Wi-Fi (at 2.4 GHz frequency). However, technologies beyond Wi-Fi are being researched and developed, such as high-frequency satellite communication systems used in military systems (e.g., Predator or Global Hawk), or Worldwide Interoperability for Microwave Access (Wi-MAX) (Dusza B, 2010). With a variety of control system technologies available for UAVs, regulations governing communication between control devices and UAVs are essential to ensure flight safety between UAVs and commercial aviation.

*3.5 Regulatory framework for unmanned aerial vehicles (UAVs)*

The establishment of a harmonious ecosystem for UAV operations has long been anticipated by stakeholders to facilitate the commercialization and certification of UAVs worldwide. Technical challenges in crafting regulations related to UAVs require significant efforts, involving various cross-disciplinary groups. The International Civil Aviation Organization (ICAO) serves as a platform to integrate countries and relevant industry organizations to discuss and develop regulations and standards for civil aviation (Everaerts, 2009). One such regulation by ICAO pertains to incidents caused by UAVs, which must be investigated by aviation authorities capable of certifying commercial aircraft and relevant ground stations.

*3.6 Integration of drone technology in military and intelligence operations*

Unmanned aerial vehicle (UAV) technology has emerged as a pivotal tool in supporting military and intelligence operations (Jean-Paul Yaacoub, 2020). UAVs developed for intelligence and military purposes must be equipped with additional technologies commonly used in remote sensing. The integration of various technologies within drones is essential to enhance their capabilities for observation and even offensive functions. However, the utilization of drones in warfare requires a novel strategy tailored to the related technologies to be employed. Therefore, the integration of drone technology with other military equipment needs to be developed with a communication system utilizing radio frequency signals.

The evolving landscape of technology may render future battlefields highly dynamic. UAV technology will be one of the platforms playing a significant role and making substantial contributions to the future military (Kindervater, 2016). A military force from one country may gain an advantage if they can master UAV technology because these platforms can integrate sensors to gather comprehensive information regarding potential threats, thus enabling effective strikes against adversaries. The integration of comprehensive sensors, coupled with efficient information processing, can shorten the Observe-Orient-Decide-Act (OODA) loop, facilitating commanders' tasks in operations.

UAVs possess advantages not found in conventional warfare instruments, notably the ability to launch attacks against enemies with minimal risk of casualties (Kazi Mahmud Hasan, 2018). This aspect provides a significant advantage to parties capable of mastering this technology. UAVs do not require human operators onboard during missions. They can be controlled remotely or autonomously, employed for single or reusable missions, carry lethal or non-lethal payloads, and operate in diverse environments. UAVs, as a nascent technology, hold tremendous potential in the military domain but are still in the early stages of development.

*3.7 Integration of warfare technologies*

The application of a technology within a field necessitates support from other technologies to form a new technological ecosystem. The development of drone technology, for instance, requires sophisticated computer systems capable of rapid data processing, such as image rendering and data transferring, to generate information swiftly. Advanced computer systems also assist the military in conducting pre-war simulations that emulate real battlefield scenarios. These simulations offer strategic advantages by allowing the application of warfare theories and strategies without engaging real enemies. Furthermore, sophisticated computer systems are instrumental during actual combat, facilitating rapid and efficient control of troops on the battlefield.

The command flow from commanders can be swiftly relayed to soldiers after monitoring the situation through existing computer systems. This capability is epitomized by the Battle Management System (BMS) (Denny Lesmana, 2021). BMS serves as a system capable of aggregating various types of data from diverse sources, including intelligence data, location maps, enemy positions, and strengths. The implementation of the Battle Management System (BMS) in wartime conditions can be integrated into tactical combat vehicles, radio signal communication equipment, and unmanned aerial vehicle technology. BMS exemplifies the integration of computer technology to meet decision-making needs in the military domain.

*3.8 Potential of drones in military and intelligence*

During an era when aerial technology was scarce, warfare heavily relied on ground forces, with air power primarily used to support ground forces. At that time, observing advanced countries like the United States, they began to recognize the potential of aerial vehicles as information gatherers, providing initial insights into battlefield conditions. Over time, the use of aerial vehicles evolved into a platform not only for information supply but also for various other purposes.

Unmanned aerial vehicles (UAVs) or drones, in general, fulfill the criteria as supporting media for intelligence operations, specifically surveillance and reconnaissance. This technology utilizes various sensors such as radar, radio frequency, and infrared to gather information about enemy territory (M. Hassanalian, 2020). Generally, surveillance drones are categorized into two types: High Altitude Long Endurance (HALE) and Medium Altitude Long Endurance (MALE). This classification is based on the drone's endurance and the altitude it can achieve. HALE drones can reach a maximum altitude of 60,000 feet and fly for up to 32 hours, while MALE drones have a maximum altitude of 25,000 to 50,000 feet and can fly for 24 hours. This classification may evolve and adapt with technological advancements.

The current development of aviation technology in the military has led to the creation of sophisticated stealth aircraft that can be remotely controlled. This technology enables remote control of aircraft, resulting in smaller-sized aircraft that are more difficult to track. In today's widespread use of drone technology worldwide, drones or UAVs are utilized for intelligence, reconnaissance, surveillance, and warfare purposes. In the future, UAV technology is expected to be employed in broader military applications with advanced remote control technology.

## 4. Conclusions

This review has provided a general overview of drones or unmanned aerial vehicles (UAVs) for remote sensing purposes, serving both civilian and military interests, including direct military and intelligence applications. By examining the history of UAVs, we can observe how this technology has been utilized for remote sensing with various prototype forms, such as balloons and kites. Present technological advancements have led to the development of UAVs, commonly referred to as drones, which are now maximized for remote sensing and photogrammetry purposes. With the technological progress achieved in drones, the imagery obtained is adequate to support the development of geoinformation products, including GPS services.

Moreover, for remote sensing purposes, regulations related to UAVs are being developed to achieve harmony in the aviation domain, considering that drones and civilian aviation operate within the same airspace. In this journal, we also discussed the development of drone technology for military and intelligence purposes. The use of UAVs in dynamic future battlefields can provide advantages to those who master the technology. The most common classification of intelligence drones separates them based on their maximum capabilities and endurance, adapting as drone technology evolves. The integration process of drone technology, such as the Battle Management System, represents the outcome of drone technology development in the military and intelligence fields. Future research directions may focus on enhancing the capabilities of drones for remote sensing, military, and intelligence applications. This includes improving data processing algorithms, enhancing sensor technologies, and furthering the development of regulations to ensure safe and ethical UAV operations. Additionally, exploring novel applications of drones in various domains, such as disaster management and environmental monitoring, can contribute to advancing UAV technology's utility and impact.

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The authors declare no conflict of interest.

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