Upcoming Military Applications of Unmanned Aerial Vehicles with Digital Cameras and Other Sensors

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ABSTRACT

Unmanned Aerial Vehicles (UAVs) have become increasingly prevalent in various civilian and military applications. With the time and money invested into their research and development, their range of applications is expected to increase. This research study focuses specifically on UAVs with digital cameras and other sensors on board and their potential future applications within the military sector. Technological advancements and research topics have been identified and classified into multiple subtopics through an extensive literature review. The method and analysis include a chart with several upcoming projects. This study identifies and elaborates on the most promising project among them comprehensively. The results conclude that the transportation of supplies and terrain scanning could spearhead the future of UAV development and real-world applications.

Introduction

In recent years, Unmanned Aerial Vehicles (UAVs) have emerged as a vital technology and have found several applications within the military and civilian sectors. Due to exponential growth in the research, funding, and development of UAVs, many organizations and individuals have started integrating them into their daily activities. According to a recent study by Lahmeri *et al*., the value and utilization of the drone market are estimated to double within the next two years (Lahmeri, 2022). This trend is specifically prominent in military applications, as a growing number of nations are funding leading-edge research ventures in drone programs. Therefore, it is almost impossible and imprudent to ignore the UAV development in the military sector for any country.

As the UAV field has advanced in the recent decade and its range of possibilities has expanded quickly, these machines' applications also vary for diverse purposes. Primarily, UAVs have been utilized in *Intelligence, Surveillance, Target Acquisition, and reconnaissance* (ISTAR) missions. However, with the emergence of underlying hardware and software technology, the limitless potential of UAVs can be expanded to various other fields. The primary objective of this research study is to investigate prospective military uses for UAVs equipped with cameras and different types of onboard sensors. Furthermore, the study evaluates the advantages and disadvantages of UAV utilization in military applications. This study is essential due to the ongoing expansion and advancements of UAVs equipped with cameras and other sensors. In addition, it also focuses on the materials and computing hardware technologies and challenges. The study illustrates that although it may not be possible to predict the future direction of UAV technology, informed and data-driven predictions can be made to explore its potential. Furthermore, the study provides best practices and recommendations for designing and deploying UAVs with digital cameras and other sensors in the military domain. Finally, it contributes to the literature by comprehensively assessing UAVs' current state-of-the-art and future possibilities.

Literature Review

According to a study by Hartmann *et al*., several risks, challenges, and opportunities manifest in using UAVs in real-life applications (Hartmann, 2016). The study focuses primarily on UAV utilization for cyber warfare rather than dropping bombs with pinpoint accuracy or other physical attacks. Some risks the authors describe are the UAVs' susceptibility to hacking cyberattacks, jamming, or signal interception. These vulnerabilities pose a serious risk to drone operators prioritizing stealth operations to avoid getting detected. However, the study also illustrates that UAVs offer several opportunities, like intelligence gathering or offensive cyber warfare. Overall, more R&D is imperative to explore the full potential of these machines in diverse applications.

The military uses multiple types of UAVs for various purposes (Chaturvedi, 2019). For instance, High Altitude Long Endurance (HALE) UAVs—as depicted in Figure 1—can reach up to the elevation of 30,000 ft. They are primarily employed for the *Intelligence, Surveillance, Target Acquisition, and Reconnaissance* (ISTAR) missions. Another type of UAV is known as Medium Altitude Long Endurance (MALE), which is utilized for airborne refueling and rocket protection applications besides ISTAR. Similarly, a smaller type of UAV is called the Low Altitude Short Endurance / Low Altitude Long Endurance (LASE/LALE) and can be typically launched by one person nearby. Various law enforcement groups and civilian authorities employ these UAVs in different applications. The research study explores the capabilities of the Indian Air Force (IAF) and its close collaboration with the Israeli Aerospace Industries, which is one of the leading UAV manufacturers worldwide.

Figure 1. An example of a HALE UAV (DRDO Ghatak) (Chaturvedi, 2019)

Another article by Al-Shareeda *et al.* briefly explains UAVs' plausible future applications and challenges (Al-Shareeda, 2023). For instance, a prominent issue of UAVs constantly investigated by various researchers and organizations is their energy efficiency. Thus, the authors propose different energy-efficient algorithms that optimize the communication, sensing, data processing, and storage attributes of a UAV. These algorithms consider that if the energy consumption of a UAV is continually optimized, it will allocate the preserved energy to other modules and components, allowing for greater endurance of the overall system. In addition, the authors discussed that an everlasting issue with UAVs—especially in military applications—is cybersecurity and potential cyberattacks due to hacking campaigns from adversaries. Therefore, it is critical to ensure the secure communication and transfer of control data to avoid the possibility of hacking without interception from the undesired actors. Thus, ensuring adequate cybersecurity is the most significant factor in future UAV designs.

Ethical Issues

A study by Konert *et al.* discusses several legal and ethical issues related to UAVs, specifically autonomous drones, which can conduct lethal strikes against enemy targets (Konert, 2021). Currently, UAVs are not entirely capable of making human-like decisions independently. Therefore, most people and organizations cannot trust fully autonomous systems requiring no human input. Nonetheless, arguments from both sides exist. Some experts believe that humans are not the most rational decision-makers, as they may incorporate emotions while making decisions, which could adversely impact the outcomes. Thus, this issue can be eliminated with autonomous systems. However, the paper offers the possibility of a "*human-machine partnership, where humans work with robots and maximize effectiveness by combining the strengths of both partners*." Based on these assertions, we can conclude that any future of UAVs and autonomous drones must include the ethical aspects of their utilization in various application areas.

Current and Future Applications

Several current and future applications of UAVs exist within both the civilian and military sectors (Muchiri, 2022). A typical example of the daily use of UAVs is in remote sensing. According to Muchiri *et al.,* "*remote sensing is the science of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation*" (Muchiri, 2022). In recent years, UAVs using cameras and other thermal sensors are often employed in the agriculture sector. Many exciting delivery and Internet service applications are available using drones, which can be very applicable within the military. For instance, if a military group requires quick and safe delivery of supplies or other small items, drones can be a perfect choice, especially if the terrain is challenging.

In a survey article by Wei *et al*., the authors describe a technique of UAVs that collects data with sensors in the Internet of Things (IoT) paradigm (Wei, 2022). UAVs benefit from IoT-based systems due to their low cost and high efficiency. A few examples of the application of UAVs in the IoTs include intelligent transportation, smart cities, intelligent homes, and smart ocean. This 2022 study also estimates that more than 100 trillion sensors will be incorporated in countless application areas globally within the next decade. With UAVs playing a pivotal role in the IoT area, their development and mass implementation into daily life will inevitably become ubiquitous. However, the article primarily focuses on UAV applications in the IoT area, including data collection and communication.

3D Visualizations

In a study by Nex *et al*., the authors describe the workflow of using drones in *photogrammetry*, a practice of using a collection of 2D images to create 3D models (Nex, 2014). In various real-world applications, 3D mapping has been extensively utilized. Some examples include mapping archaeological sites, geological and mining sites, and urban regions. As illustrated in Figure 2, a simplified workflow of 3D visualization at an excavation site can be observed. The main advantage of utilizing UAVs for this application is their low cost and high speed. Multiple examples of both manual and automated UAVs for this purpose have been discussed in the literature. Using 3D modeling and visualization for similar applications in the military sector could also be an exciting and ingenious approach.

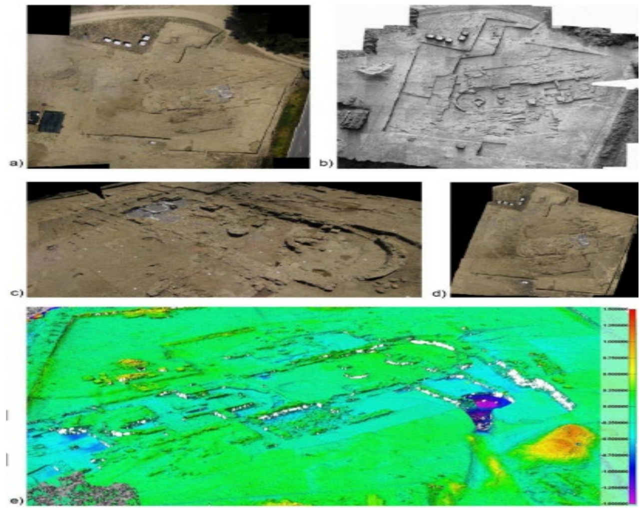

Figure 2. Images obtained with UAVs and the workflow of 3D visualization at an excavation site. (Nex, 2014)

Another key application area for drones is the Forest Health Monitoring (FHM), which has traditionally been improved significantly using UAV-based imaging and surveillance (Ecke, 2022). A simplified visual explanation of such applications is depicted in Figure 3. The pipeline for FHM applications requires data in massive volumes, high quality, and prompt. Research by Ecke *et al.* in 2022 has assessed around 100 studies from the past decade and determined the pros and cons of using drone technology for FHM. In this case, drones' primary benefits are their ability to meet the demand for high spatial resolution and flexibility. However, besides UAVs, satellite-based imaging technology can also be leveraged for remote sensing to cover large areas. Nonetheless, the results of satellite data typically have low resolution and delays.

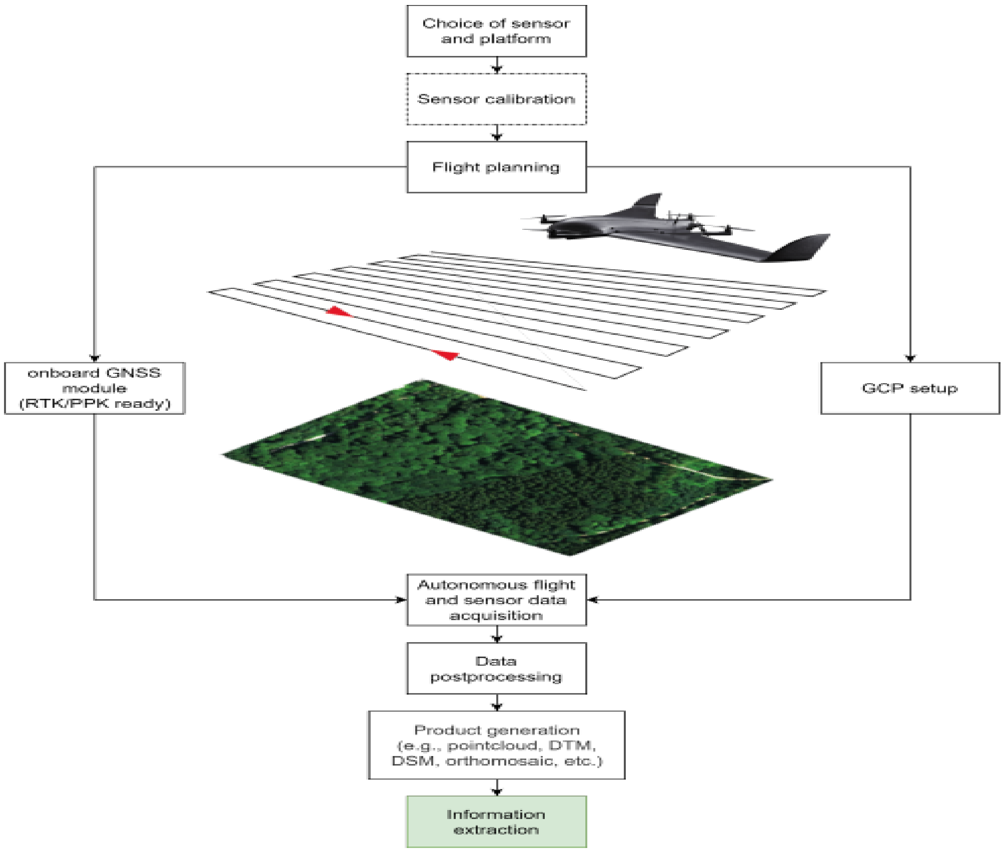

Figure 3. Workflow visualization of UAV data acquisition for Forest Health Monitoring (Ecke, 2022).

Using Machine Learning (ML) models, the military's points of interest—*e.g.,* tanks, other vehicles, bunkers, *etc.*—can be classified (Liu, 2022). The basic workflow of such models includes a few steps. First, a dataset of UAV reconnaissance imagery containing tanks—called UAVT-3—is created. Subsequently, an existing computer vision algorithm for object detection in images called *YOLOv5* is enhanced and utilized. The newly created algorithm—UAVT-YOLOv5—performs better and detects tanks in different weather conditions. Although the quest for pursuing a perfect algorithm will probably never conclude, this is a significant advancement in the field. Automated AI detection is extremely valuable in an era where operations must be performed precisely and rapidly.

Security

Abro *et al.* suggest that adversity is bound to occur with the advancements in UAV technology (Abro, 2022). The study discusses the different security vulnerabilities of UAVs. For example, *spoofing* is a cyberattack on the UAV communication system, which can bypass the GPS encryption, leading to an interception and potential alteration in GPS information and allowing the hackers to gain control of the UAV. Furthermore, sensor-specific strikes could be conducted, where the UAV gyroscope using ultrasonic waves can be compromised. The study also proposes a solution to these security threats. Figure 4 depicts various types of cyberattacks on UAVs. As technology advances, military warfare tactics, including drones, may be elevated to a new, digital level. Therefore, incorporating security issues should be a top priority when discussing UAVs.

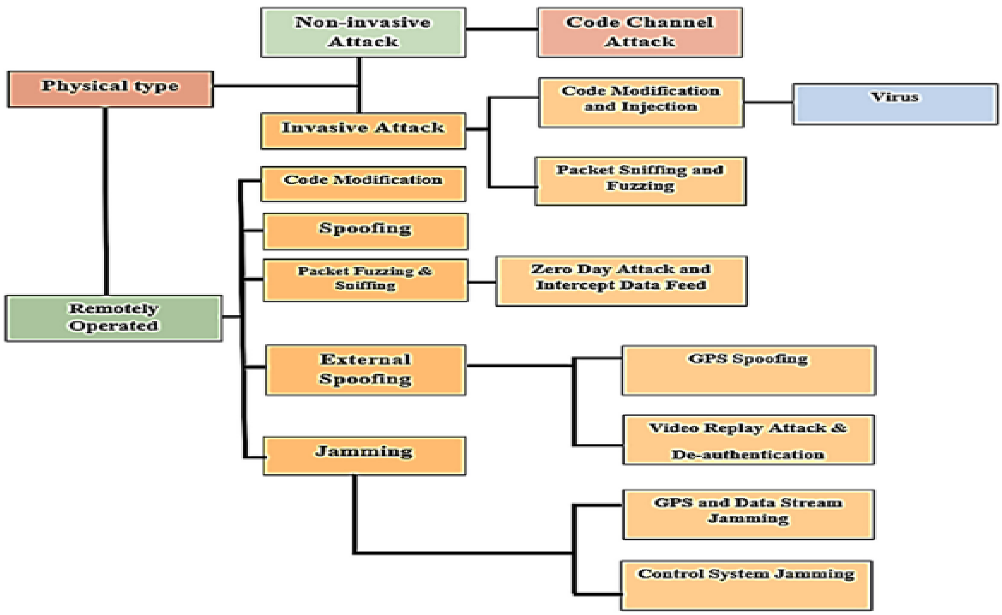

Figure 4. Types of Attacks on UAVs (Abro, 2022)

According to Siddiqui *et al.*, safety is of rising concern for both innocent citizens and drone operators, whereas the risks can be physical and remote. For instance, due to drones' low cost and availability, criminals often utilize them to conduct illegal monitoring, spying, and stalking (Siddiqi, 2022). Figure 5 depicts a chart of diverse applications of UAVs. In addition, drones capable of transporting objects open up a whole new range of possibilities for criminals, allowing them to deliver packages or transport harmful substances or explosives undetected. Therefore, safety hazards manifest in multiple forms for UAV operators. For example, they may encounter remote cyberattacks like malware injection or *spoofing*. Similarly, many common attacks for the average consumer can be physical hazards like strong winds, heat or cold, and predator birds. In addition, smaller UAVs, without proper encryption systems and protection, can be easily intercepted, as they typically use *Wi-Fi* connections.

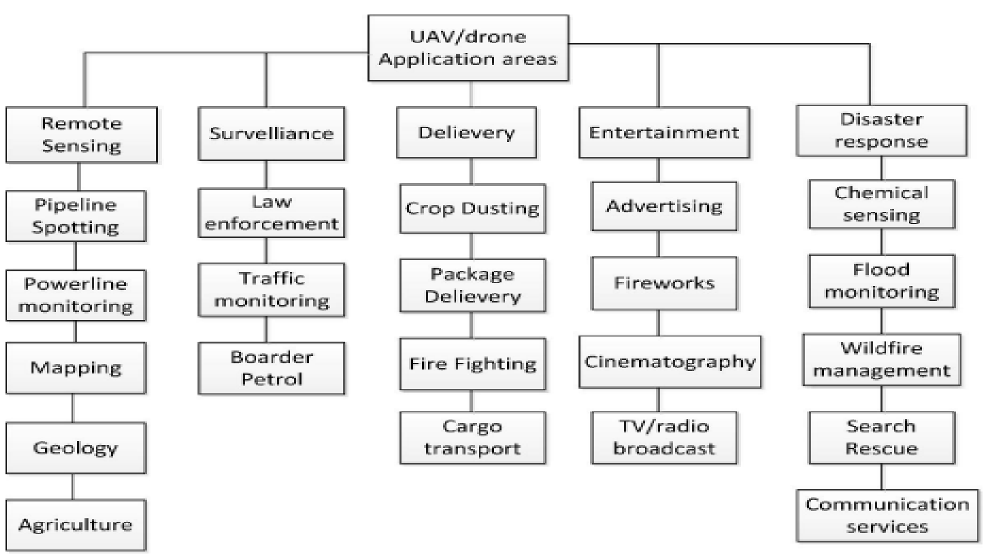

Figure 5. UAV applications in diverse fields (Siddiqi, 2022).

One of many current and future applications of UAVs is acting as signal hotspots in low-coverage areas (Khan, 2022). They can be used to enhance coverage range to serve as "*communication access points*." While these are promising applications, they do not come without many inherent problems. One of the most significant problems regarding UAV safety is their vulnerability to eavesdropping – *i.e.,* the process of intercepting valuable data. Many cybersecurity experts might suggest data encryption technologies to solve this problem. However, UAVs—which are heavily reliant on energy efficiency—will most likely underperform if presented with complex encryption/decryption algorithms. Therefore, the authors suggested implementing physical-level security systems using the *Intelligent Reflective Surfaces* (IRS). These systems can redirect signals toward the data receiver, making it extremely difficult for eavesdroppers to intercept the signal. Figure 6 illustrates a thorough detail of the IRS setup.

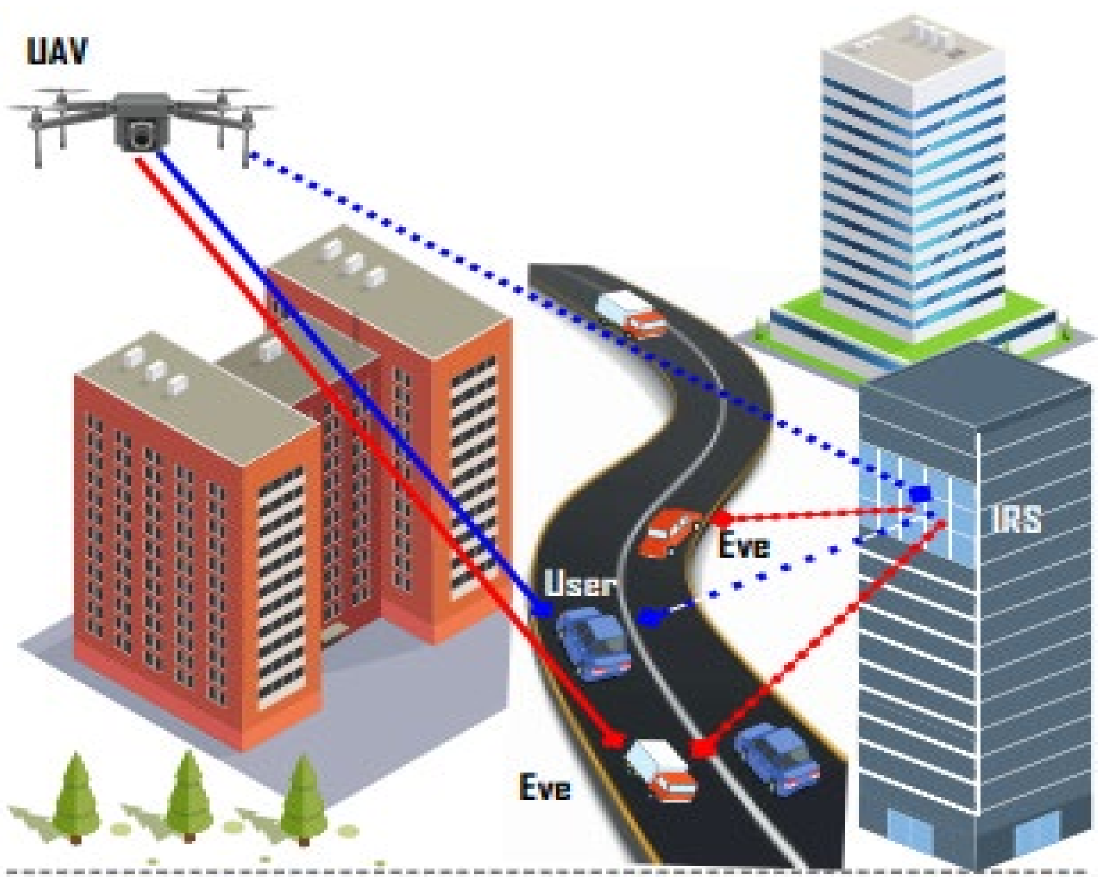

Figure 6. System model of IRS usage (Khan, 2022)

As mentioned above, one of the most significant risks of UAVs is their vulnerability to cyberattacks (Cecchinato, 2022). An outstanding achievement in the military domain UAV industry would be creating the most optimal algorithms or protocols for secure data transmission. The work by Cecchinato *et al.* proposed a design to quicken the processing of an encryption algorithm and improve the UAV transmission systems efficiently. The system enables a process to encode and encrypt the multimedia data acquired by the UAV. Subsequently, it transmits it via the Transmission Control Protocol (TCP) to sockets located on the ground. The *spectrograms* of the signals are shown in Figure 7. Once the station receives the encoded messages, it is decrypted and can be visualized. According to the authors, the spectrogram of the encrypted signals is comparable to that of white noise, making it impossible to decrypt the valuable data without the cipher key and other parameters included in the design.

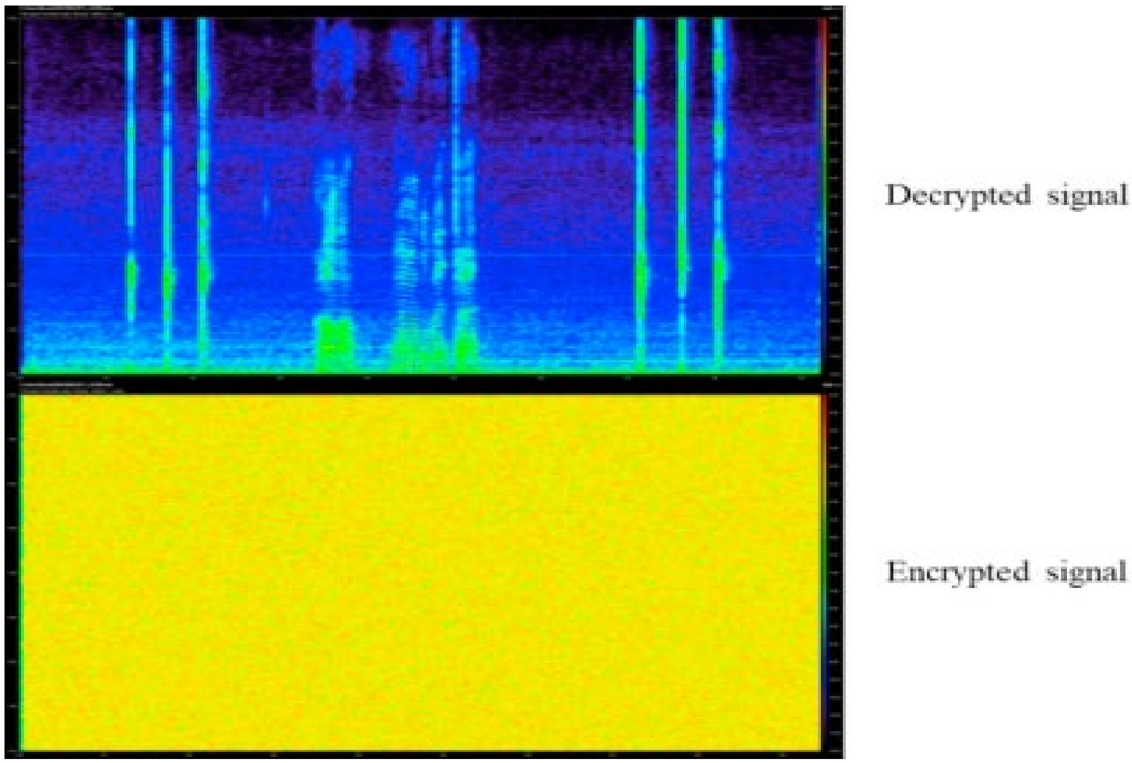

Figure 7. Spectrograms of the encrypted and decrypted signals (Cecchinato, 2022)

New Technology/Innovation

According to Mohsan *et al.,* one of the UAVs' most vital characteristics is their endurance and charging time (Mohsan, 2022). For instance, a UAV's travel distance and length of flight are directly constrained by its battery capacity and recharging ability. To address this issue, the authors suggest innovative solutions like wireless charging techniques for micro UAVs. One such charging method is called *Laser Power Transfer* (LPT), which involves pointing a laser beam toward *Photovoltaic Cells* (PCs) installed on a UAV. This beam converts the laser light into energy and charges the battery. This innovative method holds several advantages, such as the possibility of an indefinitely long flight and charging over a long distance. However, there are still some concerns, like blockage of the laser and mobility issues. Besides wireless charging, the authors also described the possibility of *Simultaneous Wireless Information and Power Transfer* (SWIPT). Overall, the technology is relatively new and requires a lot of R&D. Nonetheless, wirelessly charging UAVs without interrupting missions is extremely valuable in many military applications.

Lahmeri *et al.* estimate that the value of the drone market will double within the next two years (Lahmeri, 2022). Drones have become a significant part of multiple industries and applications, including mapping, inspection, and agriculture. Besides the overwhelmingly fast rise of drones and other UAVs, their battery capacity is a persistent issue. However, due to their energy limitations, most commercially available drones struggle to stay afloat for over half an hour, severely limiting their applicability. Therefore, LPT technology has the potential to solve this issue and allow for an indefinite flight time. Figure 8 depicts various technicalities of such systems, like their setup, safety, cooling, and tracking systems. The authors discussed a project—called the PTROL system—by the *US Naval Research Laboratory* completed in collaboration with *PowerLight* Technologies. The PTROL project successfully demonstrated an example of indoor laser powering.

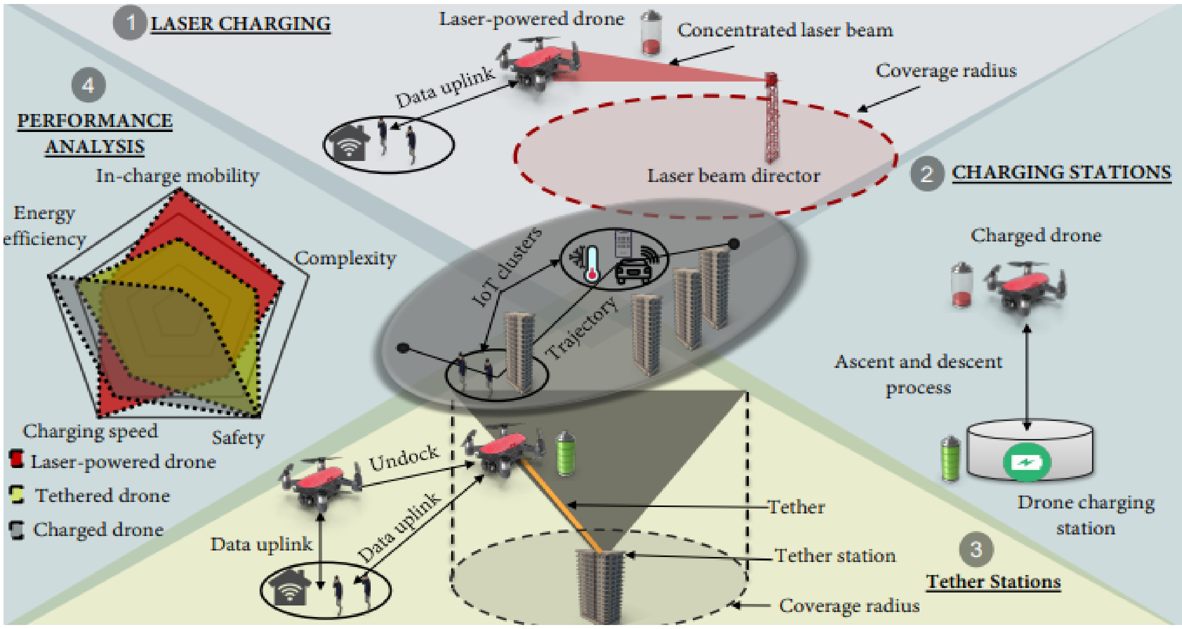

Figure 8. Overview of charging techniques (Lahmeri, 2022).

In many recent studies, AI integration into drone technology has been discussed increasingly, primarily due to the applicability and accessibility of AI models. For instance, Mohsan *et al.* have recently discussed implementing AI into drones and their missions and laser beaming as a charging method (Mohsan, 2023). Although AI models have not been fully integrated into UAVs, they could play vital roles in various applications. For instance, in various search and rescue missions administered through UAVs, AI could predict the target's whereabouts. Through ML and Deep Learning models, UAV systems can analyze different regions and look for possible clues to help in search and rescue missions. This significant idea can be utilized in many military applications, where UAVs can explore objects the human eye might not detect.

Military applications are not the only domain where drones or UAVs are used; police squadrons use them to control traffic (Fan, 2022). They can assist the police with traffic violations by identifying them and capturing evidence. Besides, many search and rescue missions have already been carried out by UAVs. For instance, the authors reported, "*Shenzhen Dajiang Innovation Technology Co., Ltd. stated that drone systems have saved 124 lives in the past two years.*" They also predict integrating UAV technology into the household for minor tasks, such as delivering food to a household member or playing music. Therefore, UAVs can quickly improve the performance of many future jobs in our everyday life.

Khalil *et al.* contemplate that for many missions, UAVs are programmed to move in various places besides remaining undetected (Khalil, 2022). One of UAVs' most significant advantages and attractive attributes to the military is their mobility. Although no mission is perfect, the operator or the drone itself has to recalculate the drone pathway. That can happen for multiple reasons, such as jamming, range issues, or enemy defense systems. The authors develop a novel framework, *FeD-UP*, for UAV path planning that incorporates ML techniques, including federated and deep reinforcement learning. Moreover, the paper described the simulation results, showing that the FeD-UP system outperformed the regular deep reinforcement learning system in complex missions like obstacle avoidance and goal completion.

Methods

This research article proposes a few critical factors of UAV applications, including cost, complexity, usefulness, and TRL, and then ranks possible applications based on those factors. Among these factors, the *Technology Readiness Level* (TRL) is a ranking system (between 1 and 9) that quantifies the maturity level of a given technology. In this ranking, 1 is the lowest maturity, and 9 manifests the highest application-ready technology. Since the proposed paper primarily focuses on the applications of UAVs with cameras and other digital sensors, TRL is a vital parameter. Table 1 presents a side-by-side comparison of different factors of various applications on a scale of low to high.

Table 1. Comparison of different factors against various applications.

Application	Cost	Complexity	Usefulness	TRL	Sensor Usage
Expanding Internet Access	Med	Med	High	6	Low
Terrain Scanning	Low	Low	Med	9	High
Electronic Warfare	Med	High	High	N/A	High
Transportation of Supplies	Low	Low	High	8	Med

Expanding Internet Access

An essential application of UAVs is expanding internet access (Richards, 2015), primarily to serve rural populations with limited facilities. However, this application domain can be implemented within the military. For instance, UAVs can help provide a temporary camp, or an immediate secure communication line needs to be set up. A drone can conveniently offer an entire squad with internet access. However, the implementation is not straightforward due to many issues, such as weather and cybersecurity. Battery life on drones is also critical and could impair the entire idea. In addition, the TRL level is not the best, requiring several revisions. Nonetheless, providing internet access in military installations is convenient if all the challenges can be addressed.

Terrain Scanning

As discussed in the article about FHM by Ecke *et al.*, UAVs with various sensors are already being used by civilians for extensive landscape monitoring (Ecke, 2022). Acquiring a large and high-resolution image of a spacious piece of land is challenging and could involve systems of drones rather than just one, but it saves time and money and is more efficient. These systems can detect plant stress and other issues within the field using thermal and other sensors and address them on time. Additionally, terrain scanning, specifically for agriculture, has been a technology for several years, and the TRL is at the highest possible level (Ecke, 2022). The technology can be extended to military applications to detect people hidden in forests or other secluded areas that are invisible to the naked human eye. Besides people, detecting radio signals or other points of interest can also benefit the military.

Electronic Warfare

In the future, wars will incorporate digital battles increasingly. Depriving a nation of its electricity or internet connection on today's battlegrounds can grant the opposing side an unimaginable advantage. Such usage includes UAVs equipped with radio jammers or interceptors (Hoehn, 2022). As the article states, not much information regarding UAV usage for electronic warfare is available to the public, so compiling a TRL score for this specific application is complicated. However, the Department of Defense (DoD) has developed missiles that jam adversary air defense systems, proving the possibility of such technology with UAVs.

Transportation of Supplies

The transportation of supplies is one of the most convenient ideas regarding the applicability of UAVs. Indeed, drone deliveries are relatively standard, as many companies utilize them commercially for short distances with small parcels. However, the military has yet to apply this idea, but it has upside potential with drones that are relatively cheap, easy to operate, and do not directly threaten crew members' lives. This idea could open up doors for even more UAV applications within the military.

Analysis

Table 2. Comparison of different projects against various factors

Name UAV project	Application - Methods	Cost	Usefulness	Complexity	TRL	Sensor Usage
High beam ARFL	Electronic Warfare	High	High	High	6	High
Army any fuel	All	N/A	High	N/A	3	None
Navy Transportation	Transportation of Supplies	Low	High	Med	8	Low
AI-based logistics planning	All	Low	High	Med	4	None
THOR air defense	Electronic Warfare	High	High	Med	6	High
TOBS	Terrain Scanning	Low	High	Med	5	Med
XQ-58A	All	Low	Med	Low	6	Med
Target Recognition	Electronic	N/A	High	Med	3	High

System	Warfare					
Skyborg	Terrain Scanning	Low	High	High	3	High
Drone-Flying AI	All	Low	High	Med	N/A	Med
Autonomous Teaming	All	Low	Med	Med	4	N/A
Sparrow Drone Delivery	Transportation of Supplies	Low	Med	Low	6	Low
Project Crimson	Transportation of Supplies	Low	High	Low	5	None
Rooster Drone	Terrain Scanning	N/A	High	Low	6	High

After surveying and exploring the UAV projects listed in Table 2, the most significant and exciting is NAVY's demonstration of using UAVs for shore-to-ship and ship-to-ship deliveries (Davis, 2023). Similarly, with the excellent cost, high usefulness, and near-perfect TRL, transporting supplies seems to be the most promising future application of UAVs. Drone delivery has existed for some time but is primarily utilized in civilian applications. While transitioning from civilian to military application may seem straightforward, the practicality of this idea can be very complex.

There are a few primary differences between civilian and military drone deliveries. First, military UAVs must be safe from electronic and physical threats. Second, the UAVs must be able to land on moving platforms since ships are not always stationary. Furthermore, UAVs for military purposes are expected to cover large distances while carrying large weights. One of the UAVs intended for this purpose "is intended to carry payloads of up to 50 pounds at distances of up to 250 miles" (Davis, 2023).

Besides the Navy, the US Army is also interested in using drones to deliver supplies. They have tested UAVs with VTOL capabilities for carrying blood and medical supplies. This approach to delivery is attractive because it attacks the most prominent issue within any military conflict: the loss of human life. According to Davis et al., the US Army has tested these drones in scenarios where sending more troops is dangerous.

Another promising project is the Rooster Drone developed by the Robotic Autonomous Robotics company. Surveillance and target acquisition are usually performed from the air by UAVs with high-altitude capabilities. However, this project fits those applications into a smaller drone that can clear buildings and gather intelligence without risking lives by traversing through the buildings. This idea has not been implemented on a large scale but can yield significant results.

Conclusions

This research study solidified the understanding of today's state of UAVs' capabilities and where the future can take it. With the advancement of UAVs, cameras, and other onboard sensors, it is vital to explore their potential in various current and future applications in the military. The paper evaluated the current knowledge of UAVs, their applications, and their uses through a comprehensive literature review. Subsequently, the article described various applications of UAVs with digital cameras and other sensors. After briefly analyzing each of these applications, the paper compared over a dozen projects, each relating to one of the four application areas mentioned in the methods section. Eventually, the study determined the most promising UAV applications as transporting supplies and terrain scanning. However, this article offers a preliminary analysis of the future use of UAVs in military applications and is far from a final recommendation. It furnishes a simple framework for the potential use of UAVs in the military, which must be further expanded in future studies. Finally, military research studies should assess the possibility of testing the transportation of supplies and terrain scanning and compare the findings with the existing alternatives to determine the most optimal options in challenging scenarios.

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