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The Optimization of the Surveillance Capabilities of UAVs

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Abstract:- The article has reviewed the efficiency of unmanned aerial vehicles in emergency situations, border security, water resource assessment and mapping, as well as in archaeological and geological research. The discussion of typical problems encountered during surveillance using unmanned aerial vehicles and the categories classified according to the area of interest have been studied, analyzed, and summarized. Additionally, the limitations of existing approaches and potential solutions, the gaps in the proposed research directions, and the discussion of future application areas have been presented. It has been emphasized that there is a significant need for researchers to investigate issues such as increasing the autonomy, reliability, and efficiency of unmanned aerial vehicle systems, as well as the artificial intelligence, big data analytical analysis, and integration of with other technologies. The methods and means for using unmanned aerial vehicles in carrying out surveillance tasks have been thoroughly studied and analyzed. It has been highlighted that unmanned aerial vehicles have been successfully used to ensure the operational efficiency of personnel in law enforcement agencies, security forces, agriculture, mining industry, mapping, and environmental monitoring activities, as well as to provide crucial reconnaissance and visual tracking data, and most importantly, to significantly reduce security risks. An investigation has been conducted on how unmanned aerial vehicles can overcome the limitations in large-scale disasters and complex scenarios, particularly in terms of flexible deployment in the field, efficient surveillance, and accurately positioning in hard-to-reach areas, starting with an overview of the main requirements for surveillance tasks. Additionally, the current problems faced by these technologies, as well as potential future development directions aimed at further increasing the role of unmanned aerial vehicles in the collection of surveillance and reconnaissance data, have been discussed. As technologies advance and the application areas of unmanned aerial vehicles expand, it has been highlighted that special attention must be given to legal, ethical, and privacy issues related to their use. It has also been emphasized that it is crucial to develop the use of unmanned aerial vehicle systems in defense and security activities carried out in complex conditions.

Keywords*:* Unmanned aerial vehicles, surveillance, optimization, electro-optical camera, artificial intelligence.

1. Introduction

The article researches the role of unmanned aerial vehicles (UAVs) in environmental monitoring, mapping, archaeological research, border security, and the mining industry, as well as how the continuous development of these areas ensures new perspectives in resource management. In modern times, as global environmental and resource management has increasingly become a key issue, the application of innovative technologies has reached its highest level. UAV technology offers new opportunities for the monitoring and control of the environment and resources.

UAVs have introduced new methods and analytical solutions for environmental protection, continuous resource use, and in solving scientific research problems through the implementation of electro-optical surveillance. For this purpose, the article will review the use of UAV surveillance in archaeology, mapping, maritime activities, forestry, smart villages, geology, mining, and the study of volcanoes [1-4].

With the help of electro-optical (day, night, thermal, and infrared) systems integrated into UAVs, the operator can observe objects of interest in real-time and gather reconnaissance data about them. Depending on their technical specifications, medium and large-sized UAVs can be characterized by their advantages in conducting surveillance:

- The ability to remain in the air for more than 20-30 hours;
- The ability to adjust the flight speed depending on the task;
- Being within higher operational limits depending on the meteorological conditions

The ability of UAVs to conduct surveillance on the environment and resources requires a more complex perspective approach and the development of innovative technological levels. Thus:

- Data summarization and centralization;
- For increasing the software capabilities for comparative analysis of image differences over time;
- The simplification of obtaining high-resolution, superior quality images that play a raw material role in the mapping industry [5-9].

When comparing patrol-control and surveillance flights conducted with manned and unmanned aerial vehicles, it becomes possible to identify both the advantages and disadvantages of UAVs. The main advantages of using UAVs include:

- Having wide tactical capabilities over long distances and in difficult-to-reach areas;
- The absence of threat or risk to human life;
- The low cost of flight;
- The low probability of detection using visual, acoustic, and radio-electronic detection methods;
- The significantly lower cost compared to manned aviation.

Despite the advantages of UAVs, some problems that impede their surveillance, application, and piloting capabilities have been observed from time to time. Unfortunately, during the early stages of UAV use, a number of accident incidents were recorded. Over time, improvements made in the navigation, aerodynamics, and avionics systems of UAVs have led to the development of a new generation of UAVs with higher quality and enhanced safety [10-13].

Another shortcoming of UAVs is that the performance of the electro-optical and infrared devices, which are intended for surveillance, depends directly on meteorological conditions (fog, mist, evaporation, season, and air clarity). The performance of the optical system is most affected by factors such as clouds and high humidity [14, 15].

To minimize the effects mentioned above for surveillance purposes, efforts have been made to eliminate these shortcomings by installing Radar Systems (RS) with Synthetic Aperture (SAR) on UAVs. However, these types of radar systems initially showed poor results in tracking moving targets. For this reason, efforts have been made to eliminate these shortcomings by integrating a movement indication system into the Synthetic Aperture Radar (SAR) systems. Such extensive functions led to an increase in the price, operation, and maintenance costs of the UAV [16-20].

2. Surveillance using UAVs during archaeological research.

In the past few decades, surveillance using UAVs in various cultural, geographical, and climatic conditions has changed the face of archaeology and provided archaeologists with a new and powerful research 'tool'. UAVs are capable of providing specialists with high-resolution photographs, for the creation of quality images and maps through wide-area surveillance when necessary. Thus, by using the payloads and sensors integrated into UAVs, surveillance (detection) with UAVs has proven to enhance the methodology of archaeological research and assist archaeologists in various cultural, geographical, and climatic contexts.

During archaeological research, UAVs can be equipped with infrared (IR), multispectral and hyperspectral cameras, ground-penetrating radars, LiDAR, and various sensor systems, as well as payload systems for conducting archaeological surveillance [21-24].

The research areas of archaeology differ in terms of morphological, stratigraphic, topographic, and the characteristics of discovering archaeological historical sites. The obtaining of data and images through UAV application is achieved using complex processing and analytical methods. This is applied to meet the need for obtaining accurate archaeological data and enriching the database. Archaeological reconnaissance, detection, and survey research with UAVs have provided a boost to the promising future development of this field.

UAVs are used in different ways depending on the task, the application site, and the characteristics of the archaeological site. Therefore, there is a need for the analysis of archaeological operations with UAVs in different regions, cultures, and historical periods. Efficient directions for the use of UAVs:

- Planning the flight route and the steps to be taken;
- Preparation of the 3D model of the area;
- Preparation of orthophotography and digital elevation modeling;
- Mapping of archaeological sites;
- Recording of images;
- Full surveillance of the area of interest by the UAV based on 3D modeling;
- Conducting monitoring.

Along with collecting data for modeling the natural environments in historical sites in their current form using UAV surveillance capabilities, they are also used for the archaeological reconstruction and formation of structures through the use of artificial intelligence [25-27].

When creating maps of rock paintings, archaeological finds and complexes, as well as potentially hazardous areas, it is required to precisely install the UAV's cameras and navigation receivers (for digital photogrammetry or remotely applied optical observation) on-site for physical observation. Later, the UAV operators, together with archaeologists, observe high-precision orthophotos of the archaeological site and images of the archaeological building complexes and the surrounding areas, and then the image data is processed. UAVs are also used for observing large-scale images of hard-to-reach hazardous areas and for obtaining efficiently usable 3D digital models under the condition of ensuring the safety of the operators.

3. The use of UAVs in aerial photography related to ground control points. RTK (Real-Time Kinematic), PPK (Post Processed Kinematic) system.

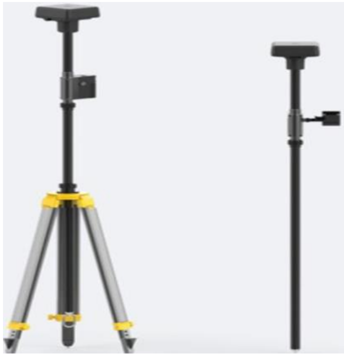
During mapping with UAV, increasing the accuracy of photogrammetric measurements requires the use of multiple ground control points with precise geolocation. The software for photogrammetry/mapping makes adjustments to the project using these ground control points to obtain accurate evaluations.

GPS Correction Technology is used to minimize or eliminate the need for ground control points, including reducing costs. In order to obtain accurate and clear information, the quality of data regarding the geographic position of ground objects and the location of the UAV in the air is enhanced by the recently proposed GPS correction technology for UAVs in photogrammetry, with the help of global positioning system (GPS) receivers. Currently, two GPS correction technologies are being applied.

- Real Time Kinematic (RTK) - a GPS correction technology that provides the real-time adjustment of positioning data when the UAV recognizes the object’s photograph for surveying.

- Post Processed Kinematic (PPK) - another GPS correction technology that works to adjust geographic position data after collecting and uploading data from the UAV.

Comparison of RTK and PPK. The main difference between RTK and PPK occurs when the position is corrected. In RTK, the correction is made during the flight, while in PPK, the correction is made after the flight. Both technologies are very similar, but PPK has a crucial advantage due to its stability and the alignment of processes.


a)

b)

Fig. 1. Ground RTK system (Real-Time Kinematic system)

UAVs working with RTK require a highly specialized base station and other equipment that work together to process data in real time. A UAV equipped with a GPS receiver and camera can determine the camera's coordinates with an accuracy of 2-3 cm based on several distances calculated from artificial satellites and ground-provided data. However, when radio communication is interrupted or the processing of satellite data becomes difficult, errors can reach several centimeters. Errors can sometimes be several meters, which is within the accuracy range of a flight without RTK.

UAVs working with PPK provide more convenience to users at greater distances from the base station and ensure a reliable flight. On the other hand, PPK processes data on geographic position and location after the flight. The data recorded by the UAV is combined with the base station data once the flight is completed. As a result, there is no risk of data loss due to radio communication interruption. The processing is similar to RTK, but PPK is slightly more accurate as it tracks the data multiple times to provide more comprehensive results.

Due to limitations or difficult measurement procedures in some areas, when there is no desire to use ground control points (GCP), RTK/PPK drones are superior to the drones without RTK. The result of both systems consists of a point cloud description of the volume, images formed as ground control points of the area to create a digital three-dimensional model (DTM, DSM, etc.) and orthophoto mosaics. The description of the GPS used in the ground system is described in fig. 1, a) and b) [28].

4. Surveillance with UAV during maritime activities.

Mapping of the shoreline and monitoring of maritime activities are among the key areas where UAV surveillance is primarily applied. This also offers invaluable opportunities for marine resource management, environmental protection, and climate researchers. The ability of UAVs to capture images from high altitudes and their agility have made them a key tool for monitoring and protecting the marine environment, as well as people working at sea [21].

The marine area has a different structure from a geographical perspective. This also complicates obtaining comprehensive and accurate information about the coastline through remote sensing methods, as well as traditional mapping work. With the help of observation cameras integrated into UAVs, it is possible to monitor the coastline and maintain surveillance over a wide radius, as well as provide users with more accurate geographic data. Thanks to UAV technology, it is possible to obtain a comprehensive, high-quality image of the coastline with a complex geographical environment at a more affordable cost.

In addition, by using the "Marine Patrol Radar (MPR)" and "Synthetic Aperture Radar (SAR)" integrated into UAVs, it is possible to monitor and control strategic objects at sea, oil and gas pipelines, as well as the environmental situation [28-32].

5. Surveillance of volcanic events with UAVs.

The use of UAVs in monitoring volcanic craters makes the work of specialists in this field even easier. It combines the integration of volcanology and advanced UAV technology to monitor ongoing geographic and geological processes.

Volcanoes are among the most dynamic and unpredictable geological events on the Earth's surface. Their activation can cause a significant threat to nearby people and the surrounding environment. UAVs play a key role in obtaining images by flying over active, dangerous volcanic craters, studying volcanic activity, and ensuring real-time monitoring. For this purpose, new methods and tools for volcanic monitoring have been developed [33-36].

6. Application of UAV surveillance in the mining industry.

UAVs play an essential role in geological exploration, land reclamation, and resource management in the mining industry. High-resolution images obtained with UAVs, along with laser scanning, thermal, infrared, and electro-optical surveillance data, enable geologists to better study the structural composition and distribution of underground deposits. This data helps ensure exploration and resource evaluation, ultimately improving the efficiency and economic profitability of mining industry operations. The obtained data is necessary for controlling the efficient use of resources and organizing environmental protection works.

UAVs are successfully used for monitoring work in mining areas, recording the progress of operations in real-time, checking safety and environmental measures, providing assistance in emergencies, as well as in the mining, land infrastructure, water management, sustainable mining infrastructure plans, ecosystem protection, and studying environmental effects [37-40].

7. Application of UAVs in organizing border security.

The application of UAVs in organizing the reliable protection and defense of borders between countries plays a crucial role in achieving effective results. The effective application of UAVs has been studied and analyzed through examples of reliable border protection and defense in the United States - Mexico, the European Union, and Israel [25, 26, 41].

Since the early 2000s, UAVs have been successfully used at the U.S.-Mexico border to prevent drug and weapon smuggling, as well as illegal immigration. During that period, the U.S. Border Patrol used "Predator-B" UAVs, along with Israeli-made "Hermes 450S" UAVs, to strengthen patrol and surveillance in border areas with large and illegal migrant flows. These types of UAVs were equipped with electronic-optical (daytime TV, thermal) systems to ensure 24-hour surveillance. With the capability to stay in the air for up to 20 hours, the technical capabilities of this UAV allowed it to detect intruders from a distance of 15-20 km.

Over time, the upgraded "Predator-B" UAVs made it possible to detect border violators at distances greater than 20 km. The obtained data was transmitted to the ground control station and then in real-time to customs and border control checkpoints.

A concept has been developed for the successful application of UAVs in organizing the reliable protection and defense of borders by enhancing surveillance over areas that could be favorable for drug trafficking, illegal migration, and terrorist crossings, such as swamps, forests, mountains, thickets, lakes, and agricultural fields located between border checkpoints.

In 2006, a decision was made to conduct patrol and surveillance with UAVs in the English Channel, coastal areas of the Mediterranean, and the Balkan Peninsula in Europe. The application of UAVs was planned as part of the implementation of a project to equip customs and border services in the European Union with modern surveillance and monitoring systems [41].

8. Gaps observed during UAV surveillance.

Significant progress has been made in environmental protection, border security, ecological research, and resource management through UAV surveillance. However, there are gaps in fully exploiting the surveillance, potential research, and reconnaissance capabilities of UAVs. In the long term, it is proposed to integrate UAVs with payload systems that have advanced functional and technical capabilities for obtaining more comprehensive and accurate ecological data [21, 42-44].

- The improvement of UAV control systems will lead to an increase in their capabilities for airborne surveillance;

- There is a great need for continued scientific research in the direction of integrating sensor systems for data reception into UAV platforms;

- The improvement and development of integrated infrared spectral scanners and LiDAR sensor systems in UAVs (drones) for the detection and neutralization of mines and unexploded ordnance (explosive devices, ammunition) is essential;

- The significant potential of UAVs' surveillance capabilities will encourage the development of this field in the future, during research and innovative solutions.

9. Optimization of surveillance of strategic objects with UAVs [45].

The use of UAVs in solving surveillance tasks has significantly increased. This has also revealed new goals and challenges in conducting surveillance with UAVs. Problems encountered during the execution of surveillance tasks with UAVs come from several main sources. This includes problems related to the coordination of multiple UAVs and their interactions, as well as issues in aligning UAVs with ground control stations, payloads, and sensors. Having up-to-date orthophoto, TIFF, and raster maps of areas of interest and strategic objects enhances the quality of surveillance and leads to the optimization of the process.

With the help of UAV surveillance capabilities, other units and areas are able to carry out their tasks more accurately and promptly, leading to improved results. For this reason, expanding surveillance data can improve the resolution of joint tasks through coordination between units and sections.

10. The following issues can be listed:

- The control of the system becomes more complex when there are more controlled elements in the UAV control and surveillance network. The optimization of UAV surveillance requires special attention to the monitoring of complex environments such as areas with variable terrain, mountains, forests, and cities. Uneven terrain, dense vegetation, and complex urban structures create specific challenges for the efficient operation and use of UAVs [46-48].

For this purpose, the application of advanced algorithms and strategies in the optimization of UAVs or UAV networks is required to increase the efficiency and accuracy of surveillance tasks;

- Mountainous and complex terrain can complicate the surveillance process. During the execution of surveillance tasks, surrounding objects can affect the UAVs' navigation, communication, and stable flight. The UAV requires advanced and autonomous decision-making capabilities to effectively detect obstacles, avoid them, remain sustained in complex environments, and provide high-quality surveillance;

- The influence of complex environmental factors on the execution of UAV surveillance tasks. Researchers previously focused only on the ideal environment for UAVs to perform surveillance tasks. However, in reality, UAVs are often required to perform surveillance tasks in complex environments such as mountainous areas, cities, forests, and so on.

Complex environments not only create significant challenges for surveillance but also create difficulties for UAVs in autonomously flying, avoiding obstacles, and planning flight routes. In order to assess complex environments and ensure high-quality surveillance, it is necessary to design optimal flight routes and configurations for UAVs [49-50].

- The integration of artificial intelligence into UAV-based surveillance. Machine learning, neural networks, and generative artificial intelligence are now at the forefront of attention for both scientific and engineering researchers. Artificial intelligence allows finding optimal technical solutions and developing specific strategies for autonomous UAV-based surveillance. Additionally, it provides significant assistance to UAVs in the execution of control-surveillance tasks, achieving the objective, evaluating the situation, and ultimately ensuring the successful completion of the task.

Artificial intelligence algorithms can assist UAVs in planning optimal flight routes and landing locations, processing large amounts of surveillance data quickly, and making precise decisions in changing conditions during flight. With machine logic, flight control in UAVs can be conducted faster and more accurately. At the same time, artificial intelligence can help UAVs perform complex tasks more autonomously, adapt to various environments and situations, improve flight safety, and reduce the risk of accidents by enhancing obstacle detection and avoidance systems.

Currently, UAVs integrated with artificial intelligence are successfully applied in several areas, such as communication, navigation, target tracking, and optimizing flight navigation in urban environments [21, 47].

- The solution to the power supply issues of UAVs. The UAV's flight range and duration limit its surveillance capabilities. In nano, micro, and mini UAVs (drones), rechargeable batteries with limited energy capacity are mainly used as the power source. In UAVs, the replacement of batteries and the need to place depleted batteries for recharging lead to time loss and increased costs. One potential research direction is to ensure the operation of hybrid UAVs or UAVs powered by hydrogen energy sources, while maintaining safety conditions, in order to increase the flight duration and flight radius of surveillance, reconnaissance, and combat UAVs.

11. CONCLUSION

1. When the target location is unknown, the use of small-sized unmanned aerial vehicles for target search over a large area will be ineffective.

2. During the active operation of electronic warfare systems, it is crucial for the UAV to have a reliable navigation and communication system for conducting surveillance.

3. When a small number of unmanned aerial vehicles are involved in gathering reconnaissance data, the cost of obtaining the information is high.

4. When observing strategic objects with an unmanned aerial vehicle, the technical characteristics of the UAV and payload, flight altitude, as well as the target's speed of movement must be taken into account.

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