Advancements In UAV Remote Sensing: A Comprehensive Review

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Abstract
Unmanned Aerial Vehicles (UAVs) with remote sensing technology have transformed the landscape of geospatial data collection geospatial analysis. This paper aims to provide a comprehensive review of UAV remote sensing technology, focusing on its applications, challenges, recent advancements, and prospects. UAVs have found diverse applications across various domains due to their agility, accessibility, and ability to capture high-resolution data. This study examines the use of UAVs in various fields such as civil engineering, archaeology, medicines, wildlife conservation and environmental monitoring, disaster management, agriculture, etc. It also explores key developments in UAV remote sensing technology, reviewing studies that have played a pivotal role in shaping these advancements. The various challenges and the way forward for an enhanced and effective mode of UAV remote sensing applications are also highlighted.

Keywords: Applications, Geospatial Data, Remote Sensing, UAV

Introduction

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have revolutionised the realm of remote sensing, offering unprecedented capabilities for data acquisition and geospatial analysis. The deployment of UAVs for remote sensing applications has gained widespread recognition due to their ability to provide higher resolution image data, ability to produce accurate elevation information and accurate ground object identification and detection [1]. The integration of UAVs with advanced sensors has propelled the field of geospatial data collection into new dimensions, enabling real-time monitoring and analysis across diverse domains.

Historically, remote sensing relied on satellite and manned aircraft platforms, presenting limitations in terms of spatial and temporal resolution, cost, and accessibility. UAVs have effectively addressed these constraints, offering a cost-effective alternative with the capability to capture data at high resolutions and in near real-time [1]. This shift has unlocked novel possibilities in environmental monitoring, precision agriculture, disaster management, and beyond.

The significance of UAV remote sensing lies in its ability to revolutionize traditional approaches to data collection. The adaptability of UAVs allows for rapid deployment, enabling timely responses in critical situations such as natural disasters or environmental emergencies [2]. Moreover, the high spatial resolution attained by UAV sensors facilitates detailed and accurate mapping, proving invaluable in precision agriculture for crop monitoring and yield estimation [27]. Recent technological advancements, as highlighted by Greenwood et al. [3] in the realm of the developing wireless sensor networks and data processing techniques to UAV collected data and also recent achievements of UAVs in post-disaster reconnaissance, construction management, geotechnical engineering and infrastructure component monitoring.

Objectives

This paper aims to provide a comprehensive review of UAV remote sensing technology, focusing on its applications, challenges, recent advancements, and prospects. The review further aims to contribute to the understanding of UAV remote sensing's current landscape and guide future developments in this field.

Methodology

The study adopted an analytical research method. It examines the specific applications of UAV remote sensing, explores the diverse platforms and sensors employed, discusses recent technological advancements, examines challenges faced by the technology, and envisions its future trajectories. The study is based on primary, secondary sources, research journals and online sources.

UAV Remote Sensing Applications

UAVs have found diverse applications across various domains due to their agility, accessibility, and ability to capture high-resolution data. This section explores key applications of UAV remote sensing, drawing insights from seminal studies that have contributed to the understanding of their practical utility.

In the field of civil engineering, the use of UAVs is varied. They are used in structural damage assessment, rock characterization, seismic geophysical methods, infrastructure inspection and construction monitoring [3]. The documentation of UAVs is already there and they are used to develop high-quality surface models eg., DEM, mesh, point cloud, etc [3]. Surface models via UAV are developed and further used in hydrodynamic modelling of flow under a bridge for risk assessment purposes [4]. According to, Greenwood et al. [3], "the most interesting UAV research developments have involved incorporating UAVs into high-functioning complex systems capable of interacting with humans and interfacing with data streams [5]. UAVs will become powerful autonomous systems having the ability to develop an action plan, collect data, process data, perform computations, analyze results, and make next-step decisions" [3, p. 16]. Desa et al. [6] investigated the use of UAVs for route surveys. The data was collected by using Kama Beta. Pix4D Mapper was used for the point cloud. For the analysis, AutoCAD 2014 was used. Root Mean Square Error (RMSE) was used to test the point cloud. The results from conventional and UAV from the point cloud data using RMSE show a minimal difference.

The conservation community has embraced UAVs as valuable tools for wildlife monitoring and anti-poaching efforts. UAVs equipped with thermal cameras and high-resolution sensors enable researchers to track and study wildlife populations without disturbing their habitats. UAVs are also widely used in wildlife conservation and play an important role in conserving the environment. One of the primary benefits of utilizing UAVs is the potential reduction in the risk of injury and fatalities, as traditional surveys conducted from airplanes or helicopters pose significant danger, often resulting in casualties among biologists in the field [7]. Additionally, UAVs offer exceptional versatility. For instance, a drone can perform a survey using a high-definition camera and subsequently be outfitted with specialized equipment for diverse tasks, such as a spraying device. Most commercially accessible drones are user-friendly, and operable via joysticks on a remote control or directly from a smartphone. Finally, UAVs are typically smaller and quieter than manned aircraft, providing a less intrusive approach to wildlife surveys in comparison.

Brinkman and Garcelon [8] assert that the use of drones will greatly help in wildlife conservation. However, the use of drones may have a certain impact on the wildlife and the environment around them. Therefore, utmost care should be taken to use drones methodically without harming the environment. Pilots are advised to aim for altitudes lower than the legal minimum for small UAVs, yet as high as practicable to minimize disturbance to wildlife while still acquiring the necessary data for the survey. Furthermore, outdoor enthusiasts might not appreciate drones flying above them in public lands where they seek to enjoy natural beauty and tranquillity. If a survey must be conducted in an area frequented by recreationists, efforts should be made to schedule flights during periods of lighter visitor activity and keep flight durations brief. Alternatively, if flying over an area with minimal visitors, it is important to show consideration for others present by either waiting until they are out of sight or approaching them respectfully to explain the purpose of the survey.

Archaeological surveys benefit from the versatility of UAVs in capturing detailed imagery of archaeological sites. The ability to obtain high-resolution aerial images aids archaeologists in mapping and documenting historical sites efficiently. Archaeological sensing methods, both remote and close-range, are crucial for uncovering fully buried historical artefacts. As archaeological remains typically lack distinctive spectral characteristics for general detection, it's proposed that they manifest localized differences within the landscape matrix. These differences can be identified using suitable sensors in specific environmental conditions. Detecting the desired contrast can occur directly through observable topographic effects or indirectly through variations in vegetation, magnetic fields, electrical properties, thermal behaviour, or spectral reflectance. Airborne light detection and ranging (LiDAR) has become a widely utilized active remote sensing method for directly measuring the impact of buried archaeological remains on landscape topography. Utilizing laser-based sensors, LiDAR can generate essential primary data for detailed digital terrain and surface models (DTM, DSM) across expansive areas [9] [10]. These models, when appropriately shaded, offer improved interpretation of features compared to original aerial surveys. Moreover, LiDAR's capability to penetrate through foliage makes it invaluable for vegetated landscapes like tropical regions, where dense vegetation often obscures the microtopography of archaeologically significant terrain [11] [12]. By employing artificial shading techniques on LiDAR-derived DTMs or DSMs, and considering factors such as principal component analysis (PCA), slope, aspect, sky-view factor (SVF), local relief modeling (LRM), and trend removal, the visibility of archaeological features can be further enhanced [13] [14]. Research by Adamopoulos and Rinaudo [15], asserts that in archaeological surveys a shift towards more accurate metric and radiometric data acquisition and production, along with the adoption of established processing techniques from satellite and airborne sensing is indicated.

Regardless of the nature of the emergency, disaster management encompasses a comprehensive approach involving mitigation, preparedness, response, and recovery efforts. The employment of drones in disaster scenarios offers several advantages: they expedite the process of locating victims and subsequent intervention by swiftly scanning vast areas, thereby providing essential information to rescuers regarding the most efficient routes for search and rescue operations [16]. Furthermore, drones equipped with sensors like noise detection, binary sensing, vibration detection, and heat sensing can effectively search for survivors buried under rubble [17]. These examples underscore the value of deploying drones during disasters and highlight their role as indispensable tools for capturing aerial imagery. Mohd Daud et al, [2] suggested that drones serve as valuable assets for tasks such as mapping, search and rescue missions, transportation, and training purposes. However, it is imperative to assess their capability in victim identification, particularly in disaster scenarios. The absence of validation regarding drones' effectiveness in aiding disaster victim identification is notable, possibly

stemming from ethical concerns surrounding research conducted in actual disaster settings. Many primary studies have documented simulated disaster events with considerable variability, highlighting the need for a standardized disaster simulation checklist to mitigate biases. In disaster situations, the disaster victim identification (DVI) team often faces challenges in locating and recovering victims, leading to delays in body retrieval and identification, along with decomposition issues. While traditional victim identification methods exist, they often prove ineffective in situations involving remote or inaccessible disaster sites.

The agricultural sector has embraced innovation by harnessing convergence technologies, with UAVs emerging as a highly utilized tool across the industry. The market for agricultural UAVs is experiencing rapid growth [18], giving rise to numerous venture companies. Market research conducted by Price-Waterhouse-Coopers projects that the agricultural UAV market will reach approximately $32.4 billion by 2050, constituting around 25% of the global UAV market [19]. Notable UAV manufacturers in this sector include DJI, Parrot, Precisionhawk, AGEagle, and Trimble Navigation. Despite the development and commercialization of various UAV models, there remain several challenges to overcome for the advancement of agricultural solutions. Key technologies driving progress include imaging, navigation, precision positioning, sensors, controls, batteries, communications, materials, circuits, and motors. The specific technologies required vary depending on the UAV's application and the characteristics of the agricultural sector, such as equipment development, nozzle controls, and big data utilization. Providing comprehensive information on all UAV technologies proves challenging. Research by Kim et al, [26] examined the hardware configurations of UAVs designed for agricultural purposes, encompassing platform types, components/sensors, and communication systems. Additionally, they thoroughly investigated and categorized the applications of agricultural UAVs, such as mapping, spraying, planting, and monitoring. Furthermore, they conducted an in-depth discussion on the limitations, including issues related to battery life, the management of multiple UAVs, and user interface challenges, as well as available applications like harvesting, AI-based precision mapping, particularly in developing countries, and current technology trends such as advancements in communications, SLAM (Simultaneous Localization and Mapping), aerial manipulation, and multi-robot systems.

UAVs are employed for monitoring disaster sites, regions prone to biological and chemical hazards, and for tracking the spread of diseases. Research has demonstrated that drones can collect data regarding the number of patients requiring medical attention and prioritizing triage in hazardous environments. After Typhoon Haiyan in 2013, drones were utilized in the Philippines to conduct aerial surveillance for assessing initial storm damage and aiding relief efforts [19]. Additionally, UAV technology has been instrumental in identifying health risks such as heavy metals, aerosols, and radiation. In a study conducted in southern Italy, UAVs equipped with advanced photogrammetry software accurately assessed and predicted cancer risk associated with elevated levels of copper in agricultural areas [21]. Moreover, drones' capability to obtain real-time, high-resolution temporal and spatial data at a low cost makes them suitable for epidemiological research. One of the most promising applications of drones is in the field of telemedicine, facilitating remote diagnosis and treatment of patients through telecommunication technologies. Nevertheless, it's important to recognize that medical applications present greater challenges due to the urgent nature of clinical situations, which often precludes control over date, time, and location [22]. There is a pressing need to expedite research endeavours concerning airspace integration, safety protocols, response times, broadening participation, and the implementation of best practices for privacy [22].

UAV Platforms and Sensors
This section explores different UAV platforms and the advanced sensors commonly employed, providing examples from notable studies in the field. From fixed-wing models optimized for long-range missions like reconnaissance to rotary-wing drones prized for their agility in tight spaces, each type offers distinct advantages. Hybrid models merge features for versatility, while micro UAVs excel in close-range operations. Additionally, fixed-wing VTOL UAVs combine the efficiency of fixed-wing flight with the flexibility of vertical take off and landing, while tethered UAVs provide continuous power and data transfer for persistent surveillance. Together, these platforms continue to evolve, shaping industries from agriculture to security with their varied capabilities.

UAV remote sensing sensors or cameras are used for various specific data collection tasks. From RGB and multispectral cameras for capturing visible and near-infrared light to thermal infrared cameras for detecting heat signatures, these sensors provide valuable insights into environmental conditions, vegetation health, and infrastructure integrity. Additionally, LiDAR systems offer precise 3D mapping capabilities, while gas and chemical sensors enable the detection of pollutants and hazardous substances. Together, these sensors empower UAVs to gather diverse datasets for applications ranging from agriculture and environmental monitoring to infrastructure inspection and disaster response.

Advancements in UAV Remote Sensing Technology
The rapid evolution of UAV remote sensing technology has been characterized by advancements that enhance the efficiency, accuracy, and scope of data collection. This section explores key developments in UAV remote sensing technology, referencing studies that have played a pivotal role in shaping these advancements.

In recent decades, there has been a notable surge in advanced technologies like three-dimensional (3D) mapping, aerial imaging, computer vision, oblique photogrammetry, efficient perception, sensing, laser scanning, the Internet-of-Things (IoT), blockchain, artificial intelligence (AI), mobile-edge computing (MEC), deep learning (DL), and machine learning (ML). These technologies significantly bolster UAV capabilities across a range of operations [25] [23]. Their integration holds the promise of substantially reducing human involvement in various complex tasks such as autonomous driving,

aerial photography, object detection and classification, 3D mapping, aerial surveillance, and medical image analysis. A rapid increase in interest and substantial growth is witnessed in merging these technologies with UAVs, resulting in significant enhancements in autonomy, motion control, trajectory planning, data collection, collaborative strategies, and other key factors essential for efficient UAV utilization in remote-sensing applications across urban, suburban, rural, and remote regions [24]. Specifically in remote sensing, the convergence of features facilitating high mobility for acquiring high-resolution images, collision avoidance mechanisms, autonomous navigation, intelligent algorithms, optimization techniques, 3D data acquisition, dynamic data collection, novel sensor platforms, advanced instrumentation, precise control, and robust communication under challenging conditions significantly contribute to the increasing adoption of UAV-assisted remote sensing across various application scenarios. The utilization of UAV technology has proven beneficial in bolstering navigation, security, and communication services. Guaranteeing resilient communication for mobile users poses a significant challenge given the dynamic nature of their movements. To address this challenge, mobile edge computing (MEC) and UAVs offer a promising solution by efficiently allocating resources to mobile users within dynamic environments, thereby enhancing connectivity. Progress in multispectral cameras and UAV technology has facilitated numerous remote sensing applications, delivering unprecedented spatial resolution. Nevertheless, uncertainties persist regarding the efficacy of radiometric calibration techniques in accurately transforming raw images into surface reflectance.

The potential for UAVs in various industries is vast and continuously expanding. Their ability to gather high-resolution data quickly and cost-effectively makes them invaluable for tasks ranging from surveying and mapping to agriculture, infrastructure inspection, environmental monitoring, and even emergency response [1]. The convergence of computer science, robotics, and remote sensing in UAV technology opens up numerous possibilities for innovation and new applications. The advancement of automation in UAV operations is poised to revolutionize various fields, particularly in geoscience and remote sensing [1]. With increased automation, UAVs can gather data more efficiently and precisely for agricultural purposes. They can monitor crop health, detect pests and diseases, optimize irrigation and fertilizer usage, and even assist in crop spraying. This helps farmers make data-driven decisions to increase yields, reduce costs, and minimize environmental impact. UAVs equipped with advanced sensors and automation capabilities can inspect critical infrastructure such as bridges, roads, pipelines, and power lines.

Automated UAV systems can be deployed rapidly to assess and monitor areas affected by natural hazards such as wildfires, floods, earthquakes, and landslides. They can provide real-time data on the extent of damage, help identify areas at risk, and support emergency response efforts. This capability is crucial for disaster preparedness, response, and recovery. UAVs play a vital role in the development of smart cities by providing valuable data for urban planning, infrastructure management, environmental monitoring, and public safety. Automated UAVs can collect high-resolution imagery, 3D maps, and other spatial data to support decision-making processes and optimize city operations. This leads to more efficient resource allocation, improved service delivery, and enhanced quality of life for residents.

Furthermore, the advantages of UAVs over manned platforms are becoming increasingly apparent, particularly in terms of data collection flexibility, resolution, and productivity. UAVs can capture data with much higher resolutions compared to manned platforms. This is especially beneficial for applications requiring detailed imagery, such as precision agriculture, infrastructure inspection, and environmental monitoring. The ability to capture fine-grained data enables more accurate analysis and decision-making. UAVs offer unparalleled flexibility in data collection. They can access remote or hazardous areas that may be challenging or unsafe for manned platforms to reach. Additionally, UAV missions can be easily customized to meet specific requirements, allowing for targeted data acquisition tailored to the needs of each project or application [1]. Advancements in UAV technology, including longer flight times, improved battery life, and faster data processing capabilities, are leading to significant increases in productivity [1]. Collaborative platforms enable multiple UAVs to work together seamlessly, increasing coverage, redundancy, and efficiency in data collection tasks. Moreover, the growing automation of flights streamlines operations, reduces human intervention, and enhances safety and reliability.

Challenges

The evolution of sensors installed on UAVs represents a significant advancement in remote sensing technology. In recent years, both passive and active sensors designed specifically for UAVs have seen considerable improvements [1]. Unlike earlier sensors, which were often adaptations of those used in terrestrial applications, modern UAV sensors are increasingly customized to meet the unique requirements of aerial data collection [1]. However, challenges such as cost, energy consumption, size, and weight still hinder the broader adoption and competitiveness of UAV technology in certain applications [1]. While advancements have been made in mitigating these limitations, they remain significant factors to consider, especially when comparing UAV solutions to traditional airborne platforms. Despite these challenges, ongoing innovation in sensor technology, along with improvements in UAV design and capabilities, continues to push the boundaries of what is possible in aerial data collection. As these technologies mature and become more accessible, one can expect UAVs to play an increasingly vital role in a wide range of applications, from agriculture and environmental monitoring to infrastructure inspection and disaster response.

Widespread adoption of hyperspectral imaging in consumer or wider professional/commercial markets has been limited thus far. Challenges such as cost, data processing complexity, and the need for specialized expertise have restricted its use primarily to research and niche applications. The assertion that traditional data processing in photogrammetry has reached maturity is largely accurate, evidenced by the abundance of both commercial and open-source photogrammetry workflow solutions available today. These solutions offer robust capabilities for processing aerial imagery, generating accurate 3D

models, and extracting valuable insights from the data. However, the evolving needs of users, particularly in the context of UAV technology, are driving the demand for new algorithms and solutions to enhance and expand the capabilities of photogrammetry workflows.

Conclusion

In conclusion, the rapid evolution of UAV remote sensing technology has enhanced geospatial data collection, revolutionizing the way one perceives and interacts with our environment. This study has explored the diverse applications, technological advancements, challenges, and future directions shaping the landscape of UAV remote sensing. UAVs equipped with advanced sensors have demonstrated unparalleled utility across a spectrum of applications. From environmental monitoring, precision agriculture, disaster management, infrastructure inspection, wildlife conservation, to archaeological surveys, UAVs have proven to be versatile tools capable of capturing high-resolution data with agility and precision. Looking ahead, the review has identified promising future directions and emerging trends. Swarming technology, edge computing, and innovations in healthcare and smart city applications are indicative of the expanding horizons for UAV remote sensing. The various challenges and the way forward for an enhanced and effective mode of UAV remote sensing applications have been critically examined. In sum, a synthesis of knowledge from environmental science, agriculture, disaster management, technology, and regulatory studies is imperative for the responsible and sustainable development of UAV remote sensing.

Conflicts of Interest: The authors declare no conflict of interest

References

1. Nex, F., Armenakis, C., Cramer, M., Cucci, D. A., Gerke, M., Honkavaara, E., Kukko, A. Persello, C. and Skaloud. UAV in the advent of the twenties: Where we stand and what is next. 2021. https://www.sciencedirect.com/science/article/pii/S0924271621003282
2. Daud, S., Yusof, M., Heo, C., Khoo, L., Singh, M., Mahmood, M. and Nawawi, H. Applications of drone in disaster management: A scoping review. 2021. 20https://www.sciencedirect.com/science/article/pii/S13550306210014772
3. Greenwood, W.W., Lynch, J.P. and Zekkos, D. Applications of UAVs in Civil Infrastructure, 2019. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29IS.1943-555X.0000464
4. Hackl, J., Adey, B. T., Woźniak, M. and Schümperlin, O. Use of unmanned aerial vehicle photogrammetry to obtain topographical information to improve bridge risk assessment. 2018. J. Infrastruct. Syst. 24 (1): 04017041. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000393.
5. Murphy, R. R., Duncan, B.A., Collins, T., Kendrick, J., Lohman, P., Palmer, T. and Sanborn, F. Use of a small unmanned aerial system for the SR-530 mudslide incident near Oso, Washington. 2015. J. Field Rob. 33 (4): 476–488. https://doi.org/10.1002/rob.21586.
6. Desa, H., Azizan, M., Khadir, M. and Suhaimi, S. Feasibility Study of UAV Implementation in Route Surveying. 2019. https://www.researchgate.net/publication/336037154_Feasibility_Study_of_UAV_Implementation_in_Route_Surveying
7. Sasse, D. B. Job-related mortality of wildlife workers in the United States 1937-2000. 2003. Wildlife Society Bulletin 31: 1015-1020
8. Brinkman, M. P. and Garcelon, D. K. Applying UAV Systems in Wildlife Management. 2020. https://escholarship.org/content/qt42s2d8q9/qt42s2d8q9_noSplash_81ae5025be97f23f914417d6d6eb3639.pdf
9. Devereux, B.J.; Amable, G.S.; Crow, P. Visualisation of LiDAR terrain models for archaeological feature detection. Antiquity 2008, 82, 470–479.
10. Challis, K.; Kokalj, Z.; Kincey, M.; Moscrop, D.; Howard, A.J. Airborne lidar and historic environment records. Antiquity 2008, 82, 1055–1064.
11. Devereux, B.J.; Amable, G.S.; Crow, P.; Cliff, A.D. The potential of airborne lidar for detection of archaeological features under woodland canopies. Antiquity 2005, 79, 648–660.
12. Chase, A.S.Z.; Chase, D.Z.; Chase, A.F. LiDAR for Archaeological Research and the Study of Historical Landscapes. In Sensing the Past; Masini, N., Soldovieri, F., Eds.; Geotechnologies and the Environment; Springer International Publishing: Cham, Switzerland, 2017; Volume 16, pp. 89–100. ISBN 978-3-319-50516-9
13. Bennett, R.; Welham, K.; Hill, R.A.; Ford, A. A Comparison of Visualization Techniques for Models Created from Airborne Laser Scanned Data: A Comparison of Visualization Techniques for ALS Data. Archaeol. Prospect. 2012, 19, 41–48.
14. Štular, B.; Kokalj, Ž.; Oštir, K.; Nuninger, L. Visualization of lidar-derived relief models for detection of archaeological features. J. Archaeol. Sci. 2012, 39, 3354–3360.
15. Adamopoulos, E and Rinaudo, F. UAS-Based Archaeological Remote Sensing: Review, Meta-Analysis and State-of-the-Art. 2020. https://www.mdpi.com/2504-446X/4/3/46
16. Tilburg, C. V. First Report of Using Portable Unmanned Aircraft Systems (Drones) for Search and Rescue, Wilderness and Environmental Medicine. 28 (2) .2017. 116–118, https://doi.org/10.1016/j.wem.2016.12.010.
17. P. Thanu Thavasi, T. P. and Suriyakala, C. D. Sensors and tracking methods used in wireless sensor network based unmanned search and rescue system - A review, in, Procedia Engineering, Elsevier Ltd. 2012. 1935–1945, https://doi.org/10.1016/j. proeng.2012.06.236.
18. Brief, L. Growth Opportunity in Global UAV Market. Las Colinas, TX, USA, 2011.

19. Mazur, M., Wisniewski, A. and McMillan, J. Clarity from Above: PwC Global Report on the Commercial Applications of Drone Technology. Warsaw, Poland: Drone Powered Solutions, 2016.

20. Hlad J. Drones: A Force for Good When Flying in the Face of Disaster. The Guardian. 2015. Available at: https://www.theguardian.com/global-development/2015/jul/28/drones-flying-in-the-face-of-disaster-humanitarian-response/

21. Capolupo A, Pindozzi S, Okello C, Fiorentino N and Boccia L. Photogrammetry for environmental monitoring: the use of drones and hydrological models for detection of soil contaminated by copper. Sci Total Environ. 2015; 514:298–306.

22. Rosser, J. Jr, Vignesh, V., Terwilliger, B. and Parker, B. Surgical and Medical Applications of Drones: A Comprehensive Review. 2018. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6174005/

23. Alzahrani, B.; Oubbati, O.S.; Barnawi, A.; Atiquzzaman, M.; Alghazzawi, D. UAV assistance paradigm: State-of-the-art in applications and challenges. J. Netw. Comput. Appl. 2020, 166, 102706.

24. Pajares, G. Overview and current status of remote sensing applications based on unmanned aerial vehicles (UAVs). Photogramm. Eng. Remote Sens. 2015, 81, 281–330.

25. Mohsan, S., Khan, M. and Ghadi, Y. Editorial on the Advances, Innovations and Applications of UAV Technology for Remote Sensing. 2023. https://www.mdpi.com/2072-4292/15/21/5087

26. Kim, J., Kim, S., Ju, C. and Son, H. Unmanned Aerial Vehicles in Agriculture: A Review of Perspective of Platform, Control, and Applications. 2019. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8782102

27. Olson, D. and Anderson, J. Review on unmanned aerial vehicles, remote sensors, imagery processing, and their applications in agriculture. 2021. https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/agj2.20595