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Surveying and Mapping Technology in Extreme Environments

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Abstract: This paper provides a comprehensive overview of advances in surveying and mapping technology applicable to special terrains and extreme environments. Highlighting innovations such as LiDAR, Geographic Information Systems (GIS), autonomous drones, and the integration of Artificial Intelligence (AI) and Machine Learning (ML), it explores how these technologies are transforming the field of geospatial data collection. LiDAR technology has emerged as a pivotal tool, capable of generating precise 3D models and penetrating dense cover to produce accurate maps in visually obscured environments. GIS has enhanced the capacity for sophisticated data analysis, enabling more informed decision-making in multiple sectors, such as environmental management and urban planning. Additionally, the use of autonomous drones has revolutionized data collection, providing safe, efficient, and cost-effective means of accessing challenging terrains. The paper also discusses future trends, including the potential integration of virtual reality (VR) and augmented reality (AR) to create immersive data interaction experiences, and the application of cloud computing and the Internet of Things (IoT) to enhance real-time data accessibility and collaboration. These technologies promise to further advance the field of surveying and mapping, ensuring more accurate, efficient, and safer geographical data collection and analysis in complex environments.

1. Introduction

In the domain of geospatial engineering, the exploration and documentation of extreme environments present a unique set of challenges and opportunities. Extreme environments, characterized by harsh and often unpredictable conditions, demand robust, accurate and innovative surveying and mapping technologies. These environments can range from the frigid expanses of polar ice fields to the scorching sands of deserts, deep ocean beds, and even the rugged terrains of volcanic regions. The purpose of this paper is to go into the intricacies of surveying and mapping technologies that make it possible to acquire accurate geospatial data under such demanding conditions.

The need to operate in extreme environments is driven by various factors, including scientific research, resource extraction, environmental conservation, and infrastructure development. Each of these applications requires precise and reliable spatial data to support decision-making processes. For example, in climate science, accurate mapping of polar ice caps is essential to understanding the impacts of global warming. Similarly, in the oil and gas industry, survey technologies allow exploration and monitoring of underwater sites that are otherwise inaccessible [1].

The evolution of surveying technology has transitioned from traditional methods to more sophisticated digital tools and techniques. Traditional surveying in extreme environments often involved manual transit and theodolite readings, which were not only time-consuming, but also susceptible to significant errors due to environmental factors. Today, technological advances have paved the way for the integration of Global Positioning System (GPS), Geographic Information Systems (GIS), Remote Sensing (RS), and recently, unmanned aerial vehicles (UAVs), all of which have revolutionized the field of surveying and mapping [2].

GPS technology, in particular, has been a cornerstone in transforming surveying practices by providing high-precision, real-time positional data. In extreme environments, where traditional survey markers are often obscured or destroyed, GPS offers a resilient solution. In addition, the integration of GPS with other technologies, such as inertial navigation systems, improves its accuracy and reliability under adverse conditions such as heavy cloud cover or in areas with magnetic interference.

GIS technology further enhances GPS capabilities by enabling the management, analysis, and visualization of geospatial data. In extreme environments, GIS helps map difficult terrains and manage large datasets effectively, providing comprehensive environmental models. This is crucial to planning and executing operations in areas where access is limited and risks are high.

Remote sensing (RS) technology offers another layer of innovation in the survey of extreme environments. It uses sensors on board satellites and aircraft to obtain information about the Earth's surface without making physical contact. This method is particularly beneficial in inaccessible or hazardous areas. For example, satellite imagery and aerial photography have been instrumental in tracking changes in glacier morphology or volcanic activity, providing vital data for disaster management and environmental monitoring [3].

The deployment of UAVs has emerged as a game-changing technology in surveying and mapping. Capable of flying in difficult weather conditions and accessing remote or dangerous sites, UAVs equipped with high-resolution cameras and sensors can gather detailed topographic information that would otherwise be unattainable. Their ability to quickly cover large areas and deliver real-time data makes them particularly effective in emergency response situations, such as post-disaster assessments, where rapid and accurate data collection is critical.

Despite these technological advances, surveying in extreme environments poses inherent risks and technical challenges. The equipment must be designed to withstand extreme temperatures, pressures, and corrosive elements. Additionally, the accuracy of data collected under such conditions often depends on the robustness of the technology against environmental disturbances. As a result, continuous innovation and improvement in survey equipment and methodologies remain essential.

This article aims to provide an in-depth review of current surveying and mapping technologies used in extreme environments. It will explore case studies demonstrating the application of these technologies in a variety of settings, discuss technical challenges and solutions, and highlight future trends in the evolution of extreme environment surveying. Through this discussion, the article seeks to underscore the critical role of advanced surveying technologies in improving our understanding and management of the most challenging landscapes on the planet [4].

In conclusion, as the demand for geospatial data in extreme environments continues to grow, driven by both economic and environmental factors, the development of more sophisticated, reliable, and resilient surveying technologies becomes increasingly important. This article contributes to the body of knowledge by providing a comprehensive overview of the latest technologies and techniques that enable effective surveying and mapping under the most challenging conditions.

Figure 1. Surveying and mapping technology in Extreme Environments

2. Surveying and Mapping Technology

2.1. Laser radar

LiDAR stands for Light Detection and Ranging, while LADAR stands for Laser Detection and Ranging. Laser Radar, or LIDAR, is a remote sensing technology that utilizes laser light to measure distances, create high-resolution digital elevation models, and generate detailed 3D maps of the surrounding environment. However, the size of their objectives creates a significant disparity between these two methods. LADAR is used for longer-range surface sensing, such as scanning the atmosphere or the ground. LiDAR, on the other hand, is used to detect concentrated objects of small volume, such as cars [5].

The use of a laser system enables day and night observation, as well as range measuring of surfaces without irregularity. The laser scanner falls within the category of active sensors. As seen in Figure 2, a laser scanner works by emitting light energy and recording the emission and return signal. This recorded signal is quickly converted to a digital representation and saved on a computer. Although LIDAR is an active technology that can potentially be used around the clock, it cannot be used when there is cloud cover, fog, smoke, mist, rain, or snow storms. Most laser systems are Nd: YAG emitting at the NIR (1064nm) wavelength with a narrow spectral width (0.1-0.5nm). Some systems emit at 810 nm (ScaLARS), 900 nm (FLI-MAP), and 1540 nm (TopoSys, Riegl). Laser systems generally emit at one wavelength only; however, bathymetric lasers emit at1064 and 532 nm to measure both the water surface and water bottom.

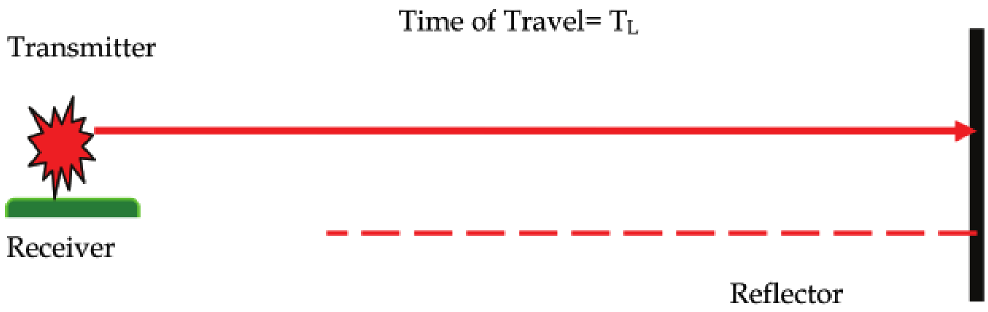

Figure 2. Principle of laser

For the laser scanner signal processing, target detection and tracking algorithms are used. The method changes the computed information of objects with properties such as scale and velocity. It is simple to adjust the number of adjustable settings to various environmental factors. For instance, employing indoor or outdoor settings, low or high speed variations, and various output design options. Alignment and co-registration in a defined reference system allow one to generate a 3D model of the object, with the possibility of associate the radiometric information useful in many applications [6].

2.2. GPS Technology

GPS is a novel positioning method that requires global positioning assistance to receive satellite data and then perform high-precision positioning. It has many advantages, such as high precision, fast speed, and good flexibility, and has received wide attention both domestically and internationally. Due to the complexity of surveying and mapping work, real terrain conditions inevitably affect and interfere with the data acquisition process, making it easy to produce errors of varying degrees during mapping. Especially in special terrain measurement, if surveyors still use common instruments like total stations and theodolites, it can be challenging to achieve the intended surveying purposes, or it might lead to slow field data acquisition, thus significantly increasing the surveying costs.

The use of GPS surveying technology can reduce the influence of external environments and terrain on surveying work. Its advantages mainly include four aspects: (i) In terrains like high mountains and jungles, GPS technology can compensate for the lack of line-of-sight capabilities of traditional surveying tools like total stations and theodolites, thus enhancing the efficiency of field survey work. (ii) By using GPS technology to measure the eccentricity of the stakeout, more accurate and reliable data can be obtained and the efficiency of the work has also been significantly improved. (iii) Using GPS positioning and setting out platforms, the efficiency of the execution of survey operations can be effectively improved, reducing the pressure of survey work and ensuring the precision of measurements. (iv) The application of GPS technology can ensure the accuracy of stakeout measurement results [7].

In extreme environments, the application of global positioning system (GPS) technology for surveying and mapping has revolutionized the field, overcoming traditional challenges associated with these harsh and often inaccessible areas. GPS provides accurate, real-time data essential for various critical applications, ranging from scientific research and environmental monitoring to military operations and emergency response.

Extreme environments such as polar regions, vast deserts, deep oceans, and active volcanic areas pose unique challenges to surveyors. Traditional survey methods in these areas often involve significant risks and logistical difficulties. GPS technology mitigates these issues by enabling precise location tracking without the need for extensive physical infrastructure or a direct line of sight to landmarks, which are often obscured or non-existent in such settings. In polar regions, where temperatures can plunge to extreme lows and icy conditions prevail, traditional surveying tools may fail due to mechanical constraints or operator difficulty. GPS operates effectively in these conditions, providing essential data for monitoring ice sheet dynamics, polar wildlife habitats, and climate change effects. The ability of technology to deliver high-precision measurements is crucial for creating accurate maps of these transient and dynamic landscapes. Deserts present another challenging environment, characterized by vast, featureless terrains and extreme temperatures. GPS technology enables efficient route navigation and landmark identification, which are vital for conducting geological surveys, archaeological explorations, and environmental studies. In these areas, GPS helps avoid common navigational errors and ensures the safety of survey teams by maintaining continuous location awareness. Deep ocean environments, largely unexplored and difficult to access, benefit significantly from GPS technology when used in conjunction with sonar and other oceanographic mapping tools. GPS data are critical to accurately guide underwater vehicles and equipment to study marine ecosystems, map the seabed, and monitor tectonic movements. These applications are essential for understanding global environmental processes and planning undersea cable routes or oil extraction sites.Volcanic areas, with their unpredictable and hazardous conditions, require robust surveying methods. GPS provides a safe means of monitoring volcanic activity from a distance, helping to predict eruptions and assess the impact on surrounding landscapes. By integrating GPS with seismic data and other geospatial technologies, researchers can develop comprehensive risk assessments and disaster response strategies.

In general, the integration of GPS into surveying practices in extreme environments has not only improved the safety and efficiency of these operations but also significantly increased the accuracy and scope of the collected data. This advancement enables more informed decision making in environmental management, resource development, and global scientific research [8].

2.3. GIS Technology

The Geographic Information System, commonly known as GIS, is a spatial information system. In the mapping process of the target area, any geographic distribution information can be supported in computation, manual data collection, data integration, and target filtering. Additionally, it can directly present various types of spatial data. Using data modeling methods, it can also visually represent the geographical environment condition of the measured area. In engineering surveying, GIS technology has obvious advantages in data computation and spatial analysis, capable of establishing a multi-platform collaborative geographic information database, indicating that GIS technology has a wide range of application prospects in data computation, map drawing, terrain simulation, and data integration and aggregation.

Geographic Information Systems (GIS) technology has become an indispensable tool in the surveying and mapping of extreme environments, offering robust capabilities for collecting, managing, analyzing, and visualizing geographical and spatial data. The application of GIS in such harsh conditions supports a wide range of critical activities, from environmental conservation and resource management to scientific research and disaster preparedness.

Extreme environments, ranging from the icy expanses of polar regions to the arid vastness of deserts, the depths of the oceans, and the unpredictable terrains of volcanic areas, pose unique challenges for data collection and interpretation. GIS technology helps overcome these challenges by enabling the integration of various data types, including satellite imagery, aerial photographs, and on-ground sensor data, into a single comprehensive geographical model. In polar areas, GIS is used to monitor changes in ice cover and study the impacts of climate change on these fragile ecosystems. By layering historical data with current satellite images, GIS can help scientists visualize the rate of ice melt and predict future environmental changes. This information is crucial for global climate models and impacts policy making regarding the mitigation of climate change. Deserts are another area where GIS technology shines, helping to manage and study ecosystems and natural resources. GIS applications enable mapping of sand movement, vegetation cover, and water sources, which are vital for planning conservation efforts and managing the fragile balance of desert habitats. In addition, GIS assists in mineral exploration by providing tools for integrating geological data, thereby aiding in the identification of potential extraction sites without extensive physical surveys. In oceanography, GIS is widely used to map ocean floors, track marine species, and monitor environmental conditions. It supports the management of marine protected areas and the planning of maritime routes that minimize environmental impact. Integration of GIS with sonar and other marine survey technologies enhances the accuracy and depth of sea mapping, which is essential for undersea cable routing, oil exploration, and scientific research. Volcanic regions benefit from GIS in hazard mapping and risk assessment. By combining real-time data from seismic sensors with topographical maps, GIS enables visualization of lava flow paths and potential impact zones. This technology is vital for emergency planning and public safety, providing authorities with the tools needed to make quick decisions during volcanic events [9].

GIS technology's power lies in its ability to bring disparate data sets into a unified platform, offering dynamic visualization and analysis capabilities. This is particularly advantageous in extreme environments, where traditional surveying methods are often impractical or dangerous. The continued advancement of GIS technology promises even greater capabilities in environmental monitoring, resource management, and the safe exploration of some of the most challenging terrains on the planet [10].]

2.4. UAV 3D Imaging Technology

UAV 3D imaging technology is a high resolution, multiangle image acquisition, processing, and analysis technology based on UAV platforms. It involves mounting multiple cameras or sensors on UAVs to capture ground object images from various angles, then processing and analyzing the images using computer vision, Geographic Information Systems (GIS), and other related technologies, and ultimately constructing three-dimensional spatial information models of ground objects. The use of this technology in special terrain surveys can achieve image information comparison, rapid photography of the entire survey area, and the construction of 3D models. This technology has apparent superiority in actual surveying work, enhancing the efficiency and quality of surveying work. Moreover, surveyors can establish various information models such as 3D spatial maps and contour maps by choosing UAVs with different precision, performance and functions, thus achieving multiangle scaling and comprehensive observation of the survey area [11].

2.5. 3S Technology

In surveying projects, the main purpose of applying this technology is to analyze and collect data resources. It features database storage, input and output of graphic data, and other functions, used for specific terrain surveying. It can provide relatively complete data support for engineering construction surveying work. According to the specific needs of the survey work, the collected data materials can be processed using computer technology to draw the corresponding terrain maps and then output them. The use of this technology on special terrains not only reduces the measurement time but also improves the efficiency of survey work, significantly reducing surveyor workload in collecting and organizing data [12].

2.6. RS Technology

Remote sensing technology is a comprehensive detection method that uses artificial satellites, remote sensing platforms such as aircraft, and various sensors to collect electromagnetic radiation information from ground objects. This information is then processed, analyzed, and imaged for exploration mapping purposes. It enables the remote detection and recognition of various landscapes on the ground by relying on the reflection, radiation, absorption characteristics of objects to electromagnetic waves, as well as their spectral characteristics and geometric texture structure. This method allows for full-range testing of objects without direct contact, effectively overcoming limitations in mapping precision for complex areas with special shapes. Additionally, it offers advantages such as high efficiency and wide coverage. The technology has been widely applied in large forested areas and can effectively investigate resources [13].

3. Key Control in Special Terrain Mapping

3.1. Collection of Special Terrain Data

When mapping special terrains, it is essential to first gather the relevant mapping data. This foundational task is crucial for ensuring the accuracy of the data. Therefore, a thorough preparation of pertinent information must be performed prior to the measurement work. Additionally, during the data collection process, it is important to align with predetermined mapping objectives and operational requirements, as well as categorize and sort the collected data accordingly. For example, when implementing an old city renovation plan, it is necessary to collect information on road facilities, housing construction, soil conditions, and surface data to select appropriate mapping methods later [14].

3.2. emphasis on terrain mapping accuracy

Precision control plays a critical role in special terrain mapping work; therefore, surveying and mapping personnel should prioritize this aspect to ensure data reliability. In projects such as old city renovations where urban housing construction is concentrated and diverse in type, maintaining accurate surveying and mapping becomes imperative to avoid errors in station measurements or directional angles due to subjective assumptions about orientation information within the old city transformation process. Henceforth, attention should be paid towards achieving measurement accuracy through suitable surveying and mapping technologies, while effectively correcting errors for better control and preventing insufficient accuracy.

3.3. GPS Measurement and Positioning

GPS technology is of great importance in surveying and mapping engineering - especially in challenging terrains -and must be used appropriately to facilitate the organized execution of surveying and mapping tasks. The application of GPS can greatly enhance measurement accuracy while ensuring quality results within shorter timeframes for engineering mappings purposes. Furthermore [15].

3.4. Rational Use of Digital Mapping

The rational utilization of digital mapping is crucial in specialized areas. This technique integrates collected images for shape mapping, improving measurement standardization and accuracy. Digital mapping technology digitally transforms all physical objects into data that can be converted into topographic maps and visually displayed using computer image processing technology. Surveyors can use the three-dimensional image to better understand the specific characteristics of the area being measured.

3.5. Develop preliminary survey sketches

To analyze the actual conditions of a particular terrain area, mappers need to observe the geographic structure map of the target area and determine the key points for measurement. Then they should draw a corresponding geographical environment observation map. After determining the purpose of the survey, a detailed topographic map analysis should be performed to select appropriate survey and mapping methods based on subsurface data calibration, point survey, and other methods. In analyzing specific conditions around rivers, potential security risks should be assessed using systematic analysis and local analysis approaches. Environmental characteristics and human history must also be considered during environmental monitoring in order to prepare adequately for work in advance.

3.6. The Application of Surveying And Mapping

The application of surveying and mapping technology in special terrains and environments, such as mountains, swamps, dense forests, and urban areas, presents a unique set of challenges due to accessibility, visibility, and the inherent dangers posed by the natural landscape. As the demand for precise and comprehensive geographic data increases, the development and application of advanced surveying technologies has become more sophisticated, paving the way for new methodologies and innovations in the field.

One of the primary technologies that has transformed surveying in challenging terrains is Light Detection and Ranging (LiDAR). This technology uses laser light to measure distances to the Earth's surface and can create highly accurate 3D maps of the terrain, even through dense vegetation or in dark conditions, such as in caves or heavily shaded areas. LiDAR is particularly effective in environments where traditional surveying methods are impractical or unsafe. For example, in mountainous regions, LiDAR-equipped aircraft or drones can survey large areas quickly, reducing the need for physical access and significantly lowering the risks associated with manual surveying.

In addition to LiDAR, Geographic Information Systems (GIS) have greatly enhanced the ability of planners and researchers to analyze and interpret environmental data. GIS applications allow for the integration of multi-source data sets into a single, detailed geographic database. This integration enables complex analyses, such as assessing flood risks in swamps or the impact of urbanization on natural habitats. GIS technologies facilitate better decision making by providing detailed spatial insights and predictive modeling, which are crucial for environmental management and urban planning.

Another emerging trend is the use of autonomous robots and drones for data collection in inaccessible or hazardous locations. Drones, in particular, have become invaluable in the surveying field due to their ability to reach difficult areas and collect data from perspectives previously considered impossible. Equipped with high-resolution cameras, multispectral sensors, and GPS, drones are changing how data is collected in special terrains, providing safer, faster, and more cost-effective solutions than traditional methods.

The future of surveying technology in special terrains and environments is likely to be driven by further integration of Artificial Intelligence (AI) and Machine Learning (ML) into existing systems. AI and ML can enhance data processing, enabling faster interpretation and more accurate predictions from large data sets. For example, AI algorithms can automatically detect changes in geographic features from sequential images, aiding in the monitoring of environmental changes or the progress of construction projects.

Moreover, the advancement of Virtual Reality (VR) and Augmented Reality (AR) technologies offers new possibilities for visualizing and interacting with geographic data. These technologies can simulate environments for planning and training purposes, allowing users to virtually navigate through terrains and analyze geographical features without being physically present. This capability is especially beneficial for the preparation of operations in hazardous or remote areas.

As technology continues to evolve, the integration of cloud computing and the Internet of Things (IoT) with surveying tools will further enhance data accessibility and real-time monitoring capabilities. Cloud-based GIS platforms can facilitate the sharing and collaboration of geographic data between different locations and organizations, while IoT devices can provide continuous data streams, improving the timeliness and accuracy of environmental monitoring.

In conclusion, the application of mapping and surveying technology in special terrains and environments is undergoing rapid transformation, driven by technological advances that offer safer, more accurate, and efficient methods of data collection. The future of surveying in these challenging environments will depend on continued innovation and integration of cutting-edge technologies, ensuring that geographic data remain robust, accessible, and integral to environmental stewardship and urban development.

4. Conclusions

In conclusion, the evolution of mapping and surveying technology in special terrains and environments is a testament to the remarkable strides made in geospatial science and technology. As this paper has explored, advances such as LiDAR, GIS, autonomous drones, and the integration of AI and ML not only enhance traditional surveying methods, but also redefine what is possible in the realm of geographic data collection. LiDAR technology, in particular, has proven to be a game changer, enabling high-precision 3D mapping in areas where conventional methods fall short. Its ability to penetrate dense vegetation and produce accurate terrain models in obscured environments underscores its value in ecological studies, disaster management, and urban planning. Similarly, the use of GIS has transformed data analysis, allowing more sophisticated modeling and interpretation that supports effective decision making in various sectors, including environmental management, public safety, and resource allocation. The use of drones has democratized access to aerial survey data, offering a flexible and cost-effective solution that ensures safety and enhances data acquisition speed. Their versatility in carrying different sensors makes them particularly useful for continuous monitoring and assessment of rapidly changing environments or disaster-stricken areas. Looking ahead, the integration of AI and ML is poised to further revolutionize the field of surveying by automating complex processes, improving data accuracy, and providing deeper insights into geographical patterns and changes. These technologies will enable for more predictive capabilities, allowing proactive rather than reactive planning and response strategies.

Furthermore, the advent of VR and AR in surveying presents novel ways of visualizing and interacting with geographic data, providing immersive experiences that could aid in planning, training, and stakeholder engagement. The potential of these technologies to simulate inaccessible terrains offers substantial benefits for hazardous area operations and remote site analysis.

Furthermore, the growing adoption of cloud computing and IoT in geospatial applications signifies a shift toward more connected, accessible, and real-time data ecosystems. This will likely lead to more collaborative approaches in geographic studies and operations, breaking down silos between different geographic information users and creators. In essence, the future of surveying and mapping in challenging terrains and environments is bright, with continuous innovations driving improvements in accuracy, efficiency, and safety. The key to harnessing these advancements lies in the integration and synergistic use of various cutting-edge technologies, which will undoubtedly continue to shape the landscape of geospatial science and open new frontiers in the exploration and understanding of our planet. Radar is rapidly developing into a powerful tool in disaster management. Its ability to quickly gather accurate and complete information on disaster-affected areas improves the ability of emergency responders and planners to make decisions and take action. Laser radar technology has the ability to help secure populations in times of crisis by helping in disaster assessment, search and rescue operations, hazard mapping, and infrastructure evaluation. As technology develops, incorporating Laser Radar into emergency management procedures may improve the effectiveness of preparedness, response, and recovery operations in the event of a disaster.

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If any, it should be placed before the reference section without numbering.

Data Availability

The data sets used during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The author states that this article does not have a conflict of interest.

References

[1] Chen, J., & Wang, L. (2020). "Advancements in LiDAR Technology for Environmental Monitoring and their Applications." Environmental Monitoring and Assessment, 192(3).

[2] Harris, C., & Wright, A. (2019). "GIS in Environmental Management: A Review." Journal of Environmental Management, 241, 170-183.

[3] Brown, N., & Green, T. (2018). "The Use of Drones in Ecological and Wildlife Research: A Systematic Review." Journal of Ecological Engineering, 45(5), 591-609.

[4] Li, X., & Zhao, Y. (2021). "Machine Learning and AI in Geospatial Data Processing: Current Trends and Future Directions." Geo-spatial Information Science, 24(1), 1-14.

[5] Patel, K., & Singh, R. (2019). "Integrating VR and AR into Geospatial Information Systems: Opportunities and Challenges." Computers & Geosciences, 133, 104331.

[6] Kumar, P., & Singh, A. (2018). "Internet of Things for Geospatial Data Collection: A Review." Sensors, 18(11), 3770.

[7] Anderson, K., & Gaston, K. J. (2019). "Lightweight Drones in Ecological Monitoring." Methods in Ecology and Evolution, 10(6), 885-893.

[8] Zhang, J., & Goodchild, M. F. (2020). "Cloud Computing in GIS and Geospatial Data Processing." Geographic Information Systems Quarterly, 44(2), 209-220.

[9] *Morrison, J. B., & Tsai, W. H. (2017). "LiDAR Data for Landscape Archaeology in Forest Environments." Archaeological Prospection, 24(3), 205-213.*

[10] *Tan, P., & Shao, G. (2021). "The Application of Artificial Intelligence in the Spatial Analysis of Environmental Data." Environmental Modelling & Software, 134, 104926.*

[11] *Reid, J. F., O'Connor, M., & Lloyd, C. (2022). "Augmented Reality Applications in Forestry and Natural Resource Management." Forestry: An International Journal of Forest Research, 95(2), 175-186.*

[12] *Freeman, E. A., & Moisen, G. G. (2018). "A Comparison of the Performance of Threshold Criteria for Binary Classification in Terms of Predicted Prevalence and Kappa." Ecological Modelling, 222(8), 1359-1369.*

[13] *Thompson, R., & Kolka, R. (2018). "Using Internet of Things to Improve Ecological Measurements." Biogeosciences, 15(8), 2589-2602.*

[14] *Mather, P. M. (2019). "Integration of Multispectral and LiDAR Data in GIS." Photogrammetric Engineering & Remote Sensing, 85(5), 365-377.*

[15] *Gupta, S., & Kumar, D. (2020). "Advanced Surveying: Integrating LiDAR and GIS for Environmental Management." International Journal of Remote Sensing, 41(9), 3462-3487.*