The Application of Remote Sensing Techniques in Ecological Environment Monitoring

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Abstract. As global environmental challenges continue to escalate, remote sensing technology has become an indispensable tool for researching, monitoring, and managing these issues. This article aims to summarize the principles of various remote sensing technologies, their primary application areas, and their crucial role in ecological and environmental conservation for sustainable development. Remote sensing technology offers a diverse array of data from multiple sources and scales, facilitating the monitoring of natural resource changes, studying ecosystem health, and assessing the impact of human activities on the environment. In-depth exploration of the latest advancements and application cases in remote sensing includes: (1) Vegetation: Applications in vegetation monitoring encompass the use of technologies such as unmanned aerial vehicle (UAV) remote sensing and laser radar (LiDAR) for monitoring forest health, vegetation cover, and changes. These applications support forest management and ecological research. (2) Water Bodies: Thermal infrared remote sensing and satellite remote sensing are utilized to monitor water quality, water level fluctuations, and aid in water resource management, addressing water resource challenges. (3) Soil: Remote sensing technology is employed in soil applications, utilizing multispectral and synthetic aperture radar (SAR) techniques for soil property assessment, soil moisture analysis, and soil erosion prediction. These applications contribute to agricultural and land management decisions, and provide suitable remote sensing technologies for the current trends in the ecological field, serving as a reference for monitoring methods.

Keywords: Application of Remote Sensing Technology, Vegetation, Water Body, Soil.

1. Introduction

Due to continuous technological advancements and the extraction of various energy sources by humans, global environmental issues are escalating. These include widespread deforestation, water scarcity, pollution, and soil degradation. Therefore, the primary task at present is to protect the ecological environment and achieve sustainability. To accomplish this goal, it is crucial to recognize the significance of monitoring the environment and gaining real-time insight into the state of the ecosystem.

There are many types of traditional environmental detection techniques, such as the use of bioindicators in water quality assessment and air sampling and analysis methods in air quality monitoring. However, these conventional techniques have significant limitations as they can only provide localized data and are often cost-intensive. Therefore, the application of remote sensing technology in environmental monitoring represents a significant advancement, enabling large-scale assessment while saving human resources and time.

Presently, remote sensing technology is widely applied in environmental detection. For instance, Shi (2021) employed UAV remote sensing technology for vegetation monitoring [1], Hu (2019) utilized thermal infrared remote sensing for water body assessment [2], and Zhang et al. (2022) along with Kim S. B. et al. (2021) employed synthetic aperture radar technology to investigate soil-related issues [3,4].

This article summarizes the principles of most remote sensing technologies and discusses their applications in the domains of forests, water bodies, and soil.

2. The Application of Remote Sensing Technology in Vegetation

The importance and convenience of remote sensing technology in vegetation detection, identification, growth assessment, and various vegetation-related computational models are undeniable. Commonly used remote sensing technologies for vegetation monitoring include laser radar (LiDAR), the use of normalized vegetation indices (NDVI) to analyze vegetation growth conditions and unmanned aerial vehicle (UAV) remote sensing technology.

2.1. Laser radar (LiDAR)

Laser radar technology is a remote sensing technique that utilizes the principle of electromagnetic wave reflection to detect, locate, and measure targets. It is not limited by weather conditions and can operate during the day, at night, or even under cloud cover [5]. This characteristic makes it highly suitable for vegetation detection, especially in rainy or cloudy regions. Moreover, radar signals possess strong penetration capabilities, easily penetrating vegetation cover to probe structures below the surface, such as tree roots and soil. With the rapid advancement of modern technology, laser radar technology can provide high-resolution images for detailed vegetation detection. Furthermore, this technology covers multiple spectral bands, including infrared laser wavelengths, near-infrared, and ultraviolet bands, offering diverse information and broad applicability in identifying different types of vegetation.

At present, many scholars utilize radar remote sensing for high-precision vegetation identification. For instance, in the identification of chlorophyll in vegetation, most solar-induced chlorophyll fluorescence (SIF) extraction algorithms achieve higher accuracy only under clear-sky conditions, whereas their performance is compromised on cloudy and overcast days [6]. However, radar remote sensing can effectively mitigate the influence of weather. Its high penetration capability enables the collection of dense data, with numerous measurement points per square meter. This high-density data is crucial for accurately capturing vegetation structures, canopy outlines, and trunk details. It can also precisely measure distances to different parts of vegetation, including the top, bottom, and other structures, facilitating the creation of high-precision three-dimensional models. Based on radar remote sensing data for chlorophyll fluorescence, Zhan (2020) successfully depicted the three-dimensional distribution of SIF in forest canopy scenes, and model validation yielded favorable results.

2.2. Normalized difference vegetation index (NDVI).

The Normalized Difference Vegetation Index (NDVI) is an effective indicator based on the absorption and reflection characteristics of plant chlorophyll. Chlorophyll in plants absorbs more red light, while near-infrared (NIR) light is primarily reflected. Consequently, healthy vegetation exhibits higher NIR reflection and lower infrared light reflection, resulting in higher NDVI values. Conversely, bare land or non-vegetated areas typically have lower NDVI values, potentially even negative values. It is used to monitor vegetation growth and changes. Combining the Leaf Area Index and Vegetation Net Primary Productivity Index can accurately assess vegetation leaf area and health conditions. One environmentally friendly aspect of NDVI is that it is a non-destructive remote sensing method, eliminating the need for on-site sampling or vegetation removal. NDVI has a wide range of applications and can be used for vegetation monitoring globally. Furthermore, satellite and aerial remote sensing data provide extensive coverage, making it suitable for various environmental and geographical conditions. However, it is worth noting that this technology faces challenges related to satellite launch and operation, which require a significant amount of energy and resources for data collection.

After applying the NDVI indicator in a natural conservation area in the Qinling Mountains region of China, the results indicated spatial differences in vegetation types between certain areas. Moreover, the vegetation growth trend showed a significant increase or remained stable in some regions. Overall,

the conservation effectiveness in the central Qinling Mountains natural conservation area was favorable, but specific areas require special attention [7].

2.3. Unmanned aerial vehicle (UAV)

Unmanned aerial vehicle (UAV) remote sensing technology is based on data collection and image acquisition from various types of land surfaces using UAV platforms, and it has a wide range of applications in various fields. Compared to traditional manned aircraft, UAVs are cost-effective, with lower maintenance and operational expenses. In recent years, UAV applications in vegetation remote sensing have become widespread. Data collected by sensors mounted on UAVs can assist farmers and forest managers in more efficiently managing land and vegetation resources, thereby reducing waste and environmental damage. UAVs also carry high-resolution sensors, such as multispectral and infrared cameras, capable of capturing surface information at a fine level of detail. This is crucial for distinguishing complex crop structures and mixed vegetation types. Another characteristic of UAVs is their ability to operate at low flight altitudes, typically ranging from tens to hundreds of meters. This allows them to get closer to the ground, reducing vegetation obstruction and making it easier to observe and record different parts of vegetation. UAV flight paths and data collection can be flexibly adjusted according to specific needs. This means that individuals can customize flight missions based on different field structures and crop types to ensure the acquisition of optimal data.

The application of UAV remote sensing technology in resource surveys has become an overall trend in forestry development. It is extensively used in forest firefighting, studying forest ecological environments, extracting forest biomass information, and detecting forest pests and diseases, among other applications. Through this method, resource surveys of forests can provide a more systematic understanding of various aspects of the forest, enabling dynamic analysis, management, and monitoring of its resources. UAV remote sensing enables rapid image acquisition, ensuring the efficient completion of forest resource surveys. Relevant organizations can use the analysis and management of forest resource data to formulate optimal forest resource planning strategies, thereby promoting the healthy growth of forest science, and laying a solid foundation for the future [1].

3. The Application of Remote Sensing Technology in Water Bodies

The applications of remote sensing technology in the domain of water cover a wide range of fields, spanning from monitoring water quality and water resource management to environmental protection and natural disaster warning. Here are some of the applications of remote sensing technology in the context of water bodies.

3.1. Hyperspectral remote sensing

Hyperspectral remote sensing technology is a method of remote sensing that captures information by measuring the reflection or radiation of objects across numerous narrow spectral bands. In the context of water monitoring and research, hyperspectral remote sensing can detect various water quality parameters with high precision, including chlorophyll, turbidity, dissolved organic matter, and pollutant concentrations. This makes it a powerful tool for water quality monitoring, aiding in the early identification of water pollution events. It can also distinguish different types of water bodies, such as freshwater, saltwater, algal blooms, and sediments, contributing to an understanding of water body dynamics. By analyzing reflectance across different spectral bands, it is possible to estimate the concentration of dissolved substances in the water, such as nitrogen, phosphorus, and silicon, which is crucial for assessing water nutrient status and ecosystem health.

Hyperspectral remote sensing technology is a non-invasive monitoring method that collects data from a distance without introducing any substances into the water. It does not require direct contact with the water body, thereby avoiding direct negative impacts on the aquatic environment and ecosystem disturbance.

Based on hyperspectral data, the identification of black and odorous water bodies within urban areas is feasible [8]. The spectral basis for identifying such water bodies lies in the fact that, compared to non-black and odorous water bodies, the remote sensing reflectance values of black and odorous water bodies are generally lower within the wavelength range of 400 to 900 nm. Moreover, the spectral slopes with lower values are concentrated in the blue-green band (400-550 nm) and green-red band (550-900 nm). Therefore, the normalized ratio of reflectance in the green-red band can better differentiate the degree of black and odorous water, indicating that the use of sensors with four bands in blue, green, red, and near-infrared can achieve precise measurement and implementation of water body monitoring.

3.2. Thermal infrared remote sensing

Thermal infrared remote sensing is a remote sensing technology that utilizes an object's infrared radiation to gather information. Its principle is based on the Stefan-Boltzmann Law, which states that an object's temperature is directly proportional to the energy it emits. An object's temperature determines the wavelength and intensity distribution of its radiation. Specifically, objects with higher temperatures emit more energy.

Thermal infrared remote sensing technology offers unique advantages when applied to water body monitoring. For instance, it can accurately measure the surface temperature of water bodies. This is crucial for monitoring temperature distribution and seasonal variations in lakes, rivers, oceans, and other water bodies. Water temperature data is of significant importance for ecosystem and climate research, as well as for monitoring potential natural disaster risks. Water temperature data can also be combined with other water quality parameters to assess the water quality and ecological health of water bodies. Anomalous temperature changes may indicate water pollution or ecosystem issues.

River water temperature is a critical factor in determining the ecological environment and metabolic processes of rivers. It is also an important indicator of river health in riverine ecosystems, and it greatly influences fish spawning and reproduction. However, there is often a scarcity of monitoring stations equipped to measure water temperature, and existing measured data are often insufficient, particularly in specific study areas [2]. Using thermal infrared remote sensing technology to measure water temperature can be employed to study the impact of reservoirs on downstream river water temperature and the effects of temperature changes on river ecosystems and their surroundings. It provides water temperature data for any research area and serves as a viable solution to address the shortage of measured data.

3.3. Satellite remote sensing

Satellite remote sensing is a technology that involves acquiring information about the Earth's surface using sensors onboard satellites. It relies on satellite sensors capturing electromagnetic radiation from the Earth and generating information about surface features and the environment through the processing and interpretation of this data. This technology finds extensive applications in various fields such as geology, meteorology, environmental monitoring, and resource management. Therefore, its application in water body remote sensing is also significant.

Satellite remote sensing can cover vast geographical areas, making it suitable for monitoring large bodies of water like lakes, rivers, and oceans, as well as smaller water bodies. This broad coverage is valuable for large-scale water resource management and monitoring. Satellites can regularly capture images of the same area, providing time-series data for water bodies. This is highly beneficial for monitoring seasonal changes, water level fluctuations, climate impacts, and so on. The widespread use of satellite resources in today's era, especially the implementation of high-resolution observation systems, has brought revolutionary changes to the field of water resources. This technological advancement has provided remarkable support and tremendous convenience for flood control, drought resistance, water resource management, and soil conservation, among other areas [9]. The data from high-resolution observation systems offer detailed surface information, enabling water management professors to monitor river and reservoir water levels more accurately, and issue timely

flood and drought warnings. and effectively mitigating the losses caused by disasters. It holds significant practical importance in comprehensively understanding changes in hydrological and water resources and improving water resource utilization efficiency.

4. The Application of Remote Sensing Technology in Soil

Remote sensing technology has played a crucial role in soil monitoring, as it provides real-time and extensive soil information. This contributes to the more effective management of soil resources and, in turn, makes a significant contribution to environmental conservation.

4.1. Optical remote sensing

The principle of optical remote sensing is based on sunlight illuminating the Earth's surface, where different surface materials interact with light in different ways in the visible and infrared spectra. Some lights reflect into the atmosphere, while others are absorbed. Optical sensors, such as cameras and spectrometers mounted on satellites or aircraft, record the intensity and wavelength information of this reflected light. By measuring the spectral characteristics of different bands, surface features such as vegetation, soil, water bodies, and buildings can be identified and analyzed. Comparing optical data at different times allows for the detection of surface changes.

Optical remote sensing technology offers high spectral resolution, making it advantageous in soil property analysis. It can capture interactions between vegetation and soil, providing a deeper understanding of various soil properties. Due to these characteristics, optical remote sensing plays a crucial role in soil monitoring.

For instance, in soil moisture retrieval analysis, Qin et al. (2021) discussed that compared to microwave methods, optical remote sensing has a longer history of data availability. The significance of optical remote sensing retrieval studies lies not only in extending the historical information about soil moisture but also in promoting the diversity and richer development of future soil moisture products [10]. This diversity could enable researchers and decision-makers to have a more comprehensive and accurate understanding of soil moisture changes, aiding in better management of agriculture, water resources, and ecosystems.

4.2. Multispectral remote sensing

Multispectral remote sensing technology typically employs several discrete spectral bands, often within the visible and near-infrared spectral range, to gather various information about the Earth's surface. These bands typically cover a broad spectrum, but the number of bands is relatively limited, usually ranging from 3 to 15 bands in common experimental setups. Multispectral imagery provides fundamental land cover and land use classification information.

Given that soils exhibit specific reflectance characteristics in the spectral domain, and different types of soils absorb and reflect light waves in different ways, multispectral data can be utilized for identifying and analyzing soil properties such as moisture content, nutrient levels, and organic matter content. These aid agricultural managers in gaining a better understanding of soil conditions and in formulating suitable planting and soil improvement strategies.

For instance, in studies related to soil moisture retrieval in bare soil, multispectral remote sensing technology is often preferred due to its cost-effectiveness. Furthermore, this technology efficiently enhances workflow, reduces workload, expands the scope of experiments, and enables rapid detection, meeting a range of urgent needs [11]. Multispectral remote sensing technology addresses the limitations of traditional detection methods and exhibits promising development trends.

4.3. Synthetic aperture radar (SAR)

The SAR (Synthetic Aperture Radar) system creates images by transmitting microwave signals and recording the signals reflected. SAR images are two-dimensional and, like LIDAR technology, can be acquired under various weather and time conditions. Unlike the XYZ coordinate information

that LIDAR can generate, SAR images are grayscale and do not provide direct three-dimensional information. However, they possess excellent surface-penetrating capabilities and can be used for subsurface detection. Additionally, in soil monitoring applications that often require time-series data, SAR satellites can cover the same areas regularly, providing broader coverage and more frequent observations compared to LIDAR. Therefore, Synthetic Aperture Radar technology finds broader applications in soil detection.

Synthetic Aperture Radar, with its high resolution, all-weather and all-time observation capabilities, polarization capabilities, and strong penetration abilities, especially its sensitivity to soil moisture content, is widely used in soil moisture retrieval research [3].

5. Conclusions

This article focuses on the applications of remote sensing technology in various environmental assessments, specifically analyzing and describing its use in vegetation, water bodies, and forests. It introduces the principles and advantages of various remote sensing technologies and their relevant applications.

In the context of vegetation, one of the major advantages of radar technology is its independence from weather conditions. However, the applicability of this technology depends on the size of the study area. Given the relatively high cost of laser radar technology, its cost allocation can be relatively high for smaller areas. Interpreting vegetation normalized difference indices provides valuable insights into vegetation types and overall conditions, enabling agricultural and forestry managers to gain a clear understanding of vegetation health. The use of unmanned aerial vehicle (UAV) remote sensing technology significantly reduces the workload for operators, and low-altitude observations provide clearer images compared to other technologies, making its advantages more pronounced in today's technological era.

The application of remote sensing technology in water body detection is extensive. The advantage of hyperspectral remote sensing technology in water body monitoring lies in its ability to provide rich water quality information, including chemical composition, turbidity, and pollution levels, contributing to effective water resource management and protection. Thermal infrared remote sensing technology excels in precisely measuring water body temperatures, which is valuable for detecting water flow, lake temperature variations, and water quality conditions, providing robust support for understanding water body dynamics. Satellite remote sensing technology offers advantages in providing broad coverage, frequent observations, real-time monitoring, and global-scale water resource information.

In soil monitoring, multispectral remote sensing technology's advantage lies in its provision of multi-band image data for detailed soil property and land use analysis. Optical remote sensing technology captures interactions between vegetation and soil, offering higher precision and resolution in understanding soil texture compared to other technologies. Synthetic aperture radar technology's greatest advantage is its powerful surface penetration capability, making it well-suited for soil detection.

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