Research on the Application of Multi-Source Remote Sensing Technology in Dynamic Investigation and Monitoring of Natural Resources

Wang Shujie, Xu Pengpeng
Jiangxi Vocational Transportation College of Communications, Nanchang, China

Abstract: Conventional ground-based measurement methods suffer from prominent drawbacks including long cycles, high costs and limited coverage in the dynamic investigation and monitoring of natural resources. Multi-source Remote Sensing Technology is adopted to address the foregoing dilemmas. This paper analyzes Multi-source Remote Sensing Technology from dimensions of data acquisition, information extraction and change detection, and establishes a collaborative application mechanism. Research results indicate that Multi-source Remote Sensing Technology can effectively remedy the shortcomings of conventional methods by constructing an integrated "Space-Air-Ground" monitoring system, which acts as a critical approach to break through the bottleneck in dynamic monitoring of natural resources. In the future, its development should be further advanced toward intellectualization and comprehensiveness.

Keywords: Multi-Source Remote Sensing Technology; Natural Resources; Dynamic Investigation; Monitoring

1. Introduction

Natural resources constitute the material foundation and spatial carrier for human survival and development. Dynamic monitoring of their quantity, quality and ecological changes provides fundamental support for optimized territorial spatial management, ecological civilization construction and implementation of sustainable development strategies. Particularly with the growing impact of human activities, natural resource systems are under mounting pressure. Accurate and timely acquisition of the spatio-temporal distribution patterns and change rules of natural resources has become an urgent demand for decision-making in natural resource management. Conventional ground-based investigation and measurement methods present multiple limitations. Despite relatively high accuracy at local scales, such methods feature low efficiency, high costs and long data update cycles, and can hardly satisfy the timeliness requirements for large-scale natural resource investigation and dynamic monitoring across China. Accordingly, Multi-source Remote Sensing Technology should be employed to build a dynamic monitoring mode with multi-platform, multi-sensor and multi-temporal phase collaboration.

2. Major Deficiencies of Conventional Natural Resource Investigation and Monitoring Methods

2.1 Long Monitoring Cycles and Insufficient Timeliness

Conventional natural resource investigations are dominated by manual field mapping. Substantial human and material resources must be invested, and surveyors are required to carry measuring instruments to collect data point-by-point and plot-by-plot on-site. Restricted by human and material input, traffic conditions, weather and other factors, a complete regional investigation often takes several months or even more than one year to finish, resulting in an obvious time lag between monitoring data and real-world conditions. Especially given the increasingly frequent changes in natural resources, the monitoring frequency at inter-annual scales can no longer meet practical demands for dynamic supervision.

2.2 High Costs and Poor Economic Efficiency

Conventional ground-based investigations require long-term on-site work by numerous professional technicians, accompanied by various expenditures covering transportation, accommodation, instruments and equipment. For terrains with complex landforms and poor accessibility, the costs of field investigations rise exponentially. Studies have pointed out that although manual field investigations deliver high accuracy, they are plagued by excessive resource consumption and slow data refresh, failing to update data in a timely manner. Take aerial photogrammetry as an example: its prohibitive costs prevent many regions from adopting aerial photographs for annual land-use status surveys. Exorbitant monitoring costs directly limit investigation frequency and coverage.

2.3 Narrow Coverage and Discontinuous Spatial Information

Conventional measurements only obtain point-scale information, making it difficult to generate continuous characterizations of natural resource conditions across an entire region. This is especially true for extensive areas such as woodlands, grasslands, wetlands, alpine zones and deserts that are barely accessible to humans, where conventional investigation methods prove inadequate. Traditional monitoring approaches cannot achieve an overall understanding of the spatial distribution patterns of natural resources.

3. Solutions and Applications of Multi-Source Remote Sensing Technology

3.1 High-Frequency Revisit and Short-Baseline Monitoring to Address Timeliness Challenges

Excessively long monitoring cycles represent the most conspicuous drawback of conventional monitoring practices, which can be mitigated by the high-frequency revisit capacity of multi-source remote sensing satellites. China has established an Earth-observation constellation composed of multiple satellites including the Zi-Yuan (Resource) series, Gao-Fen (High-resolution) series and Huan-Jing Jian-Zai (Environment and Disaster Reduction) series, enabling high-frequency coverage over large-scale domestic areas. By integrating multi-temporal remote sensing data, a quarterly monitoring technical route of "three-dimensional collaboration" has been constructed. Monitoring cycles are shortened from annual to quarterly units, and operational efficiency is further improved. Synthetic Aperture Radar (SAR) satellites feature all-time and all-weather imaging capacity, overcoming severe constraints imposed by weather and illumination on conventional optical remote sensing and guaranteeing continuous monitoring time[1].

3.2 Wide-Coverage and Low-Cost Alternatives to Lower Economic Thresholds for Monitoring

Multi-source Remote Sensing Technology adopts a hierarchical observation mode of "satellite-based general survey + aerial detailed survey + Unmanned Aerial Vehicle (UAV) verification". Compared with conventional monitoring approaches, this mode substantially cuts monitoring costs per unit area. Satellite remote sensing images can realize one-shot large-area coverage, with a single scene covering thousands to tens of thousands of square kilometers. Meanwhile, UAV remote sensing supports low-cost and high-precision supplementary investigations in key regions. Multi-source Remote Sensing Technology demonstrates prominent economic advantages over manual field surveys and aerial photogrammetry[2].

3.3 Continuous Areal Observation to Realize Full-Domain Spatial Coverage

In the traditional detection, most of the cases are 'point' surveys, which have obvious coverage defects, but the remote sensing technology has formed a 'planar' imaging ability, which makes up for the shortcomings of traditional technology. Multi-spectral, hyperspectral and radar remote sensing images can provide continuous physical quantity information such as surface reflectance and backscattering coefficient for the detector, and further realize the global coverage of regional natural resources in the region. Extracting natural resource change spots through geographic information system software can expand discrete observation points into continuous spatial distribution maps. Because the hyperspectral remote sensing satellite itself has the detection ability of 'map integration' at present, the emergence of this technology also provides a more refined 'holographic perspective' for the investigation of natural resources.[3].

3.4 Time-Series Analysis Database to Ensure Consistency and Comparability of Datasets

Conventional investigation data suffer from poor historical comparability, which can be resolved by Multi-source Remote Sensing Technology combined with long-term time-series remote sensing image databases. For instance, the Landsat satellite series has accumulated more than 50 years of continuous Earth-observation data since 1972, and the Sentinel satellite series has provided high-frequency standardized data products from 2014 onwards. Researchers can conduct long-term change analysis using cloud-based platforms such as Google Earth Engine on indicators including time-series Normalized Difference Vegetation Index (NDVI). Such standardized and traceable data systems fundamentally guarantee the comparability of monitoring outputs from different periods[4].

3.5 Active Remote Sensing and Multi-Source Complementation to Mitigate Weather and Topographic Constraints

In dynamic investigation and monitoring of natural resources, Multi-source Remote Sensing Technology can penetrate cloud layers and vegetation canopies. Active remote sensing tools such as SAR and Light Detection and Ranging (LiDAR) can acquire structural information beneath the land surface or vegetation cover. Collaborative fusion of optical and SAR data gives full play to complementary strengths of the two sensor categories. In practical applications, an intelligent multi-source remote-sensing image fusion framework should be built to support collaborative analysis of multi-platform data from satellites, aircraft and UAVs. This system significantly reduces monitoring interferences caused by cloud occlusion. UAV-borne hyperspectral remote sensing further helps analysts bypass cloud interference and rapidly deliver high spatio-temporal resolution datasets[5].

3.6 Intelligent Interpretation via Deep Learning to Improve Change-Detection Accuracy

In most cases, the traditional change detection method relies on manual visual interpretation or simple threshold segmentation. In the process of overall detection, both the pertinence and the degree of automation are relatively limited. Artificial intelligence technology represented by deep learning algorithm has gradually become one of the key technologies for remote sensing image change detection tasks. The feature fusion module based on deep learning can automatically extract multi-scale change features, which aims to overcome the environmental adaptability defects caused by the traditional threshold method. The NDVI time series difference that can be directly established at present, combined with the DBCE double baseline change detection model of the survey database, will reduce the false change detection rate from 28.7 % to 6.3 %. In addition, a series of deep learning models based on twin residual neural network have been applied to high-resolution remote sensing image change detection, and their performance is better than that of traditional models, which can meet the actual needs of detection.

3.7 Construction of a Comprehensive Monitoring System to Achieve "Space-Air-Ground" Integration

Integrated application of Multi-source Remote Sensing Technology in dynamic natural resource investigation and monitoring ultimately targets the construction of an integrated "Space-Air-Ground" monitoring system. A multi-level three-dimensional monitoring network is formed: satellite remote sensing undertakes macro-scale general surveys; UAV-borne hyperspectral and aerial remote sensing conduct meso-scale detailed surveys; ground sensor networks perform micro-scale verification. This comprehensive "Space-Air-Ground-Network" monitoring system enables efficient overall sharing of data resources and integrated application of diverse technologies. It effectively circumvents limitations of single technical approaches and realizes all-factor, full-coverage and all-weather dynamic monitoring of natural resources.

4. Conclusion

To sum up, conventional ground-based monitoring methods have inherent limitations. Their deficiencies in monitoring cycles, economic costs, spatial coverage, data continuity and environmental adaptability can hardly meet demands for refined and dynamic natural resource management in the new era. In dynamic investigation and monitoring of natural resources, Multi-source Remote Sensing Technology offers a systematic solution to the above-mentioned challenges through a "Satellite-Air-Ground" collaborative data-acquisition network, multi-source-data-fusion-driven information-extraction workflows, deep-learning techniques and big-data-supported intelligent change-detection tools. Practical results show that Multi-source Remote Sensing Technology can lift monitoring frequency from annual to quarterly levels, considerably lower false-change detection rates, and provide robust support for intelligent supervision of natural resources.

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