Original Research Article

Research and implementation of an intelligent cultivated land protection and stewardship monitoring platform

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Abstract: To prevent and control the "non-agriculturalization" and "non-grainization" of arable land and permanently designated basic farmland, China must comprehensively establish a Field Manager System aimed at the protection of these lands. This platform is supported by digital technologies and focuses on the regulation of arable land use. By integrating microservices architecture, distributed storage and search technologies, and relational databases, the system ensures the real-time availability, accuracy, and security of data. This integration facilitates large-scale, high-concurrency storage, querying, loading, and high-quality management of arable land-related data. Ultimately, by constructing an intelligent supervision platform for the Field Manager System in arable land protection, the platform achieves functionalities including arable land data management, field inspection task management, anomaly reporting and handling, problem verification and rectification, equipment maintenance, personnel management, and responsibility assessment. This integration forms an end-to-end closed-loop process encompassing the monitoring, discovery, warning, reporting, review, rectification, and case handling of arable land issues. Consequently, it enhances arable land protection planning and supervision, standardizes the management processes for arable land protection, strengthens interdepartmental collaboration and coordination, and effectively improves the standardization, precision, intelligence, and efficiency of arable land protection efforts.

Keywords: Cultivated land protection ; Field chief system ; Distributed storage ; RS ;GIS

1. Introduction

Food is regarded as paramount by the populace, with grain production fundamentally rooted in arable land; thus, arable land serves as the lifeline of food production. In his significant directives concerning arable land protection and food security, General Secretary emphasized the implementation of the strictest arable land protection system and the resolute prevention of the "non-agriculturalization" and "non-grainization" of arable land and permanently designated basic farmland. On April 1, 2021, the General Office of the Ministry of Natural Resources proposed the establishment of the "Field Manager System," advocating for a three-tiered, city-county-township-village integrated and comprehensive grid-based supervision network for arable land protection. In recent years, provinces such as Guangdong, Zhejiang, and Sichuan have explored and implemented the "Field Manager System" in accordance with local conditions. These regions have established Field Manager Offices at various administrative levels and actively promoted the construction of a "person-field correspondence" system, which assigns arable land protection responsibilities to specific villages, individuals, and land parcels[1-3]. The Zhejiang Provincial Development Planning Institute has emphasized seizing the opportunities presented by digital transformation to modernize spatial governance within national land spatial management[4].Traditional agricultural management methods primarily rely on manual operations, resulting in low management efficiency and high error rates. Therefore, there is a need to transform the working methods and supervisory approaches for arable land protection by leveraging the Field Manager System and digital technologies to enhance the level of

arable land protection[5].

Currently, China has preliminarily established policies and grid-based systems for the Field Manager System in arable land protection, utilizing intelligent information systems for management. Guo Chen designed and implemented an arable land supervision platform oriented towards the "Field Manager System" through the division of grid data and the construction of management models[6]. Yi Zhihui et al. proposed the development of an intelligent comprehensive management platform for the Field Manager System, creating a precise, real-time, and efficient closed-loop management system[7]. Tu Yongneng constructed an information management platform for the Field Manager System based on the concept of "Internet + Field Manager System"[8]. To promote the normalized implementation of the "Field Manager System," Zhejiang Province developed a "human defense + technical defense" digital supervision system for arable land protection, which has been comprehensively applied to village-level field managers and field patrol personnel via mobile applications[9]. The establishment of an intelligent Field Manager System information management platform can effectively enhance the grid-based management level and the strict implementation of arable land protection systems. However, challenges remain in the system's construction and usage. Firstly, arable land-related data are complex in type, large in volume, slow to update, difficult to store, and slow to query and manage. Secondly, traditional manual field patrol methods involving visual interpretation and verification are time-consuming, labor-intensive, costly, and inefficient. Lastly, the grid-based implementation of the Field Manager System involves numerous departments and institutions with different user groups and objectives. Independent information systems lack interconnectivity, necessitating multi-terminal products to achieve data integration and information sharing to meet diverse needs.

To address these issues, this paper employs a combination of microservices architecture, distributed storage and search technologies, and multiple relational databases to achieve the storage, querying, loading, and management of arable land-related data. By establishing a triple prevention model of "human defense + technical defense + institutional defense," and incorporating technological methods such as remote sensing (RS), Geographic Information Systems (GIS), the Internet of Things (IoT), artificial intelligence (AI), and mobile communications, the platform enables intelligent and dynamic monitoring and early warning of arable land issues[10]. Ultimately, by developing a PC-based intelligent supervision platform for the Field Manager System, a smart Field Manager System mobile application, and a WeChat public account, a comprehensive and multi-level arable land protection management system is formed. Through resource sharing and business collaboration across multiple terminals, the efficiency of monitoring, discovering, warning, reporting, reviewing, handling, and rectifying arable land issues is significantly enhanced, achieving a closed-loop operation. This comprehensive approach substantially improves the management capabilities and execution efficiency of the Field Manager System in arable land protection.

2. Key technology development

2.1. Storage and loading technology for farmland data

The platform manages a diverse and substantial array of arable land-related data types. These include unstructured vector data such as fundamental geographic information of arable land, results from the Third National Land Survey, historical land change survey outcomes, permanently designated basic farmland, high-standard farmland, arable land reserve resources, current land use status, administrative divisions, arable land compensation balance, and construction land approvals. Additionally, the platform handles unstructured raster

file data encompassing multi-temporal satellite remote sensing images, three-dimensional oblique photography models, panoramic images, photographs, videos, and various documents. Structured data managed by the platform include records of arable land patrols, anomaly issues and their rectification audit logs, personnel user information, and system settings.

Considering the diversity of data types, the variations in data volume, and the requirements for frontend visualization, the platform employs appropriate storage and query strategies in conjunction with an efficient Geographic Information System (GIS) service framework. This integrated approach facilitates the efficient management and rapid access of data, ensuring that the platform can handle large-scale and complex datasets effectively while meeting the demands of real-time data retrieval and presentation.

2.1.1. Storage of vector data using postgreSQL with PostGIS extension

PostGIS is an extension of PostgreSQL that facilitates the efficient storage and querying of spatial data, including the boundaries of arable land and plot attributes, while also supporting complex spatial analysis functionalities In this platform, spatial information from arable land-related vector shapefiles and other unstructured data are imported into the PostgreSQL database through PostGIS. Subsequently, SQL language is employed to perform intricate spatial data queries and analyses.

2.1.2. Storage of unstructured data using MinIO

MinIO is a high-performance distributed object storage system suitable for storing large volumes of unstructured data . In this platform, unstructured data including remote sensing images, three-dimensional oblique photography models, panoramic images, documents, audio files, photographs, and videos are stored within the MinIO distributed file system.

2.2. Dynamic monitoring and early warning technology for arable land

To address the challenges associated with large-scale manual field patrols, low efficiency, and the difficulty of accessing personnel in regions with complex terrains, this platform upgrades “arable land protection” to an “intelligent arable land protection” (Smart Protection) model . By integrating various monitoring resources and devices such as satellite remote sensing imagery, unmanned aerial vehicles (UAVs), and cameras, and combining the generated image data with structured informational resources, the platform leverages big data services and artificial intelligence (AI) for structured analysis. This enables intelligent monitoring of contiguous and key protected arable land areas.

This approach not only resolves monitoring issues in complex geographical regions but also enhances the efficiency and accuracy of arable land monitoring while reducing labor costs. The specific implementations are as follows:

2.2.1. Satellite remote sensing image recognition

Remote sensing technology, as an advanced high-tech tool, has been extensively applied in various domains, including land resource surveys, ecological environment monitoring, and hydrology. Among its numerous capabilities, land cover classification and parameter inversion have demonstrated significant advantages and practical value, particularly in agricultural monitoring

1. Integration of Prior Data: Data from the Third National Land Survey (TNLAS), land-use change surveys, farmland distribution records, and attribute categories were integrated to construct a comprehensive prior knowledge base. This knowledge base serves as the foundational framework for subsequent remote sensing image analysis.

2. Image Acquisition and Preprocessing: High-resolution GF-2 remote sensing imagery was acquired and subjected to preprocessing to ensure data quality. The preprocessing steps included radiometric correction, geometric correction, noise reduction, and cloud removal. Utilizing the prior knowledge base, phenomena such as "non-agriculturalization" (e.g., construction and industrial land use) and "non-grainization" (e.g., planting non-grain crops) were identified and annotated within the imagery to establish a training sample dataset.

2.2.2. UAV-Based high-altitude farmland patrol

The acquisition of satellite remote sensing imagery is often limited by the satellite's revisit cycle, posing challenges in meeting the real-time and periodic requirements of specific application scenarios. Furthermore, for small-scale areas or applications demanding high precision, the spatial resolution of satellite imagery is frequently inadequate. In contrast, UAV-based visible light remote sensing imagery offers significant advantages, including high temporal resolution, ultra-high spatial resolution, flexibility, and superior precision for fine-scale detection . UAV imagery can capture detailed features of buildings and accurately depict the texture, shape, and types of crops within farmland parcels, thereby providing essential technical support for identifying "non-agriculturalization" and "non-grainization" issues ("two violations") in small-scale regions.

To address the challenges associated with monitoring complex and inaccessible areas, this platform has developed an automated UAV patrol system tailored for large-scale, disaster-affected, and geographically constrained regions. UAVs are deployed to key or inaccessible locations, with flight routes optimized based on terrain characteristics, obstacles, and monitoring requirements. Managed through a remote control center, the system allows for unattended operations, enabling UAVs to be remotely controlled for scheduled or real-time image acquisition, thereby dynamically completing patrols and evidence collection.

The imagery collected by UAVs undergoes systematic processing, including orthorectification, image stitching, and color space transformation as part of the preprocessing workflow. These steps enhance image quality and consistency. Subsequently, high-resolution imagery is analyzed using spectral, texture, and shape features to perform intelligent classification and change detection. This process facilitates the automatic identification of farmland parcels exhibiting the "two violations." The results are then uploaded to the system platform, enabling real-time reporting and early warning of problematic parcels, thereby providing a robust technical foundation for precision farmland protection.

By leveraging UAV-based visible light remote sensing imagery, this platform significantly enhances the efficiency and accuracy of farmland patrols and the detection of "two violations." It effectively addresses the inefficiencies and labor-intensive nature of traditional manual inspections while reducing operational costs, offering a highly effective solution for precision farmland monitoring and management.

2.3. Multi-terminal technologies for meeting diverse user requirements

Farmland protection involves numerous departments, a diverse array of personnel, and complex issue-handling processes. It requires the participation of farmland stewards and grid managers across multiple administrative levels, including provincial, municipal, county, township, and village tiers. Additionally, various agencies such as the Natural Resources Bureau, Agricultural Bureau, Forestry Bureau, Public Security Bureau, and judicial courts must collaborate to ensure effective implementation. However, the current landscape is characterized by isolated information systems across departments, which hinders effective information sharing and cross-departmental collaboration.

To address the diverse needs of different units and user groups, this platform integrates data and provides

multi-terminal solutions, enabling seamless information sharing and cross-departmental coordination. The specifics are outlined as follows:

2.3.1. PC client

The intelligent supervision platform for the Field Manager System in arable land protection has been developed as a PC client application, primarily targeting field managers and administrators at provincial, municipal, county, and township levels. This platform facilitates a comprehensive understanding of arable land data overviews and provides critical information related to issue resolution. The key functionalities of the platform include:

- **Comprehensive Overview Map:** Provides a holistic visualization of arable land distribution and status across various regions.
- **Basic Data Management and Query:** Enables efficient management, retrieval, and analysis of foundational arable land data.
- **Personnel Management:** Facilitates the administration and coordination of staff involved in farmland protection efforts.
- **Patrol Record Statistical Analysis:** Analyzes patrol activities to assess coverage, frequency, and effectiveness of monitoring efforts.
- **Anomaly Issue Handling:** Manages the identification, classification, and resolution of irregularities in arable land use.
- **Rectification Audits:** Oversees the verification and approval processes for corrective measures implemented to address identified issues.
- **Case Processing:** Handles detailed case management from initial identification through to resolution, ensuring accountability and traceability.
- **Performance Assessment:** Evaluates the performance of personnel and the effectiveness of protection measures through quantitative and qualitative metrics.
- **System Settings:** Allows for customization and configuration of platform parameters to meet specific operational requirements and user preferences.

2.3.2. Mobile application

To accommodate the mobile office requirements of field managers at various administrative levels, grid managers, and affiliated units, the platform has designed and developed dedicated mobile applications: the Field Manager APP and the Grid Manager APP. These applications are tailored to the distinct responsibilities and functionalities of each role.

Field Manager APP:

Field managers at provincial, municipal, county, and township levels can utilize the Field Manager APP to:

- **Real-time Monitoring:** Access real-time information on problematic arable land within their jurisdictions.
- I**ssue Management:** View, process, and conduct verification and audits of reported issues directly through the app.
- Progress Tracking: Monitor the patrol progress and assessment rankings of subordinate grid managers.
- **Specialized Patrol Tasks: Initiate and manage specialized patrol missions by** defining patrol areas and key focus points. Field managers can actively participate in patrol activities, directly report illegal

activities, and submit issue reports via the mobile platform.

Grid Manager APP:

Village-level grid managers use the Grid Manager APP to:

- **Task Reception:** Receive patrol assignments and clearly delineate patrol areas.
- **Daily Patrol Logging:** Perform daily patrol check-ins, ensuring consistent monitoring activities.
- **Issue Reporting:** Capture and report discovered issues by taking photos, recording videos, and documenting problem descriptions through the app.
- **Rectification Reporting:** Upon receiving tasks for issue rectification, grid managers can report the completion status as required.
- **Performance Monitoring:** Continuously view their patrol assessment rankings, allowing grid managers to understand their performance within the team.

By leveraging these mobile applications, the platform effectively addresses the challenges of large-scale, geographically dispersed farmland protection efforts. The Field Manager APP and Grid Manager APP collectively ensure that farmland protection responsibilities are meticulously delegated, monitored, and executed, thereby providing robust technical support for the comprehensive and efficient implementation of farmland protection measures.

2.3.3. Public platform

To engage users such as the general public and farmers, an open WeChat public account has been established. Firstly, the account regularly disseminates news and announcements related to arable land protection, enabling users to stay informed about the latest developments in the field. Secondly, it compiles and publishes national and local laws, regulations, and policy documents pertaining to arable land protection, thereby enhancing users' legal awareness. Additionally, the platform provides online channels for reporting, facilitating users to report issues of "non-agriculturalization" and "non-grainization" in arable land, as well as various types of illegal activities. Concurrently, detailed electronic archives for each parcel of arable land are created, allowing users to access fundamental information such as parcel identifiers, ownership, and supervision authorities. This initiative increases the transparency of arable land management and ultimately establishes a mechanism of collective participation and mutual supervision.

3. Platform implementation and application

3.1. Platform architecture

3.1.1. Fundamental support layer

This layer encompasses the computational resources, storage resources, network infrastructure, backup systems, virtualization management and services, security protection services, and GIS services that support the system's operation. These services are primarily provided through government administrative cloud resources .

3.1.2. Data layer

The data resource layer is responsible for the unified organization and management of data, thereby providing comprehensive data services for the entire platform . It includes foundational natural resource information databases such as basic geographic data, current status data, planning and control data, and management data. Additionally, it encompasses specialized databases for the Field Manager System, including arable land resources, arable land supervision, and performance indicators. This integrated database consolidates

resources and ensures data integration, ultimately providing robust data support to the application layer and ensuring reliable database support for the intelligent, grid-based comprehensive management platform of the Field Manager System.

3.1.3. Middleware layer

Aligned with the top-level design requirements for natural resources, the middleware layer offers various foundational, general, shared, and tool-based services necessary for system construction based on the spatial foundational information platform. This ensures the platform's scalability and compatibility. The middleware layer includes data services, functional services, technical services, interface support, microservice components, and specialized services, among other support services.

Within the natural resources intranet, the system offers services for farmland monitoring, management, and decision-making support to natural resource authorities. Through the government extranet, it facilitates collaborative and shared services for other government departments. On the internet, it provides a platform for the public to report illegal activities related to farmland use.

3.2. Platform implementation

The platform is developed using a decoupled front-end and back-end architecture. The back-end is constructed on the SpringCloud microservices framework, which provides various platform application services through a unified spatial foundational information platform. It is fully compatible with domestically developed Xinchuang (information innovation) products, including cloud GIS service platforms and relational database platforms . The management interface is developed using HTML5 technology in conjunction with the Vue and Element Plus front-end frameworks. Map data is published as Mapbox Vector Tiles (MVT) services via GeoServer, and the front-end interface loads and displays these maps using Mapbox. The mobile applications are developed using the official Android Studio for the APP client and the native WeChat public platform for the WeChat Official Account.

Considering the confidentiality of foundational geographic information data related to arable land and the system's security requirements, the PC management interface of the platform is strictly restricted to operate within an internal network environment. Users must authenticate through Qihoo 360 (Qiananxin) VPN to obtain system access credentials; only after successful verification can users log in and access the system.

Ultimately, the PC management interface implements functionalities including comprehensive large-screen data visualization, unified mapping ("One Map"), grid management, monitoring management, task management, issue reporting, verification and rectification, case processing, supervision and assessment, personnel management, and system settings. The Grid Manager APP facilitates grid managers with functionalities such as patrol check-ins, anomaly reporting, and issue rectification reporting. The Field Manager APP enables field managers to handle issues, verify tasks, and conduct specialized patrols.

3.3. Platform application and practice

Currently, the platform has been undergoing a 12-month pilot operation in Shiquan County, Ankang City, Shaanxi Province. During this period, it has managed 199,700 mu of arable land parcels and coordinated 1,557 field managers and grid managers. The platform facilitated 12 rounds of patrol check-ins, identifying 1,138 instances of "two violations" (non-agriculturalization and non-grainization) in farmland operations, followed by verification and rectification processes.

The management platform has achieved significant results and received widespread social recognition, garnering attention and coverage from multiple platforms and media outlets, including the Shaanxi Science and Technology Department and Shiquan County. It has also received positive evaluations from users across various units.

Future plans include integrating arable land data from additional provinces, cities, and counties, thereby supporting farmland protection efforts in more regions. By continuously expanding the data coverage, the platform can more comprehensively reflect the status of arable land protection nationwide, providing more comprehensive and accurate information support to governments at all levels and various societal sectors.

4. Conclusion

The intelligent supervision platform for the Field Manager System in arable land protection, as described in this paper, optimizes data management technologies by employing diversified data management strategies for various data types. This optimization enhances data storage and query efficiency as well as loading performance, thereby facilitating the integration and sharing of diverse datasets. By comprehensively applying technologies such as satellite remote sensing (RS), Geographic Information Systems (GIS), the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and mobile communications, the platform constructs an integrated grid-based solution for the Field Manager System. This solution encompasses satellite remote sensing ("sky view"), UAV patrols ("air patrol"), video monitoring ("real-time view"), grid manager patrols ("ground patrol"), and public participation ("snapshots"). These integrated approaches improve the efficiency and accuracy of field patrols while reducing labor management costs.

Furthermore, the establishment of a triple prevention model—comprising human defense, technical defense, and institutional defense—ensures the effective implementation and operationalization of various technological measures, thereby forming a comprehensive and multi-layered prevention system.

Ultimately, the platform operates an integrated, information-driven closed-loop process through the unified management of arable land data, the issuance of patrol tasks, task execution, issue reporting, audit and rectification, and responsibility assessment. This comprehensive workflow ensures the entire arable land protection process is displayable, analyzable, assessable, traceable, and shareable. Consequently, the platform enhances the informatization and convenience of the Field Manager System's management, fully establishing a management mechanism for arable land protection that is clearly responsible, coordinated and orderly, strictly regulated, and effectively protected.

Looking ahead, with continuous technological advancements and the expansion of application scenarios, the platform is anticipated to achieve more intelligent and precise management. It aims to promote the "Smart Farmland Protection" model across more regions' arable land protection informatization initiatives, ensuring the long-term and effective operation of the Field Manager System for sustainable farmland protection.

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