The Research of Collaborative System of Remote Sensing Monitoring Based on Bimodal Cloud

Kaijun YANG [1,2,3], Fan LEI [2,3], Li CAO [1,2,3], Jide WEI[2,3], Zhe ZHANG [2,3]

1.China University of Geosciences(Wuhan), Wuhan, 430078, China;
2. The Second Surveying and Mapping Institute of Hunan Province, Changsha, 410029, China;
3. Key Laboratory of Natural Resources Monitoring and Supervision in Southern Hilly Region, Ministry of Natural Resources, Changsha, 410029, China;

Keywords: Cloud service, remote sensing monitoring, bimodal cloud, load balancing.

Abstract:

Cloud service is based on cloud computing, Offering a On-Demand service to every terminal equipment of computing resource pool. This paper designed and developed a coordinated operating system based on bimodal cloud. This system is taken mutual scheduling mechanism into account, which is capable of storing massive amounts of heterogeneous remote sensing data and provides fast indexing of data based on various characteristics, integrated Satellite transit forecast, DOM Produce, coordinated change information extraction and results sharing based on Nginx load balancing, in addition, the system designed two layer security system to ensure the safety of data results.The "YunYao" geographic information service rendering engine built on the dual-state cloud platform significantly outperforms mainstream platforms in the same testing environment. Its rendering speed surpasses ArcGIS Desktop by more than two times, exceeds GeoServer by more than four times, and is over seven times faster than ArcGIS Server.. Remote sensing practitioners can quickly and conveniently utilize this system, while providing convenient functionalities that enable remote sensing scientists to independently conduct scientific research and development using this system. Experimentation and practice shows that this system simplified routine work flow, improved work efficiency, has a important reference meaning to remote sensing monitoring.

1.Introduction

Remote sensing monitoring, a technique utilizing remote sensing technology for surveillance purposes, has seen continuous success in China's land sector for many years, conducting dynamic monitoring of national land use status. This has led to the establishment of a mature operational workflow. Taking the Land Resources All-Weather Remote Sensing Monitoring Project as an example, this monitoring system operates dynamically. Its surveillance scope transitions progressively from comprehensive coverage on the surface to a focus on newly developed areas showing anomalous land usage, implying a shift from larger to smaller monitoring units. Correspondingly, this involves remote sensing images with resolutions ranging from low to high. Simultaneously, the monitoring frequency is dynamically adjusted to achieve cost-effective surveillance, promptly identifying critical targets. This monitoring operational system demands high levels of operational coordination, robust data confidentiality, and a comprehensive business management system. However, the current flow of remote sensing monitoring operations heavily relies on manual operational coordination and management capabilities, resulting in numerous instability factors within the monitoring operational system.

1.The operational workflow is bloated and suffers from misalignment between upstream and downstream processes. While a considerable number of manual operators are required, the individual efficiency of each operator is not maximized. This is due to the current use of standalone computing software, where the waiting time for processing by operators is at least five times longer than the actual processing time, resulting in the necessity to wait for completion before proceeding to the next step.

2.Low confidentiality exists concerning remote sensing data and monitoring results. Numerous computers within the operational business system contain a vast amount of remote sensing digital orthophoto map (DOM) results and monitoring plot outcomes. Due to the involvement of numerous operators, ensuring data security becomes challenging.

3.There is a significant economic cost associated with hardware investment. Due to the massive volume of monitoring data requiring processes such as orthorectification, stitching, and color adjustment, it necessitates providing each technician with computers possessing large storage and operating memory. With rapid advancements in computing technology, the short usage cycle and high obsolescence rate of equipment result in substantial wastage.

4.There is a lack of standardized data management and service systems. With the increased frequency of monitoring, numerous monitoring results are distributed across various computers, making data management challenging. Additionally, the inability to swiftly send monitoring results to downstream monitoring agencies results in significant business delays.

The cloud service model represents a significant transformation in the current development of internet information technology. Cloud computing enables the sharing of centralized computer resource pools as measurable public services based on user demand. Users can efficiently allocate cloud service resources as needed through the network. This study aimed to address the characteristics of remote sensing monitoring business processes by designing a collaborative remote sensing monitoring business system in a private cloud environment under a dual-state cloud service model.

2.Previous work

Construction of Remote Sensing Technology and Informatization Platform have played a pivotal role in reshaping the approach to monitoring global croplands, land use and cover, as well as sustainable development goals. The Global

Agriculture Monitoring (GLAM) project, introduced by Becker-Reshef et al. (2010) in Remote Sensing, emphasized the application of coarse-resolution earth observations to monitor global croplands. This project highlighted the immense potential of remote sensing in providing crucial data for agricultural monitoring.The work of REN Fuhu and WANG Jinnian (2012) in the Journal of Remote Sensing delved into the conversion of remote sensing into cloud services, focusing on technical research and experiments. Their study contributed significantly to a deeper understanding of how remote sensing technologies can be integrated into cloud-based services.Furthermore, Amani et al. (2020) authored a comprehensive review in the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, emphasizing the Google Earth Engine cloud computing platform's significance in managing remote sensing big data applications. Sun et al. (2019) introduced an efficient and scalable framework for processing remotely sensed big data in cloud computing environments in the IEEE Transactions on Geoscience and Remote Sensing, showcasing the feasibility of processing large volumes of remote sensing data in the cloud.Moreover, Ferreira et al. (2020) described the application of remote sensing images and cloud services on AWS (Amazon Web Services) to enhance land use and cover monitoring, presented during the IEEE Latin American GRSS & ISPRS Remote Sensing Conference. Additionally, Wu et al. (2020) demonstrated the potential of cloud services combined with big data for monitoring and tracking sustainable development goals in the Geography and Sustainability journal.Several other papers also contributed to understanding cloud computing, security (Chen & Zheng, 2009; Feng et al., 2011), and novel strategies such as Li Rongya's RAM-Drive Cloud-based Strategy for High-resolution Remote Sensing Data Storage and Computation Integration.These collective studies underscore the critical role of cloud computing in processing, storing, and analyzing vast amounts of remote sensing data, thereby paving the way for the construction and evolution of dual-state cloud systems for remote sensing applications (Becker-Reshef I, et al., 2010).The research mentioned above lacks the underlying design of the dual-state cloud, and does not deeply analyze the adaptive characteristics of the dual-state cloud for different types of geographic information data. There is a lack of comprehensive analysis and comparison of data interaction modes between the storage cloud and memory cloud based on geographic information data models. Consequently, the system platform exhibits better processing performance for field-type data and file-type data, but weaker performance in handling geographical spatial format data.

3.Materials and Methods

3.1 System Objectives

The system, supported by cloud services, establishes a platform within the entire private cloud service framework for collaborative image processing, information extraction, result analysis, thematic presentation, and other auxiliary remote sensing functions. At the core of this platform is a central processing cluster responsible for processing and analyzing all vector and raster data, while also providing a dual-state cloud service mechanism for all platform users. The dual-state cloud comprises the Memory Cloud (Flash Cloud) and the Storage Cloud (Persistent Cloud).

The Memory Cloud uses memory as a medium for data storage. It is characterized by its rapid and efficient data read-write and computational capabilities. However, in terms of data storage persistence, the Memory Cloud is not as reliable as storage devices such as disk arrays and hard drives. Due to the non-steady state nature of handling and managing data, the term "flash state" is used to describe this unstable state (Li Rongya, et al., 2014).

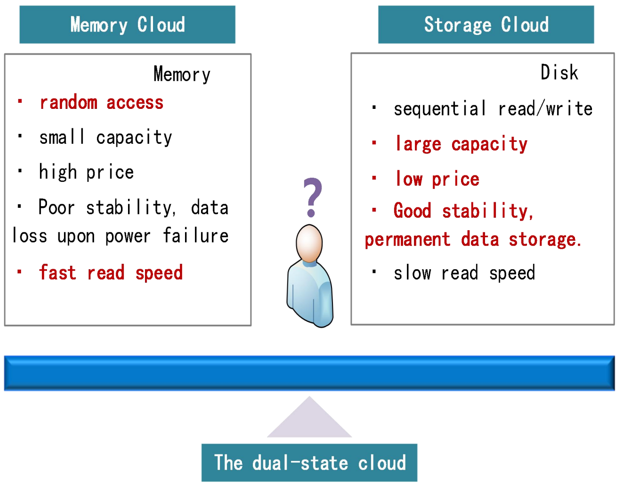

Figure 1. Dual-state Cloud Characteristics.

Additionally, the system comprises numerous terminal operation devices available for technicians to schedule and process computing resources on the central processing cluster. Unlike the current environment, terminal devices in the cloud service model only require lightweight devices with browser scheduling capabilities. There is no need to equip each terminal with high-performance or large storage hardware. All terminals access their assigned tasks and submit results by logging in through a browser to their respective accounts. This means that mobile devices (such as smartphones or iPads) can play a role in scheduling computing resources within the private cloud, enabling all devices to share the entire resource pool.

Taking Hunan Province as an example, the system adopts a dual-layer cloud mechanism on the cloud side. All original remote sensing image data is transmitted via the public network from the national primary center in a 1+31 pattern, receiving real-time domestically produced satellite images within the transit scope. The primary center utilizes a commercial cloud service model, employing Alibaba Cloud technology for image management and transmission. Upon receiving the image data pushed by the upper-layer cloud, the Hunan sub-center, as the lower-layer cloud, utilizes a private cloud service mechanism to disseminate computing services across the entire internal network. Within the entire business flow system, the dual-state cloud efficiently cooperates to maintain the stable operation of the computing resource pool.

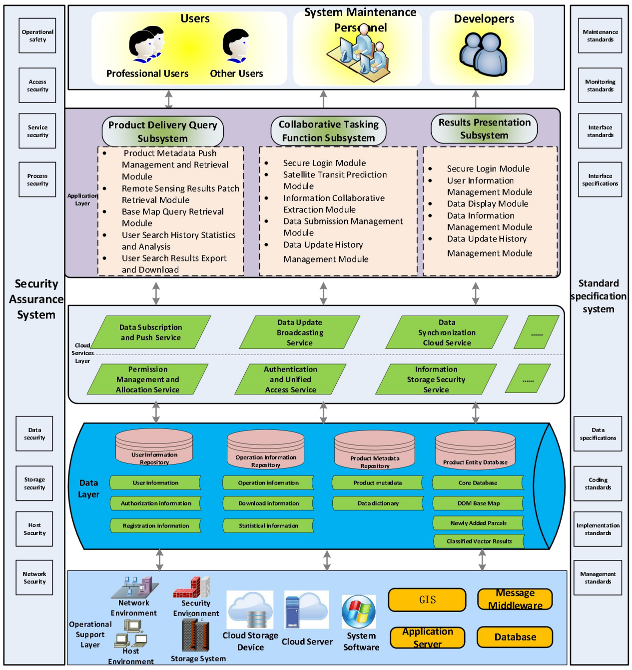

Figure 2. System Overall Architecture.

3.2 Database Design

The platform utilizes MongoDB as the foundational database, which is a collection-oriented NoSQL non-document-oriented database. MongoDB stores data in BSON (Binary Serialized Document Notation) formatted documents, which are collections of key-value pairs. Keys are strings, and values can be any type within the data type collection, including arrays and documents (Bradshaw S, et al., 2019). As a NoSQL database, MongoDB offers comprehensive index support, dynamic querying, query monitoring, and an effective load balancing mechanism. Each cluster comprises one or multiple mongod processes, responsible for MongoDB's core services and data storage. Typically, each shard opens multiple services to enhance service availability. These mongod processes within the shard constitute a replica set, providing redundancy and fault tolerance.

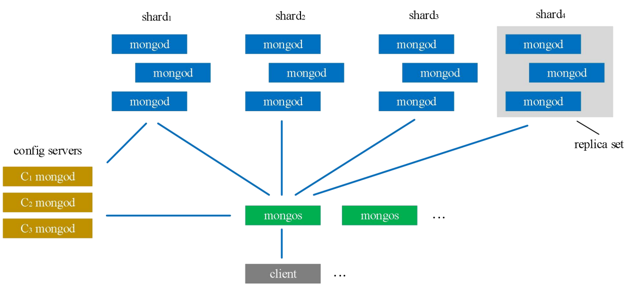

Figure 3. MongoDB Cluster Structure.

3.3 Horizontally Scalable Bipolar Cloud Storage Architecture

In general, computer storage media comprises various types such as disks, solid-state drives, memory, CPU cache, and others. As the distance to the CPU decreases, the speed of the storage media increases, while the storage capacity decreases. The efficiency of spatial data access is closely related to the storage medium of spatial data. The overall improvement in spatial data access efficiency is accomplished by replacing slower storage devices with faster ones. Thus, for different storage media, the same set of spatial data may exist in different forms. This system, based on a bipolar cloud spatial data storage architecture, primarily divides into Memory Cloud and Storage Cloud. The system constructs a multi-level caching mechanism to ensure that clients can access hot-spot spatial data as quickly as possible, categorized into Client-side cache, Reverse Proxy Cache, Distributed Application Cache, Database Cache, and Distributed File System Cache.

(1) Storage Cloud Design: Persistent storage of spatial data mainly adopts disk storage, including mechanical hard drives and solid-state drives. Spatial data storage methods can either be disk files or database records. The system's storage cloud primarily relies on cloud object storage for distributed storage, encompassing storage types like original image files, DOM results, and vector feature files.

(2) Memory Cloud Design: Memory computing stores the data to be analyzed within memory for processing, avoiding the performance bottleneck of disk I/O, significantly enhancing the system's execution efficiency, making it suitable for handling massive data and real-time response systems. Presently, 32GB, 64GB, or even larger memories are commonplace in servers, enabling large-scale computation based on memory cloud. The goal of memory computing is to enhance memory and CPU efficiency.

Regarding the caching system architecture, memory is a commonly used data caching medium, but in reality, data caching is more complex. The memory cloud storage types include geospatial processing results, cached tiles, cached vector information, etc. Memory cloud caching utilizes high-speed storage devices to cache frequently accessed hot-spot data, avoiding performance loss caused by frequent reads from slower devices. Additionally, it caches computational results to avoid resource waste and performance loss due to frequent redundant computations. The fundamental idea of data caching in this system is to store hot-spot data on high-speed devices and bring data as close to the client as possible. Moreover, it requires a well-designed scheduling strategy to ensure that the cached data remains hot-spot data, while timely removing less frequently accessed data from the cache.

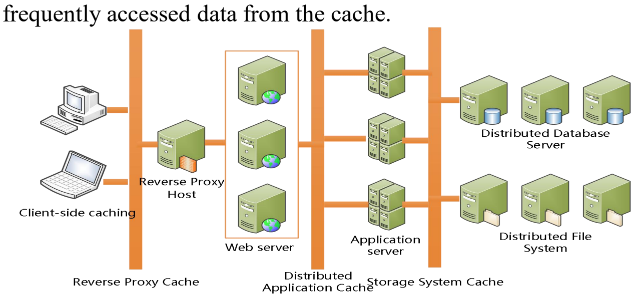

Figure 4. Multi-level caching system architecture.

(a)Client-Side Caching The closest to the user yields the best results, directly avoiding the need for client requests to the server's data. Client-side caching of spatial data encompasses both memory caching and local file caching. Data suitable for caching on the client-side typically includes static HTML, JavaScript, CSS, image files, as well as bulk DEM (Digital Elevation Model) and model data extensively used in grid data and three-dimensional systems. These data share a common trait: they exhibit very infrequent changes. Various client-side tools can devise and implement their unique client-side caching strategies. For instance, conventional 3D clients often opt to cache DEM data and model data to achieve higher efficiency.

(b)Reverse Proxy Cache The reverse proxy caches requests' results as (key, value) pairs in its cache, utilizing the request's

URL as the key, ready for direct use upon subsequent visits. Initially intercepting the user's request, the reverse proxy first checks within its cache to determine if the request is cached. If found, it retrieves the data directly from the cache and sends it back to the client. Otherwise, it forwards the request to the Web server. The reverse proxy cache obviates the need for a substantial amount of disk I/O and server computing operations, significantly amplifying the system's throughput.

(c)Distributed Application Cache This is the cache within distributed application servers, serving as a cache for core business logic. The range of data cached within application servers is vast, covering grid image data, frequently used vector data, user permission data, address matching result data, server traffic monitoring status data, WFS (Web Feature Service) GetFeature query result data, WMS (Web Map Service) GetMap real-time map data, SQL query result data, database table records, real-time GPS signal data, and more. Essentially, almost any data that can be involved may potentially be cached here. Caching substantial volumes of data in this context often necessitates the use of distributed caching. The keys used for caching here may vary based on the content and data, requiring different key generation strategies.

(d)Database Cache Database caching involves caching data that is infrequently modified but frequently read, such as account data, frequently used spatial index data, SQL query results, etc. Once this data is cached, the database can directly return the data from memory to the application upon subsequent retrieval, eliminating the need for disk read operations and significantly improving speed.

(e)Distributed File System Cache Similar to database caching, the distributed file system cache is more straightforward. It involves caching file data blocks that are frequently read into memory to achieve faster access. Typically, server operating systems support the caching of data files.

3.4 Cloud Service Load Balancing

In order to enable the cloud platform to respond rapidly and non-blockingly under multiple concurrent user conditions, the backend adopts a dual-system, multi-node Nginx load balancing mechanism that combines Linux and Windows. The load balancing is geographically structured into Local Load Balance and Global Load Balance. Local Load Balance refers to load balancing within the local server cluster, while Global Load Balance, also known as geographical load balancing, involves load balancing among server clusters placed in different geographic locations with distinct network structures.

Local Load Balance effectively addresses issues related to excessive data traffic and network overload without the need for investing in expensive, high-performance servers. It optimally utilizes existing equipment, avoiding data loss due to single-point server failures. Its flexible and diverse balancing strategies allocate data traffic reasonably among the servers within the cluster, allowing them to share the workload collectively. Even with upgrades or expansions to existing servers, it merely involves adding a new server to the server group without altering the existing network structure or disrupting ongoing services.

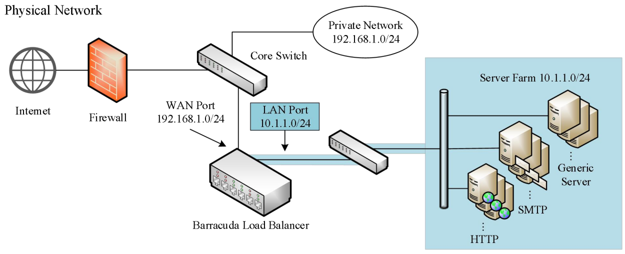

Figure 5. System Load Balancing Mechanism.

4.Results

The collaborative workflow, supported by the dual-state cloud, spans the entire remote sensing monitoring project and comprises several core stages: satellite image transit prediction, initial data quality inspection and archiving, ortho-product generation, change detection for land use information extraction, and result analysis. Each stage undergoes scheduling and processing at the terminal, while the cloud handles data processing and analysis in the Memory Cloud mode and stores and archives data in the Storage Cloud mode.

4.1 Satellite Image Transit Prediction

Satellite orbit transit prediction offers reliable data support for the initial planning of remote sensing monitoring tasks. It provides comprehensive oversight of satellite coverage within the monitoring time frame to determine the necessity of supplementing additional data sources to achieve monitoring goals. Visual multi-satellite task simulation technology, adapted to planned multi-satellite observation tasks, integrates the characteristics of multiple domestic high-resolution remote sensing satellites like ZY1-02C, GF1, and GF2. This technology uses two-dimensional visualization to simulate the operating status and trajectories of multiple satellites, enabling comprehensive scheduling and coordinated observation of multiple high-resolution satellite tasks.

Figure 6. Satellite Overflight Prediction Analysis.

Using the SGP4/SDP4 (Simplified General Perturbation Version 4/Simplified Deep-space Perturbation Version 4) satellite orbit estimation method proposed by the North American Aerospace Defense Command, precise orbit estimation of the satellite is carried out based on the initial satellite motion state. This method accounts for perturbation forces such as Earth's non-spherical gravity, solar and lunar gravity, solar radiation pressure, and atmospheric drag. It demonstrates high predictive accuracy and superior predictive convergence effects(Dutt P, et al., 2023).

Specific features include:

Providing location search functionality: offering search capabilities for regions at or above the county level nationwide, highlighting the user-entered area and enabling its preservation in the observation area.

Image prediction functionality for observation areas: providing emergency-accessible data and area lists within the forthcoming 1 to 7 days.
Additionally, this technology integrates common GIS functionalities into the simulation system, facilitating future applications. It utilizes OpenLayers for visualization, ensuring real-time daily updates to satellite orbit data to ensure accurate satellite orbit prediction (Hazzard E, et al., 2011).

4.2 Pixel-level Image Processing Chain in the Memory Cloud Environment

The cloud-end deploys PCI GeoImaging Accelerator (GXL), featuring characteristics such as multitasking parallel computing, GPU-accelerated graphics processing, and distributed processing. It automates time-consuming image processing tasks, including control point collection, image rectification, image mosaicking, and image fusion, throughout the image processing workflow, maximizing efficiency and minimizing the waiting time for manual image processing. Technicians can directly call upon computing resources through a web client, generating level-four image products. An experiment involving ortho-processing for 40 scenes of GF2 imagery showed an 8-10 times increase in overall efficiency compared to single-machine operations.

4.3 Image Service Publishing

After generating ortho-image DOMs, these DOMs are published as cloud-based Web Map Services (WMS) using OGC (Open Geospatial Consortium) standards, accessible to all applications (using the OpenLayers framework) within the private cloud. OGC and ISO/TC211 jointly introduced spatial data interoperability specifications, including Web Map Service, Web Feature Service, Web Coverage Service, and the Geography Markup Language (GML). WMS utilizes geospatial data with geographic location information to create maps. This service efficiently transforms Storage Cloud data into Memory Cloud, offering robust browsing speeds. Dynamic access to heavyweight DOMs in the cloud-based browser mode is faster than browsing copies in a single-machine version, significantly reducing storage resource wastage and data redundancy.
It is prohibited to modify vector data requiring association, and administrative boundary vectors are made accessible through WMS calls. Modified vectors utilize WFS service mode for access, providing a bidirectional interactive service that allows users to modify vector attributes in addition to obtaining their boundaries. Technicians can directly modify and submit vectors based on their current permissions.

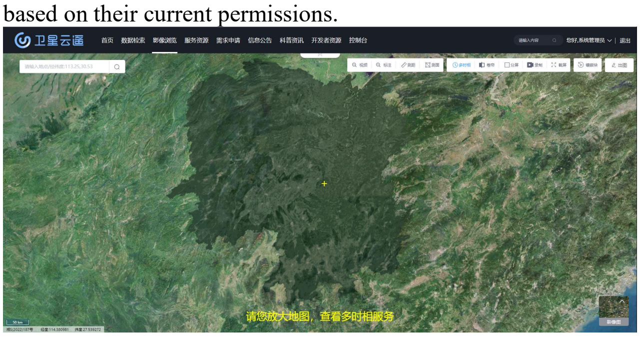

Figure 7. Platform Image WMS Service(Mosaic Image).

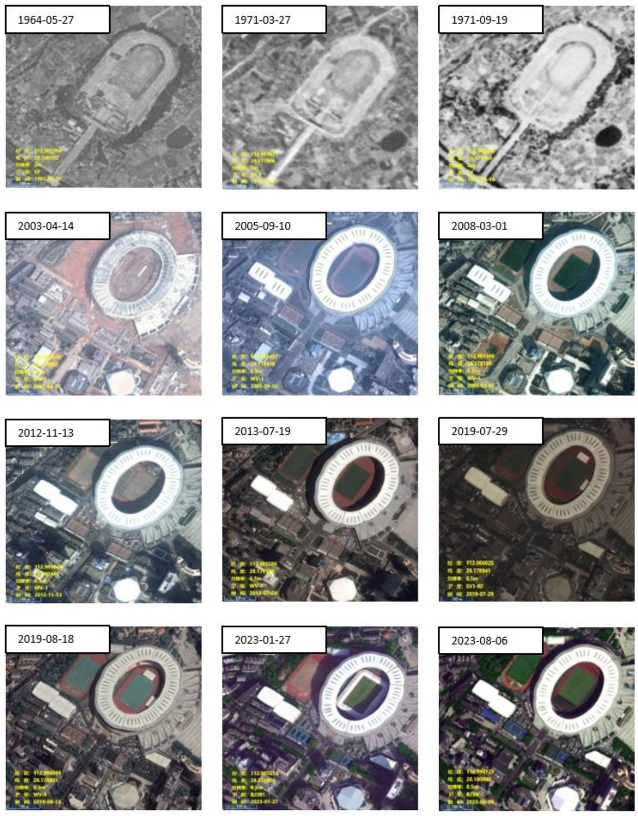

Figure 8. Platform Image WMS Service(Large-scale remote sensing image time series).

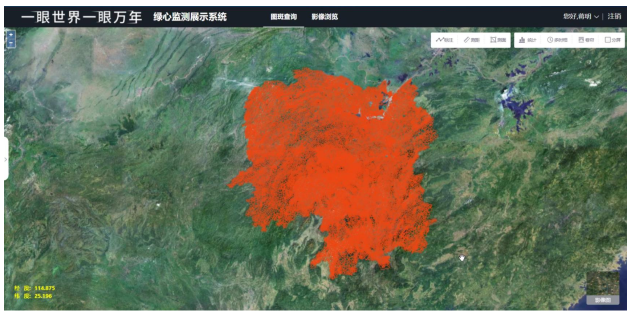

Figure 9. Platform Vector WMS Service.

In our experiment, we conducted a detailed comparison between our developed Cloud Remote Sensing Geographic Information Service Engine and globally renowned Geographic Information Service Rendering Engines. The compared products primarily include ArcGIS Desktop, ArcGIS Server, GeoServer, among others. The main parameter for comparison was the number of rendered tiles loaded within a unit time, which intuitively reflects the rendering performance of the Geographic Information Service Engine. The experiment was conducted under identical software, hardware, and network conditions with the following specific configuration: (1) Specification: 4U Rack-mounted Server; (2) Processor: 4 Intel Xeon 6130 (2.1GHz/16C); (3) Memory: 4 units of 32GB DDR4 memory; (4) Hard Drive: 2 units of 300GB 15K RPM SAS hard drives; (5) RAID: Configured with SAS 9361 RAID (1G cache); (6) Network: Single-port 10 Gigabit optical network card (including multimode optical modules). The comparative experiments revealed that the performance of the Cloud Remote Sensing Geographic Information Service Engine, utilizing a bipolar cloud architecture, significantly surpassed other service engines. It achieved a rendering rate exceeding 120 tiles per second, more than double that of ArcGIS Desktop, over four times that of GeoServer, and more than seven times that of ArcGIS Server.

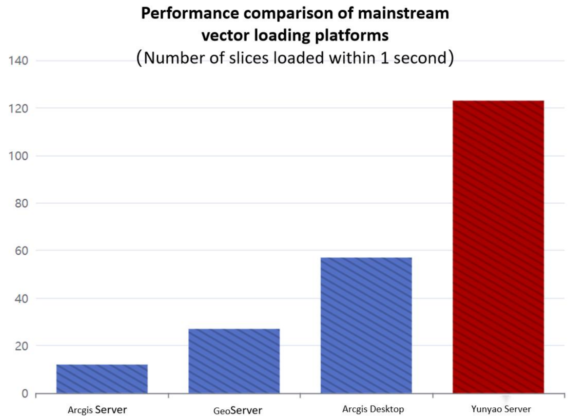

Figure 10. Performance comparison of mainstream vector loading platforms.

4.4 Collaborative Information Extraction Platform

The information extraction system adopts a cloud-based WebGIS architecture, with MongoDB serving as the supporting database. To enhance user access efficiency, it deploys 100 Mbps fiber optics and 100TB-level data storage space for data storage and transmission services. Additionally, the backend system utilizes Node.js for web services, which encapsulates the Google V8 engine known for its rapid execution of JavaScript. Node.js offers optimizations for specific use cases, providing alternative APIs that enhance V8 performance in non-browser environments. The software environment supports the deployment of Node.js, and due to spatial data conversion requirements, the system simultaneously deploys GDAL (Geospatial Data Abstraction Library), an open-source raster spatial data conversion library operating under the X/MIT license. The frontend adopts the OpenLayers framework, loading map data from Tianditu (TianDiTu) and WMS/WFS services published by Geoserver as the basic framework, incorporating user login permissions control, GIS analysis, task assignment submission, and multiple sub-functional modules (Krylov G,, et al., 2020).
The information extraction platform employs a user hierarchical mechanism, granting different operational functionalities to information extractors, quality inspectors, and reviewers based on their permissions. Information extractors utilize web-based image comparison to assess and attribute image patches using loaded image bases and current recognition images, employing common GIS analysis tools for statistical analysis. Quality inspectors and reviewers have higher privileges, conducting comprehensive evaluations of the quality of personnel's outputs and entering the assessments into the system. All roles collaborate, participating in the overall cloud-based project implementation.

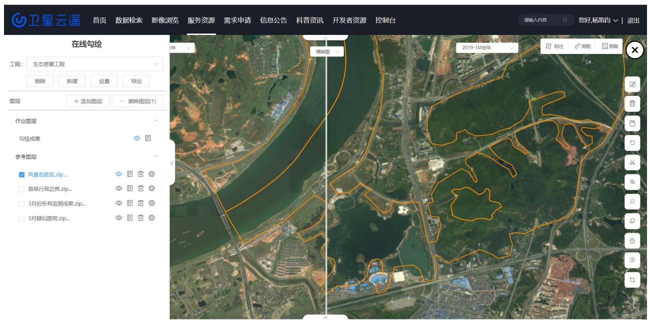

Figure 11: Swiper Information Extraction Module.

4.5 Security Assurance System

The entire collaborative workflow involves image and result data that possess high levels of confidentiality. Therefore, the platform has been designed with two security assurance systems to ensure the security of the project implementation.
Firstly, when transmitting data from the upper-level cloud to the lower-level cloud, a data transmission layer security assurance system has been implemented. This transmission process utilizes the WebSocket data transmission protocol, revolutionizing the conventional one-way polling operation and enabling full-duplex communication between the browser and the server for active data push. It breaks through key technologies involving spatial metadata extraction synchronization, secure data push, and data integrity verification. It realizes active spatial information parsing, data packaging, dynamic key creation, secure push, key loading implementation, automated decryption, and automatic data unpacking in a one-stop push process. Additionally, in response to unstable networks and specific unexpected situations in various regions, a breakpoint resumption mechanism has been added to actively push and maximize the integrity and reliability of the data transmission link. Images are made available for download through a cloud server-generated download link, which must include user authentication information. To ensure the security of this information, all user information involved in the download link is encrypted using MD5 into non-plaintext strings. As the system provides open download links to the outside, to prevent malicious dissemination and unauthorized downloads of images, a random code parameter is set at the end of the link. The download link also has a specified expiration period. After the deadline, the cloud re-generates a random code to create a new download link, rendering the old link immediately invalid. Moreover, the upper-level cloud server can record user information and IP addresses during downloads, preventing the misuse of download links and data leaks.
Secondly, within the lower-level cloud, a strict user management system has been established, physically isolating operations from the external network, providing an additional layer of security. All ortho-image results are released in sliced form within the private cloud, accessible only to users with corresponding permission levels. Additionally, they cannot be copied or written into; for new results of operational vectors generated by staff, modifications are subjected to an application-based system. If modifications are required for the submitted results, users must submit a modification request through the user center to higher-level permission users for online approval before making the necessary changes.

5.CONCLUSION

The establishment of a collaborative remote sensing monitoring system under the dual-state cloud service mode is an exploration within the current cloud service model in the field of remote sensing. Contrasted with the traditional manual single-machine operation as the primary operational mode, the cloud service collaborative working mode has significantly liberated the waiting time and data redundancy within the operational workflow. Spanning the entire service chain from satellite prediction to result publication, it greatly optimizes production efficiency, minimizing the time cycle from raw data to service delivery. Furthermore, the novel management mode under the cloud service model maximizes the security of data and results. Shifting from handling big data to lightweight operations, users under the cloud service model no longer need to focus on the data processing process, freeing up more time to explore and analyze the value of image data. Presently, this research technology has been fully applied in the "Natural Resources Satellite Remote Sensing Cloud Service Platform" of the Ministry of Natural Resources and the "Satellite Cloud Remote Sensing" system of the Hunan Provincial Department of Natural Resources, both achieving favorable application effects.

However, the satellite remote sensing domain's cloud service technology still requires further advancement. Particularly, in the establishment of private clouds, internal collaborative computing and deployment mechanisms in the remote sensing field lack mature reference cases. For instance, GIS analysis functions on the web interface do not yet match the speed of standalone software. Load balancing mechanisms are insufficient to handle a vast number of visitors, and there is still a considerable geometric exponential increase in hardware investment required in the cloud. In the long term, these issues represent challenges that the cloud service model needs to overcome, ultimately integrating the cloud service model completely into the remote sensing monitoring domain.

References

Becker-Reshef I., Justice C., Sullivan M., etc, 2010: Monitoring global croplands with coarse resolution earth observations:the global agriculture monitoring(GLAM) project. *Remote Sensing*. 2(6):1589-1609［DOI:10．3390/rs2061589］

REN Fuhu., WANG Jinnian,.2012: Turning remote sensing to cloud services: Technical research and experiment. *Journal of Remote Sensing*. 06(01):1331-1346.

Amani M., Ghorbanian A., Ahmadi S A., etc, 2020: Google earth engine cloud computing platform for remote sensing big data applications: A comprehensive review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. 13: 5326-5350.

Sun J., Zhang Y., Wu Z., etc, 2019: An efficient and scalable framework for processing remotely sensed big data in cloud computing environments. *IEEE Transactions on Geoscience and Remote Sensing*. 57(7): 4294-4308.

Ferreira K R., Queiroz G R., Camara G., etc, 2020: Using remote sensing images and cloud services on AWS to improve land use and cover monitoring.*2020 IEEE Latin American GRSS & ISPRS Remote Sensing Conference (LAGIRS)*. IEEE, 558-562.

Wu B., Tian F., Zhang M., etc, 2020: Cloud services with big data provide a solution for monitoring and tracking sustainable development goals. *Geography and Sustainability*.1(1): 25-32.

Chen K., Zheng W M., 2009: Cloud computing: system instances and current research. *Journal of Software*. 20(5): 1337–1348

Feng D G., Zhang M., Zhang Y., Xu Z,. 2011: Study on cloud computing security. *Journal of Software*. 22(1): 77–83 [DOI: 10.3724/ SP.J.1001.2011.03958]

Li Rongya., 2014: A RAM-Drive Cloud-based Strategy for the High-resolution Remote Sensing Data Storage and Computation Integration. *Zhejiang University*.

E. Soulard C., J. Walker J., E. Petrakis R.,2020: Implementation of a surface water extent model in Cambodia using cloud-based remote sensing. *Remote Sensing.* 12(6): 984.

Xu C., Du X., Yan Z.,2020: ScienceEarth: A big data platform for remote sensing data processing. *Remote Sensing.* 12(4): 607.

Bradshaw S., Brazil E., Chodorow K.,2019: MongoDB: the definitive guide: powerful and scalable data storage. *O'Reilly Media*.

Matallah H., Belalem G., Bouamrane K., 2021: Comparative study between the MySQL relational database and the MongoDB NoSQL database. *International Journal of Software Science and Computational Intelligence*, 13(3): 38-63.

Filip P, Čegan L., 2020: Comparison of mysql and mongodb with focus on performance. *2020 International Conference on Informatics, Multimedia, Cyber and Information System (ICIMCIS)*. IEEE, 184-187.

Palanisamy S., SuvithaVani P.,2020: A survey on RDBMS and NoSQL Databases MySQL vs MongoDB. *2020 International Conference on Computer Communication and Informatics (ICCCI)*. IEEE, 2020: 1-7.

Medina J M., Blanco I J., Pons O,. 2022: A fuzzy database engine for mongoDB. *International Journal of Intelligent Systems*. 37(9): 5691-5724.

Chauhan A., 2019: A review on various aspects of MongoDb databases. *Int. J. Eng. Res. Sci. Technol*, 8(5): 90-92.

Kuyumdzhiev I., 2019: Comparing backup and restore eficiency in MySQL, MS SQL server and MongoDB. *International Multidisciplinary Scientific GeoConference: SGEM.* 19(2.1): 167-174.

Harrison G., Harrison M., 2021: MongoDB Performance Tuning: Optimizing MongoDB Databases and Their Applications. *Berkeley, CA: Apress*. 2021.

Makris A., Tserpes K., Spiliopoulos G., etc. Performance Evaluation of MongoDB and PostgreSQL for Spatio-temporal Data[C]//EDBT/ICDT Workshops. 2019.

Dutt P., Mutyalarao M., Bhanumathy P., etc, 2023: Assessment of in-house algorithms on re-entry time prediction of uncontrolled space objects. *Advances in Space Research*, 72(7): 2535-2551.

Hickson P., 2019: OCS: A Flexible Observatory Control System for Robotic Telescopes with Application to Detection and Characterization of Orbital Debris. *First International Orbital Debris Conference*, Sugarland, Texas.

Mukundan A., Wang H C., 2021: Simplified Approach to Detect Satellite Maneuvers Using TLE Data and Simplified Perturbation Model Utilizing Orbital Element Variation. *Applied Sciences*. 11(21): 10181.

Xiao-li X U., Yong-qing X., 2019: Study on the orbit prediction errors of space objects based on historical TLE data. *Chinese Astronomy and Astrophysics.* 43(4): 563-578.

Yang Kaijun., Jiang Weiping., Lei Fan., Cao Li., 2023: A Method of Strain Rate Calculation Based on GNSS Time Series and Its Accuracy Analysis. *Geomagnetism and Aeronomy*. Vol. 63, No. 1, pp. 41–50.

Wen G., Xu Y., Liu C., etc, 2022: A Simulation System of Space Object Images for Space Situation Awareness. *2022 15th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics* . IEEE, 2022: 1-6.

Hazzard E., 2011: Openlayers 2.10 beginner's guide. *Packt Publishing Ltd*.

Maiti A., Majumdar S., Shukla S., etc, 2018: An open source web-gis based precise satellite tracking and visualisation tool using two line element data. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 4: 109-114.

Sharma V K., Amminedu E., Rao G S., etc, 2017: Assessing the potential of open-source libraries for managing satellite data products-A case study on disaster management. *Annals of GIS*, 23(1): 55-65.

Gwinn J A., Thomas P M., Kielkopf J F., 1968: Satellite bands in the emission spectrum of cesium. *The Journal of Chemical Physics.* 48(2): 568-572.

Krylov G., Patrou M., Dueck G W., etc, 2020: The evolution of garbage collection in v8: google's javascript engine. *2020 9th Mediterranean Conference on Embedded Computing (MECO)*. IEEE, 1-6.

Martinsen J K., Grahn H, Isberg A.,2017: Combining thread-level speculation and just-in-time compilation in Google's V8 JavaScript engine. *Concurrency and computation: practice and experience*. 29(1): e3826.

Michaelis C D., Ames D P., 2008: Web Feature Service (WFS) and Web Map Service (WMS)..

Michaelis C D., Ames D P,. 2012: Considerations for Implementing OGC WMS and WFS Specifications in a Desktop GIS.

Song X., Kono Y., Shibayama M., 2004: The development of web mapping application using open source GIS solution. *Proceedings of International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences.* Hanoi, Vietnam. 1-6.

Lemenkova P., Debeir O,. 2023: GDAL and PROJ Libraries Integrated with GRASS GIS for Terrain Modelling of the Georeferenced Raster Image. *Technologies*,.11(2): 46.

Kaijun Yang., Fan Lei., Li Cao., Jide Wei., Zhe Zhang., Tang Wei., 2023: Research on the method of pure deformation field by GNSS and InSAR. *International Conference on Remote Sensing, Surveying, and Mapping (RSSM 2023)*. 1271003 (1 June 2023); doi: 10.1117/12.2682583.

Jiang Y., Sun M., Yang C,. 2016: A generic framework for using multi-dimensional earth observation data in GIS. *Remote sensing.* 8(5): 382.

Masó J., Pons X., Singh R., 2010: OGC WMTS and OSGeo TMS standards: motivations, history and differences. *FOSS4G* .