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Research on Intelligent Platform Construction and Pavement Management of Expressway Operation and Maintenance Based on BIM+GIS Technology

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ABSTRACT

With the advent of the information age, the traditional pavement management technology of operating expressways can no longer meet the higher requirements for the improvement of engineering quality in the information age. This paper proposes a method of integrated analysis based on BIM (building information modeling) and GIS (geographic information system), builds an intelligent platform for highway operation and maintenance, and solves the problem of data islands in highway maintenance and management.

KEYWORDS

BIM, Fusion Analysis, GIS, Highway, Pavement Gap

1. INTRODUCTION

Expressways have the characteristics of multiple points and long lines. For key point-like projects such as Bridges and tunnels, their structure is complex and the number of fine model components is huge (Di Graziano et al., 2023; Duong, 2021; Sheina et al., 2022). For lines, their length is usually measured in kilometers, requiring a very wide viewing range and complex terrain along the lines. Therefore, the operation and maintenance management of expressway requires both fine management based on the BIM model and macro-management supported by GIS. The two technologies complement each other. In the field of expressway operation and maintenance, BIM can provide complete basic data on road, bridge, and tunnel engineering consistent with the actual situation (Bracht, Melo, & Lamberts, 2021; Li, Lai, Ma, & Wang, 2021; Saman & Esmatullah, 2021), while GIS can provide more macro geospatial positioning information. It includes the geographical location information of the road, the surrounding environment information, and other spatial macro information. The integration of BIM and GIS can achieve the effect of interconnection and complementariness.

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Compared with the separate applications of BIM and GIS, the modeling quality, analysis accuracy, decision-making efficiency, and other aspects have been significantly improved, playing a huge role in the field of highway operation and maintenance. In addition to the ability to store, analyze, manage (Marco, Sebastian, & André, 2021; Qian et al., 2021; Vito et al., 2021), and query data and to display the panorama of external maps, GIS technology makes up for the lack of BIM computing ability in data processing. In addition, GIS technology can provide an external environment and geographic information for BIM model items, especially when it is used in BIM modeling of long-mileage roads, and GIS can provide a more comprehensive information platform. In general, BIM and GIS complement each other's strengths and are widely used in the digital management platform of road maintenance (Liu et al., 2021; Tan, Grant, Eleni, & Liu, 2021; Tang et al., 2021).

BIM combined with data analysis technology has promoted the development of road nursing management platforms and provided a new way for nursing management decision-making (Alireza, 2021; Filip et al., 2021). In the literature (Bonsang et al., 2021), the developed pavement damage analysis and evaluation program was used to analyze and evaluate the pavement damage in the model road section (Jakob & Guido, 2021), and a reasonable maintenance plan was proposed according to the severity degree (Yu et al., 2021). This research is based on the analysis of two-dimensional data and does not involve GIS technology. At present, road maintenance management platform is widely used in airport pavement management. Literature, combined with software, proposed a web-based three-dimensional (3D) model of airport pavement quality difference expression numerical twin method, which effectively improved the intelligent and intelligent level of airport pavement management system (APMS) (James et al., 2021).

This paper takes the BIM model as the base for fine management, GIS as the support for macro management, builds a highway operation and maintenance platform based on BIM+GIS technology, realizes the multidimensional visualization of the entire highway, and comprehensively uses image analysis technology to detect the pavement gap according to the pavement management requirements, thus improving the highway pavement management level.

- The innovation point is to conduct fine management based on the BIM model and macro management supported by GIS. The integrated analysis method of Building Information Modeling (BIM) and Geographic Information System (GIS) was introduced into the expressway operation system, and the three-dimensional roaming of the expressway was carried out based on BIM+GIS.
- Combined with BIM (Building Information Modeling) and GIS (Geographic Information System), the actual pavement gap was detected, which greatly improved the pavement management technology of operating expressways.

2. CONSTRUCTION OF HIGHWAY OPERATION AND MAINTENANCE PLATFORM BASED ON BIM+GIS TECHNOLOGY

This paper intends to build a highway operation and maintenance platform based on BIM+GIS technology. The overall architecture technology of the platform includes collaborative visualization of the inclined photography model and BIM model, the bidirectional query of BIM and GIS, and the dynamic association between highway operation and maintenance data and the BIM model. This section describes the data association mechanism, emphasizing that O&M service data can be automatically associated with the model through attribute matching so that service information can be viewed on the model. At the same time, you can consider talking about the business information located by the mileage value, latitude, and longitude value. The business data can be located on the BIM model through the above-mentioned bidirectional query technology of BIM and GIS. It is recommended to put one or two renderings, which can be used to display business data on the box with ten meters.

2.1 Overall Architecture

The 4D-BIM cloud platform application file storage component stores unstructured data. During the actual construction project (Rodrigo & El-Diraby, 2021), a large amount of data is generated in unstructured form, including some geometric data, various scanning files, audio and video materials, etc. (Lindberg et al., 2021).

The 4D-BIM cloud platform file Storage component uses the Network Attached Storage (NAS) service, which is a file storage service for cloud server instances and provides standard file access protocols. Users do not need to modify existing applications. You can use a distributed file system with unlimited capacity and performance expansion, single namespace, multi-sharing, high reliability, and high availability. After the NAS file system instance and mount point are created, you can mount the file system on compute nodes such as ECS, HPC, and Docker using standard NFS protocols and access the file system using standard Posix interfaces. Multiple compute nodes can mount the same file system and share files and directories at the same time.

The application NAS service has the following advantages: Multiple compute nodes can access the same file system instance at the same time, which is suitable for applications deployed across multiple ECS instances to access the same data source.

The capacity of a single file system is large, and the file system is paid according to the actual usage, fully meeting the elastic expansion requirements. It provides high throughput, high IOPS, and low latency storage performance for application workloads. In addition, the performance is linearly correlated with the capacity, meeting the demand for more capacity and storage performance as services grow.

2.2 Establishment of BIM Cloud Platform

The 4D-BIM cloud platform architecture is divided into two parts, that is, the "business platform" for processing highway business data, and the "analysis platform" for analyzing and mining highway multi-source heterogeneous data (Marco, Sebastian, & André, 2021; Tan, Grant, Eleni, & Liu, 2021). The business platform interconnects with different highway management systems to realize highway asset management based on BIM+GIS; The analysis platform integrates data from different participants, fuses data from different data sources and different data types, and then converts data to processing, statistics, analysis, mining, and deeply mining the hidden value of data. In the 4D-BIM platform, the data generated in the project is the basis for creating value. The business platform continuously provides data for the analysis platform, and the knowledge and value obtained by the analysis platform will benefit the actual projects of the business platform and its services in reverse, thus forming a complete and benign big data ecosystem in the field of high-speed operation and maintenance. The 4D-BIM cloud platform is shown in Figure 1 below:

The 4D-BIM business platform is the core platform for processing business data, providing services for platform clients and users (Li, Lai, Ma, & Wang, 2021), and also providing data sources for analysis platforms. The business platform has a hierarchical structure, including a storage layer, computing layer, network layer from bottom to top, and queue module to realize message distribution (Bracht, Melo, & Lamberts, 2021), as shown in Figure 2.

The following will introduce the specific components of the service platform. The network layer provides two types of service components: load balancing and content distribution. Load balancing is used to deal with high concurrency (a large number of users access the server at the same time). The load balancing evenly distributes the access load to each server to ensure that all users can obtain the required services and ensure service stability. Content distribution greatly improves the acquisition efficiency of engineering data by caching frequent client requests and related resources on multiple terminals.

The Content Delivery Network component of the 4D-BIM cloud platform uses the Content Delivery Network (CDN) and Object Storage Service (OSS) services to implement content distribution. CDN is a distributed network that is built and covered on the bearer network and is composed of

Figure 1. Overall architecture of 4D-BIM

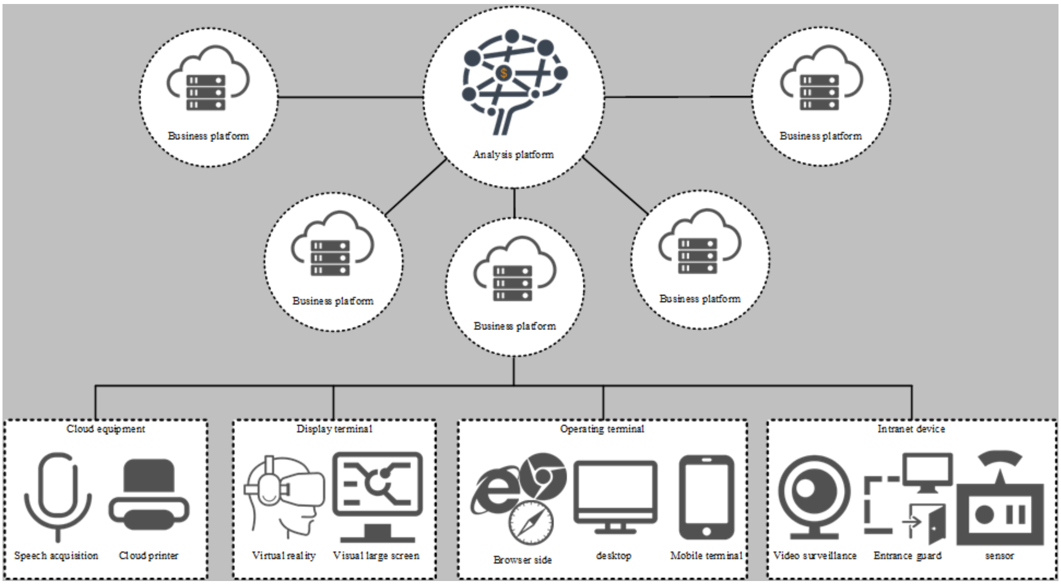
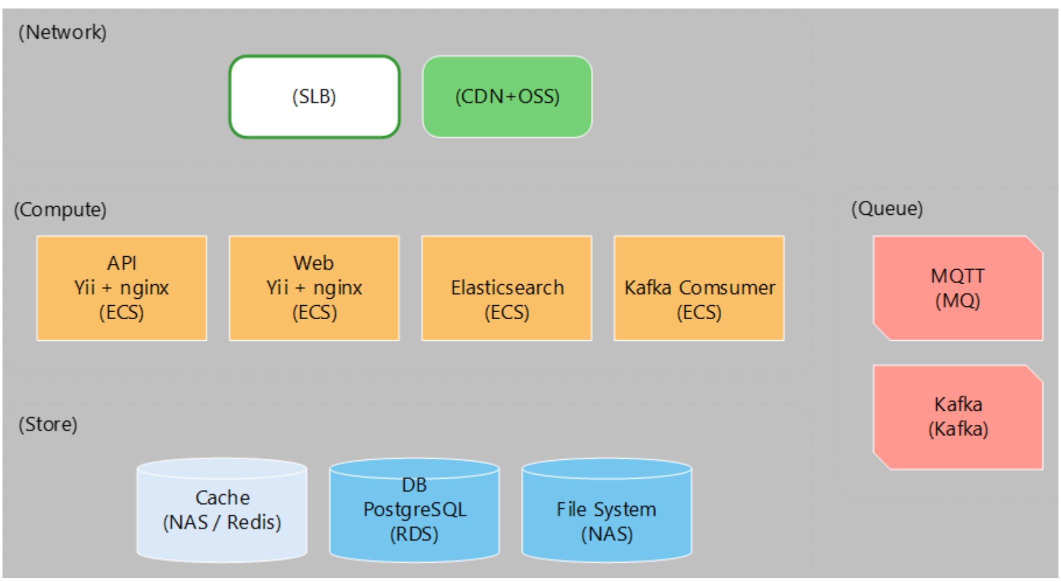


Figure 2. Queue module to realize message distribution

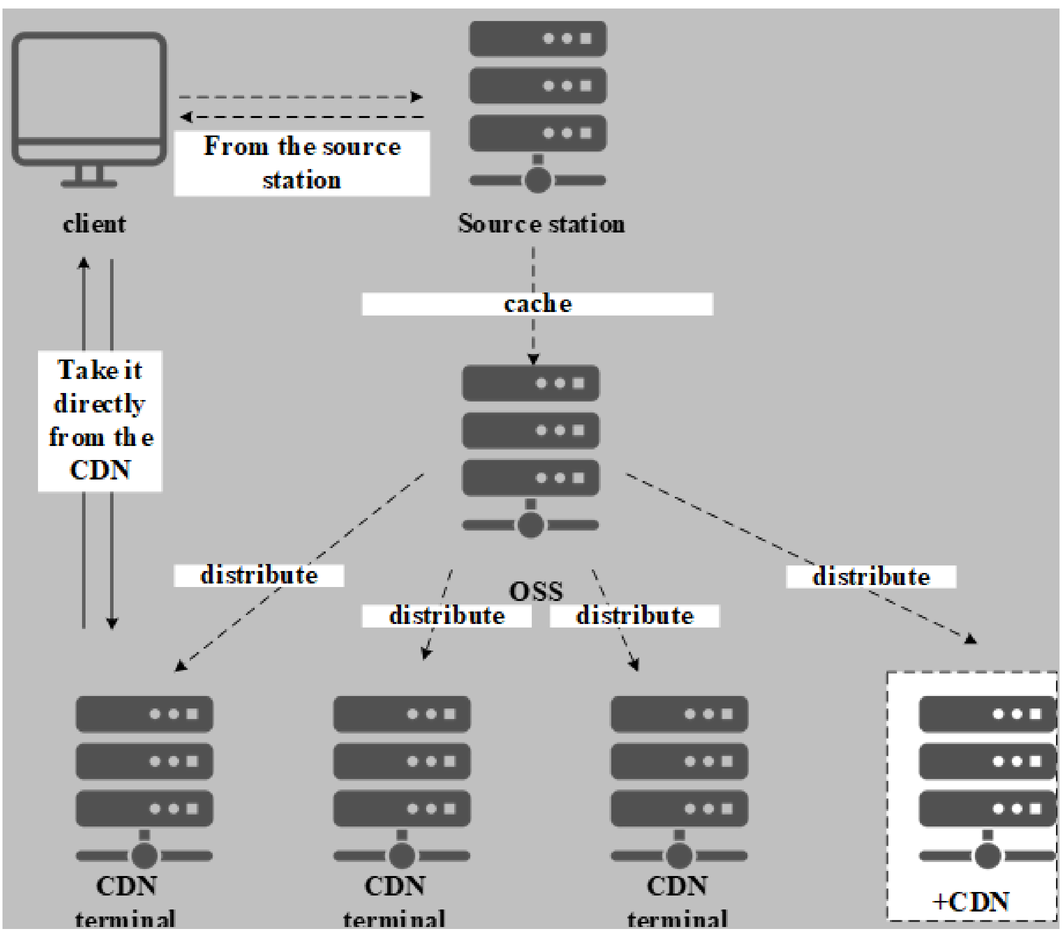


edge node server clusters distributed in different areas. OSS is a massive, secure, low-cost, and highly reliable cloud storage service. When a user sends a request to the 4D-BIM cloud platform, the server first searches the CDN for cached resources. If there is a cached resource, it is returned directly. If there is no cached resource, the resource is pulled from the source server and returned. If the resources pulled from the source station meet the caching conditions set by the 4D-BIM cloud platform, they are cached in OSS and submitted to the CDN for content distribution. The content cached in OSS includes commonly used HTTP request results, video, audio, pictures, model geometry information, and so on. It is worth mentioning that the CDN service has unlimited bandwidth. The bandwidth of servers and databases is limited, and the cost of increasing bandwidth is high. Storing large, unstructured files on OSS and distributing them via CDN not only improves download speeds with high bandwidth but also greatly reduces service costs. Its principle is shown in Figure 3.

The 4D-BIM platform provides a Server Load Balancer (SLB) component to handle high concurrency (a large number of users accessing the server at the same time). The SLB evenly distributes the load of users accessing the server to ensure that all users can obtain the required services and ensure service stability. With the support of load-balancing components, the 4D-BIM cloud platform can freely expand the number of servers and quickly expand the load capacity of the platform when the service demand increases.

The Load-balancing component of the 4D-BIM platform consists of the following parts: Server Load Balancer instances are load-balancing services that receive traffic and distribute it to back-end servers. To use the load-balancing service, you must create a load-balancing instance and add at least one listener and two API servers. Listeners are used to examine client requests and forward them to back-end servers. Listening also performs health checks on back-end servers. Backend Servers are a group of two API servers that receive front-end requests. You can add two API servers to a server pool independently, or batch add and manage them through virtual server groups or primary and secondary server groups. After a client request passes through a load balancing instance, the

Figure 3. Schematic diagram of the content distribution process



listener sends the request to the two API servers added at the back end for processing according to the configured listening rules, as shown in Figure 4.

In actual balancing, the SLB virtualizes the added Elastic Compute Service (ECS) instances into a high-performance and highly available application service pool by setting virtual service addresses and distributing requests from clients to the ECS instances in the cloud server pool based on forwarding rules. By default, the SLB checks the health status of ECS instances in a cloud server pool and automatically isolates abnormal ECS instances. This eliminates the single point of failure of a single ECS instance and improves the overall service capability of an application. In addition, load balancing also can resist DDoS attacks, enhancing the defense capability of application services.

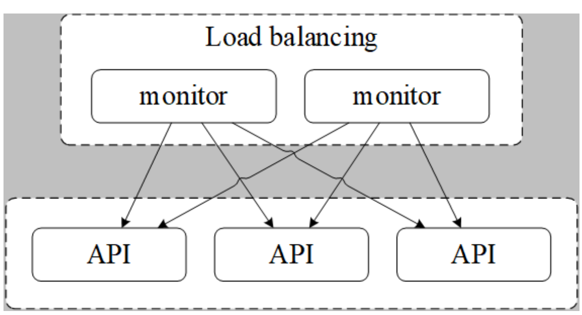
2.3 Collaborative Visualization of Tilt Photography Model and BIM Model

Oblique photography technology is a new technology in the field of international surveying and mapping. The UAV is used as the carrier to collect image data from multiple angles such as one vertical and four tilts. While collecting data, detailed data such as height, speed, direction, and coordinates are accurately recorded. BIM model through the reference point positioning, that is, to determine the latitude and longitude coordinates of the reference point, the elevation, while formulating the direction of the X axis in the earth coordinate system, can achieve the collaborative integration of tilt photography model and BIM model display.

The oblique photography technology mainly has the following four characteristics: to truly present the actual condition of the object, compared with the orthographic image, the oblique image can observe the natural scene and architectural condition on the ground from multiple angles, truly present the actual condition of the object, and at the same time, the oblique photography increases the side depth and other information; Single image measurement. Combined with the use of supporting software, the length, height, area, Angle, and slope can be measured according to the results. Capture the side texture of the building. Aiming at different 3D digital city applications, the characteristics of UAV aerial survey and the advantages of oblique images are fully utilized, and the cost of 3D real city modeling is effectively reduced. It can share the tilted image data through various channels such as the network through mature technology, which can be easily shared.

The oblique photography data in osgb format can be converted through cesiumlab, and the oblique photography data will be converted into 3dtiles graphics files supported by the graphics engine. Through the tilt photography import function of the client, the 3D files will be uploaded to the cloud for rendering in the graphics engine. 3D real GIS combined with oblique photography provides a comprehensive map management solution for information construction and makes spatial information present in 3D visualization. In this context, the “3D roaming” function can help users browse the overall highway through the perspective of the big scene, accurately locate the specific location of the project, analyze the environmental conditions, and assist users in evaluating the

Figure 4. Schematic diagram of load balancing components



rationality, scientificity, and feasibility of highway planning and design. Oblique photography model rendering effect. Figure 5 shows the import of the photographic model.

2.4 Bidirectional Query Technology of BIM and GIS

The integration of BIM and GIS involves the conversion of BIM three-dimensional coordinates and GIS longitude and latitude coordinates. At the same time, since it is oriented to the field of highway operation and maintenance, the management dimension of the highway is line + mileage, so it is necessary to establish the conversion relationship between the three. Specific solutions are as follows:

In the system Settings, set the longitude and latitude coordinates of the BIM model base point and the corresponding direction of its X-axis.

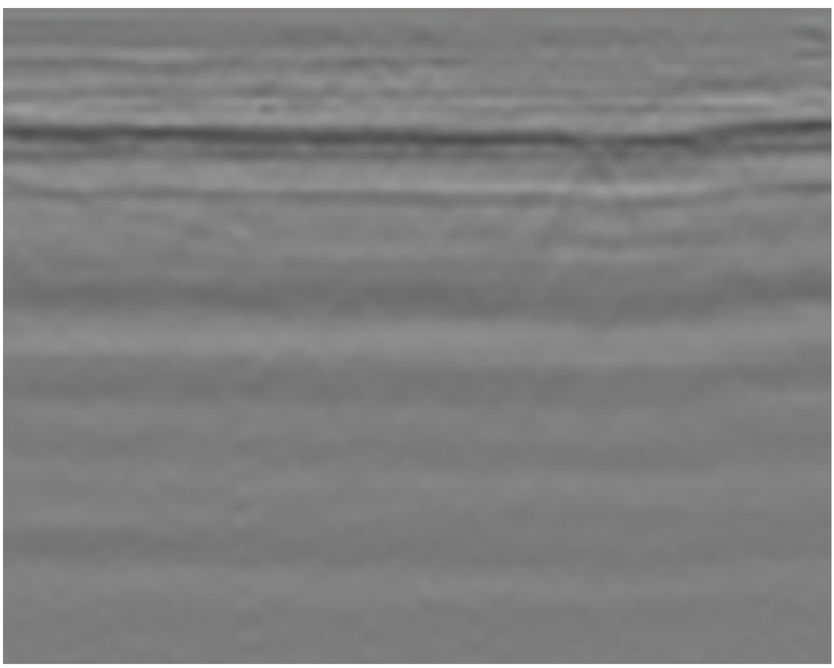
For BIM coordinates to GIS latitude and longitude: For BIM Coordinate point (x,y,z), firstly calculate the (x0,y0,z0) coordinates of BIM reference point in earth Coordinate System through the calculation formula of World Geodetic System-1984 Coordinate System. Then calculate the coordinates of the coordinate points in the earth coordinate system (x0+x,y0+y,z0+z), and finally calculate the corresponding longitude and latitude values of the coordinate points through the formula.

For GIS latitude and longitude to BIM coordinates: For the longitude and latitude coordinates, firstly calculate their Coordinate values (x,y,z) in the earth coordinate System through the calculation formula of the WGS-84 Coordinate System (World Geodetic System - 1984 Coordinate System). Then subtract the coordinate values of the BIM model base point in the earth coordinate system (x0,y0,z0), and finally get the BIM coordinates corresponding to the latitude and longitude. Figure 6 is the intelligent modeling of the highway foundation unit, Figure 7 is the radar picture of the road surface, and Figure 8 is the identification of the road surface disease pothole.

Figure 5. Import of photographic model

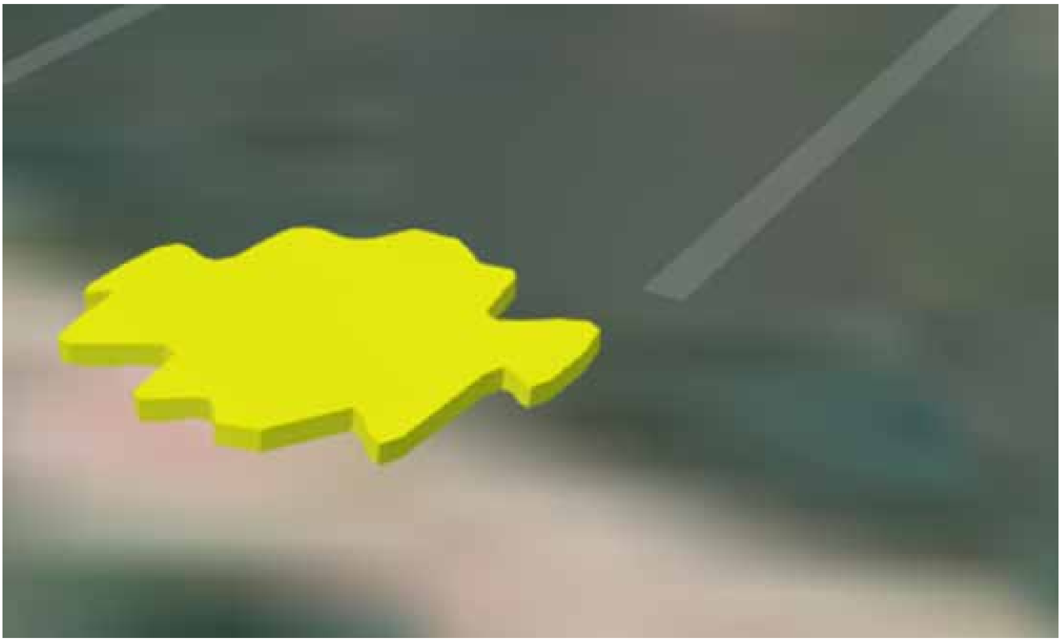
Figure 6. Intelligent modeling of highway foundation unit

Figure 7. Radar picture of road surface



From highway mileage to GIS latitude and longitude, a list of highway marking points is stored in highway information, including the correspondence between mileage value and GIS latitude and longitude. For a given highway mileage, interpolation is carried out in the calibration points to obtain the value of GIS latitude and longitude. For highway mileage to BIM coordinates, the highway mileage

Figure 8. Identification of pavement disease potholes



is first converted into GIS longitude and latitude according to the mileage marking information in the highway, and then the BIM coordinates of the highway mileage are calculated through the conversion of GIS longitude and latitude to BIM coordinates.

The core of a high-speed km asset intelligent management platform is data, and massive data will be generated during operation and maintenance engineering. How to store massive data in an orderly manner and how to organize and retrieve massive data quickly is a very key issue. In the design process of the platform, we take the 10-meter section of the highway as the core, and all other relevant data will be associated with the 10-meter section of the highway. In this way, a network association relationship centering on the 10-meter section of the highway will be formed in the database, and the full operation and maintenance information of this section of the road can be quickly retrieved from the 10-meter section of the highway.

2.5 Automatic Association Technology Between Highway Operation and Maintenance Data and BIM Model

The O&M service data can be automatically associated with the model through attribute matching so that the service information can be viewed on the model. Service information located by mileage value, latitude, and longitude value is located on the BIM model through the bidirectional query technology of BIM and GIS.

4D-BIM cloud platform innovatively introduces search engine technology for component retrieval and dynamic association between components and business, revolutionarily improves the speed of model attribute retrieval, liberates users from the complicated data association process, and puts more energy into the use of data and mining the value of data.

The 4D-BIM cloud platform uses the open-source Elasticsearch search engine. The Json format used by Elasticsearch is combined with the JsonB field used by PostgreSQL to store attributes. When the database adds, modifies, or deletes the attributes of a model or business, its attribute content will be pushed to Elasticsearch in the form of JSON. Elasticsearch will automatically index the retrieved content. When a user queries a property or gets an association between a business and a model through a property, the client sends a request to the API server, which in turn sends an HTTP request to Elasticsearch. The request contains the criteria for the query and the sorting rules. Elasticsearch gets the ID of the model or business based on the query criteria and index and returns it to the client in JSON format.

The reason why Elasticsearch can be very fast is related to its implementation principle. Elasticsearch is a distributed RESTful style search and data analysis engine that implements inverted indexing for full-text search through finite state machines, BKD trees for storing numerical and location data, and column storage for analysis. Since every piece of data is indexed, Elasticsearch's full-text search is very fast. Elasticsearch supports horizontal scaling to automatically manage how indexes and queries are distributed in a cluster and can handle petabytes of structured or unstructured data.

In the automatic association between components and business data, n conditions of business data are usually matched with m conditions of the model. If it is an exact match, there is a little mistake in the mapping process, and the matching will fail, and the actual application situation is often more troublesome. To improve the accuracy of automatic association, we introduce a string fuzzy matching algorithm based on Hamming distance. As long as the matching degree of two strings exceeds 75%, we think they are the same. In this way, business data and models are matched based on fuzzy matching. If each layer is fuzzy-matched, the accuracy rate of association is as follows:

$$P=1-(1-0.75)^{n}$$

When n=5, the correlation accuracy can reach 99.9%, which greatly improves the success rate of matching.

Through network isolation (private network)/user isolation (classic network), file system standard permission control, permission group access control RAM master sub-account authorization, and other security mechanisms, the file system data security is guaranteed. Figure 9 Schematic diagram of file storage components. To show the database model, unified management of high-speed operation and maintenance business data is done. Figure 10 is the database table structure of some business data, which can be associated with BIM.

2.6 Value of Highway Platform Based on BIM+GIS

Help engineering involves surveying the terrain environment and assisting in evaluating the rationality and feasibility of project planning and design. Roam according to the route Settings, and observe the

Figure 9. Schematic diagram of file storage components

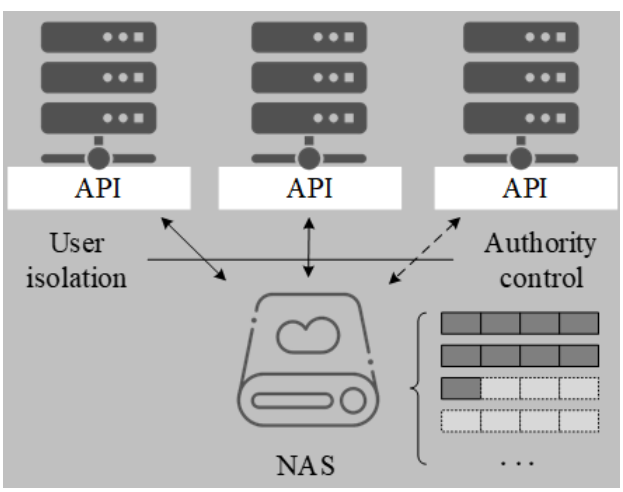
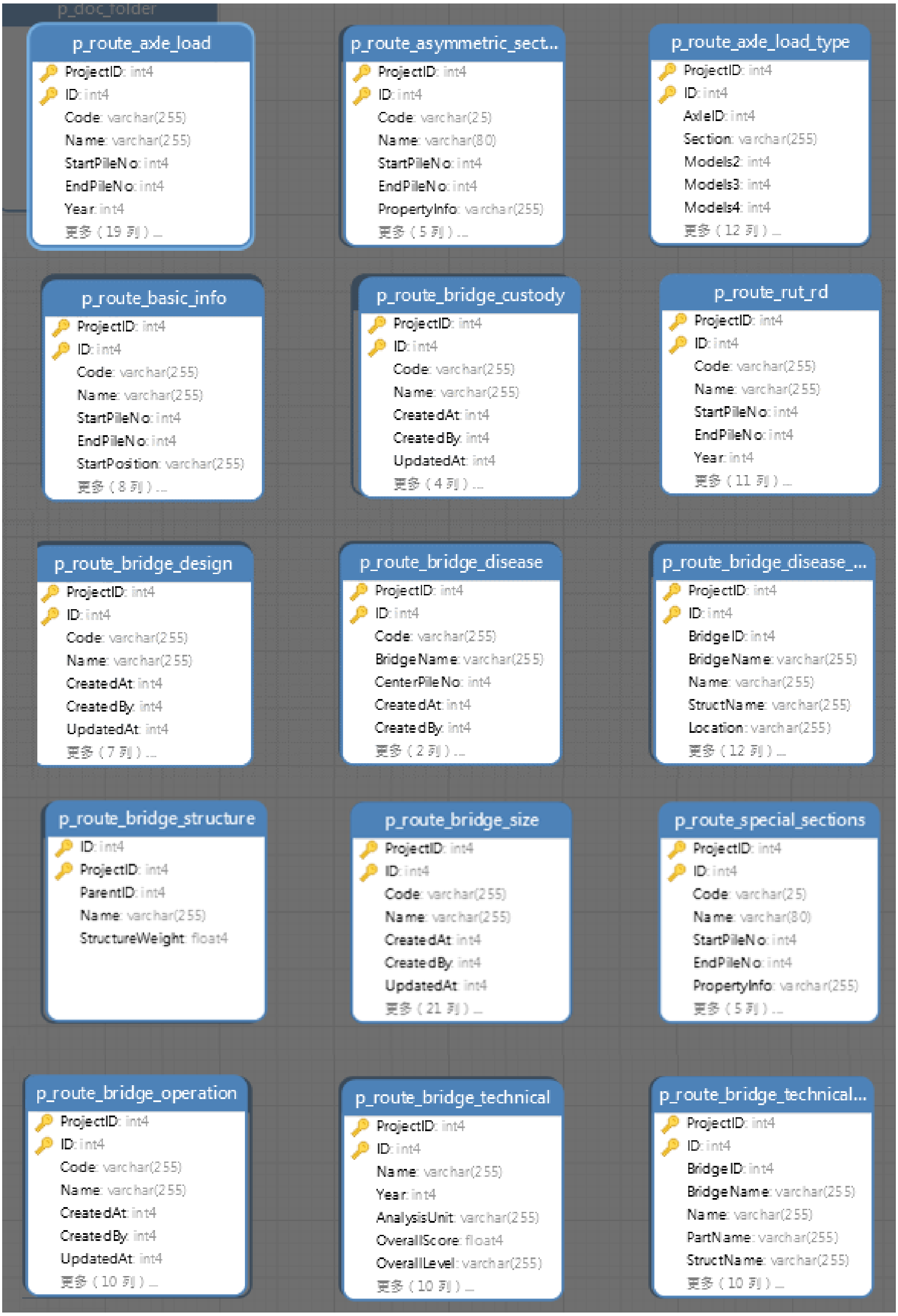


Figure 10. Database model diagram



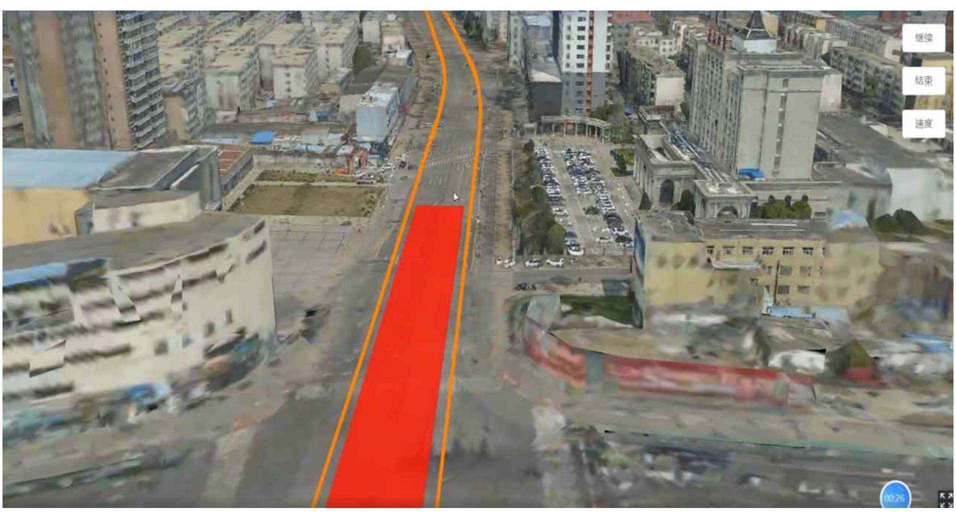
geographical environment according to the specified location, direction, Angle, and other elements. Compare and report on multiple schemes. Figure 11 shows the selection of the roaming area of the 3D roaming technology, and Figure 12 shows the selection of the roaming section of the 3D roaming technology.

3. APPLICATION EXPLORATION OF BIM+GIS-BASED PLATFORM IN ROAD HEALTH MANAGEMENT

First of all, the original image is imported into the BIM intelligent system, the histogram equalization process is carried out, the histogram binary legend is carried out, and the binary image is filtered for preliminary crack identification. By introducing row projection and column projection, cracks can be accurately identified in the BIM intelligent system, and the road cracks can be judged to be horizontal or vertical, and the road cracks can be intuitively understood. It can be seen from the

Figure 11. Selection of roaming area for 3D roaming technology

Figure 12. Selection of road segment roaming in 3D roaming technology



images that there is an accurate recognition of road cracks. Figure 13 is the original image, Figure 14 is histogram equalization, Figure 15 is binary processing, Figure 16 is binary image filtering, Figure 17 is crack recognition, Figure 18 is row projection, Figure 19 is column projection, and Figure 20 is crack recognition.

The figures in Figure 18 and Figure 19 represent horizontal and vertical distances, respectively,In image recognition, the image contains location information. Through BIM and GIS two-way query

Figure 13. Original image

Figure 14. Histogram equalization

Figure 15. Binarization process

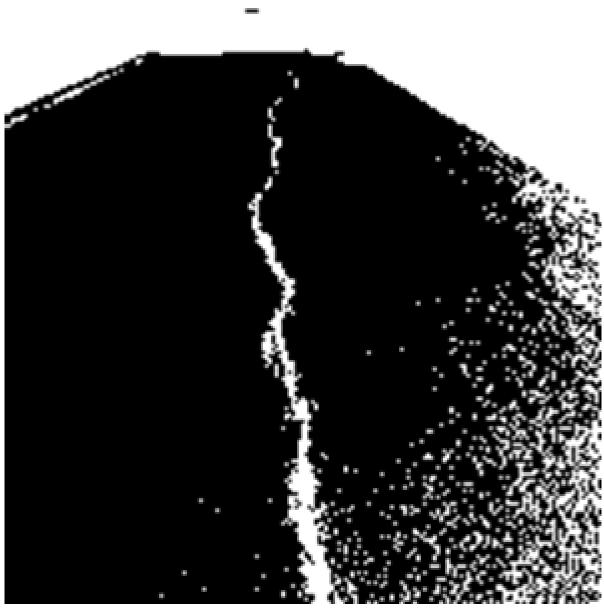
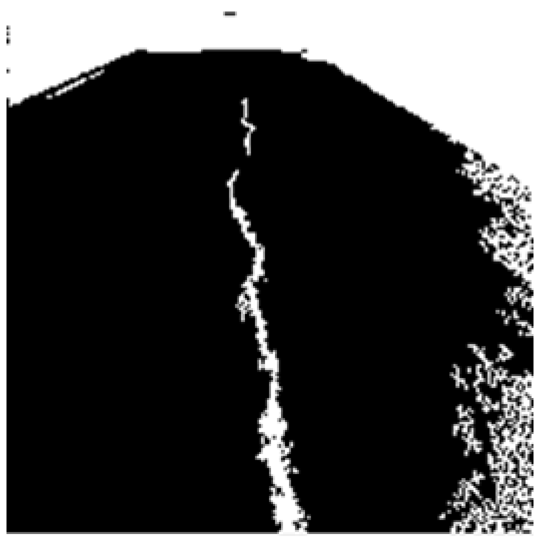


Figure 16. Value image filtering



technology, crack information and BIM models are generated managed, and positioned on the overall model for unified display. At the same time, other business information in the platform can be extracted, such as road age, maintenance records, maintenance records, various monitoring information, etc., and this business information can be combined with the identified crack information to provide customers with intelligent maintenance decision-making assistance.

Figure 17. Crack identification

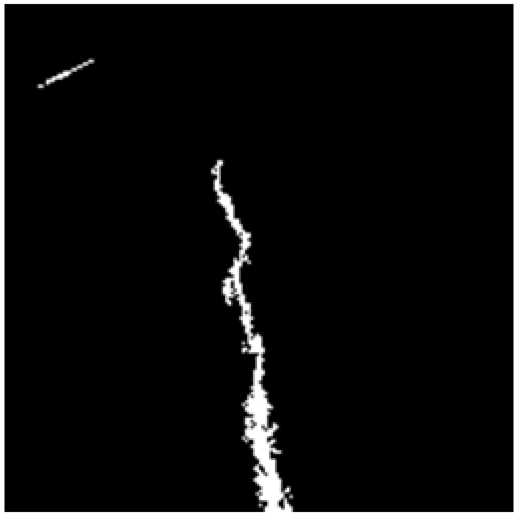


Figure 18. line projection

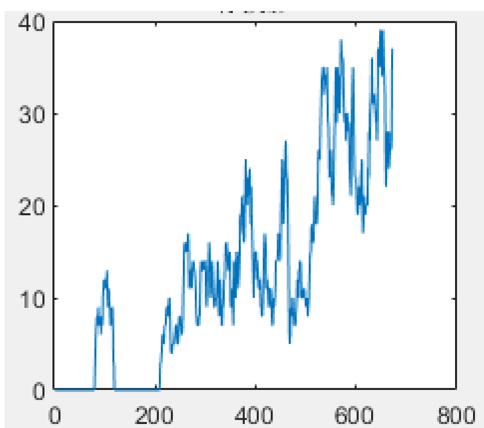


Figure 19. Crack identification

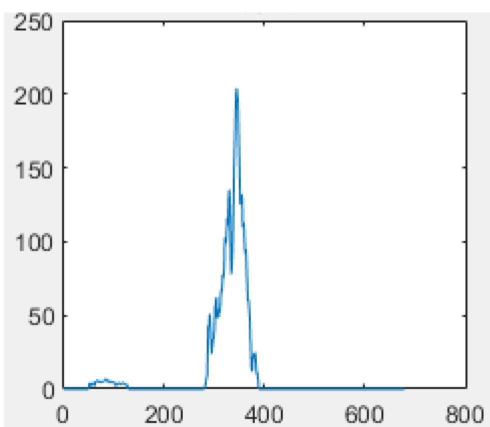
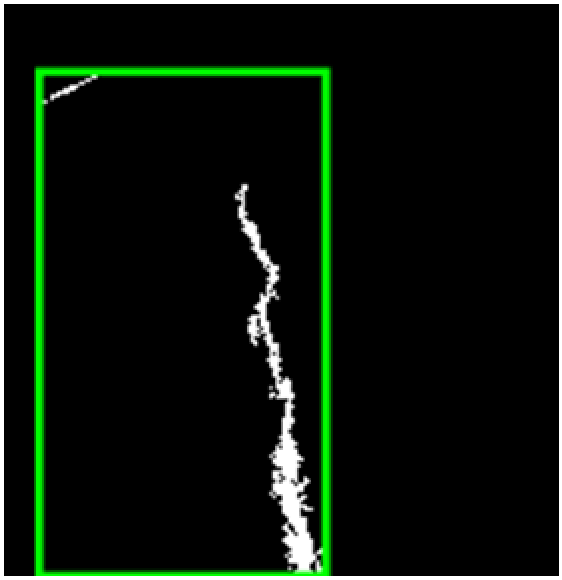


Figure 20. Crack identification



4. CONCLUSION

This paper uses the BIM model as the base for fine management, and GIS as the support for macro management. The integrated analysis method of Building Information Modeling (BIM) and Geographic Information System (GIS) was introduced into the expressway operation system, and the three-dimensional roaming of the expressway was carried out based on BIM+GIS. Combined with BIM (Building Information Modeling) and GIS (Geographic Information System), the actual pavement gap was detected, which greatly improved the pavement management technology of operating expressways.

From the perspective of theoretical significance, this paper innovatively applies the integration technology of BIM and GIS to the research of pavement crack detection. Therefore, in practice, it solves the previous pain points of pavement detection and identification to a large extent from the perspective of intelligence, which can better improve the safety of pavement. However, the current research in this paper is still limited to pavement detection. In the future research work, the application of BIM+GIS combined system will be strengthened, and other highway facilities besides pavement will also be intelligently analyzed, so as to better digitize and intellectualize the highway system.

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