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Design and Implementation of Full-process Management System of Highways based on Linear Location

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Abstract

Linear referencing and dynamic segmentation are becoming important means of geographical information system (GIS) development, along with the continuous development of GIS technology. They have specific applications to road maintenance, railway operation and maintenance, and pipeline and urban road management. However, traditional GIS technology only considers space and attributes; it cannot express time, which is an important dimension in the field of rural highway maintenance. To solve the data management problem in the construction-management-maintenance-operation process of rural highways and data sharing problems among business systems of rural highways, as well as to facilitate the perfection of the full-process management system of rural highways, a full-process management basic data model of rural highways based on dynamic linear location was proposed in this study in accordance with their management characteristics, great cardinal number, extensive distribution, and relatively weak management. A full-process management dynamic linear referencing system for the construction, management, and maintenance of highways was established by combining the linear location technology and introducing the time dimension. Finally, a rural highway management system based on linear location was developed, and its convenience was verified by the basic data updating of rural highways in Xianyang City, China. Results show that the proposed full-process management basic data model can realize dynamic changes and trace management of the linear referencing system, while conforming to characteristic of data on rural highway management and maintenance. The built rural highway management system meets the dynamic management requirements of rural highways and can inquire the path information in a timely manner. The proposed management system can improve the accuracy and completeness of basic data by 12% and by 24%, respectively, in the process of concrete application, effectively solving the lag of basic data of rural highway.

Keywords: Road engineering, Linear referencing, Dynamic segmentation, Data model, Process management

1. Introduction

Rural highways are a major component of the road network and are basic facilities that guarantee rural economic development. With the continuous construction of rural highways, their overall appearance has changed drastically. However, information management of rural highways remains in the traditional manual effort stage and cannot meet the current needs for rural road management. Therefore, how to use and integrate information on existing rural highway networks to establish a new set of information management systems is of great significance to achieving the full-process management of rural highways.

As a kind if spatial data management technology, geographical information system (GIS) has been extensively used in the highway industry, involving highway statistics, planning, construction, maintenance, and operation. Over the years, the management systems of various business areas of highways, developed based on the GIS "one map" technology, have realized the information management of highway data collection, annual report data statistical summary reporting, project plan declaration, road maintenance, and operation and highway road properties, among others. However, the traditional information management system cannot realize the basic data sharing of various business ends and is not equipped with dynamic management of basic data. Therefore, such a system is unable to meet rural highway management needs at present.

Nowadays, linear referencing and dynamic segmentation have very strong practicability in the location of highway events. Establishing dynamic linear referencing can lay the foundation to building a full-process management basic dataset of rural highways. Moreover, dynamic linear referencing has obvious technological advantages in improving system operation efficiency and decreasing data access time. Thus, this study proposes a dynamic linear referencing system through the linear location technology by introducing the time dimension to investigate the full-process highway management application technologies. This work aims to improve the full-process management level of rural highways.

2. State of the art

Full-process highway management covers all stages of the "construction, management, maintenance, and operation" of highways, as well as the corresponding event process and spatial positions in different stages. For example, the construction stage requires the dynamic management of the implementation, progress, construction schedule, and quality of new highway construction, highway reconstruction, and

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expansion projects. Moreover, there's a need to import the newly added basic highway data into the database and update the electronic map data upon completion of a project. In the management stage, the basic road database and electronic map data of the section with adjustment of route, route coding, or mileage pile number must also be updated and maintained. In the maintenance phase, the daily inspection and maintenance of roads, the management and long-term observation of integrated risk road-bearing bodies, and the management of maintenance data also require updating and maintenance in a timely manner. How to correlate these processes and build an underlying linear basic database that fits the characteristics of the road industry is a key factor in this undertaking.

Linear location is a kind of spatial location that uses linear referencing as the core and dynamic segmentation as the mean, and is closely related with the data management of the highway industry. The relevant GIS technology has been applied to road maintenance as well as to railway, pipeline, and urban road management. As an important technical aspect of GIS network analysis, dynamic segmentation can effectively solve the dynamic analysis problem based on linear characteristics [1]. Using dynamic segmentation in road maintenance information management system can not only decrease data redundancy and repeated digitalization of road maintenance system but can also effectively solve the management and inquiry of multi-attribute data of highways and facilitate event analysis during road maintenance [2]. The linear referencing system is a key problem in the research and practical applications of GIS theory for highways and can be used to accurately describe physical position in linear network [3-4]. In recent years, studies on linear referencing have deepened continuously. For example, Park and Bigham et al. [5-6] built a linear referencing system of highways by connecting existing reference markers and current digital street networks. Wang et al. [7] established a one-dimensional linear reference system of linear elements, such as roads, and analyzed relevant steps and problems by establishing the mileage events and water-destroyed events. Fu et al. [8] proposed a method of calculating the positions of mileage piles according to the linear referencing system, which can increase the data production efficiency and lower operation cost. However, it still has to be adjusted by combining practical situations and relevant indexes in specific application cases. The linear referencing system of highways is not static, but changes dynamically with time. In other words, changes in new construction, reconstruction and extension of highways, route coding and pile numbers may cause skewing of the original linear routes. Hence, there is an urgent need to establish a corresponding linear referencing system according to the practical needs of highway industrial management.

With the continuous development of Geo-informatics technology, the sampling frequency of traffic data has increased quickly. However, the traditional GIS cannot accurately describe traffic characteristic information and characterize the life cycle of traffic characteristics [9]. Therefore, researchers and scholars have proposed various spatiotemporal models for temporal GIS, including the sequence snapshot, base state with amendments, time-space composite, space-time cube, event-based spatiotemporal data, feature-based spatiotemporal data, and object-oriented spatiotemporal data models [10]. The base state with amendments model was proposed by Peuquet and Duan for the first time in 1995. It is one of the most important models in spatiotemporal data model and it can reflect temporal changes of linear referencing well [11]. The model stores the complete data as a ground state and then stores only the changed parts for each event change. When it is necessary to query historical data, only the ground state data are superimposed on the corresponding time nodes according to the time series for query [12-13]. Although the traditional base state with amendments model decreases data redundancy, it brings difficulties in the indexing of spatiotemporal objects, spatiotemporal relationship expression, and spatiotemporal analysis.

To increase retrieval efficiency and meet the application requirements, scholars have implemented a series of improvements to this specific model. For example, Yang et al. [14] proposed an amended dynamic base state model, in which the base state changes according to practical situations, and the increment is the difference between practical situations and database construction state. This method saves on storage space, which is convenient for the use of practical data and recovery of historical data. Lin et al. [15] managed the increment information and historical data using the base state with amendments model and proposed an incremental data model. According to the experimental results, this model can effectively store incremental information and quickly integrate incremental information into the old database. Zhang et al. [16] suggested increasing single- and multi-stage time indexes, keeping the base state number unchanged, and increasing a difference document among base states to overcome excessive base states and low retrieval efficiency. Wang et al. [17] proposed a dynamically selected base state with amended spatiotemporal data model and solved the redundancy operation caused by the wrong selection of the base state in the temporal retrieval method. With the continuous improvement and development of the base state with amendments model, some scholars explored the relevant application fields. Feng et al. [18] organized, stored and scheduled three-dimensional (3D) model data in a region of Dezhou City by using the multi-base-state and multi-stage difference document amendment model, which realized the 3D dynamic exhibition of city changes. Therefore, the goal of 3D spatiotemporal visual expression of city changes was realized. Chen et al. [19] designed a multi-base-state amended expansion spatiotemporal model that was appropriate for spatial detection data, as well as designed and developed the management system software. Their results showed that this system could organize and manage spatial environmental data well, decrease storage space, and improve the efficiency of spatiotemporal data operation. Hu et al. [20] proposed a low-redundancy and high-efficiency base state with amendments model that was appropriate for land survey data management and can realize the storage, management, and tracing of land survey data. Based on the above studies, the multi-base-state with amendments model has been widely applied in various fields and has some references to the full-process management of highways. However, it needs to be refined and perfected according to the specific management demands of highway industries.

However, no mature spatiotemporal data model for high-efficiency organization and management of full-process management data of rural highways has yet to be proposed. Therefore, the current study proposed a full-process management basic data model of rural highways based on linear location, using the relevant application technologies, and built a dynamic linear referencing system based on the existing research. Moreover, a management system of rural highways was developed, with the aim of providing references to solve the data overall planning of the full-process management of rural highways.

The remainder of the study is organized as follows: Section 3 introduces the technical principle of linear location and full-process highway management basic data model, Section 4 introduces the building and application of the rural highway management system based on linear location, and Section 5 summarizes the study and presents the conclusions.

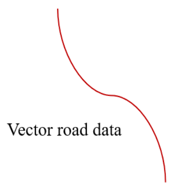
3. Methodology

3.1 Technical principle of linear location

Linear location is different from spatial location based on a geodetic coordinate system. In particular, linear location determines the specific location of linear events in accordance with the linear referencing measurement system and dynamic segmentation technology based on the one-dimensional (1D) space of linear elements. The location of a highway event can be identified through the mileage pile number in the highway system as well as some attributes of highway linear elements. It not only meets the demands for highway business management but can also avoid the deviation between collection points and inquiry points of highways due to spatial location errors [21].

3.1.1 Linear references

A linear reference stores information on geographic positions according to relative positions along the measurement linear elements. In other words, positions along the line are determined by distance. The essence of linear reference lies in a continuous 1D field structure based on the discrete “node-segmental arc” data structure. It can associate multi-attributes and some linear elements, as well as store multiple attributes of single linear elements, laying the foundation for subsequent dynamic segmentation. A linear system storage structure of roads is shown in Fig. 1, in which he vector data of roads is stored in the system according to geometric attributes, while the remaining attribute data of roads are stored in the corresponding attribute table. Moreover, changing data in the attribute table cannot influence the linear elements.



Road attribute table

Project	Pavement material	Start mileage	End mileage
1	Asphalt	0	30
2	Cement	30	55
3	sand and stone	55	70
4	lime soil	70	80
…	…	…	…

Fig. 1. Linear reference storage structure

3.1.2 Dynamic segmentation

Dynamic segmentation refers to the dynamic analysis of attributes of linear characteristics. Here, the attribute sets and spatial positions of roads are associated under the premise of constant element position description (x, y). Moreover, the dynamic logic segmentation of linear elements can be implemented with direct references to distance values in the event attribute table during the display and analysis process, which avoids the data error of two-dimensional (2D) spatial coordinates caused by segmented differences of attribute sets.

Implementing dynamic segmentation first requires the creation of a path element class and the path encoding of the path element so that it has a unique path identifier. Then, the M value is set. Next, an event table must be created so that multiple attributes (e.g., measurement values and path identifiers stored in the event table) are associated with some of the path elements. The attribute information is distributed along the path, as shown in Figure 2.

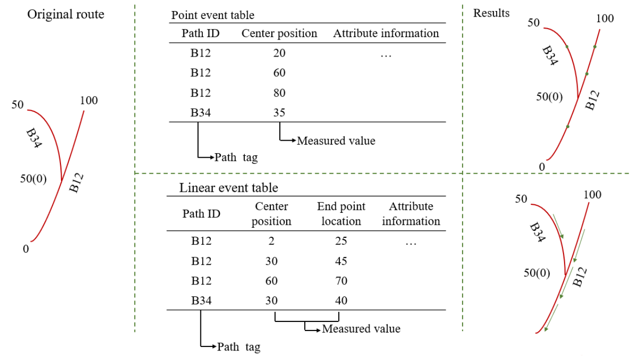


Fig. 2. Dynamic segmentation

3.2 Basic data model based on highway process management

The core point of establishing a GIS system based on process management for the whole highway process management is to establish a linear location system that is suitable for the management of the highway industry. With the help of linear reference and dynamic segmentation technology, this study proposes a basic data model for highway process management based on a multi-base state amendment model, with additional process elements and around highway requirements. The linear reference in this model takes the path as the linear element and the milepost number as the metric system, thus providing dynamic segmentation of the linear element, as well as dynamic change and trace record management of the linear reference system. The specific workflow is shown in Fig. 3.

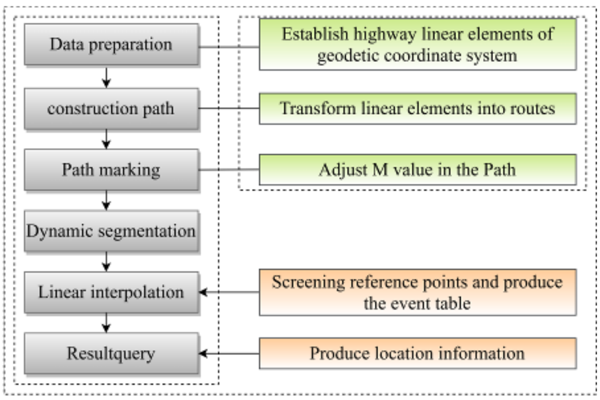


Fig. 3. Data model workflow

3.2.1 Construction of highway linear referencing system

At present, the highway basic database is mainly built based on the field data collected by Global Positioning System (GPS). Data were stored in a plane coordinate system and (x, y) then used to record the linear trajectory of highway without dynamic segmentation. The mileage pile number was used as the basic highway data and serves as the basis upon which to realize the linear location of highways. However, the mileage pile number must be re-adjusted due to the changes in route and route number (Fig. 4). Therefore, to ensure that the highway pile number can reflect highway status and to achieve the dynamic management and node correction of pile numbers, the measured values of pile numbers in the linear referencing system were adjusted in a timely manner through the interpolation of pile number and extrapolation method by setting the pile number control points. This step ensures that pile number can be corrected in a timely manner during adjustment. Moreover, the collected highway linear trajectory was superposed with pile number at the mileage control point, forming linear trajectory of highways with linear referencing (Fig. 5).

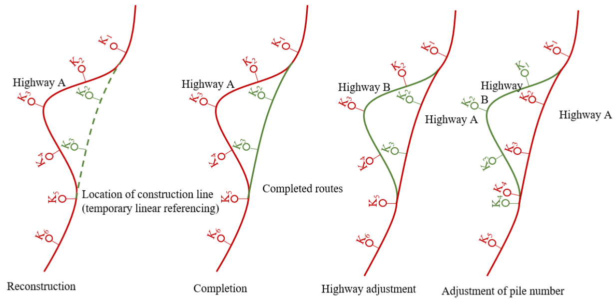


Fig. 4. Changes in the linear referencing of reconstruction and extension highways

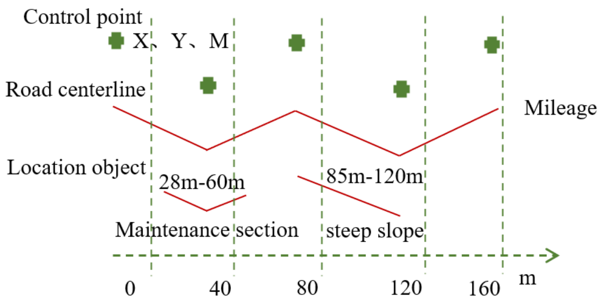


Fig. 5. Data storage structure of linear location

Fig. 5 presents the spatial positions of control point cover longitude (X), latitude (Y), and mileage (M). It can increase space and distance accuracy of data to guarantee accuracy of data. The road axis is formed by the dataset of control points and corresponds to practical pile number. Each position and section on the road axis can obtain specific spatial positions through mileage information and data adjustment technology. A "location object" refers to affiliated facilities on the road axis or within certain distance range to the road axis. Spatial positions and sections of all location objects can be gained through relative pile number, distance and angle.

3.2.2 Basic data processing of the highway industry

(1) Acquisition of data

Acquisition of data is the key part of the road information system, as it can provide theoretical references to achieve full-process highway management. The advancement of GPS technology and smartphones brings new opportunities for the acquisition of road data. In this study, a data acquisition app for smartphones is developed using high-resolution remote sensing, GIS, GPS location, mobile internet and cloud computing services. It has relatively strong flexibility, convenience, and applicability, and a major auxiliary mean for the acquisition, inquiry, and management of basic road data. Based on this information, the current study used a mobile data acquisition APP software to obtain linear trajectory data of rural roads. Then, it will upload the collected data directly to the server to form linear data with a linear reference system through data interaction.

(2) Data extraction

Dynamic segmentation extraction technology can be used to locate, inquire, and make linear extraction of the dynamic segmentation of linear trajectory using the linear referencing measurement system based on linear referencing. During dynamic segmentation, it is unnecessary to have logic segmentation in the traditional significance. Therefore, this study uses segment staking for trajectory segmentation and data extraction. Then, it appends new linear reference and attribute information to the newly generated roadway trajectory to achieve dynamic segmentation and trajectory extraction of roadway linear trajectories.

(3) Data conversion

The plane coordinates (x, y) and the measured M value of linear referencing pile number were stored in the basic database of highways. The two coordinate systems are often used at the same time in highway industry management. For example, the road data (x, y) collected by GPS in the field must be converted to mileage pile number during use, which must be converted into geodetic coordinates. Therefore, the integration and high-efficiency conversion between the linear referencing system and geodetic coordinate is an important basic task [22].

In this study, the conversion of plane coordinates and linear location was implemented using the interpolation of adjacent points. During data calculation, the curve must first be processed as a broken line, after which the acquired coordinate set of adjacent structural points must be stored into the array for data conversion (Fig. 6). Direct interpolation was performed to points on the linear trajectory. Following a different approach, interpolation was performed after projecting the data points beyond the linear trajectory onto the linear trajectory at the shortest distance.

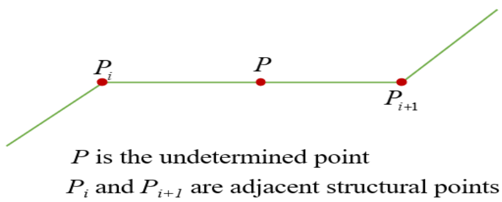


Fig. 6. Linear interpolation

1) Conversion of a rectangular plane's rectangular coordinates into linear mileage coordinates

First, we determined the node side where P is located and search i from 1 to n, thus calculating $\min\{|P_iP|+|PP_{i+1}|\}$. Then, we determine the calculated side $|P_iP_{i+1}|$ and then calculate the mileage coordinates of P as follows:

$$\mu = \left|\frac{x - x_i}{x_{i+1} - x_i}\right| \tag{1}$$

$$L_P = \sum_{m=1}^{i-1}(|P_mP_{m+1}|) + |P_iP_{i+1}| \cdot \mu \tag{2}$$

2) Conversion of linear mileage coordinates into plane rectangular coordinates

First, we determine the node side where P is located and search i from 1 to n. Then, we determine P_i and P_{i+1} that meet $L_{P_i} \le L_P \le P_{i+1}$. Then, we calculate the plane rectangular coordinates of P:

$$P = P_i(\mu) + P_{i+1}(\mu) \tag{3}$$

$$\mu = \left| \frac{L_P - L_{P_i}}{L_{P_{i+1}} - L_{P_i}} \right| \tag{4}$$

In the above equations, L_P is the linear mileage coordinates of P, and x_i is the x-coordinate in the plane rectangular coordinates and μ is the relative position coefficient.

4 Results and discussions

4.1 Research and development of a rural highway management system based on linear location

The basic core of the research and development (R&D) of a rural highway management system lies in the linear location of a linear referencing and dynamic segmentation. Through linear location, the spatial location of various events in the whole process of rural highway management can be obtained, which has the characteristics of convenient query and management. During system R&D, considerations shall be given to software structure, highway basic database design based on linear referencing, pile number management, and data updating and maintenance.

4.1.1 Software structure oriented toward full-process rural highway management

The B/S structure was used to establish a full-process rural highway management system to achieve high-efficiency steady system operation and for the purpose of inquiry of highway basic data, construction project management, construction scheduling monitoring and data acquisition check. The software structure is shown in Fig. 7. This system is operated in the network environment. The hardware requirements included Intel(R) Core(TM) i5-3220M CPU, memory >8G, hard-disk space>2T, and SQL Server 64-bit database software. The development environment used the .NET development platform, Microsoft IIS server as the Web server, APP server as ArcGIS Server platform, and ArcSDE as spatial data engine for operations between spatial data and relational database.

The software structure of the proposed remote-sensing comprehensive service rural highway management system is mainly divided into supporting layer, data layer, information service layer, and comprehensive service APP layer. The details are introduced as follows:

(1) Supporting layer: It provides support for basic software and hardware environments (e.g., basic server, storage, operation system, and database) through the cloud service platform.

(2) Data layer: High-resolution remote-sensing images, topographic data, highway data, slope data, maintenance data, and village data are normalized. Different data categories are associated, forming chains of mutual data verification.

(3) Service layer: API calling interfaces oriented toward highway collection, highway project management, highway maintenance management and highway inquiry and analysis are studied and developed using the standard OGC and Web Service Interface.

(4) Application layer: This includes PC-end data management, mobile-end data acquisition, inquiry, and browsing.

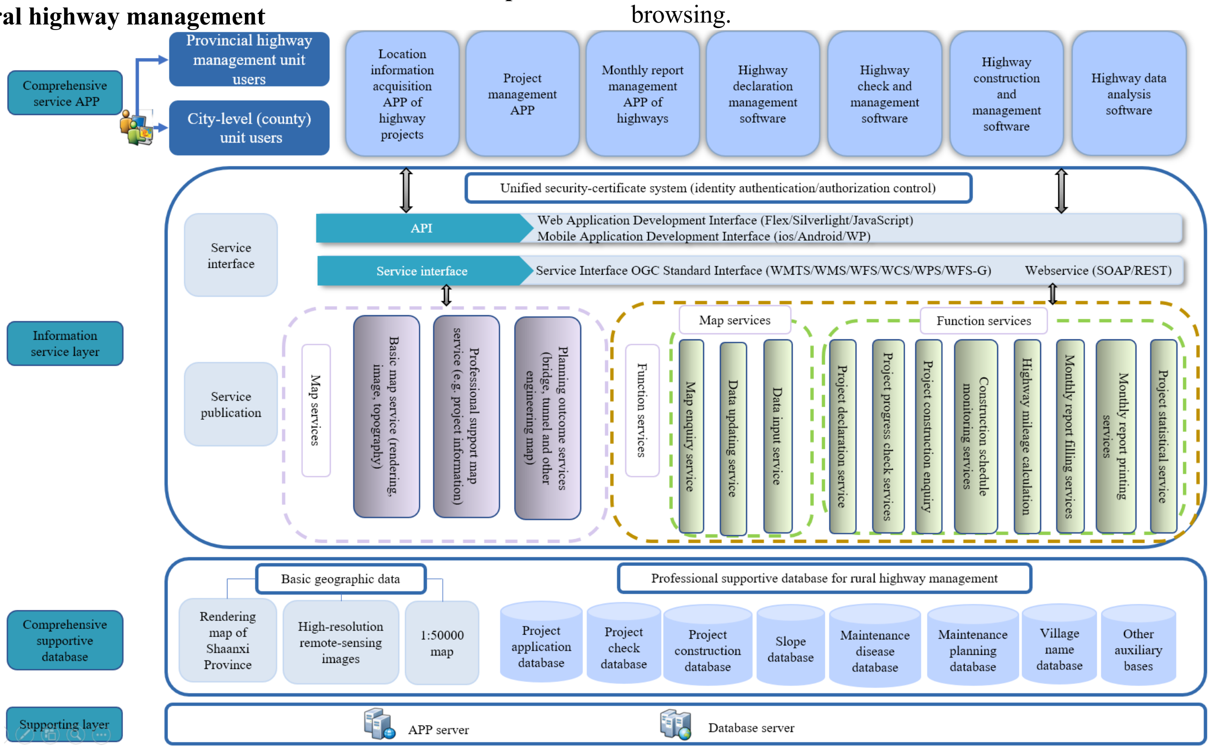


Fig. 7. Software structure of the proposed highway management system based on linear location

4.2 System function module

The remote-sensing comprehensive service management system interfaces of rural highways include the exhibition zone, functional zone, and working zone of electronic map. Specifically, the exhibition zone of the electronic map is formed by calling the sky map, remote-sensing images and highway basic data, further forming the zone for basic data inquiry of highways. The functional zone covers relevant management modules, including system management, road construction, road management, road maintenance, and road operation. Each management module has corresponding working contents in the working zone (Fig. 8). The highway management provided by the system mainly focuses on basic database and the electronic map management of rural highways, which can realize the dynamic management of highway basic data (Fig. 9). This shows that such a platform can connect the business of rural highway management and realize the full-process management of rural highways.

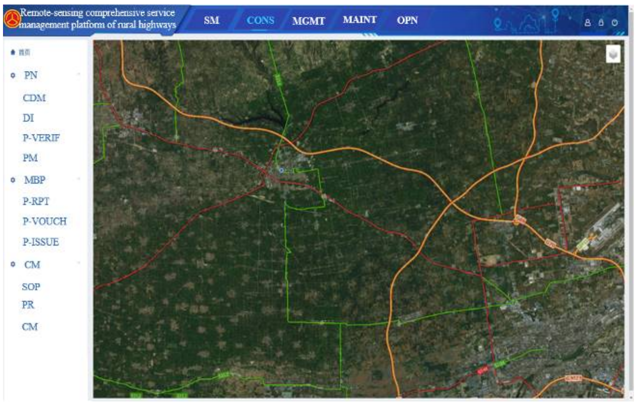


Fig. 8. Remote-sensing comprehensive rural highway service management platform interfaces

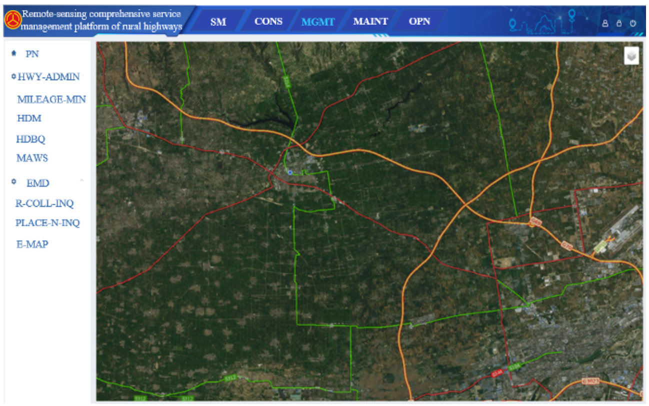


Fig. 9. Highway management system interfaces

4.1.3 Full-process database design of highways

A good database design must be able to achieve the full-process management of rural highways, except the industrial management needs. Therefore, a basic highway database that can provide dynamic management was established through the linear referencing technology (Fig. 10). It provides a dynamic linear referencing trajectory base with linear location to achieve the full-process management of rural highways.

Updating and maintenance of basic highway data include maintenance and updating of highway linear trajectory, and attributes of sections, road numbers, and pile numbers. The database updating process is shown in Fig. 11. The specific data updating period was determined according to types of highway events (e.g. reconstruction and extension, maintenance, and major and minor repairs).

4.2 Applications

The proposed system was applied to the basic database and electronic map project of rural highways in Xianyang City, China. The electronic map data of rural highways in the zone were superimposed, and the section for correction was determined by using high-resolution remote-sensing images as the basic data. Meanwhile, the basic information of the section for correction, including practical route trajectory and pavement type, was extracted under the assistance of high-resolution remote-sensing images. Such basic information was inputted into the basic database of highways to correct and update the existing rural highway sections with linear trajectory skewing over the years. Hence, the dynamic management of rural highways is realized.

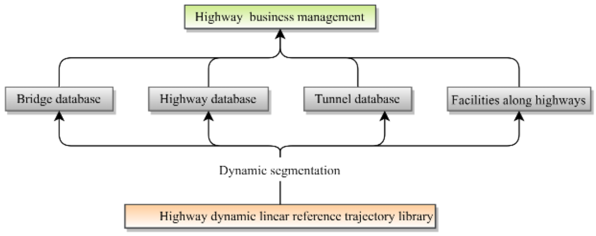


Fig. 10. Overall structure of the full-process rural highway management database

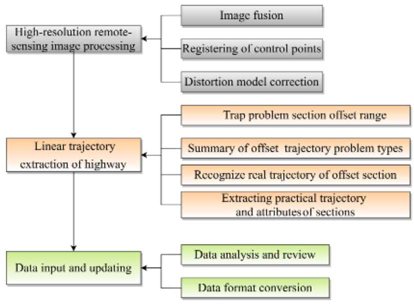


Fig. 11. Updating process

4.2.1 Remote-sensing image processing

This project in this study mainly used the data of China's GF-2 Satellite in 2018, and the annual report data collected from Xianyang City, China, comprised the basic highway data. The mileage of rural highways was 11300 km. The correction and updating steps of high-resolution remote-sensing basic database and electronic map are introduced as follows:

(1) Implementing geometric correction and increasing location accuracy

Through the overall evaluation of remote-sensing images of China's GF-2 Satellite in Xianyang City, China, the location accuracy ranges from 10–30 m. However, high-resolution remote-sensing images have great errors before processing and cannot easily meet the extraction needs of highway trajectories. To improve data extraction quality, the 1:10000 topographic map data, ground control points (GCPs), and DEM data were used for the geometric correction of high-resolution remote-sensing images. The location accuracy of remote-sensing images after geometric correction can be controlled within 2 m.

(2) Implementing remote-sensing image fusion

High-resolution remote-sensing images of China's GF-2 Satellite cover one 0.8 m panchromatic band and several 3.2 m multispectral bands. To increase the resolution of remote-sensing images and the recognition rate of road pavement types, images of the panchromatic band and multispectral bands were fused. The panchromatic band and several multispectral bands were preprocessed before fusion. Specifically, the brightness of the panchromatic data was improved to strengthen local contrast, highlight texture details, and decrease noises. Meanwhile, the multispectral bands were processed according to the recognition needs of pavement types. We focused on improving color boost; adjusting brightness, chromaticity, and saturation; highlighting road color range; and intensifying contrast among different surface features.

4.2.2 Information extraction and updating

(1) Basic information extraction of rural highways

The processed and matched high-resolution remote-sensing images were inputted into the rural highway management system. The basic data of rural highways were superposed onto the high-resolution remote-sensing images, and the practical route position was determined by using the unified coordinates system. Moreover, the vector-based extraction of the offset trajectory was performed using the spline fitting curve in the rural highway management system. Meanwhile, the practical features of rural highway pavement in Xianyang City, China, were compared with the characteristics of high-resolution remote-sensing images (Fig. 12).

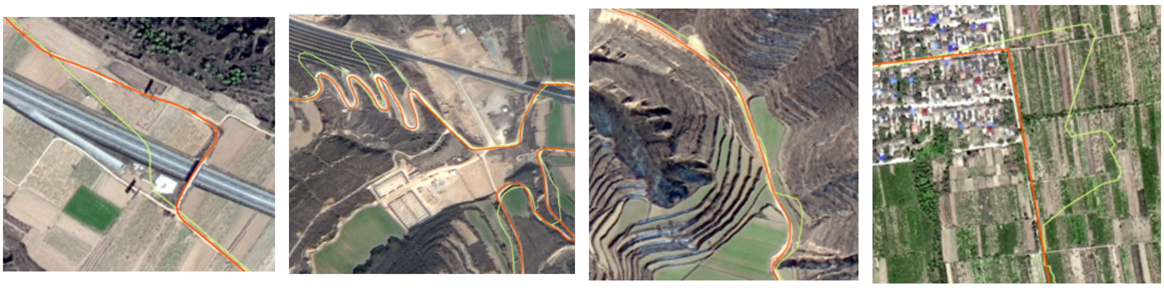
(a) (b) (c) (d)

Fig. 12. Remote-sensing images of different pavement types

According to the remote-sensing image characteristics, the pavement of rural highways can be divided into several types. Specifically, asphalt pavement is generally dark [23-24] and stripe linearity could be observed faintly along the road, has flat and straight edges at both sides of the road, and has a stable width (Fig. 12(a)). Cement pavement is generally bright white, has uniform colors, has flat and straight edges at two sides of the road, and has a stable width (Fig. 12(b)). Sand and stone pavement has light colors with the occasional dark spots and has smooth edges at two sides (Fig. 12(c)). Earth road has light and uneven colors, with uneven edges at both sides (Fig. 12(d)). Given that the asphalt and cement pavements have obvious image features, the extraction rate can exceed 90%. On the contrary, gravel pavement and unsurfaced pavement have complicated influencing features, and the recognition accuracy is 60%.

(2) Extraction of practical linearity and pavement type

To ensure the accuracy of linearity extraction, the offset sections in the whole region of Xianyang City, China were analyzed (Fig. 13. The offset section is in light yellow, and the corrected section is in red).



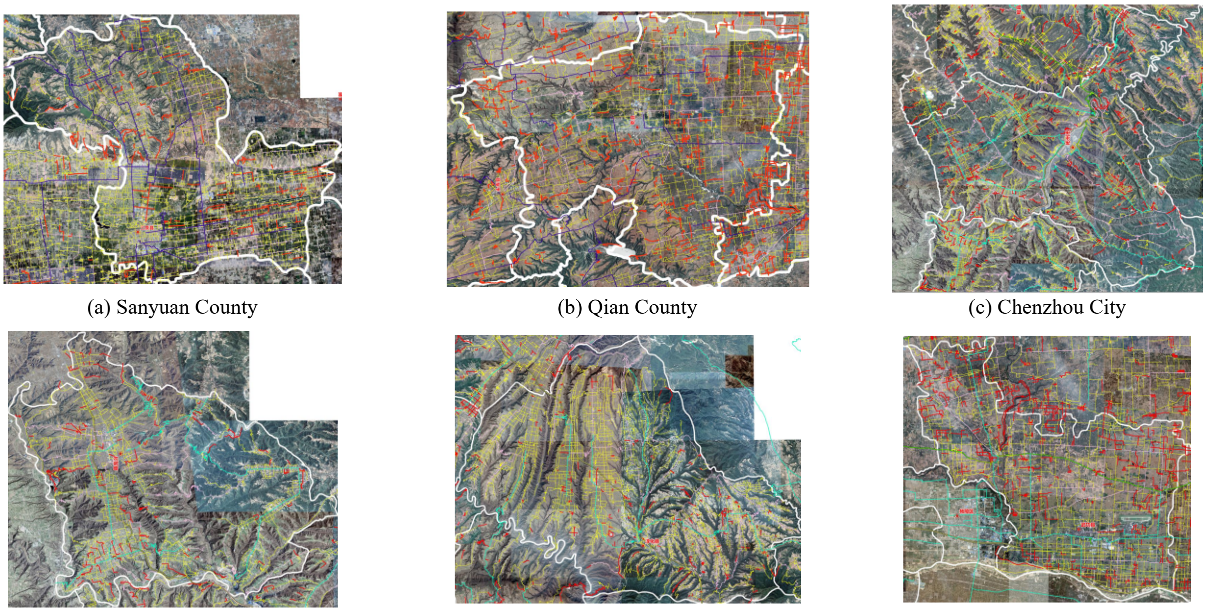
(a) (b) (c) (d)

Fig. 13. Skewed sections and corrected sections

Based on the analysis of the offset sections throughout the study area, the offset aspects include highway re-routing (e.g., Fig. 13(a)), mountainous back bay sections (e.g., Fig. 13(b)), unstable GPS signals during the acquisition process (e.g., Fig. 13(c)), and other factors, such as human interference (e.g., Fig. 13(d)). At the same time, combined with the characteristic signs and highway surface attributes of each offset highway section, the actual linear position of the offset highway section can be determined into the linear vector data extraction. In this way, we can obtain the actual linear trajectory of each highway section (e.g., the red line segment in Fig. 13).

(3) Updating of basic data and electronic map

The extracted practical linear trajectories of the offset sections (Fig. 14) were inputted into the basic database of rural highways to replace the original sections. The corrected line types of rural highways matched the existing electronic map and basic database of rural highways in Xianyang City. Meanwhile, the basic database information of rural highways was corrected. Newly constructed rural highways in the recent two years were plotted to the electronic map of rural highways, and the basic data were filled in.



(a) Sanyuan County (b) Qian County (c) Chenzhou City
(d) Changwu County (e) Chunhua County (f) Wugong County

Fig. 14. Correction of the remote-sensing images of rural highways

5. Conclusions

A full-process management basic data model based on dynamic linear location was proposed in this study according to the existing application results of linear referencing in GIS. This work also achieved the dynamic management of the linear referencing system of highways by researching and developing a rural highway management system. Moreover, the convenience of this system was verified according to the basic data of rural highways in Xianyang City, China. The following major conclusions have been drawn:

(1) The full-process management basic data model of highways can realize management over dynamic changes and trajectory records of the linear referencing system.

(2) The built rural highway management system allows for the inquiry of rural highway information and offers a convenient way for highway management departments to acquire route data and conduct decision-making analysis.

(3) The proposed rural highway management system is applied to rural highways in Xianyang City, China. The system realizes the visualization of local rural highway network information and improves the informationization degree of local rural highway management.

Overall, the proposed rural highway management system can master the highway network status comprehensively, increase the utilization rate of highway information sources, and provide solutions to the full-process management of rural highways and basic data sharing among different business systems. In future studies, the proposed system shall be further refined, optimized, and simplified according to practical needs of rural highways.

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