A Research on Fast Acquisition Technology of Spatio-Temporal Data of Railway Infrastructure Based on Measurable Real Image

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ABSTRACT

The spatiotemporal data of railway infrastructure plays an important role in the development of railway informatization, but existing collection technologies have problems such as low efficiency, high cost, and many limitations. Starting from different business application scenarios in railways, this article first conducts a comprehensive investigation and analysis of the business requirements for spatiotemporal data of railway infrastructure. Then, by studying new surveying and mapping technologies such as GNSS+IMU combined positioning technology, laser point cloud scanning technology, and real scene video acquisition technology, a railway measurable real scene image acquisition device is developed to achieve the integrated collection of device operation trajectory positioning data, point cloud data, and real scene video data. At the same time, real scene image calculation technology is used to obtain measurable real scene image data along the railway line, thereby achieving rapid collection of railway infrastructure spatiotemporal data based on measurable real scene images. Finally, experimental verification was conducted on the circular railway line of the National Railway Test Center, successfully collecting and obtaining the spatial and mileage coordinates of various professional infrastructure along the circular railway, as well as accurately measuring the geometric dimension information of various facilities and structures.

Keywords: Railway spatiotemporal data; Real time image acquisition; New surveying and mapping technologies; GNSS+IMU; Laser point cloud.

1. INTRODUCTION

In May 2020, General Secretary Xi Jinping made an important approval to promote the safety management of railway external environment. In August, 2020, China State Railway Group Co., Ltd. issued the Outline of Railway Advance Planning for Powerful Transportation Countries in the New Era [1], which also pointed out that China's railways will continue to advance towards digitalization, intelligence and intelligence, and the spatio-temporal data of railway infrastructure is the most basic and core data foundation in the development of railway informatization.

At present, traditional operation methods such as mileage measurement, middle base leveling and traverse (GPS) control network are mainly used for spatio-temporal data acquisition of railway infrastructure in China, which have many working procedures, complicated operation and low efficiency. With the continuous emergence of new surveying and mapping technologies, some scholars at home and abroad have also applied satellite remote sensing surveying and mapping technology, three-dimensional laser scanning technology and aerial photogrammetry technology to three-dimensional spatial data acquisition of railway infrastructure: using satellite remote sensing surveying and mapping technology to realize the measurement of three-dimensional coordinates of existing lines and orbits [2-3], high-speed railway precision measurement [4], etc.; Using three-dimensional laser scanning technology to obtain track center line, rail, catenary and other equipment and facilities[5-7]; Using aerial photogrammetry technology to obtain and monitor water and soil information, screen geological disasters and evaluate railway infrastructure status in key sections around the railway[8-10]; Using rail trolley to realize accurate three-dimensional coordinates, long track measurement and high-precision line measurement of railway track center line[11-12]; Using mobile measurement technology to realize the collection and measurement of geographical basic information along the railway [13].

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Table 1. Comparison of advantages and disadvantages of spatiotemporal data collection technology for railway infrastructure

Number	Measuring method	Advantages	Disadvantages
1	Traditional operation mode	High measurement accuracy	Large personnel investment, high risk and low efficiency
2	Satellite remote sensing mapping technology	The location information of the target can be obtained quickly	Data acquisition can not be carried out in the satellite signal occlusion area
3	3D laser scanning technology	The point coordinate data with high precision can be obtained quickly	The post-processing of data is complicated and the cost of data acquisition is high
4	Aerial photogrammetry technology	Flexible operation and high work efficiency	The accuracy of data is low, and the qualification examination of aerial photography by railway is strict
5	Mobile measurement technology	The relative precision is high, and the railway track adjustment can be output	The acquisition speed is slow, and the accuracy of the line curve is greatly affected

From Table 1, it can be seen that the relevant collection techniques for spatiotemporal data of railway infrastructure have their own advantages and disadvantages, which are limited by factors such as collection time cycle, investment cost, and technical difficulty, and cannot be fully promoted. This article studies a measurable real-life image acquisition device suitable for railways. By quickly obtaining measurable real-life images along the railway line, relative measurements (height, slope, etc.), absolute coordinate measurements, and attribute information of various facilities along the railway line can be achieved on the measurable real-life images, obtaining spatiotemporal data for obtaining railway infrastructure.

2. REQUIREMENTS ANALYSIS

2.1 Railway Equipment Management

In terms of railway equipment management, railway infrastructure spatial data can provide a quick means of querying the location of equipment, statistical analysis of the spatial distribution of equipment along the entire railway line or a certain section, spatial correlation management of equipment, and viewing the changes of equipment in time and space.

Realize comprehensive and precise management of railway equipment in terms of spatial location and distribution throughout the entire cycle. By utilizing spatial relationships and establishing relationships between railway equipment, it is possible to achieve linkage management between different railway equipment. By utilizing the temporal relationship of spatial data, it is possible to analyze the spatial displacement changes of railway equipment. At the same time, it can also achieve the overlay display of data from different sources of railway equipment, and achieve unified and centralized management of railway equipment data from multiple directions, levels, and angles.

2.2 Railway maintenance and repair

By utilizing the mutual conversion relationship between the spatial coordinates and mileage coordinates of railway infrastructure, it is possible to quickly locate maintenance equipment and diseases on the map, enabling maintenance personnel to quickly locate the location of maintenance equipment and carry out timely maintenance work. At the same time, based on the spatial relationship of railway maintenance and repair equipment, its impact range can be quickly analyzed, providing reference for staff to carry out on-site maintenance and repair work of railway equipment.

2.3 Railway Line Patrol

When conducting railway line patrol work, utilizing spatiotemporal data of railway infrastructure can enable on-site patrol personnel to quickly locate the location of infrastructure along the railway line. Before carrying out patrol tasks, the starting position of patrol personnel and the position of patrol equipment can be used to simulate patrol routes, providing multiple alternative patrol route schemes for patrol personnel. Meanwhile, utilizing spatiotemporal data of railway infrastructure through GIS network analysis, the optimal patrol route can be calculated, providing reference for patrol personnel to formulate reasonable patrol plans.

2.4 Railway Emergency Rescue

In terms of railway emergency rescue, the use of railway infrastructure spatiotemporal data can quickly locate and locate the location of the accident point, quickly search for rescue resources around the accident point, and quickly select the nearest rescue vehicle to the accident point. Railway infrastructure spatiotemporal data, accident location, rescue vehicle location, and electronic map information can also be used to digitally simulate the rescue route, calculate the optimal rescue route, familiarize workers with the rescue route, and achieve smooth and rapid rescue work at accident points, minimizing accident injuries. At the same time, utilizing spatiotemporal data of railway infrastructure can quickly analyze the scope and level of impact caused by accident points.

2.5 Railway terrain and landform monitoring

Based on the spatiotemporal data of railway infrastructure, digital simulation of the terrain and topography along the railway can be carried out, which can roughly understand and grasp the settlement of slopes and roadbeds along the railway, as well as the slope and aspect of the terrain along the railway, providing reference for the acquisition of railway geography and topography.

2.6 The demand for spatiotemporal data in railway line retesting

According to the relevant provisions of the "Code for Surveying of Railway Reconstruction Projects" TB10105-2009 [14] on the re survey of existing lines, the content required to be included in the re survey results of the line includes: topographic plan of the line, longitudinal section map of the line, line plan map, etc.

Table 2. Contents of retest of railway public works lines

Classification	Main content
Basic inform ation of the l ine	Line mileage, plan, longitudinal section (slope, change of grade p oint), stations (turnout, track, signal, etc.), structures, building lin e boundaries, line spacing, etc.
Precision con trol network	Divide by line and type of pile point, with pile points as the un it, including their number, location (mileage and location, etc.), ti me and result, and maintenance status of pile points (initial const ruction, damage or loss, restoration, etc.).
Surrounding environmental information	Terrain and landforms, vegetation coverage, up and down passag e, sand excavation and soil extraction, illegal construction, illegal occupation of land, illegal construction, foreign object intrusion, etc.

3. RESEARCH ON MEASURABLE TECHNOLOGY

3.1 GNSS + IMU combined positioning technology

GNSS is a global navigation satellite system, which is a collective term for GPS system, Galileo system, Glonass system, and Beidou navigation system. When conducting satellite positioning, it is necessary to ensure that there are at least four visible satellites, and their position estimation equations are shown in equation (1):

$$\begin{aligned} \rho_1 &= \sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2} + c\times\delta_t \\ \rho_2 &= \sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2} + c\times\delta_t \\ \rho_3 &= \sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2} + c\times\delta_t \\ \rho_4 &= \sqrt{(x-x_4)^2+(y-y_4)^2+(z-z_4)^2} + c\times\delta_t \end{aligned} \tag{1}$$

Among them, x, y, z represent the position of the receiver, c represents the speed of light, δ_t is the delay amount of the receiver, ρ_1, ρ_2, ρ_3, ρ_4 represents the distance from the satellite to the receiver, x_1, y_1, z_1 represents the spatial position of the satellite.When the signals of more than four satellites are obtained, the least square method or Kalman filter [15] is generally used to solve the position.

Relying solely on GNSS for positioning can only achieve meter level accuracy, and cannot provide higher precision location services and meet location accuracy requirements. In order to achieve centimeter level positioning accuracy, real-time dynamic carrier phase difference technology (RTK technology) is required [16]. The precise coordinates of the RTK reference station with known precise coordinates and the corrected values of the carrier phase are sent to the user, and the user receiver calculates the accurate position results through the established carrier phase difference observation model [17]. However, its positioning accuracy is greatly affected by GNSS satellite signals and is susceptible to human interference and electronic deception.

Inertial navigation systems have advantages such as concealment, persistence, and strong anti-interference ability, as they do not require external signals. When satellite navigation fails, the inertial navigation system can continuously output the information required for navigation. It can not only provide the speed and position information of the carrier, but also the attitude information of the carrier [18].However, inertial navigation systems have the disadvantage of divergent positioning accuracy over time (i.e. poor long-term stability).

Therefore, this article adopts a deep coupling integrated navigation system of GNSS and Inertial Measurement Unit (IMU) to improve the overall performance of the positioning system. The GNSS system includes three satellite positioning systems: Beidou, GPS, and GLONASS, with seven frequency points of L1, L2, B1, B2, B3, G1, and G2. The single point positioning accuracy is 1.2m horizontally and 0.6m vertically, and the RTK positioning accuracy is 0.02m horizontally and 0.03m vertically. Dual antenna heading accuracy of 0.09 ° . The IMU system adopts high-precision industrial grade inertial devices, with an output frequency of 200Hz and a combined navigation attitude accuracy of 0.02 ° . The working temperature of the integrated navigation system is -40 ℃~70 ℃.

3.2 Laser Point Cloud Scanning Technology

The working principle of laser point cloud scanning technology is to emit detection signals (shock beams) to the target, and then compare the received reflection signal (target echo) with the transmission signal. After appropriate processing, relevant information about the target can be obtained, such as distance, orientation, height, velocity, attitude, shape and other parameters, so as to detect, track and recognize the target [19]. The use of laser point cloud scanning technology can also collect depth information of the target surface, obtain relatively complete spatial information of the target, reconstruct the target's three-dimensional surface through data processing, obtain three-dimensional graphics that better reflect the geometric shape of the target, and obtain rich feature information such as reflection characteristics and motion speed of the target surface, providing sufficient information support for data processing such as target detection, recognition, and tracking, and reducing algorithm difficulty, Featuring high measurement resolution, strong anti-interference ability, strong penetration ability, and all-weather operation.

3.3 Real-life image solution technology

Using the multi baseline digital close range photogrammetry method to achieve accurate geographical location calculation of targets in real scene images, based on the principle of computer vision (multi baseline) instead of traditional photogrammetry principles of binocular vision (single baseline), the basic rule of photogrammetry changes from the intersection of two rays at a spatial point to the intersection of multiple rays at a spatial point [20], Using multi baseline forward intersection instead of single baseline forward intersection in traditional close range photogrammetry, by shooting a large number of sequence images with short baselines and different intersection angles, and establishing spatial relationships through a small number of control points and their corresponding pixel coordinates, the phase parameters and external orientation elements of the image are calculated, and then the spatial coordinates of the same named point obtained by the matching algorithm are calculated to obtain the spatial position of the target.

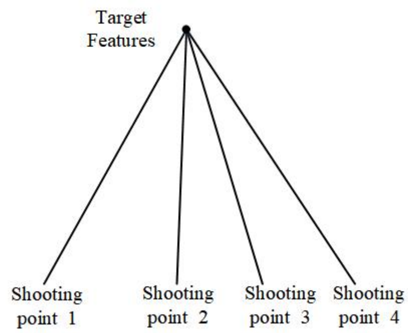


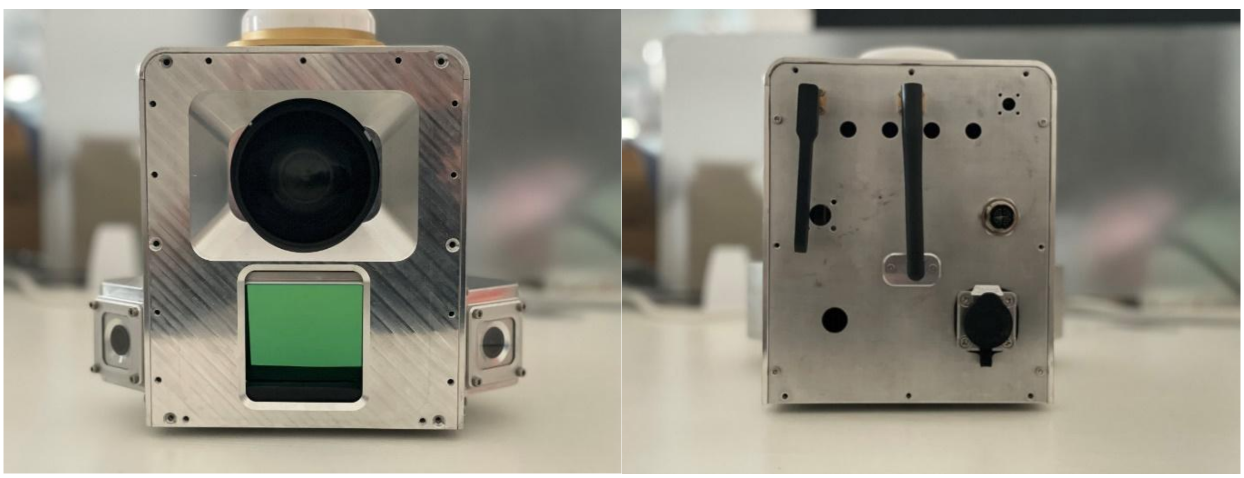
Figure 1. Schematic diagram of multi-baseline-digital close-range photogrammetry.

4. RAILWAY SPATIOTEMPORAL DATA COLLECTION TECHNOLOGY

4.1 Measurable real-life image acquisition device

4.1.1 Design of Acquisition Device

Based on the design concept of "integrated acquisition", professional equipment such as 3D laser scanning equipment, real scene image acquisition equipment, combined navigation and positioning equipment, as well as non professional equipment such as lenses and battery modules are embedded and integrated into one. The operation is portable and simple, achieving data acquisition at a horizontal field of view of 180 degrees and a vertical field of view of 180 degrees. Simultaneously use three suction cup bottoms to strongly adsorb the collection device onto the car window, ensuring the stability of the device during the collection process.



（a）the front （b）the back

Figure 2. Prototype of the appearance design of the collection device.

4.1.2 Functions of the acquisition device

(1) Collect high-precision three-dimensional coordinates and mileage information of railway lines;

(2) Collect measurable real-life images along the railway line;

(3) Collect point cloud data of railway infrastructure such as overhead contact wires and signals along the railway line;

(4) Collect video data of the surrounding environment along the railway line.

4.1.3 Collect results and technical indicators

The collection results and technical indicators achieved are as follows:

(1) Combination positioning data

The accuracy of plane coordinates is better than 20cm; Attitude accuracy roll/pitch 0.02 °, heading 0.09 °.

(2) Point cloud data

The accuracy of plane coordinates is better than 15cm, and the accuracy of elevation coordinates is better than 10cm; Up to an average of 200 points per square meter (within 100 meters, up to 100 km/h speed).

Real time images: The accuracy of plane coordinates is better than 20cm, and the accuracy of elevation coordinates is better than 15cm.

(3) Collection speed

Maximum 160km/h.

(4) Camera resolution

Photo resolution: 4096 * 2160; Video resolution: 1920 * 1080.

(5) Field of view angle

The horizontal and vertical field of view angles of the real scene image are both 70 °;

The horizontal and vertical field of view angles of the line video are both 180 °.

4.2. Extraction of spatio-temporal data of railway infrastructure

Based on the fusion of mobile rapid positioning and inertial navigation technology, the real scene camera parameters, including camera position and attitude information, are obtained using the GNSS+IMU combined positioning system. Then, based on real scene image processing and comprehensive data fusion iterative solution, depth information is assigned to each real scene image using laser point cloud data to obtain the depth image of the real scene image. Finally, using computer image recognition algorithms and real-time image comprehensive solution technology, the infrastructure along the railway line is extracted and solved, achieving the measurement of three-dimensional coordinates and spatial geometric information of railway infrastructure on a single image.

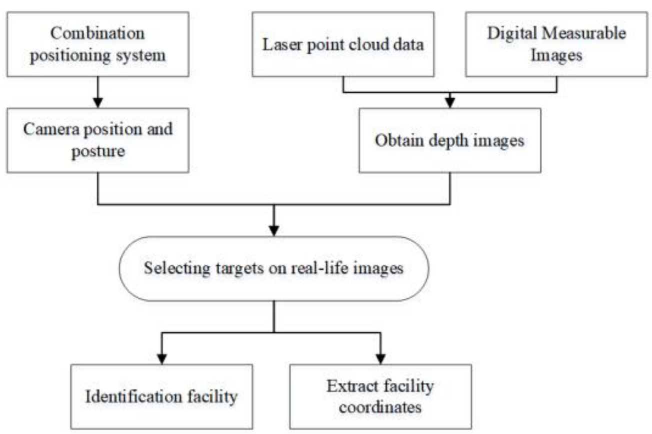


Figure 3. Extraction process of spatio-temporal data of railway infrastructure.

4.3 Research on Fast Matching Technology of Railway Spatial Coordinates and Mileage Coordinates

Based on high-precision and high-density driving trajectories, and based on the given starting and ending point information of a road section, a railway linear mileage system is constructed using linear reference dynamic segmentation technology. It can dynamically calculate the actual geographic coordinates corresponding to the relative positions on the linear data based on the relative position information stored in the attribute table and the corresponding linear data, thereby achieving rapid matching between railway infrastructure spatiotemporal data and mileage coordinates.

4.4 Test

The measurable real scene image acquisition device was experimentally verified on the circular railway of the National Railway Test Center. The experiment adopted a technical route of rapid acquisition of real scene images, extraction and construction of facility and hidden danger data databases, and integrated updating mode, as shown in Figureure 4. The final measurable real scene image obtained is shown in Figureure 5.

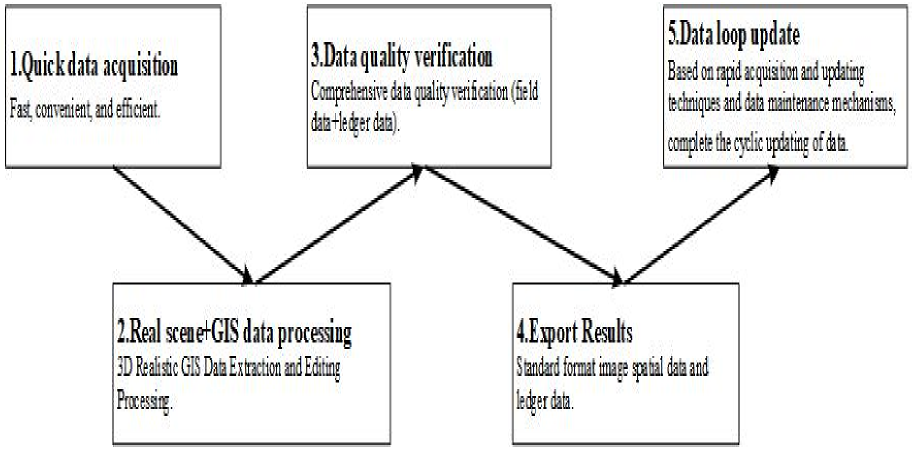


Figure 4. Technical route of the experiment.

Figure 5. Measurable real-life image.

The operations that can be achieved on measurable real-world images include:

(1) Extract the spatial coordinates and mileage coordinates of various equipment and facilities in the entire railway profession;

(2) Accurately measure the dimensional information (length, width, height) of railway equipment, facilities, and structures;

(3) View real external environmental information along the railway line;

(4) Identify various safety hazards and extract data.

5. SUMMARY

In response to the existing problems such as incomplete spatial information of railway infrastructure, difficulty in collecting and low efficiency of existing technological means, high cost of collecting new technologies, and difficulty in promoting and applying them, we fully combine the needs of various railway business application scenarios for railway infrastructure spatiotemporal data, and integrate GNSS+IMU combination positioning technology, laser point cloud scanning technology, and real scene image solution technology, Develop a measurable real-time image acquisition device suitable for railway operation status, to achieve rapid collection of railway infrastructure spatiotemporal data, provide fast, independent, on-demand, economical, long-term, and safe technical means for obtaining railway infrastructure spatiotemporal data, and provide data completion and rapid updating means for existing railway infrastructure spatiotemporal data, To provide data support for the preparation and verification of completion acceptance materials for new railways, and to provide basic spatiotemporal data support for the digitization, intelligence, and intelligence of China's railways.

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