Research on the application of BDS/GIS/RS technology in the high speed railway infrastructure maintenance

Jianfeng Yang¹, Xuejiao Bai²*, Zhuoxin Zhang¹, Meihao Yang², Peifen Pan², Tao Liu², Lijun He², Jifeng Zhang² and Tao Tao²

¹ Tianjin Railway Section, Beijing Railway Administration, Tianjin, 30011, China
² Institute of Computing Technology, China Academy of Railway Sciences Corporation Limited, Beijing, 100081, China
*Corresponding author’s e-mail: baixuejiao@rails.cn

Abstract. The high-speed railway infrastructure maintenance is the key to ensure the safe operation of the railway. The technical characteristics and advantages of BeiDou Navigation Satellite System (BDS), Geographic Information System (GIS), and Remote Sensing (RS) are analysed for integrated application based on the practical application of professional engineering infrastructure monitoring, equipment inspection, disaster prevention and warning, workers management and time synchronization, and the solution of intelligent monitoring system for high-speed railway infrastructure maintenance was proposed. And this system supports visual display of vector and electronic map, status query of workers, trains, equipment and infrastructure for remotely monitoring, detecting and managing, which can provide low-cost, reliable and accurate information services for the security monitoring and management of the high-speed railway infrastructure maintenance.

1. Introduction

With the rapid development of China’s railway technology, service, turnover volume and rail network scale, a high-speed railway network with reasonable layout, wide coverage, safety and efficiency has basically been formed. Railway infrastructure maintenance is an important part of the railway system and also a key infrastructure in the process of high-speed railway construction, operation and maintenance [1]. The high speed and high density of high-speed trains have different degrees of impact on the infrastructure equipment along the line, leading to an increase in the rate of train failures. It is essential to improve the maintenance and inspection efficiency of the engineering department, improve the monitoring level of infrastructure, and form a reliable maintenance management process [2]. In recent years, with the development of emerging technologies such as BDS Satellite Navigation System (BDS), Geographic Information System (GIS), and Remote Sensing (RS) in China, the detection and monitoring accuracy of facilities and equipment along the rail track has been improved. These technologies have great advantages in reasonably arranging and controlling the construction work of railway critical staff, saving the manufacturing and maintenance of existing equipment and labour costs as well [3,4].

In this paper, the technical integration of BDS, GIS and RS were concerned for railway equipment testing, facility monitoring, environmental disaster monitoring, safe operation management and other aspects, which forms a professional solution in the field of inspection and monitoring of high-speed rail facilities. A dedicated intelligent monitoring system software is designed to effectively improve
the information level of high-speed railway operation and maintenance, which is convenient for managers to perform remote monitoring and early warning.

2. BDS, GIS, RS TECHNOLOGY

2.1. BDS
Focusing on the needs of national security and economic and social development, China has built and operated independently BDS satellite navigation system. BDS-3 system inherits the BDS-1 active positioning system and the BDS-2 passive positioning system, also can reach the performance requirements of 10 meters worldwide and 5 meters in the Asia-Pacific region, 20 nanosecond timing accuracy, and service availability better than 95% [5,6].

In terms of railway engineering project applications, some departments apply BDS high-precision positioning and short message communication services in the field of safety operations [7], disaster monitoring [8], etc. The equipment of track inspections, rail-car monitoring and personnel positioning terminal is still based on GPS technology, which is difficult to meet the actual positioning requirements for monitoring facilities along the high-speed railway.

2.2. GIS
GIS is a technical method, research entity and application tool for comprehensive storage, management, analysis, display and application of geographic information [9]. Through professional technologies such as remote sensing and drone aerial surveying, geographic information can be collected on key areas, line elements, and special buildings along the railway.

China's railway engineering project information management system is generally based on GIS, such as the former Ministry of Railways Electronic Center's public works management information system based on Mapstreme, and the Beijing Railway engineering works geographic information query system based on Geo Graphics Gis, which are mainly static applications.

2.3. RS
RS is a tool for spatial data collection, identification and classification [10]. RS is characterized by its ability to collect spatial information in a dynamic and multi-temporal manner, and it is an important means to obtain ground resources and environmental information.

The characteristics of RS can be summarized as: ①Wide detection range and rapid data collection; ②Dynamic reflection of ground environment, facilities and state changes; ③The data has the same current status in time, and can form two-dimensional or even three-dimensional distribution information.

3. TECHNOLOGY INTEGRATION AND PRINCIPLE
Through the analysis of the technology application, BDS, GIS and RS have important application value in high-precision positioning and timing, basic location data and status data management analysis, data collection and change monitoring, any technology cannot be separated from the other two technologies [11]. Combine BDS, GIS and RS organically to establish an interface mechanism for management system to realize the comprehensive processing, dynamic analysis, integrated management, and visual display of multi-source spatiotemporal data and information.

3.1. BDS and GIS integration
GIS services include vector maps, track electronic maps, 3D image maps, etc. The track electronic map is a part of the railway infrastructure and operation and management elements. The second-level classification of railway geographic information involving public works and infrastructure monitoring includes: railway roadbed, tracks, bridges, culverts, tunnels and security facilities [12].

Basic data of railway lines generally include drawings and parameter data, and the generated line space data with mileage information can be produced through professional tools. Export the data to ArcGIS shapefile format to extract orbit feature point information from the map data, and use the
extracted orbit feature point information for actual site sampling surveys. The procedure is shown in figure 1.

Figure 1. Procedure of track electronic map production.

Based on the national basic geographic information and railway basic information to display the relationship of the location of the engineering infrastructure along the line, it can locate the status monitoring of facilities and equipment, and display the location of high-speed integrated inspection trains, track inspection vehicles, and tunnel inspection vehicles in real time.

Through the GIS 3D model of stations, sections and special equipment, the high-speed railway equipment is refined management and the 3D model of bridges, tunnels, towers and other infrastructures are displayed. These constitute high-speed railway engineering facilities 3D monitoring network combined with BDS positioning and communication methods.

3.2. GIS and RS integration
BDS cannot directly reflect the changes along lines, environment, and conditions during the construction and operation and maintenance of railway engineering projects. RS can monitor railway external safety hazards and safety protection, also update GIS map information in real time.

GIS provides important auxiliary information for RS image processing, effectively improving the resolution and information of remote sensing images, and correcting RS images through digital related technologies [13]. The large span of the high-speed railway and the complex environment along the line make the RS images with medium and low spatial resolutions insufficient to express their complex feature information in detail, while the high-resolution remote sensing images can be better on a smaller spatial scale. Integrating multi-source data, spectral characteristics, spatial relationships and other context relationships, it can effectively extract bad geological information in sensitive areas, display surface deformation and subsidence on GIS maps comprehensively. The GIS-assisted environmental RS change detection process along the high-speed railway is shown in figure 2.

3.3. BDS and RS integration
BDS and RS have monitoring capabilities at different application levels, the combination of the two technologies can improve the monitoring level of facilities along the high-speed railway, covering all monitoring objects such as bridges, tunnels, roadbeds, slopes and so on, realizing the improvement of monitoring accuracy in the same area and the complementary monitoring methods.

It can effectively promote the data interaction and the integration within the region of different types of rail information systems through integrated BDS, GIS and RS techniques.

4. REPRESENTATIVE APPLICATION
After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared
4.1. Application of the railway infrastructure monitoring and detecting

It can perform high-precision calculations in real time and meet the different positioning accuracy and continuity requirements in the field of professional infrastructure inspection and monitoring of public works by receiving the signal from the BDS satellite and the differential correction broadcast by the railway ground-based augmentation system. The monitoring and detecting of the on-site railway infrastructure can be achieved through combining the scene monitoring terminals and other sensors, such as the inertial measurement unit (IMU), the accelerometer, etc. It will output accurate, reliable, continuous and stable results according to the corresponding logic determines after data aggregating and processing.

The installation location and deformation trend of the railway infrastructure were displayed using GIS to realize remote real-time measuring and monitoring of monitoring points. This will help to short detecting cycle and cost of the key equipment, and to improve the level of monitoring and detecting in the full cycle of construction and operation maintenance of the high-speed rail. The application architecture diagram was shown in figure 2.

Figure 2. The application architecture diagram of the railway infrastructure monitoring and detecting
4.1.1. Monitoring of the railway track bed
To enhance the real-time monitoring of embankment settlement, improve accuracy, the work has become an important railway work. The monitoring of the railway embankment based on BDS and GIS include the real-time monitoring of embankment settlement, the real-time monitoring of the thaw deposit and frosting heaving deformation and the detecting of compacted quality of roadbed.

The monitoring of embankment settlement: The embankment settlement monitoring was mainly to monitor the thickness, compactness, abnormal water content, and subsidence of the high-speed railway embankment. The BDS observation station was set up to monitor the railway track bed, and the settlement of the railway embankment surface was calculated and analysed though the sedimentation amount and the pressure variation based on the BDS high precision positioning technology, and the abnormality detection thresholds were set or different environments and terrain requirements.

The real-time monitoring of the thaw deposit and frost heaving deformation. The thaw deposit and frosting heaving deformation are mainly distributed in the cold region of in the northeast and northwest China, the roadbed surface bump caused by the frozen soil swelling, which will lead to railway track irregularity of high-speed lines. It can monitor the trend of subsidence and accurately determine the base surface uplift caused by temperature and moisture based on the BDS high-precision positioning technology, which as an auxiliary for frost heave monitoring and track smoothness detection.

The detecting of compacted quality of roadbed. The high-precision positioning device can provide the location information of each detection point during the compacting process of roadbed by the road roller at the stages of engineering design or construction transformation. The inspection line was planned based on the GIS map, we can obtain the distribution condition of the compaction status along the railway roadbed according to the collected vibration signals to realize the remote management of the compaction quality inspection.

4.1.2. Detecting of the railway track condition
Irregularities of high-speed rail tracks can cause train shaking, abrasion of rails and wheels, this will affect the stability, comfort and safety of trains during operation, and even serious traffic accidents. Track irregularities mainly include four types: longitudinal level of rail, horizontal level of rail, track irregularities and gauge irregularities. And the main inspection equipment includes the dynamic track inspection car, light track inspection car, measuring chord length and rail gauge, etc. one of the mature technology is the light track inspection car with the core measuring equipment of the high-precision total-station, which can reach an absolute position accuracy of 1.5mm. However, the measurement efficiency of the total station from pillow to pillow is low, and the measurement conditions are demanding, and the original CPⅢ reference network needs to be retested many times.

The BDS measurement antennas, the high-precision processing and solving unit, IMU and other sensors can be added to the existing track inspection trolley, that is the integrated positioning by the BDS technology and the inertial navigation technology is used to carry out high-precision measurement of orbit. Combining with the reference coordinates provided by the BDS reference station (the error of the real time kinematic (RTK) result was increased with the increase of the distance of the BDS stations, the error is usually represented as 0.5-1ppm×1km, so the distance between the reference stations is about 2km.) laying along the track, the track inspection car can move to measure and detect the in real time. At the same time, fusing the information of the BDS static positioning and multi-sensors to make the absolute measurement. And the high-precision united computation was taken using the post-processing calculation software to meet the requirements of track regularity with the accuracy of the millimeter level. In the process of measuring, the suitable points were selected to statically received the satellite signal for 3-5 minutes according to the requirements of the measuring length. when a problem arises, the GIS map can be used to pinpoint the location of irregular track for checking out and dealing with the irregular. The detecting technology of the track smoothness based on the BDS high-precision positioning technology can meet the requirements of measuring accuracy, and effectively improve the detecting efficiency and reduce the costs, the technology has the advantages of automation, all-weather, accurate positioning, etc.
4.1.3. Monitoring of the bridge condition
The bridge-monitoring is mainly for the self-deformation, fracturing and other phenomena that occur when the train passes due to uneven ground pressure. According to the technical conditions of railway bridge operation monitoring, the main monitoring item is the vertical deformation monitoring of the bridge. The fusion of BDS and other sensors can also be used to monitor the vertical deflection and vibration of the bridge. Different monitoring locations, such as the mid-span and beam ends of girder bridges, the vaults and feet of arch bridges, and the piers of large bridges, are set up according to different types of bridges. The BDS high-precision monitoring equipment which the receiver and the antenna can be installed separately was used to monitor the bridge condition. It should be ensured that the BDS antenna installed at the monitoring point where has a good view of the air, and the satellite signal is connected to the receiver in the equipment box by the coaxial signal cable within the lightning arrester. For bridge monitoring, the BDS reference stations should be placed along the railway where settlement or deformation is not prone to occur, and the differential correction data and the ephemeris should be broadcast to the data convergence center. The high-precision calculation was achieved by the data convergence center using the received data from the reference station and the monitoring station at the same time, and the accuracy can reach centimeter level or more. The monitoring management center was used to establish a warning mechanism of deformation threshold to trigger an alarm when abnormal deformation occurs, and to maintain the automation and continuity of the monitoring process.

4.1.4. Monitoring of the tunnel and the slope condition
The monitoring of the tunnel and the slope condition mainly includes horizontal and vertical displacement monitoring of the tunnel entrance and exit slope, slope platform and slope top. The monitoring of the tunnel and the slope condition, like the track bed monitoring and the bridge monitoring, uses BDS and GIS technology to dynamically analyze the displacement and deformation trends of key facilities in real time. And combined with traditional displacement sensors or grating sensors, to accurately determine and locate the stability of tunnels, uphill slopes and high slopes. And the results can be used for predicting the development trend of slopes. GPS-based monitoring methods are mature currently, and the upgrading and replacement of BDS equipment can effectively improve the accuracy and reliability of the monitoring results.

4.1.5. Positioning of the detection car
There were a large number of special-purpose vehicles, such as various types of public works inspection vehicles and mechanical vehicles, which are responsible for the dynamic inspection of domestic high-speed railway lines and the fixed facilities of existing lines and road maintenance. The BDS+ GPS dual system positioning unit has been installed and applied on the high-speed comprehensive inspection train right now. Because of the single-point positioning method the positioning accuracy is from meter to 10 meters. The inspection vehicles equipped with GPS units inspection vehicles equipped with GPS units should be retrofitted to a single BDS or BDS+GPS module, and the satellite antenna should be reconfigured to increase the frequency band of BDS-3.

The inspection vehicle also can support the collection of geographic information data and the location data of key facilities to form and continuously update the railway GIS database. Therefore, the vehicle-mounted positioning terminal should support pseudo-range differential and RTK to realize the signal acquisition and processing under high dynamic conditions based on multi-channel parallel acquisition and high-speed computation (data update rate up to 100Hz), and the satellite data was organically combined with the inertial navigation to realizes continuous output of solution results. The positioning accuracy of RTK can reach the sub-meter level, and combining the map matching technology to realize accurate vehicle strand-level identification, which effectively improves the accuracy of detecting vehicle positioning and operation efficiency.
4.2. Disaster Monitoring and preventing
Both the high-speed railway and existing railways are facing the impact of disasters which resulting in economic losses and safety accidents. Among various disasters, the abrupt geological disaster, such as landslides, collapses, and mudslides, account for a huge proportion. BDS technology can accurately monitor landslide disasters in real time, and provide assistance for disaster early warning.

Also, like both the slope monitoring and the tunnel slope monitoring, BDS RTK and BDS precise point positioning (PPP) were applied to achieve rapid, accurately and real-time acquisition of observation data for deformation monitoring. The RTK technology based on BDS can reach a horizontal accuracy of 2-3mm and an elevation accuracy of about 5mm, which can meet the needs of disaster warnings of landslides and the treacherous mountainous areas. Furthermore, BDS can provide a reliable emergency communication link in the event of disasters, driving accidents or other emergencies. It can support short messages service between the geological hazard points and the emergency operation center even in areas with poor mobile net or no mobile net coverage.

4.3. Dynamic Monitoring of Environment
It is a most quick and most effective approach to monitoring and identifying environment along the high-speed railway used multi temporal remote sensing images at present. The multi-temporal remote sensing images covered the high-speed railway were collected and pre-processed for visual interpretation, object identifying, decision tree classifying, quantitative retrieving to detect the inclusion distribution and endanger degree of the illegal construction, the illegal appropriation, the invasion of the trees and other things outside the geofence in key areas, so based on above process the database for environmental safety hazard identifying using the high-resolution remote sensing technology were constructed. The types of hidden hazards and its effect factors can be identified based on the database, the orientation information by BDS were combined to add the hidden dangers areas and environmental anomaly regions to GIS map for constructing the dynamic environment monitoring system based on BDS, RS and GIS (figure 3).

Figure 3. Environmental dynamic monitoring using BDS+GIS+RS technology
The environment along the railway can be dynamically inspected by combining with the BDS handheld terminal, and the returned information of environmental safety hazard location can be used to quickly viewing in remote sensing images and GIS maps for precise positioning, the site personnel can be guided to take timely and accurate measures.

4.4. Management of Patrol Operators

The real-time location coordinates for engineering surveys, line patrol, and constructing operations can collected by BDS high-precision positioning, and the information were transferred through a dedicated network transmission channel to realize the location monitoring, progress management, safety early warning, equipment management, historical track playback and other functions for patrol operators.

The patrol operators were equipped with the BDS intelligence terminal and monitored in the whole process based on GIS map, and it support the safety warning of human and vehicle, electronic fence alarm, production plan management, trunked communication, status self-inspection, etc. The terminal received the high-precision differential data with sub-meter positioning accuracy which computed using the RTK technology and broadcasted by the railway BDS service platform. The distance between people and vehicles was accurately calculated through obtaining the location information of the high-speed trains, the detecting vehicles and other vehicles, and the operators were urged to evacuate to a safe area based on the alarm threshold set by the system. The patrol operators can collect the information of the potential security liability and regional abnormalities to assist in environmental monitoring, equipment checking, etc., and maintain contact with the professional systems to cooperate with on-site management. Figure 4 shows the schematic of the patrol operators management.

4.5. Application of the Time Synchronism

The GPS-based railway time synchronism system has a three-level structure of China Railway, the railway bureau and the railway sectional station, the time server transfer time information to the sub-system of this layer after GPS timing device receiving the satellite time service, yet the monitoring system of various railway maintenance infrastructures, the testing equipment and the inspection vehicles have not achieved time synchronization. Time information is the basis for providing data for the infrastructure monitoring, the emergency rescue and daily maintenance, The BDS system can provides precisely timing with an accuracy of 50ns. The time synchronism network was building to ensure the unification of the internal clocks of various monitoring equipment and terminals, and to realize the time synchronization of the inspection vehicle, the equipment, and the management
organization, which can provide an accurate and unified time tag for data collecting, abnormal monitoring, message feedbacking, safety warning, etc. to perform scientifically and accurately events retrospective and big data analytics.

5. STUDY ON THE INTELLIGENT MONITORING SYSTEM SCHEME

The intelligent monitoring system is based on BDS technology as the main monitoring method, and integrated with the intelligent infrastructure monitoring system, the equipment monitoring system and the people and vehicles positioning monitoring system which supported by GIS and RS to realize the functions of infrastructure monitoring, key equipment detecting, dynamic environment monitoring, disaster preventing and early warning, personnel and vehicle positioning, remote communication, and GIS visualization operating, etc. The intelligent monitoring system can monitor bridges, tunnels, roadbeds, slopes, changes of environment in real time based on the reference stations placed near the monitoring body, the monitoring and detecting objects can be dynamic visibility for querying information in real time by the maintenance administrator. Issue early warnings and important news notifications in a timely manner.

The system structure is composed of fieldwork collecting devices, data aggregation of BDS/multi-source sensors, intelligent monitoring center software and other auxiliary support applications. After the location, status, and other business data collected by the on-site collection device were aggregating through public network of the operator, the data were safely isolated and processed through the railway computer network security platform, and then entered the central computer room of the station and section for providing visibility into the amount of change and real-time location and status of the people, vehicles and other things. The overall structure is shown in figure 5.

The intelligent monitoring center visually displays the BDS high-precision data and the multi-source fusion results according to the needs of monitoring, detecting and other important applications of Railway Maintenance. The software includes 9 parts:

1) The time-changing trend diagram and warning of the roadbed settling and deformation monitoring, the 2-D display and the 3-D display of the monitoring position and equipment.
2) results outputting of the track regularity detecting, pre-warning of abnormal conditions, data logging and replay of the track position and equipment status.
3) visual display and forewarning analysis of the monitoring results of the vertical deformation, vibration and deflection for a structure of bridges.
4) visual display and monitoring of displacement and deformation of the tunnel, the slope and the landslide, which equipped with stability analysis, disaster warning prediction and prompt function.
5) position orientation of the railway inspection vehicle and the track inspection vehicle, and it’s visual display and data integration.
6) the task management and early warning for railway patrol person, and real-time message reporting and processing for abnormal points.
7) Real-time monitoring of the surrounding environment of high-speed rail, visualizing the potential safety hazards, and issuing early warnings in time.
8) abnormal event tracing and big data analyzing.
9) Integrate with railway BDS application service platform, railway geographic information platform, remote sensing technologies and other services, and posting early warning and abnormal information to the railway dispatching stations and the station management.

The software displays monitoring data and analysis results to managers with a nicer interactive interface constructed by HTML/CSS/JS technologies, and uses WebGIS technology to render maps and WebSocket technology to achieve communication of monitoring data, message data, and abnormal information. The core components include the WebService data receiving components and the TCP/UDP network communication components, and displayed through the combination of Thymeleaf template engine and SpringBoot. The software integrates BDS, GIS and RS technologies for support applications such as infrastructure monitoring, equipment detection, disaster warning, and
human, vehicle and environmental supervision. Figure 6 describes the interface of the software application.

Figure 5. The intelligent monitoring system
CONCLUSION

The intelligent high-speed railway is the future directions for global railways, so it is an important research trend to improve our country's high-speed rail secure guarantee ability using the emerging technologies. In this paper, we hammer out an application solution for the railway infrastructure maintenance by researching the technical integration and service capabilities of BDS, GIS and RS, and the intelligent monitoring and management system for the railway infrastructure maintenance is developed to realize the railway infrastructure monitoring, the equipment detecting, the disaster monitoring and early warning, the environment dynamic monitoring, the security management of people and vehicles, the time synchronism and other functions, which have important and practical significance for building an intelligent operation system of the railway infrastructure maintenance.

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