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REVIEW ARTICLE

Railway Defect Detection Method: A Review

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ABSTRACT – The railway is indeed one of the main transportations means in the world. However, with the rapid development and advancement of the railway industries, more railways accidents occur mainly due to its defects which result in economic losses. Traditionally, the railway defect detections process which is deems to be dirty, difficult and dangerous are done manually by the railway maintenance workers. In the recent years, many sophisticated equipment such as portable detectors, track inspection trolleys, track comprehensive inspection vehicles, etc had been developed. This article outlines two main mode of inspection namely static and dynamic inspection, which are commonly used in the railway defect detection and maintenance work. Furthermore, the railway inspection equipment used by the major countries are summarized and the impact on railway inspection based on deep learning and artificial intelligence are appropriately predicted.

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INTRODUCTION

The train transport is the one of the important methods of transportation which transfer passengers and goods on wheeled vehicles running on rails. The railway track is made up of many important equipment, for example rail, sleeper, ballast, track bed and so on. Indeed, the railway equipment is the basis of rolling stock and train operation and directly bears the pressure from the wheels of rolling stock. In order to ensure that the train can operate safely, smoothly and uninterrupted at the specified maximum speed, the railway transportation department can complete the task of passenger and freight transportation with good quality, the railway lines must be kept in good condition at the time. However, with the continuous rolling of locomotives and long-term train loads, the track geometry of the railway line continues to deteriorate. The subgrade and ballast bed continue to produce deformed rails, couplings and sleepers, resulting in continuous changes in the technical status of the line equipment. In order to keep the railway line in good condition for a long time to ensure the safe and stable operation of the train, regular maintenance and repair operations are required. If maintenance are carried out in accordance with the standards and cycles, the track may deviate from the design value which may cause discomfort to the passengers and in worst condition may lead to rollovers or casualties, which in turn cause irreparable economic losses [1].

Currently, high-speed railway mileage in many countries is increasing year by year, such as China, the United States, France, Spain, Germany, Japan, etc. [2], as shown in Figure 1. The continuous increase in railway mileage has caused a corresponding increase in labour costs and decrease in net profit. In order to improve the line detection ability, different inspection equipment have been put into maintenance work. This article discusses the common inspection equipment used for railway defect detectors and compares it according to its advantages and disadvantages.

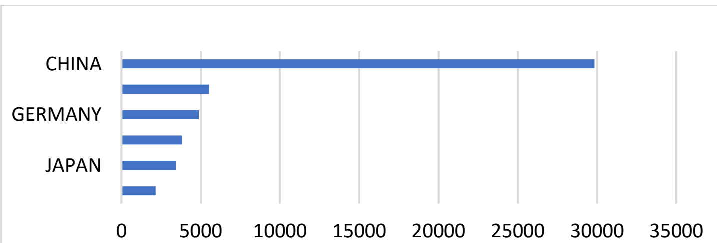

Figure 1. High-speed railway mileage.

TRACK STATIC INSPECTION

Static inspection has changed from traditional manual inspection to new inspection methods such as mechanical and electronic circuit inspectors and three-dimensional precision measurement systems. In the process of track static inspection, worker need detect track gauge, track cross level, track alignment etc. [3]. Standard-gauge railway refers to the standard gauge of 1435 mm (4 feet 8½ inches) established by the International Union of Railways in 1937. The gauge is wider than the standard gauge. It is a wide gauge, and a narrower gauge is called a narrow gauge. The gauge of 60% of the railways in the world is standard gauge [4]. As shown in Figure 2, when a train takes a curve, centrifugal forces come

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into play. In order for the train not to derail in a curved track, a positive track cross level difference between the outer and inner rails needs to be in place. The level difference between the rail heads also called track cross level or super elevation is one key parameter to calculate at which speed a train can travel through a curve [5].

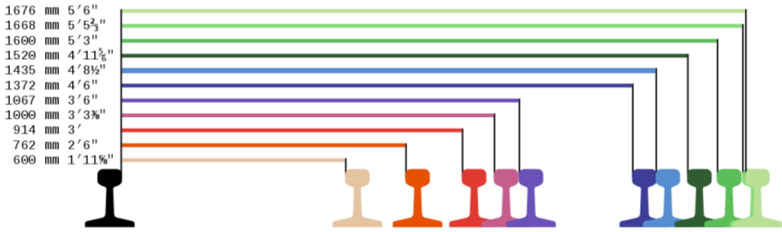

Figure 2. Railway Gauge.

Track Geometry Gauge

Vibrations and the impact of high-speed trains are affecting track geometry to a huge scale. Besides heavy wear and tear of the track, the track gauge, track cross level and track alignment are getting affected. The track geometry gauge is mainly used to measure the gauge and cross level (super elevation) of the line. The accuracy is divided into three levels: 0, 1, and 2; the 0-level gauge is used to measure the line with the allowable speed less than 350 km/h, and the first-level gauge is used to measure the allowable speed less than 250 km/h. The line, the level 2 gauge is used to measure the line with the allowable speed not greater than 160 km/h [6].

Manual gauge is a traditional measure instrument. Manual gauge is usually used to measure railway speed not greater than 160 km/h. During the measurement process, the accuracy of the values can be affected by many aspects, such as the checking time, the judgment standard of the personnel, the position of the observation, the placement of the instrument, etc. Therefore, this instrument is not suitable for high-precision high-speed railway line detection, and if there are occurrence of combination factors as discussed above, it may also affect the line status of ordinary-speed railways [7].

Digital gauge is a new type of track geometry gauge. Comparing with the manual measure instrument, the digital gauge greatly improves the accuracy and ease the measurement work in track maintenance since it is equipped with records such as rapid numerical display, automatic temperature compensation, and over-limit alarm [8]. The CALIPRI measurement module ‘Track Geometry’ evaluates track gauge, super elevation and rail cants. Furthermore, it has the capability to calculate the twist in order to detect irregularities during the measurement on site and initiate the necessary maintenance tasks directly. In combination with the CALIPRI measurement modules ‘Rail’ and ‘Equivalent Conicity’, the maintenance worker would receive information on track geometry, rail wear and equivalent conicity values with only two measurements. Therefore, in an environment where railway speeds continue to increase and work intensity increases, digital gauges provides and easier and safer working environment.

In daily maintenance, workers use the track geometry gauge to detect the gauge, track cross level, and super elevation. The purpose is to keep the two rails at the correct standard value. The value needs to be based on the relevant maintenance standards [1]. But at present, the track geometry gauge can only complete some basic data detection, and the workers need to consume a lot of physical energy, and the work efficiency is low.

Track Inspection Trolley

The geometric state detection of high-speed railway tracks is to detect the vertical and lateral deviations and irregularities of the track under the condition of no train load, and the detection results are used as the main basis for track adjustment. It is a new technology to use the track inspection trolley to detect the geometric state of the track. It calculates the centre mileage of the line by measuring the prism coordinates installed on the track inspection trolley. The prism coordinates on the track inspection trolley are not the centre coordinates of the line. Characteristics, the calculation and conversion model of mileage and coordinates of straight line, circular curve and transition curve are studied, and the track detection calculation software is compiled, and it is successfully applied to the geometric state detection of a high-speed railway track [9].

The track inspection trolley consists of a measuring trolley composed of gauge and track cross level measuring devices, a fuselage prism and an industrial computer, a high-precision total station, and a wireless communication unit. It detects the internal geometric status of the railway track and external geometric state (track centreline deviation, elevation deviation). It is the great significance to the laying of high-speed railway ballast bed structure, the laying of long rails, the fine adjustment of long rails and the later maintenance [10].

GEDO CE

The GEDO CE track inspection trolley produced by the German Sinning company, which has a mature and stable measuring system, which is suitable for fine adjustment of double sleeper type ballastless track (such as Radar 2000, manual construction by Schuplin), turnout laying, long rail laying, joint adjustment and joint test, line maintenance, etc. Engineering projects on the railway. GEDO Vorsys is a very complete solution in the GEDO track measurement system family. It has been widely used in the European railway industry. Its function is to quickly collect line data, obtain the deviation between the design value and the measured value, and analysing it through software. The data of the optimal starting amount and shifting amount are transmitted to the tamping machine in a digital way. At the same time, the tamping operation plan is designed to guide the accurate operation of the tamping machine [11].

The GEDO CE test shows that when the equipment is in a static and moving state, the error of the measurement point data is very small. When the equipment is in different speed states, it adopts automatic mode to collect, the result shows that the error is very small. In summary, it is shown that GEDO CE performs well under various conditions and the data is stable [12].

Figure 3. GEDO Vorsys system.

Amberg

Amberg GRP 1000 track inspection trolley is mainly used for track geometry measurement. It uses built-in gauge measurement, ultra-high measurement and mileage measurement sensors to perform measurement operations. At the same time, it uses LEICA total station and its own prism to determine the track inspection trolley's position to provide the absolute coordinates and orbital parameters of each measurement point on the orbit [3].

Amberg GRP VMS adopts the relative measurement principle based on absolute control, which perfectly combines absolute measurement and relative measurement, and uses CPⅢ more efficiently, which can greatly improve the measurement efficiency while ensuring high accuracy. The system consists of a data collection car and a satellite car. In addition to integrate mileage, super-elevation and gauge sensors, the data collection car is also equipped with a control point measuring instrument, which can measure the horizontal and vertical distances from the track to the control point. A total station with automatic target tracking function is installed on the satellite launching trolley. The total station uses an automatic levelling base without manual levelling, which can save a lot of time. A wireless communication device is used for communication between the two cars. The product has been tested by the German market and has mature performance [13].

Figure 4. Amberg Mobile Mapping.

SOUTH

The SOUTH track inspection is made of China. TGS FX standard hand-push type track inspection trolley assembled with sensors for track gauge measurement, track super elevation measurement and relative mileage measurement. It can automatically identify the target LEICA TCA2003, TCA1800, TCARA1200, TCRA1201 and other total stations, which can ensure the accuracy and reliability of the measurement. At the same time, the track inspection trolley has strong field operations and data processing capabilities. A radio modem can be used for data communication between the computer and the total station. The equipment has stable performance and high accuracy. It is currently used by many companies in China and has also been used in railway construction in countries along the 'Belt and Road' [14].

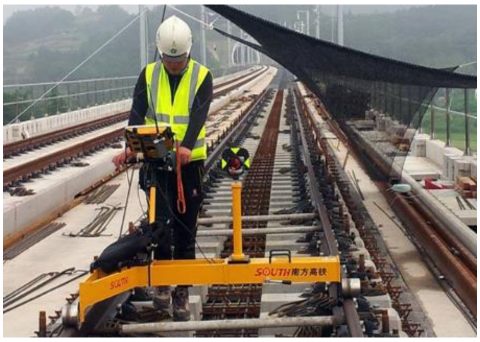

Figure 5. South Inspection.

Rail Defect Detector

With the development of ultrasonic testing technology, ultrasonic testing technology has become the main method of railway track defect detection. European countries and Japan and other developed railway countries have successively launched various forms of ultrasonic rail defect detection equipment, including portable hand-push defect detectors, automatic rail defect detection vehicle and special rail defect detection train.

Portable Hand-Push Defect Detector

Portable rail detector is a multi-channel defect detection device that uses ultrasonic probes to detect defect inside in-service rails. It is mainly composed of a defect detector host, a probe, a water tank and a carrier trolley, etc., in addition to a display that can display the rail defect in real time, and the partition displays A-scan and B-scan images for on-site observation by defect detectors. However, the defect detection trolley requires the maintenance worker to push forward, and there may be underreports while walking. Therefore, the data collected by defect detection generally has to implement the secondary playback mode to detect the defect of the rail, the first time is that the line defect detector employees are at the scene according to the display of the A-type image wave, and judge on the spot whether there is defect to the road section being detected; the second is to send the stored B-type image data to the data centre for playback analysis, and review whether to defect again or not [15].

Figure 6. Hand Push Portable Rail Defect Detector.

Rail Defect Detection Train

Rail defect detection trains (Figure 7) are high-speed rail defect detection equipment, which can be in service at the same time the two rails are defect detection. Due to its high cost, it is mainly used for the detection of trunk railways and subways. It has high efficiency; however, the original system cannot be optimized for independent learning, and the detection effect of small-sized rail head nuclear injuries is poor, and it is prone to miss inspections and cause false alarms. High-speed railways and ordinary railway tracks are relatively smooth, and the detection performance of steel rail defect detection is less disturbing; in heavy-duty railways, the track line conditions are poor due to the larger pressure, resulting in a low detection rate of small target defect in the rail defect detection process [16].

Figure 7. Rail defect detection train.

Automatic Rail Defect Detection Vehicle

Due to the higher cost of large defect detectors, small hand-pushed defect detectors are less efficient. Subsequently, engineering research experts invented an automatic two-track trolley, which has better detection performance and higher work efficiency than the trolley, which can achieve effective defect detection [17].

Figure 8. Automatic rail defect detection vehicle.

Track Dynamic Inspection

Track dynamic inspection is the geometric state detection of the line by the train at a constant speed. At present, track dynamic inspection has gradually formed a detection system with comprehensive inspection cars and track inspection cars as the main part, supplemented by vehicle-mounted line checkers and portable line detectors [18].

France Iris 320 High-Speed Inspection Vehicle

At the end of 2006, the SNCF 4530 train was transformed into an “Iris 320” measuring train, making it possible to have a complete locomotive dedicated to monitoring high-speed lines in France and Belgium. Therefore, this can reduce restrictions on the use of “Melusine” trailers and traditional survey trains (for example, VSEhuo Corail+BB 22200 cars with a speed limit of 200 km/h). Although the power car was not modified, the trailer was modified. The Iris 320 train adopts the power mode of two trains and trailers [19].

The Iris 320 high-speed inspection vehicle simplifies the infrastructures inspection work for high-speed railways and some existing railways, and the total length of the railway lines that have been inspected has reached 7,500 km. This new type of inspection vehicle can only complete the inspection of various functions at the highest line speed, but also provide commercial services on the line. One advantage of using this new type of inspection vehicle is that it is no longer necessary to inspect high-speed railways during the maintenance period. More frequent and rigorous inspections of tracks, electrical equipment, signals and telecommunications systems are also conducive to improving maintenance efficiency, changing the way of passive maintenance of line infrastructure, and developing to preventive maintenance. The goal of the research and development of the new line infrastructure inspection vehicle is: the inspection vehicle has a high driving speed, has the ability to complete all inspection items in one journey, can conduct frequent inspections, and can more easily prevent failures through data analysis. A train of Iris 320 high-speed inspection vehicles can inspect 3500-5000 km lines every week, and can inspect 20,000 km lines every year. According to technical development requirements, the high-speed train and on-board equipment are maintained every 3 months [19].

Figure 9. Iris 320.

CIT

Abbreviation for high-speed comprehensive inspection train, CIT is a series of the railway's comprehensive inspection of EMU trains is for high-speed railway infrastructure with a speed of more than 200 km/h implement regular inspections, comprehensive inspections and high-speed inspections. Important technical equipment, with the right track, basic equipment such as pantograph contact network, communication signal, etc.

CIT001 detection train: it is 250 km/h comprehensive inspection train; the official name is “0 high-speed comprehensive inspection train”. It integrates the world’ s advanced dedicated detection system line track, traction power supply, communication signal, etc. Infrastructure, wheel-rail and bow-net contact status and when the train comfort index and other high-speed dynamics null synchronization detection, and real-time data transmission, storage and analysis processing functions. Achieved the modern measurement, spatial-temporal positioning synchronization, large-capacity data exchange, real-time image recognition and data integration office advanced technology, such as science and technology, is to improve the foundation of high-speed railway infrastructure inspection efficiency, guide maintenance and repair, important technology to ensure the safety of high-speed railway operations equipment [20]. CIT-380A detects train: it is speed 350 km/h high-speed comprehensive inspection train. The train is to obtain the CRH-380A EMU the aerodynamic efficiency of the new head type of the group and the actual vehicle test data, using CRH-380ANew head type, added on the basis of the original EMU testing equipment and transformed into a formal high-speed comprehensive check the train together. CIT-400A detects the train: it is the 400 km/h high-speed comprehensive inspection train. Based on the new head type CRH-380A line modified inspection train, designed maximum speed 500 km/h. CIT-500 test train is now in the latest high-speed comprehensive inspection train of the National Railway [21].

Figure 10. CIT-500.

GeoRail-Xpress

The inspection vehicle was jointly developed by the German GBMWiebe Rail Engineering Machinery Company, Bennlec Systemtechnik Joint Stock Company and Deutsche Bahn. The visible and invisible parts of the line can be fully digitalized measurement, collection and analysis, and the detection speed is designed at 100 km/h.

The main equipment of the GeoRail-Xpress comprehensive inspection vehicle includes: (1) Geological survey equipment, consisting of a radar system equipped with 4 antennas, with a maximum detection depth of 4m; (2) Tunnel inspection equipment, consisting of a side wall equipped with 4 antennas and top detection radar system; (3) line and environment detection device, composed of 4-dimensional orbit environmental cameras; (4) track detection device, composed of 6 laser sensors and 2 digital line scan cameras; (5) sleepers and ballastless track detection device is composed of 4 digital line scan cameras for detecting concrete cracks; (6) The rail head detection device is composed of 2 high resolution line scan cameras for detecting the condition of the rail head; (7) The absolute position is determined Satellite positioning synchronization device. When these devices work synchronously, the positioning accuracy can reach 0.5 m [22].

East-1

As the train speed continues to increase, the inspection vehicle is required to increase its speed accordingly to obtain the same inspection data as the train's maximum operating speed and shorten the inspection time; in addition, the inspection vehicle must meet the inspection requirements for the direct operation of the Shinkansen and existing lines. The East-I Shinkansen electric rail comprehensive inspection train of East Japan Railway Company was put into use. The train uses the 700 series electric vehicle group, 6 marshalling (the 3rd car is the track inspection car, the rest are the communication signal and power inspection car), and it is used on the Shinkansen and the existing line running directly with the Shinkansen. The maximum speed is respectively 275 km/h and 130 km/h, thus realizing the integration of maintenance and management of Shinkansen and existing lines. The inspection items of the inspection train have been expanded from the original 59 items to 88 items. The overlapping parts of the contact wires and the crossover parts that have been manually inspected have all been automatically detected. The head of the train is equipped with a camera device, which can monitor the condition of the track and surrounding structures at any time; other detection devices include the opposite train detection device, lateral acceleration detector, bogie detection device, laser gyroscope, noise meter, contact wire interval measurement Device, impact detector, pantograph height detector, contact wire wear detector, etc [23].

Figure 11. East-I.

Archlmede

The Archimede high-speed comprehensive inspection vehicle of the Italian Road Network Company (RFI) is manufactured by MerMec and consists of a dual-stream E402B series locomotive, 4 trailers and 1 driving car. Archimede is used to measure track geometry, rail cross-section and wear, and running quality, and to detect contact wire geometry, wear and pantograph-net contact, including video inspection of track and catenary. It can also detect signals and communication equipment [24].

Locomotive Vehicle-Mounted Track Dynamic Monitoring System

The locomotive vehicle-mounted track dynamic monitoring system" consists of a monitoring device installed on the locomotive and a ground receiving system. It comprehensively judges the smoothness of the line according to the locomotive vibration level caused by the uneven line during the operation of the train, and the magnitude of the acceleration in the two vertical directions. Degree. The system can automatically identify the deviation level according to the deviation standard, and generate guidance line maintenance through computer processing. It has the characteristics of short detection cycle, strong continuity, uniform standards, no human factor, and clear disease search. When the data exceeds the alarm value , the system will give real-time voice and SMS alarms, and timely eliminate the premises that seriously exceed the standard through on-site inspections, and further scientifically guide the railway department to maintain the lines to ensure safe driving [25].

Portable Line Tester

Portable line tester is one of the important line test equipment. It is a kind of high-tech testing equipment that mainly uses the line management personnel to place the portable line detector in the locomotive cab, and judges the line status through the vibration acceleration during train operation. By using the checker to add trains, it is possible to timely and accurately find the faulty location of the line, and carry out targeted repairs to prevent the aggravation of the disease, improve the maintenance efficiency, ensure the quality of the line, and ensure the safety of the train [26]. However, the currently used portable line detectors have the following problems, among which mileage drift is one of the most common data quality problems in the current track dynamic detection data. In order to solve the problem of mileage drift, Qin Jinqing adopted a new type of portable line detector based on inertial sensor components, which effectively improved the accuracy of mileage calculation and calibration of urban rail transit line detection data [27].

Figure 12. Portable line tester.

COMPARISON OF DIFFERENT DETECTION METHODS

The detection methods of track static detection and track dynamic detection are systematically summarized above. By enumerating the testing equipment in different railway countries, it can be concluded that there are corresponding testing tools for static testing and dynamic testing.

Table 1. Table Railway detection Comparation.

Item	Track static inspection	Track dynamic inspection
Principle	In GPS positioning, it is considered that the position of the receiver antenna remains unchanged relative to the earth throughout the observation process, and in data processing, the position of the receiver is regarded as a non-time-varying quantity.	Every 300 mm forward of the vehicle, the computer collects data for each monitoring project once. When the acquisition amount of a project exceeds the minimum disease limit value for three consecutive times, it is counted as an initial defect. The maximum acquisition value of the defect is the amplitude of the overrun defect, and the minimum defect starting point is the length of the defect.

Table 1. Table Railway detection Comparation (cont)

Item	Track static inspection	Track dynamic inspection
Detection method	The track detector or track gauge is used to detect the track irregularity. Although the speed is slow, the track gauge can obtain the absolute coordinates of the track. Combined with the design data, the deviation of the plane position, the absolute deviation of the elevation, the ultra-high deviation and the deviation of the track distance can be obtained, which can be used to guide the fine adjustment of the high-speed railway.	High-speed inspection vehicle can quickly reflect the track statue, such as gauge, level, height, cross level etc. The maximum detection speed is determined by the different countries' inspection vehicle.

Future

Through the analysis of the railway inspection methods and equipment in the fast-developing countries in the world, it is concluded that the railway department should establish a relatively complete railway line dynamic and static inspection, maintenance and management system. Through continuous optimization of testing equipment, we can better meet the requirements of high-speed and safe railways, improve testing speed, reduce labour costs, and further realize the scientific development concept of low carbon and environmental protection. Based on existing cloud computing, Internet of Things, and big data , Artificial intelligence, robotics, next-generation communications, satellite navigation, BIM and other new technologies, through the comprehensive perception of railway mobile equipment, fixed infrastructure and related internal and external environmental information, ubiquitous interconnection, fusion processing, active learning and scientific decision-making, efficiently and comprehensively utilize all railway resources such as mobile, fixed, space, time, and human resources to realize highly informatized, automated, and intelligent railway construction, transportation, and entire life cycle, making it safer, more reliable, more economical, efficient, and more comfortable. A new generation of railway transportation system that is more convenient, faster, more energy-saving and environmentally friendly.

For the part of detection, more and more companies use the detection machines which apply the deep learning. The technology not only can use the big data to detect the railway structure damage, but also it can record the data efficiently and effectively more. Besides that, using the artificial intelligence also can achieve the intelligent monitor to reduce the labour strength.

SUMMARY

As the world's railway traffic and traffic density continue to increase, the external loads on rail structures are also climbing. Although static detection and dynamic detection can effectively detect the geometric data and internal state of the track structure respectively. If they cannot be used in combination, damage would still be missed. Therefore, the railway department must reasonably formulate the inspection cycle and detection range according to the line condition and actual situation when formulating dynamic and static inspections.

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