Missing Detection System of Railway Track Fastener Based on Machine Vision

Part1、Framework Conditions of the Solution

In recent years, the rapid development of railway construction in China has put forward higher requirements for the modernization of track repair and maintenance.

Due to the role of driving load and natural environment, the track will produce various defects in the process, which poses a threat to the safety of train operation. Such as rail damage, sleeper damage, fastener missing, the whole track bed cracking, etc.

At present, the manual inspection method has a large workload and lacks systematic detection records. The accuracy and frequency of detection have difficulty in meeting the specified requirements especially in complex lines, such as rain and snow, sand and dust, high cold and long tunnels.

For the main diseases of the line occurring on the rails, fasteners and other components, the inspection vehicle can detect the inside of the rail by taking the flaw detection method. But it has not realized the effective detection of the surface, especially for the fasteners missing.

Part2、The Goal of the Solution

In order to deal with the problems above and improve the efficiency of the detection, we devote to studying the missing detection method of rail fasteners based on machine vision. We put forward a new method to solve the problem of

the lack of the automatic rail inspection equipment in our country. That is the research of the portable visual detection system for the rail-fasteners missing. The requirements of the system are as follows:

(1) The hardware structure of the system should be portable and removable.

(2) The architecture of the detection system should fully consider the actual detection environmental conditions of the line, such as the shooting conditions provided by the field detection space, the interference degree of the external light source to the system, and the normal operation ability of the system in a harsh environment.

(3) The overall cost of the testing system should be controlled to avoid the high expense. So as not to prevent the promotion of this testing equipment.

(4) Accurate detection of missing fasteners on railway tracks.

Part3、①Technical Proposal

(1) Detection Equipment

In order to meet the requirements of the portability, we build a rail inspection trolley that can run directly on the railway track. Its shape refers to the design of the metal flaw detection car. And a light shield should be added to the surface of the rail. The trolley has good scalability to meet the needs of the rapidly developing railway for the inspection.

(2)Image acquisition device

The image acquisition device is mainly composed of a CCD camera, a light source, and

an image acquisition card.

The CCD camera generates the original data of the orbit area image, collects the image data through the frame grabber and sends it to the computer processing system.

（3）Algorithm and software implementation

After the collected data is sent to the computer, the original image is directly located by the regional localization algorithm based on the sudden change feature of the track H value, and the rail surface image and the fastener area image are obtained, and then the track defect detection is realized by combining other image processing methods.

Vision and LabVIEW were then used to write image processing models and system software according to algorithms.

（4）The human-computer interaction system

LabVIEW was used to write a human-computer interaction system based on portable track defect vision system. The interactive system could directly observe the original image information collected by CCD camera, the setting of relevant camera parameters, and the real-time track defect detection results. The defect alarm was represented by buzzer and red light flashing.

②Functional description

(1) Image acquisition and processing.

The car is equipped with high-definition cameras, which can collect images of railway tracks in real time.

The acquired images will go through pre-processing and image enhancement steps to improve image quality and contrast and ensure the accuracy of subsequent defect detection.

(2) Missing fastener detection.

Machine vision algorithms, such as feature extraction and template matching,

are used to analyze the pre-processed images.

Through comparison and analysis, the system can automatically identify and locate the position of the fastener.

When a missing fastener is detected, the system will immediately sends an alarm and marks the exact location of the missing fastener.

(As shown in the figure, theoretically real-time detection of 3.51m/s~3.84m/s can be realized, then it can be concluded that the system processes each picture for 245.61ms in the detection of missing fasteners, and the system can replace manual inspection to a certain extent, and realize the digital management of track defects.)

(3) The structure is stable. Able to adapt to the different environments and conditions of railway tracks.

(4) Human-computer interaction operation, result display and recording function. According to the actual situation of on-site staff, simple human-computer interaction operation is designed. The human-computer interaction system provides real-time detection screens, and the staff can confirm the detection results on the spot, and adjust the system parameters in time to ensure the best operation of the system. The interface of the human-computer interaction system can display real-time dynamic waveforms of detection results, and also has the function of automatic data classification and recording and printing reports. This function can be used for predictive analysis of track status and guidance for on-site construction by maintenance personnel.

Part5. Secure indexing

(1) In terms of system reliability, the detection system should have high

reliability, be able to operate stably under various environmental conditions, and ensure the accuracy and credibility of the test results. This includes the ability to resist disruptive factors such as inclement weather, light changes, track dirt, and more.

(2) In terms of detection accuracy, the system should have high detection accuracy and be able to accurately identify the absence of fasteners. This requires a high degree of sensitivity and specificity of the system's image processing and analysis algorithms to reduce the possibility of false positives and false negatives.

(3) In terms of real-time, the detection system should have real-time detection capabilities, so as to detect the missing fasteners in time and take corresponding safety measures. This requires efficient image processing and analysis speeds, as well as fast data transmission and responsiveness.

(4) In terms of stability and robustness, the system should maintain stability during long-term operation, and have strong robustness to various interferences and noises in the process of image acquisition, transmission and processing of rail fasteners to ensure the stability and reliability of the detection results.

(5) In terms of ease of use and maintainability, the detection system should have a good user interface and operation process, which is convenient for staff to operate and maintain. At the same time, the system should have

self-diagnosis and self-recovery functions to reduce manual intervention and maintenance costs.

Part6. Operational guidance

6.1、Preparation

(1) Check the power supply. Make sure the power supply of the trolley is normal and the switch is off.

(2) To connect the device. Make sure all relevant devices and accessories are connected, such as cameras, sensors, etc.

(3) Check the device status. Make sure the device is in place and in good condition.

6.2、Start & Stop

(1) Start-up. Press the start button and wait for the system self-test and calibration to complete.

(2) Upper rail. Move the trolley from the parking position to the track, making sure that the wheels are firmly attached to the track to ensure stable operation.

(3) Control. Through human operation, the forward and backward actions of the trolley are controlled.

(4) Stop. Slow down and stop first, then press the stop button and disconnect the power supply.

6.3. Testing process

(1) Operation control. After starting the trolley, the direction and speed of the trolley are controlled by human operation to ensure that it follows the predetermined route.

(2) Image acquisition. During the inspection process, pay attention to the image display and data acquisition to ensure that the data is accurate.

.(3) Pay attention to the results displayed. Pay attention to the human-computer interaction system to display the test results, and confirm the correctness of the comparison test results.

6.4 Precautions

(1) Maintenance: Regularly maintain and maintain the trolley, and check whether the equipment and accessories are in good condition.

(2) Standard operation: Follow the complete standard procedure to ensure the accuracy of the test results.

(3) Safety observation: During operation, observe the surrounding environment and risks to ensure the safety of personnel and equipment.

(4) Emergency response: In the event of an abnormal or unexpected situation, stop the vehicle immediately and take corresponding measures.

(5) Maintain communication: Keep communication open throughout the inspection process for rapid response in case of emergency. 7 Planning and Implementation Steps:

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7.1 Information gathering and planning phase

7.1.1 Collection of Information

(1) Research status of foreign orbital detection systems. At present, based on non-contact visual inspection, foreign countries have developed and

produced an automated inspection vehicle system that can basically replace manual inspection. Its general characteristics are a high degree of automation, high detection accuracy and effective recording of defect locations, which can guide the repair and maintenance of the line in a targeted manner. Such as France IRIS320 track detection system; United States ImageMap's track inspection system; Japan's East-i orbital detection system; Australia's EM-250 orbital detection system, etc.

(2) Research status of domestic rail detection system. At present, China has developed five generations of comprehensive rail inspection vehicles: GJ-3, GJ-4, GJ-4G, GJ-5 and No. 0. Due to the high cost of rail inspection cars, the number of railway bureaus is limited, and they cannot be used for daily inspection of lines. The detection content mainly includes track gauge, track direction, height, triangular pit, level, car body acceleration, etc., but lacks the detection of rail defects such as rail wear, rail surface defects, and missing fasteners.

7.1.2 Planning stage

In view of the shortcomings of the current domestic track detection, according to the basic principle of machine vision, the design scheme of the railway track fastener missing detection system is determined, which mainly includes four parts: image acquisition, image processing, data recording and detection trolley design. Equipment selection is carried out according to the testing requirements and site conditions; In terms of software, a fast and effective

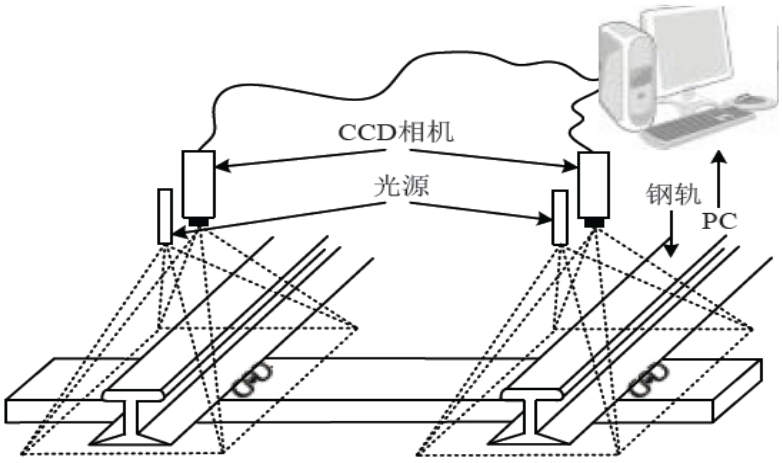
image processing algorithm is proposed, and the program is written by using LabVIEW. From the perspective of the portability of the system, the rail inspection trolley that is easy to handle and disassemble is designed, and the field experiment is verified.

7.2 Decision-making phase for (digital) hardware and/or software use

7.2.1 Decisions on Hardware Usage

(1) Lighting scheme

Based on the design principle of the lighting scheme dominated by the characteristics of the detected object, the fastener area is taken as the basis of the analysis and processing of the acquired images, and their surface features, shape features, position features and their effects on light are fully utilized to obtain high-quality images of the detected objects. Therefore, considering the complex background factors of the track area, the white LED light source and the vertical track surface irradiation method are selected, as shown in Figure 1.



(2) Equipment selection

According to the basic principle of the camera, the FOV of the camera's field of view is as follows:

$$FOV = \frac{1-b}{a} \times \frac{1000}{N}$$

Among them, a is the width of the sleeper (generally 22cm~25cm), b is the sleeper spacing, and N is the number of sleepers per kilometer. According to the classification of sleeper material, the laying status of sleepers in China is counted, of which the spacing of type III sleepers is 60cm, and the sleeper spacing of ballastless track of passenger dedicated line is 62.5cm~65cm. Therefore, the acquired image must contain at least 65cm in length range of the actual line, that is, the longitudinal distance of the image camera's field of view needs to be greater than 650mm.

7.2.2 Decisions on the Use of Software

On the software side, LabVIEW is used for programming.

Picture1. Schematic diagram of a visual track defect detection system

According to the basic design idea based on machine vision and the analysis of the functional requirements of track detection, a fast and effective image processing algorithm was proposed, a portable rail fastener visual inspection model was established, and the software design of the rail fastener detection algorithm system was completed according to the basic method of image processing.

7.3 Specific Implementation Phase

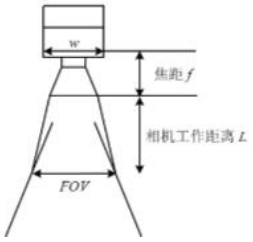
(1) Camera selection

(1) Camera selectionCamera type selection: Combined with the proposed hand-pushed detection method of this system, considering the current system cost in the affordable range and camera imaging quality, the area array CCD image acquisition system is selected for the railway track fastener missing detection system based on machine vision. According to the content to be shot, including the rail surface area and the fastener area on both sides, the longitudinal distance of the camera's field of view should be greater than 650mm. At the same time, the resolution of the image is not less than 0.5mm, and the resolution of the camera selected in this paper is 2048*1536. Microvision's MV3000UC-type color area scan CCD camera was selected,

which was connected to a laptop via USB.

(2) Lens selection

The lens is an important device of the image acquisition device, and the reasonable selection and installation of the optical lens is the basis to ensure the clear imaging. The lens of an area scan CCD camera mainly concentrates the reflected light from the object onto the imaging element to form a clear image projection, as shown in Figure 2.



Picture2 Schematic diagram of the imaging principle of the lens

According to the principle of lens imaging:

$$f = \frac{w}{FOV} \times L$$

Where w represents the size of the imaging element of the CCD camera, FOV represents the field of view of the camera, f represents the focal length of the lens, and L represents the working distance of the camera.

Therefore, the image acquisition device selects the color area array CCD image size of 2048*1536, and the focal length f=16m,the shooting range is 896mm*672mm.

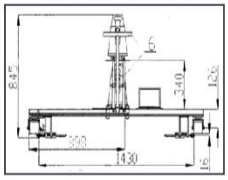
(3) Hood design

Considering the influence of stray light on the detection of defects on the rail surface, the lens hood was designed to avoid the direct irradiation of natural light on the rail surface, and the attitude adjustment device was designed to allow the camera to move up and down, rotate left and right, and move forward and backward in six directions.

(4) Image processor

(5) Considering the cost and portability, the industrial notebook is used as the image processing and interface display carrier.

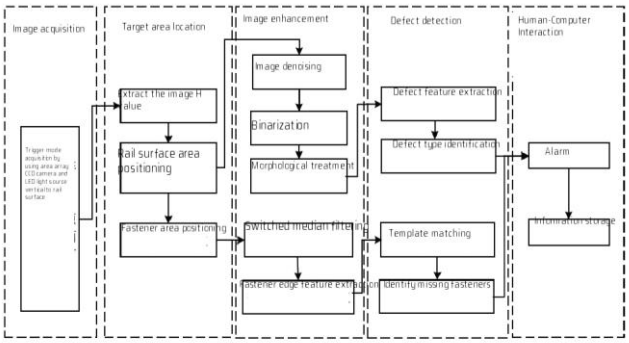
(5) Architecture design



Picture3 Schematic design sketches Picture4 Frame the physical object

(6) Software design

The system realizes track area detection through image acquisition, target area positioning, image enhancement, defect detection, and human-computer interaction design, as shown in Figure 5.



Schematic diagram of software structure of railway track fastener missing detection system based on machine vision

Compared with the traditional method, the system locates the target area in advance, uses the geometric features of the track area to quickly locate the rail area and the fastener area, and then carries out small-scale image preprocessing for the target area, so that the overall speed of the algorithm is greatly improved. The system uses NI's vision development module VBAI to establish the orbital image processing model. This module has a wealth of image processing tools and functions, and is an important tool for those engaged in machine vision and image applications.

7.4 Presentation of the work

(1) Prototype

Fig. 6 Static detection experiment under laboratory conditions

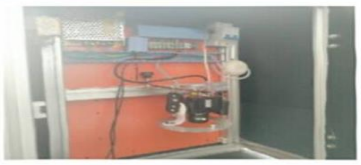


Fig. 7 Dynamic detection experiment under laboratory conditions

Fig. 8 Development of testing machine

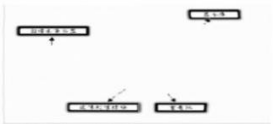


Figure 9 System Prototype

Fig. 10 Development process of system prototype

Figure 11 System Pro totype

(2) Effect demonstration of rail fastener missing detection system

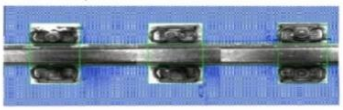
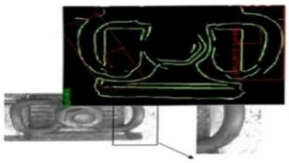


Fig. 12 Acquisition of image information Fig. 13 Fastener area pos itioning



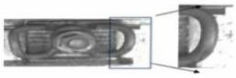


Fig. 14 Original Image Fig. 15 Grayscale Processing Fig. 16 Filtering an d Drying

Figure 17 Image edge extraction Figure 18 Fastener spring bar detectio

8. Description of the tool data used

Serial number	Name	Tool description
1	High speed [CD camera	The system uses high-speed CCD camera as an image acquisition tool, which can quickly capture the clear image of the railway track. The camera has the characteristics of high frame rate and high resolution, which ensures that high-quality image data can still be obtained during high-speed travel.
2	Visual Development Module	The module has a wealth of image processing tools and functions, is engaged in machine vision, image, VBAI of NI
		An important tool for application personnel.
3	LabVEW	A program development environment developed by National Instruments (N1). It has a huge function library, covering data acquisition, GPB, serial port control, data analysis, data display and data storage functions.

9 Time plan

Serial number	Programme of work	Start and end date	Stage work content and planned completion index
1	Field and literature investigation	2023.01-2023.03	Investigate the latest progress at home and abroad, carry out relevant theoretical research, learn from domestic and foreign solutions, and find a breakthrough point.
2	Scheme planning	2023.04-2023.05	According to the research results, the solutions, methods and expected functional effects are determined.
3	Design hardware and software framework	2023.06-2023.08	Hardware and software are designed and selected according to the working environment and expected functions.
4	Construction of detection system	2023.09-2023.12	The hardware and software of the detection system will be built according to the design framework.
5	Test and commissioning	2024.01-2024.03	Carry out relevant tests, obtain test data, and analyze and improve them. Apply for relevant invention patents.
6	Writing materials	2024.04-2024.06	Write reports, PPT and other presentation ma