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Research on Gauge-Ultra-High Dual-Parameter Fusion Measurement Method under ARM Architecture

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Abstract: This study innovatively proposes a synchronized gauge-overheight dual-parameter measurement method based on ARM architecture, aiming at solving the problems of low efficiency, high cost, and insufficient accuracy in traditional railroad track inspection. The method realizes efficient and accurate measurement of track geometric parameters by integrating a high-precision magnetotropic displacement sensor and LCF-100 inclinometer sensor. The system adopts a modularized design, uses an ARM processor as the core, and combines Bluetooth wireless transmission technology to construct a low-cost and high-reliability track inspection system. The application of the Bluetooth module not only simplifies the system wiring but also significantly improves the data transmission rate, which makes real-time uploading and processing of measurement data possible and further improves the system's response speed and work efficiency. In the experimental validation phase, the research team verified the measurement accuracy and stability of the method through multiple sets of comparison experiments. The experimental data show that the repeatability accuracy of the data measurement meets the experimental standards. In addition, the system has good environmental adaptability and anti-interference ability and can operate stably under complex working conditions. Through the in-depth analysis and processing of the experimental data by MATLAB software, the research team further optimized the algorithm, reduced the measurement error, and improved the system's overall performance. Compared with traditional track detection methods, this technology has significant advantages. The research results have important theoretical significance and practical application value in the field of railroad safety monitoring, laying a solid foundation for the development of a real-time track condition monitoring system, and also providing a valuable reference for precision measurement in other engineering fields.

Keywords: Gauge-ultra-high dual-parameter synchronization, ARM processing core, high-precision sensor, Gauge Sensors, Ultra-high sensors.

1. Introduction

In recent years, the global rail transportation field has presented a rapid development trend of high-speed and heavy-duty parallel, and the density of traffic and transport loads of the significant jump on the railroad infrastructure service performance put forward more stringent requirements[1]. As the lifeblood supporting the smooth operation of a huge transportation network, the structural damage evolution mechanism of core facilities such as tracks, bridges and tunnels under long-term high-frequency loading is becoming more and more complex, and the dynamic stability of their service state has become a key bottleneck restricting the enhancement of the efficiency of railroad transportation

According to the Railway Technical Management Regulations[2] issued by China Railway Corporation in 2014, the gauge is the minimum distance between the working edges of two strands of rails within a range of 16mm below the tread surface of the rail head. The straight gauge is 1435 mm, while the super-high gauge refers to the slip of the train when traveling on a round curve due to transverse force or centrifugal force, to offset the centrifugal force generated when the vehicle is traveling on a round curve section, and to ensure that the train can pass through the round curve safely and stably, meeting the design speed, and economically and comfortably, the unidirectional transverse slope of which the outside is higher than the inside is set up on the cross-section of the road section[3][4][5]. The traditional gauge and super-high measurement method mainly adopts manual mechanical measurement, which is inefficient in practical use and consumes a lot of manpower and material resources. The gauge measurement designed by Shi Hongmei et al[6] utilizes least squares curve fitting, a technique that takes machine vision technology to new heights in track applications but lacks dynamic research. Yilmazer et al[7] utilize image processing techniques to measure gauges, again lacking dynamic research. Tsubokawa et al[8] significantly reduce gauge and overheight measurements by employing a vehicle-mounted laser sensor with a lightweight design, which significantly reduces the equipment purchase cost and compensates for the inability of static measurements to capture the deformation of the track implementation under vehicle loading, but the stability of the sensor may be compromised if it is in an extreme environment. To realize the dynamic study, we used the sensors to collect the values of track gauge and super height respectively, and mounted these two sensors to the bottom of the trolley to prevent the vehicle jitter from affecting the sensor's value changes.

In this paper, a set of detection equipment can be installed on the track, through the embedded system to collect the value of the sensor, and then through the Bluetooth system to send the sensor data to the data processing system, and then the data processing system for the uploaded data algorithms to process, to calculate the value of the gauge and the super-high. After obtaining the data, MATLAB is used to verify the data, the gauge is compared with the standard rail, and the height is compared and analyzed with the actual value to verify the validity of the sensor and the reliability of the algorithm, and to ensure the accuracy and scientificity of the detection results.

2. Detection Systems

The detection system includes an embedded system and a data processing system. The embedded system is based on a dual STM32F103 microcontroller rail inspection parameter acquisition system that adopts a modularized design architecture, and its signal conditioning and transmission process can be elaborated as follows: the gauge sensor and the ultra-high sensor are independently accessed to the two STM32F103 main control units, constituting a dual-core parallel processing architecture. The architecture through the analog-to-digital converter (ADC) for synchronous sampling of the original signal. For high-frequency electromagnetic interference and mechanical vibration noise, the system innovatively introduces a second-order low-pass digital filter. The processed digital signals are encapsulated into data frames by the Bluetooth dual-mode module (supporting BLE5.0 protocol), and the CRC-16 check mechanism is used to ensure the reliability of transmission, and the data are finally sent to the data processing system for processing and analysis. The detection system is shown in the figure below.

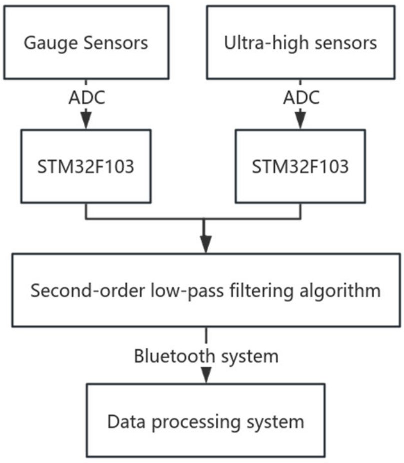

Figure 1, Embedded Part

3. Principles of Measurement

As shown in Figure 2, the gauge monitoring system adopts an innovative mechanical-electronic integrated design scheme, and its core component gauge sensor is installed on the inner side of the wheel pair at the bottom of the detection trolley in an embedded layout. The sensor through the special spring-loaded caliper mechanism maintains dynamic contact with the track, its unique elasticity of the clamping structure can form three-point adaptive constraints: in the straight rail section to maintain the standard gauge monitoring, when the vehicle enters the large radius curve section, the caliper mechanism with the curvature of the track automatically adjusts the clamping angle changes through the bilateral differential displacement compensation principle to ensure that the measurement of the stability of the benchmark, and effectively avoid the impact of centrifugal deformation on the detection accuracy of the car body. The influence of deformation on detection accuracy.

The ultra-high sensor component that works together with it adopts the principle of non-contact photoelectric angle measurement and is integrated and installed in the middle of the reference beam at the bottom of the trolley. The sensor through the precision laser ranging module to build a space triangulation system, can have real-time access to the top surface of the inner rail relative to the top surface of the outer rail of the three-dimensional spatial inclination.

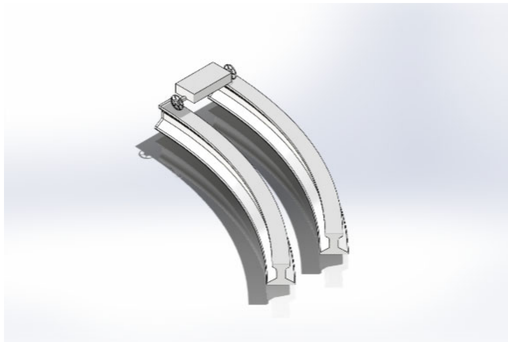

Figure 2. Schematic diagram of a cart on a track

Trolley in the cross-section of the track as shown in the figure, point A and Point B are the two sides of the track, and the chord length AB is the gauge, in the track through the gauge sensor after data processing to get the actual gauge of the track, and then through the super-high sensors to get the angle α, and then through the triangle's interior angle and the theorem, the value of the super-high can be calculated.

$$AC = AB \bullet \sin\alpha \tag{1}$$

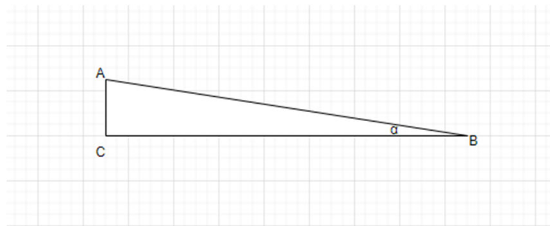

Figure 3. Cross section of the track

4. Systems Program

The entire measurement system is fundamentally based on the need for a gauge sensor and an over-height sensor to obtain a reference value.

4.1. Magnetostrictive displacement sensors

This series of magnetically induced displacement sensors uses a modular architecture to achieve full-spectrum hardware compatibility, and its industrial-grade performance is reflected in three areas:

1. Environmental Tolerance Breakthrough

Wide temperature operating range covering -40℃ to +85℃ extreme working conditions, special packaging process to ensure that high-temperature environment still maintains 0.01% FS linearity stability, through the nano-magnetostrictive materials and aviation aluminum base composite structural design, impact resistance up to 50g, vibration resistance in line with IEC60068-2-6 standard.

2. Distributed Measurement Innovations

Unique 30-node magnetic grid array achieves nanometer resolution (typical ±2μm) with meter scale range, multi-pole matrix encoding technology eliminates cumulative error, supports absolute position and incremental synchronous output, and meets the full closed-loop control requirements of ultra-long travel equipment.

3. Intelligent Integration Advantage

Provide six mainstream industrial Ethernet protocol interfaces such as EtherNet/IP, POWERLINK, Ether CAT, etc., support multi-network mixing and grouping, equipped with Tempo Link intelligent diagnostic system, real-time monitoring of the magnet coupling status, temperature drift coefficients and mechanical stress parameters, and realize predictive maintenance through the digital twin technology Embedded Web server supports remote Parameter configuration and firmware upgrade, equipment status LED and diagnostic output to form a visual human-machine interface.

4.2. LCF-100 inclination sensor

As a high-performance attitude measurement device, the LCF-100 inclination sensor adopts a dual-axis design to realize simultaneous pitch/roll measurement and meet the needs of complex spatial attitude monitoring. The sensor is specially optimized for the field of rail transportation monitoring and shows excellent reliability in applications such as track geometry detection and vehicle overturning warning.

The main parameters of the LCF-100 inclination sensor are as follows.

Input voltage range (VDC): ±12 to ±18V

Operating temperature range: -40°C to +80°C

Input current (mA, max.): ±15

Output impedance (ohm, nominal): 100

5. Experimental Validation

After the trolley runs along the railroad track and completes the whole inspection, the system collects a total of 249 gauge data points. To ensure the accuracy and reliability of the sensor measurement data, we placed the detection trolley on six different standard rails to repeat the experiment, to obtain six sets of independent gauge measurement data sets. Each data set contains 249 measurement points, which completely record the gauge changes of the trolley during track operation. To verify the accuracy of the measurement results, we used MATLAB software to systematically analyze the six sets of experimental data, compared and analyzed the measured data with the standard gauge value (1435 mm) and plotted the corresponding error distribution graphs (shown in Figure 4 below). Through the comparative analysis, the deviation between the sensor measurement value and the standard gauge can be visually assessed, thus verifying the accuracy and stability of the measurement system.

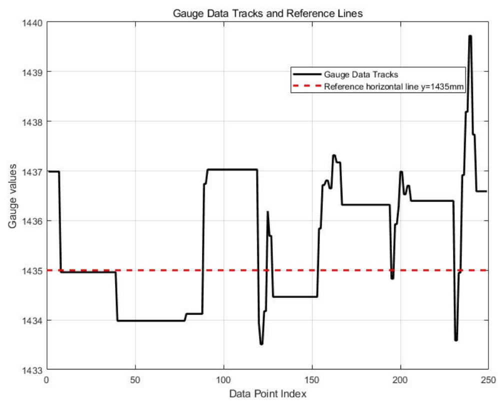

Figure 4. Gauge vs. Standard Gauge(1)

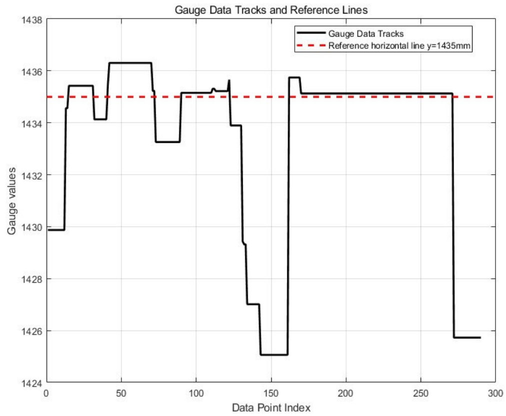

Figure 5. Gauge vs. Standard Gauge(2)

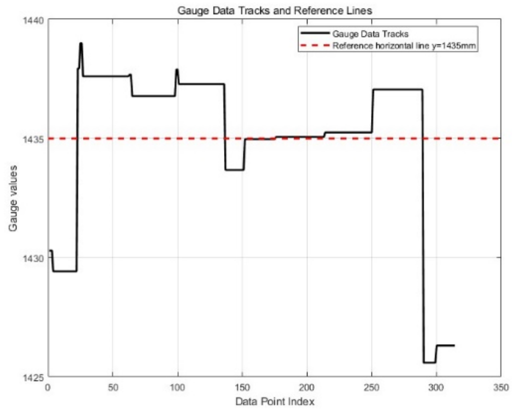

Figure 6. Gauge vs. Standard Gauge(3)

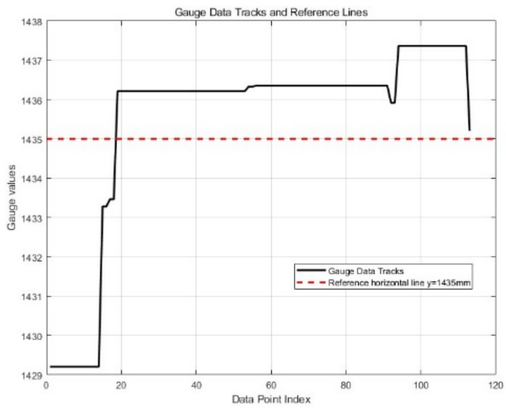

Figure 7. Gauge vs. Standard Gauge(4)

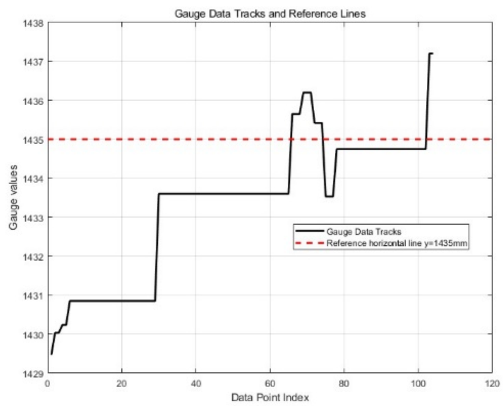

Figure 8. Gauge vs. Standard Gauge(5)

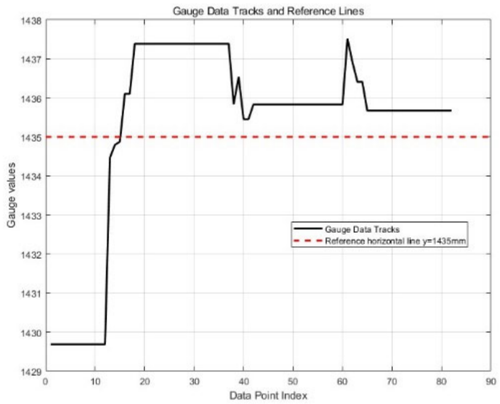

Figure 9. Gauge vs. Standard Gauge(6)

As can be seen from the above diagram, the difference between the gauge and the standard track is within ±10mm, which is in line with the accuracy standard.

In the case where the gauge error is within acceptable limits, the value of super high is calculated from the values of gauge and tilt angle, and the angle of the tilt angle obtained is shown in the following Figure 10.

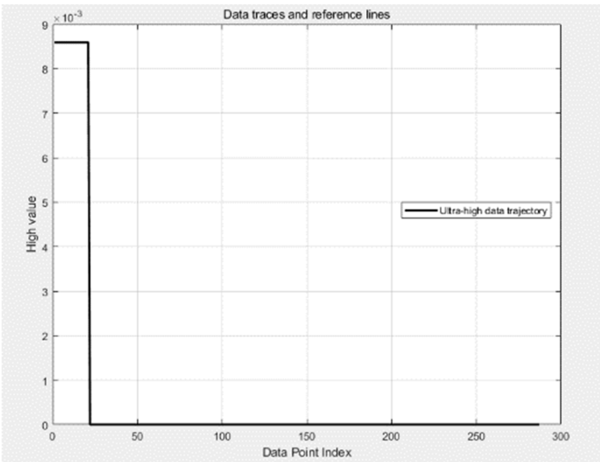

Figure 10 Changes in the angle of inclination

As can be seen from the above figure, most of a track is inclined at an angle of 0 without any change, and in this case, the track was measured using a gauge for over height, and the value of over height in the section after the 23rd point is 0, which is in line with the results shown in the experiment.

6. Conclusion

In this study, the reliability and accuracy of the magneto strophic displacement sensor and LCF-100 inclinometer sensor in the measurement of track geometric parameters are fully verified by in-depth analysis of the actual test data generated during the motion of the trolley. In the experimental process, we constructed a complete test system, and pre-processed the raw data through second-order low-pass filtering, effectively eliminating the influence of environmental noise and electromagnetic interference. The experimental data show that the repeated measurement accuracy of magneto restrictive displacement sensor in gauge measurement reaches ±10mm, which fully meets the technical requirements of railroad track detection. Meanwhile, the LCF-100 inclinometer sensor shows excellent stability in ultra-high measurement, and its dynamic measurement accuracy reaches 0.01°, which can accurately capture the tiny changes in track cross slope. In addition, in the continuous operation test, the sensor system shows good environmental adaptability and long-term stability, without obvious zero drift and sensitivity decay phenomenon. The experimental results show that the sensor system not only has high measurement accuracy but also has good repeatability and reliability, which provides reliable technical support for real-time monitoring and accurate assessment of railroad track conditions. These research results will provide an important theoretical basis and technical support for the intelligent detection and maintenance of railroad infrastructure.

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