Platform of Attitude Monitoring for Freight High Speed Trains

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Abstract—For freight high speed railways with increasing speed up to 250 km/h, it is vital to monitor the running attitude of the high-speed railways in real time. By reviewing and analyzing the existing train attitude detection technologies at home and abroad, this paper presents a novel platform of attitude monitoring for freight high speed trains. We take the inertial navigation unit as the core unit, and develop a platform system to detect the running attitude detection straightforwardly. Various tests are implemented in the laboratory to validate the platform, demonstrating the superiorities and potentialities in railway applications.

1. Introduction

Due to the counterweight and fixed position of cargos, the high-speed running of freight electric multiple units raises higher requirements on the stability of train operation. However, there have been usual accidents caused by derailment of freight trains, such as force majeure, strong wind, subgrade deformation and other reasons which may result in unstable train operation.¹²³ In order to monitor the occurrence of such accidents, it is urgent to detect the vehicle attitude during operation, and provide alarm information when the center of gravity of the vehicle inclines, so as to remind the driver that the train might be in an unsafe state with taking emergency brake to prevent accidents.

2. Research at home and abroad

Most existing domestic and foreign studies on the detection of the operating attitude of freight motor cars mainly focus on analyzing, describing or modelling the vehicle clearance in the process of operation.⁴⁵ The attitude detection equipment for freight train can be divided into three categories.⁶⁷⁸

1. Train attitude detection based on laser rating
2. Train attitude detection based on inertial navigation unit
3. Train attitude detection based on satellite positioning system.

We provide the brief analysis for the tree technologies as follows.

2.1. Train attitude detection based on laser rating

The Institute of Railway Architecture, Institute of Railway Science, has proposed to monitor the train running attitude by using laser ranging technology.⁹ This method adopts the principle of two-dimensional laser scanning to measure the lateral dynamic vibration offset of the train. Several lasers are arranged in the suitable area beside the track. When the train body enters the sensor measurement range, the sensors can scan the outline of the train body and get the foot. With enough sensor data, the dynamic envelope of the train can be obtained to calculate the train attitude.

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Laser Flex, developed by Balfour Beatty, UK, has been widely used in the measurement of the absolute boundaries of trains. It scans the body of a train based on laser triangulation to obtain cross-sectional information of the body, and the system can provide a measurement rate of 1 kHz. With measurement modeling and process using the software, the vehicle attitude can be effectively evaluated and calculated.

The Italian Sezze Romano segment railways use a modular railway vehicle contour monitoring system, TCCS, developed by Ansaldo STS, which works in conjunction with several laser scanners installed on the line to scan, monitor and manage the contours of various types of railway trains. The high precision three-dimensional laser scanner used in this system can scan 800 times per second and measure 900 target points in a single scan. When the train speed gets 120 km/h, a 40 mm interval measurement point can be obtained, and the accuracy of the system can keep within (+) 10 mm for 10 m distance measurement. [10][11]

2.2. Train attitude detection based on inertial navigation unit
For attitude measurement, gyroscopes and accelerometers have been usually used for the inertial navigation to perform attitude detection. At present, the commonly used attitude measurement equipment include MEMS gyroscope, laser gyroscope, optical drilling gyroscope, magnetometer, etc. Laser gyroscopes and optical fiber gyroscopes have high measurement accuracy and quick start abilities, but they are not suitable for attitude measurement and positioning navigation of high-speed railway due to their high price and low earthquake resistance. Therefore, MEMS gyroscope is usually used to measure the attitude of high-speed railway, as shown in Fig1. [12]

![Inertial navigation experimental platform.](image)

Figure 1. Inertial navigation experimental platform.

MEMS gyroscope can measure the attitude information of the object robustly, and can also obtain the speed, position and other information through mathematical calculation, so it can be used as the attitude determination system of the train. MEMS gyroscope uses micro electro mechanical technology to transform the motion information of an object into an electrical signal, and then the corresponding attitude information of the object can be obtained by identifying the electrical signal. Generally, the MEMS gyroscopes have superiorities of being low-cost and easy to install. The precision of modern MEMS gyroscopes has been improved and the price is getting lower, so it has been gradually commercialized. However, MEMS gyroscope has poor seismic performance, and its accuracy is easy to be affected by external temperature. Considering various factors, MEMS gyroscope with high precision is used in train attitude measurement. [13]

2.3. Train attitude detection based on satellite positioning system
Based on the principle of relative positioning, the carrier attitude measurement is to solve the vector description of the baseline formed by the antenna installed on the carrier in the reference coordinate system through the basic observation measurement of the satellite and the multi antenna configuration
technology, and then realize the carrier attitude measurement by using the attitude parameter calculation technology. [14]

Most existing methods perform the attitude measurement test of EMU based on satellite navigation, test the measurement of vehicle body attitude in the safe operation detection of EMU, and carry out the installation of vehicle antenna in single baseline mode and system load test. Based on the analysis of vehicle body attitude data, the heading angle, side tilt angle, three dimensional coordinates (longitude and latitude, elevation angle), real-time speed and time information of the EMU can be effectively obtained. This can provide data support for EMU safe operation management and wind disaster reduction design. [15]

3. Attitude monitoring platform

3.1. System architecture

According to the above investigation and analysis, we propose an attitude detection device for freight high speed trains using the inertial navigation unit, which is composed of vehicle attitude monitoring device and attitude data GUI software. The vehicle attitude monitoring device is mainly composed of MPU6050 sensor and STM32-f429 controller, used to collect the data information of vehicle body attitude. The attitude data GUI for displaying the monitoring results is developed with the virtual instrument named as LabVIEW, which is used to record the attitude data information sent by the vehicle hardware terminal, and display the corresponding data with data storage.

3.2. System design

For system design, the STM32-f429 development board is selected as the data acquisition board, as shown in Fig.2.

![Figure 2. Data acquisition module.](image)

The Igt6 chip is used as the core of the development board, and mpu-6050 gyroscope is used for attitude data acquisition. Besides, the USART serial port transmission module is equipped. The upper computer is responsible for receiving the attitude data from all acquisition boards, and the multi-point data is utilized with the mathematical method to establish the train attitude model. In the whole process, we need to transfer, store, model and display.

Gyroscope sensors can be digitally programmed to a full range of (+) 250, (+) 500, (+) 1000 or (+) 2000 degrees (dps) per second. The ADC sample rate can be programmed from 8,000 sampling points per second to 3.9 sampling points per second, and a wide cutoff frequency can be achieved by selecting a low-pass filter by the user. Embedded Digital Motion Processor (DMP) is located inside MPU-60X0 and can uninstall the operations of motion processing algorithms from the host processor. DMP acquires and processes data from accelerometers, gyroscopes, and other third-party sensors such as magnetometers. Result data can be read from registers in DMP or buffered in FIFO.
STM32 series 32 bit Flash microcontroller based on ARM Cortex-M processor, designed to provide MCU users with new degrees of freedom to develop, as shown in Figure 7. It includes a series of 32-bit products, which combines the features of high performance, real-time function, digital signal processing, low power consumption and low voltage operation, while maintaining the features of high integration and easy development, and is suitable for this design.

Firstly, we configure the serial port receiving module, as shown in Fig3. In the serial port receiving sub VI, the visa resource is used to modulate the serial port, and the common settings such as global variable baud rate and parity check are set to ensure the normal use in the main program. The data is read into a string by using the reading program.

![Figure 3. Data transmission program.](image)

The received data is converted to a number using VI's "string to byte array". According to the communication protocol, the first four bytes of the data are the header "AA", and the middle six bytes of useful data are yaw, pitch, roll, two bytes per data. After recognizing the frame header, take out the corresponding data and divide it into three groups, each group of two eight-bit integer data. In each group, convert the eight-bit integer into 16-bit integer. According to the sending rules of single-chip computer, the calculated data is 100 times the actual data, so divide each data by 100 to get the corresponding angle data which retains two decimal places as shown in Fig4.

![Figure 4. Data solution program.](image)

Then, the Kalman filter is applied to the data before modeling the train running attitude. It is known that the Kalman filter is an algorithm for the optimal estimation of the state equation of linear system by using the input and output data. It can update and process the collected data in real time. At the same time, when receiving the data, every ten data is considered as a group. Based on the continuity of train posture changes, a 5-order moving average smoothing filter is designed to filter this set of data to reduce the impact of burr noise in the data, and then a set of data is averaged to get the final instantaneous posture data. Then, the data is displayed, and the train model is built by SolidWorks, so that a new 3D image is created in VI as shown in Fig5. Meantime, the model with proper settings are used and adjusted for display, and then the rotation tool of X, Y, Z axis is used to input the corresponding angle for rotation.
Using the symmetric characteristics of the train to solve the center of gravity, when leaving the factory, the train has a specific re-height parameter to use, select the appropriate type in the menu bar to obtain the corresponding center of gravity height. When the front, back or left inclination angle of the train changes, the projection of the center of gravity can be obtained by multiplying the original center of gravity by the cosine value of the corresponding inclination angle. The projection of the center of gravity can be displayed in a two-dimensional coordinate system, and a boundary is defined to display the posture, and to judge the warning when the projection of the center of gravity of the truck exceeds the time limit as shown in Fig6.

3.3. Test results
After proper setting and multi-scenario operation, we get the test results for the proposed platform. To this end, the software and hardware of the system are jointly debugged, and the vehicle hardware terminal and software are connected by means of serial communication. It can be seen that when the attitude of the hardware terminal varies with time, the data image of the upper computer software can be updated accordingly, so as to display properties of real-time attitude data.
Then, the sensitivity of the software for varying attitude and inclination angle is tested. When the train stops, the equipment is set on the train. After a period of time, the interface is shown as shown in Fig.8. We can see that when the train is stationary, the inclination angle varies as well. The left and right inclination angles of the train change slightly, but the front and rear inclination angles vary obviously. The reason is that the train vibrates when it is stationary due to the influence of gale weather on that day. The proposed platform can effectively monitor the attitudes of the train in various scenarios.

Figure 8. Static test.

4. Conclusion

In this paper, the commonly used methods for the attitude detection of freight high speed trains are investigated and analyzed. The basic principles are briefly introduced to show the properties of the monitoring platform to be develop. Then, the attitude detection device and platform based on the inertial navigation unit MPU6050 is proposed. The on-board hardware terminal is designed by adopting the STM32F429 as the main control chip. The data display interface is developed using the virtual instrument LabVIEW. Experiments show that the proposed attitude monitoring platform can effectively detect and display the real time status of the freight high speed trains, and thus provides technical support for ensuring higher reliability of future train operation in more complex conditions.

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