Research of autonomous moving track detection vehicle

Chao Tang¹, Jing Jia¹, Chuang Chen¹, Siyu Zhao¹, Tianci Zhu¹, Xiaojun Lv², Sihai Zhao¹,*

¹China university of mining and technology (Beijing), Beijing, China
²China Academy Of Railway Science, Beijing, China

*Corresponding author e-mail: zsh@cumtb.edu.cn

Abstract. At present, track measurement instruments are mostly manually driven for measurement, and the detection efficiency is not high, which cannot meet the needs of rapid development of rail transit. In this paper, an autonomous moving track detection device driven by wheel hub motor is developed, and the inertial measurement method is applied to track parameter detection to improve track detection efficiency and accuracy. And realize the remote control of wheel motor by GSM module.

1. Introduction

Railway is the core backbone of the national transportation system. But the number of independent track inspection vehicles independently developed and produced in China is still very small. The research purpose of this paper is to design an autonomous moving track inspection vehicle for the characteristics of high-speed railway detection and maintenance as well as the research status of track monitoring in China, and put forward the corresponding track parameter detection method.

2. The overall design of self-propelled track testing vehicle

The track test car is mainly composed of four parts, including the body mechanical system, the driving system, the detection system and the control system. Figure 1 shows the system composition diagram of track detection trolley.

![Fig.1 Trolley system](image-url)
2.1. Mechanical system

The body mechanical structure is the main structure part of the rail inspection trolley, which is mainly used for carrying power, sensors, industrial personal computer, camera and other functional modules. Figure 2 is the simple structure diagram of rail inspection vehicle.

![Fig. 2 Simple structure of rail car](image)

![Fig. 3 Physical drawing of the wheel motor](image)

2.2. Driving system

The wheel motor is selected as the driving element for the autonomous moving track inspection vehicle. Hub motors as a special structure of stepping motor, with the advantages of simple structure, flexible layout, easy to control. Figure 3 are the physical diagram and internal structure diagram of hub motor wheel respectively[1,2,3].

According to the overall mass (20kg), driving speed (8km/h) and rolling friction coefficient (0.06) of railway track, the functional parameters of wheel hub motor are determined. According to the functional requirements of track detection trolley and formula (1), the performance parameters of wheel hub motor can be determined as follows:

\[
P = \frac{F \cdot v}{\eta_1 \cdot \eta_2}
\]

(1)

According to the functional requirements of track detection trolley and formula (1), the performance parameters of wheel hub motor can be determined as follows:

- Rated power: 350W;
- Rated voltage: 24V/36V/4V;
- Rated speed: 300-800r;
- Feet: 6 inch

2.3. Detection system

The contents of track detection mainly include: gauge, direction, superelevation, height and unsmoothness. Table 1 shows the detection method and sensor requirements of track parameter

| track detection parameters | detection method           | acquisition sensor               |
|----------------------------|----------------------------|----------------------------------|
| track gauge                | image processing           | SONY hd night vision camera      |
| orbital                    | image processing           | SONY hd night vision camera      |
| height exceeded            | inertial measurement technology | MPU6050 module[4]               |
| longitudinal irregularity  | inertial measurement technology | MPU6050 module               |
2.4. Control system

Track inspection car remote control system hardware is mainly composed of the wheel hub motor, TC35 GSM module and microcontroller STC89C52, relay control switch and peripheral control circuit. It can control the working state of the relay switch, so as to realize the hub motors of connected to relay switch control. When the working state of the relay circuit switch changes, the GSM module will feed back to the staff's mobile phone in the form of SMS, and display the working state of the relay on the LCD screen.

3. Structure design and simulation of track detection vehicle

3.1. The structural design of track inspection car

3.1.1. Track inspection car body structure design. The specific components required by the designed autonomous moving track inspection vehicle are as follows: Three wheels (one hub motor drive wheel, two guide driven wheels), three cameras (one for track peripheral environment monitoring and two for rail image information collection), elevating and rotating head (a combination of roller screw and rotating head for installation of environmental surveillance cameras), inertial measurement module (MPU6050 module), speed and mileage measurement module, power supply, industrial computer.

![Fig.4 Trolley machine structure](image1)

![Fig.5 Wheel set physical map and work diagram](image2)

3.1.2. Wheel set of design. When the rail inspection trolley is moving forward, the outer side of the wheel sleeve runs along the inner side of the rail. Figure 5 show the wheel set physical map and the working diagram of wheel and rail respectively.

3.2. Finite element simulation analysis of track detection vehicle

UG10.0 has advanced simulation module, so it can directly use UG10.0 to conduct finite element analysis of rail inspection frame. Taking aluminum profile as an example, the finite element analysis process of track inspection vehicle's mechanical structure is analyzed [5].

Create advanced simulation, set physical properties, mesh separation, add constraints, apply load, solve calculation, view the solution results. Figure 6 for track inspection frame after the constraint and load simulation model.

Through the structure stress cloud chart can be intuitive to see the derailment inspection car frame stress deformation. The maximum stress deformation of each axial direction can be accurately obtained through the settlement result graph. Figure 7 is the stress cloud diagram of rail inspection vehicle structure after the completion of the calculation task.
Compared with the simulation results of other materials and the physical properties of materials, the advantage of aluminum profile is very obvious, which is far less than the error range of track detection. In the range of the permitted error detection, will not affect precision orbit parameters, so the mechanical structure and material selection is rational and feasible, thus eventually choose aluminum alloy material as a track inspection car frame.

3.3. Module distribution and construction of track detection trolley

The sensor installation and mass distribution of the track detection trolley will affect the detection results and accuracy as well as the realization of each functional module. The bearing function modules required by rail inspection trolley, their specific functions and sizes are shown in table 2. According to the simulation results of the car body structure, the quality and size of each functional module and the testing requirements, each module should be reasonably distributed and installed. Figure 8 is the three-dimensional layout diagram of the distribution of each functional module.

| Code name | The name | The size (mm) | The usage |
|-----------|----------|---------------|-----------|
| 1  | Rail camera | 60*60*20 | It is used for image information collection of two side rail. |
| 2  | Industrial PC | 340*240*30 | The data of track parameters measured by the detection device are processed comprehensively and transmitted to the remote user. |
| 3  | GPS module | 100*80*60 | It is the realization of rail inspection vehicle positioning function. |
|   | MPU6050 module | 100*80*60 | It measured the uneven height of the railway tracks. |
| 4  | Hub motor controller | 100*80*60 | It drives the hub motor. |
|   | TC35 module | 100*80*60 | The remote communication control of track inspection vehicle is realized. |
| 5  | Environmental surveillance camera | 120*200*80 | Used to detect the surrounding environment, whether there is a foreign object on the railway track. |
| 6  | battery | 400*122.5*150 | Power supply is provided for the drive of track inspection vehicle and track information acquisition module |
According to the simulation results of track detection trolley frame, each module is installed on the frame according to the specified position. Finite element analysis is carried out on the whole again to analyze the stress situation after installation, so as to ensure that the track parameter acquisition accuracy will not be affected after the track detection trolley bears the load.

4. Design of remote control system for track inspection trolley based on GSM network

4.1. The hardware design of remote control system for track detection vehicle

Currently, the track parameter detection devices commonly used in the public works section of high-speed railway in China are all pushed forward by the staff, which wastes manpower and material resources and has very low detection efficiency. Especially at night or in severe weather, it will bring great inconvenience to the track detection, resulting in slow and slow progress of track detection. By use of the global mobile network of telecommunication transmission function[6], combined with the intelligent control function of single chip microcomputer (STC89C52) on the relay switch. It can control the start and stop of the wheel motor of track inspection vehicle by sending SMS through the mobile phone, and then realize the remote control of autonomous operation and automatic detection of track inspection vehicle.

The hardware part of the remote control system of rail inspection vehicle is mainly composed of hub motor, GSM module TC35, single chip microcomputer (STC89C52), relay control switch and peripheral control circuit. Figure 9 shows the overall scheme flow chart of the remote control system of the track inspection vehicle.

![Fig. 8 Overall layout of a trolley for track detection](image)

**Fig. 8** Overall layout of a trolley for track detection

According to the simulation results of track detection trolley frame, each module is installed on the frame according to the specified position. Finite element analysis is carried out on the whole again to analyze the stress situation after installation, so as to ensure that the track parameter acquisition accuracy will not be affected after the track detection trolley bears the load.

4. Design of remote control system for track inspection trolley based on GSM network

4.1. The hardware design of remote control system for track detection vehicle

Currently, the track parameter detection devices commonly used in the public works section of high-speed railway in China are all pushed forward by the staff, which wastes manpower and material resources and has very low detection efficiency. Especially at night or in severe weather, it will bring great inconvenience to the track detection, resulting in slow and slow progress of track detection. By use of the global mobile network of telecommunication transmission function[6], combined with the intelligent control function of single chip microcomputer (STC89C52) on the relay switch. It can control the start and stop of the wheel motor of track inspection vehicle by sending SMS through the mobile phone, and then realize the remote control of autonomous operation and automatic detection of track inspection vehicle.

The hardware part of the remote control system of rail inspection vehicle is mainly composed of hub motor, GSM module TC35, single chip microcomputer (STC89C52), relay control switch and peripheral control circuit. Figure 9 shows the overall scheme flow chart of the remote control system of the track inspection vehicle.

**Fig. 9** Rail car remote control system

![Fig. 10 The main program flow chart](image)

**Fig. 10** The main program flow chart
4.2. The software design of remote control system for track detection vehicle

After the hardware connection of the remote control system of the track detection car is completed and powered on, the system will automatically initialize the microcontroller STC89C52 and TC35 modules, and then wait for SMS instructions\(^7\). After receiving the instruction of "open" by SMS, TC35 module will transmit the SMS instruction to MCU through serial port. STC89C52 The microcontroller will call the corresponding sub-function to identify and convert according to the instruction received. The relay connected to the serial port of the microcontroller will be opened and the hub motor will start running. The working state of the relay will be fed back to the mobile phone through SMS, and the working state will be displayed on the LCD screen. Similarly, when TC35 module receives the "close" instruction, the control system will operate accordingly, close the relay, and the hub motor will stop running. So as to realize the remote control of track detection car running through mobile phone short message. Figure 10 shows the main program flow of STC89C52 microcontroller in the remote control system.

4.3. Remote control experiment of track inspection trolley based on GSM

The hub motor is connected to the controller and the relay circuit is connected to the controller circuit. The microcontroller STC89C52 module and TC35 module are connected by three dupont wires. The lithium polymer battery is depressurized by transformer and then supplies power to each module through the circuit board.

After the system is confirmed to work normally, the remote control experiment of track inspection vehicle can be carried out. When the preset mobile phone number is used to send the short message instruction "K" to the SIM card in the TC35 module, the single-chip microcomputer will control the relay to open, and the track detector starts to move forward under the drive of the hub motor. Meanwhile, the mobile phone sending the instruction receives the feedback information from the TC35 module and displays " Relay open " on the LCD screen. At this time, continue to send SMS instruction "G", MCU will control the relay to close, the track detection car will stop running, the cell phone sending instructions receives the feedback information of TC35 module and displays " Relay closing " on the LCD screen.

5. Experimental Verification

5.1. Formula Deduction

The working principle of MPU6050 module is that the system integrates the estimated value of the gravity vector measured at the last moment with the angle value measured by the gyroscope, calculates the gravity vector value of the side object at the current time, and then carries out the weighted average with the vector value measured by the accelerometer at the current time, so as to obtain the optimal estimated value of the current vector direction\(^8\). W is the weight of the gyroscope. The optimal estimated value of the gravity vector at the current time \(\overrightarrow{\text{Rest}}(n)\) is obtained by the weighted average of the gravity acceleration vector measured by the accelerometer \(\overrightarrow{\text{Racc}}(n)\) and \(\overrightarrow{\text{Rgyro}}(n)\).

\[
\overrightarrow{\text{Rest}}(n) = \frac{\overrightarrow{\text{Racc}}(n) + W \cdot \overrightarrow{\text{Rgyro}}(n)}{1 + W}
\]

\(W = \frac{1}{(G)^2 + 0.01}\)

Angle calculation formula:
- Roll angle (x-axis): \(\text{Roll} = [(\text{RollH} \ll 8) | \text{RollL}] / 32768 \times 180^\circ\) (4)
- Pitch angle (Y-axis): \(\text{Pitch} = [(\text{PitchH} \ll 8) | \text{PitchL}] / 32768 \times 180^\circ\) (5)
- Yaw angle (Z-axis): \(\text{Yaw} = [(\text{YawH} \ll 8) | \text{YawL}] / 32768 \times 180^\circ\) (6)
- Temperature calculation formula: \(T = [(\text{TH} \ll 8) | \text{TL}] / 340 + 36.53^\circ\C\) (7)
- Checksum: \(\text{Sum} = 0x55 + 0x53 + \text{RollH} + \text{RollL} + \text{PitchH} + \text{PitchL} + \text{YawH} + \text{YawL} + \text{TH} + \text{TL}\)
Formulas (5), (6) and (7) are respectively the formulas for the change of module attitude angle in the three directions of X-axis, Y-axis and Z-axis. The parameters in the formulas can be extracted from the data packets collected by the module.

5.2. Debugging experiment of inertial measurement system

After the completion of the design of the inertial measurement system, through the use of inertial measurement components to measure the inclination and attitude of the object, the function realization of the inertial measurement hardware system and data processing system is verified, and the overall debugging of the measurement function is completed[9].

First, move the detection car on a section of track, observe and record the inclination values of X, y and Z axes collected by the inertial measurement component on the control panel, reset the track inspection car, move the track inspection car repeatedly, and observe and record the inclination change curve of X, y and Z axes collected by the upper computer. Table 3 shows the angle experiment data collected by LABVIEW control panel, and figure 11 shows the angle change curve of X, y and Z under the same conditions displayed by upper computer.

**Tab.3** Experimental data collected from LABVIEW control panel

| Time (s) | 0.5 | 1   | 1.5  | 2   | 2.5  | 3   | 3.5  | 4   | 4.5  | 5   |
|---------|-----|-----|------|-----|------|-----|------|-----|------|-----|
| X (degree) | 15.3 | 22.7 | 23.2 | 23.3 | 22.5 | 15.6 | 35.6 | 31.7 | 22.4 | 21.2 |
| Y (degree) | 0.1  | 4.5  | 5.9  | 7.5  | 10.5 | -7.6 | -2.2 | 6.3  | 8.1  | 6.2  |
| Z (degree) | 36.1 | 34.9 | 33.5 | 28.5 | 30.1 | 34.3 | 27.5 | 28.9 | 30.7 | 30.5 |

**Fig.11** The upper computer displays the axial angle change curve

By comparing the three-axis angle value collected by LABVIEW data processing under the same conditions with the three-axis curve change diagram displayed by the upper computer, it can be found that the X, y and Z axis changes obtained by the two acquisition methods are consistent, and the attitude change angle of the rail inspection trolley can be correctly detected. It shows that the angle value of the three-axis attitude change during the moving process of the rail inspection vehicle can be collected through the MPU6050 module, which can be used as the basis for measuring the height and irregularity of the track. The track inspection car has realized the preliminary track information collection function.

6. The Conclusion

With the rapid development of high-speed railway in China and the continuous improvement of safety and comfort of high-speed trains, track detection becomes more and more important. The research and development of efficient and convenient track detection equipment will meet a very
broad demand. The mature and intelligent development of MEMS technology lays a good foundation for the research and manufacture of track detection equipment. The innovation of this design is to apply the hub motor as the driving element to the track detection car, improving the detection efficiency; using the GSM module TC35, the automation and remote control function of the track detection equipment can be realized by the way of mobile phone short message; at the same time, the collection function of some track parameters can be realized by the inertial measurement technology and image processing method[10].

7. Acknowledgments
This work was financially supported by China university of mining and technology (Beijing) college students innovation training project funds.

References
[1] Qinghua Meng, Jin Xu, Dongfeng Wang. Research on power system of electric vehicle driven by hub motor [J]. Chinese journal of agricultural machinery, 2013,2-4
[2] Yutao Luo, Zunyou Chen. Design of new wheel hub motor structure and construction of test platform [D]. Master thesis of south China university of technology, 2012,3-7
[3] Zhuoping Yu, Yuan Feng, Lu Xiong. Overview of dynamic control development of distributed drive electric vehicle [J]. Chinese journal of mechanical engineering, 2013,1-4
[4] Jie Li, Huihui Hong. Research on MEMS microinertial measurement combination calibration technology [D]. Journal of sensor technology 2-3
[5] Qi Wang, Chengcheng Yuan, Mingju Liu. UG based welding seam modeling and finite element analysis technology [J]. Mechanical engineering and automation, 2011,1-3
[6] Eduardo Alvarez-Miranda, Jordi Pereira. Designing and constructing networks under uncertainty in the construction stage: Definition and exact algorithmic approach [J]. Computers and Operations Research, 2017,81,21-27
[7] Kai Chen, Shihong Qin, Min Wang. Design of transceiver control system based on GSM module TC35I [J]. Engineering journal of wuhan university of engineering, 2011,3-4
[8] Wei Wen. Development status and application of inertial measurement devices and systems based on MEMS technology [J]. Control and guidance, 2013,1-3
[9] Yang Song, Fan Wu. Rail Damage Detection Based on AE Technology and Wavelet Data Processing [J], Trans Tech, 2015,1-3
[10] Wang yue, Mao zehui. Observer-based fault detection for Rail Vehicle Suspension Systems [J]. 26th Chinese Control and Decision Conference 2-5