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Design and Implementation of 4WD Intelligent Car System Based on Integrated Navigation

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Abstract

Focuses on the basic principle of integrated navigation system based on geomagnetic sensor, three-axis gyroscope and three-axis accelerometer. A four-wheel independent driving car platform is designed with STM32F4 MCU as the control core and RZ7899 as the motor drive. The vehicle heading angle is obtained through the quaternion obtained by MPU6050, and combined with the geomagnetic parameters, the serial double PID control algorithm is used for navigation by correcting the deflection angle, the intelligent car can run in a straight line without other navigation systems within a certain range.

Keywords: geomagnetic sensor, integrated navigation system, MPU6050, cascade double PID control

1. Introduction

Navigation and positioning systems have flourished in the world today, especially with the emergence of commercial applications such as GPS navigation and positioning systems, Beidou navigation and positioning systems, and GLONASS navigation and positioning systems, making it easy to achieve navigation and positioning in global regions. However, when these methods rely on satellite navigation and positioning indoors or in areas with large obstructed objects, due to weak or non-existent satellite signals, it is difficult to achieve navigation and positioning using this method, and the accuracy is difficult to guarantee. To solve the above problems, especially in the field of indoor navigation and positioning, using a combination navigation system instead of a satellite navigation and positioning system is one of the commonly used methods.

2. Overall System Design

2.1 System Overall Composition Design

The intelligent four-wheel independent drive car system can be divided into four parts (as shown in Figure 1): the mechanical structure of the car body, the power control of the car body, the navigation system of the car, and the intelligent control software of the car. Among them, the mechanical structure of the vehicle body is the carrier that carries the last three parts, mainly including four independently driven wheels, an electric motor connected to the wheels, and a fixed motor that forms the frame of the vehicle body. The vehicle power control part mainly includes: 12V lead-acid battery, STM32F407V microcontroller core control circuit board, and motor drive circuit (STMicroelectronics, 2009). The car navigation and positioning system mainly includes: MPU6050 three-axis gyroscope and three-axis accelerometer sensor (MPU-6000 and MPU-6050 Register Map and Descriptions (Revision 4.2), n.d.) and its peripheral circuits, MAG3110 geomagnetic sensor and its peripheral circuits. The intelligent control software for the small car mainly reads the raw data of the MPU6050 sensor, MAG3110 geomagnetic sensor (Xtrinsic MAG3110 Three-Axis, Digital Magnetomete, 2019), and motor encoder. The above data is fused through a two-stage series PID control algorithm framework to obtain the current operating attitude of the small car, thereby achieving intelligent control of the small car's travel and achieving the navigation purpose of system motion control.

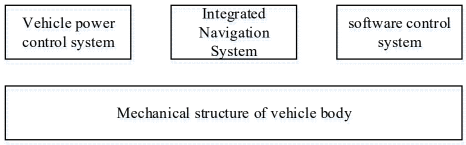

Figure 1. Overall composition of the intelligent 4WD vehicle system

The intelligent four-wheel drive vehicle system can accept remote control for driving, or automatically navigate according to preset paths. It can also transmit the current operating posture, position, and power system status of the vehicle to the control center through wireless communication interfaces.

2.2 Design of Intelligent Control for System Data Fusion

The MPU6050 integrates a three-axis gyroscope sensor and a three-axis acceleration sensor internally. In order to reduce the load of external controllers on raw data fusion calculation processing, sensor synchronization, and attitude sensing, the MPU6050 also integrates a data motion processing engine (DMP: Digital Motion Processing), which can be accessed by accessing the DMP standard library processing file (inv_mpu_dmp_motion_driver. c) provided by InvenSense_ read_ The fifo function directly outputs quaternions, and through quaternions, pitch, heading, roll angle, and Euler angle can be easily obtained. Therefore, this series of sensors is widely used in unmanned aerial vehicle flight control systems and ground intelligent robot control systems. The relationship between quaternions and motion attitude angles and Euler angles is shown in the following expression (Qin Yongyuan, 2014) (quaternions are Q1, Q2, Q3, and Q4 respectively; motion attitude angles rotating around a fixed coordinate system X-Y-Z in sequence are: P, R, Y; Euler angles are:,, and):

$$Q=(\mathrm{Q}_0,\mathrm{Q}_1,\mathrm{Q}_2,\mathrm{Q}_3) \tag{1}$$

$$Q=\begin{bmatrix}\cos\frac{\gamma}{2}\\0\\0\\\sin\frac{\gamma}{2}\end{bmatrix}\begin{bmatrix}\cos\frac{\beta}{2}\\0\\\sin\frac{\beta}{2}\\0\end{bmatrix}\begin{bmatrix}\cos\frac{\alpha}{2}\\\sin\frac{\alpha}{2}\\0\\0\end{bmatrix}=\begin{bmatrix}\cos\frac{\gamma}{2}\cos\frac{\beta}{2}\cos\frac{\alpha}{2}+\sin\frac{\alpha}{2}\sin\frac{\beta}{2}\sin\frac{\gamma}{2}\\\sin\frac{\alpha}{2}\cos\frac{\beta}{2}\cos\frac{\gamma}{2}-\cos\frac{\alpha}{2}\sin\frac{\beta}{2}\sin\frac{\gamma}{2}\\\cos\frac{\alpha}{2}\sin\frac{\beta}{2}\cos\frac{\gamma}{2}+\sin\frac{\alpha}{2}\cos\frac{\beta}{2}\sin\frac{\gamma}{2}\\\cos\frac{\alpha}{2}\cos\frac{\beta}{2}\sin\frac{\gamma}{2}-\sin\frac{\alpha}{2}\sin\frac{\beta}{2}\cos\frac{\gamma}{2}\end{bmatrix} \tag{2}$$

According to Formula 1 and Formula 2, the inverse solution, i.e., the quaternion, can be obtained to obtain the Euler angle as Formula 3:

$$\begin{bmatrix}\alpha\\\beta\\\gamma\end{bmatrix}=\begin{bmatrix}\arctan\frac{2(\mathrm{Q}_0\mathrm{Q}_1+\mathrm{Q}_2\mathrm{Q}_3)}{1-2(\mathrm{Q}_1^2+\mathrm{Q}_2^2)}\\\arcsin(2(\mathrm{Q}_0\mathrm{Q}_2-\mathrm{Q}_1\mathrm{Q}_3))\\\arctan\frac{2(\mathrm{Q}_0\mathrm{Q}_3+\mathrm{Q}_1\mathrm{Q}_2)}{1-2(\mathrm{Q}_2^2+\mathrm{Q}_3^2)}\end{bmatrix} \tag{3}$$

And Formula 3 should be noted that there are 12 rotation orders for converting quaternions to Euler angles. The above formulas are based on the Z-Y-X order. If other conversion orders are required, the corresponding calculation formulas will be different, and this article will not introduce them one by one.

The 4WD intelligent car system utilizes the MPU6050 sensor, MAG3110 geomagnetic sensor, and motor encoder to obtain the car's running attitude data, the geomagnetic line direction data where the car is located, and the rotational speed data of the four driving wheels of the car. In practical applications, quaternions and geomagnetic sensor angles are combined (Song Jing, 2011) and expressed in the form of state vectors as formula 4:

$$x=[Q_0 \quad Q_1 \quad Q_2 \quad Q_3 \quad \theta] \tag{4}$$

Among them, Q0, Q1, Q2, and Q3 are quaternions obtained through the DMP output of MPU6050, and are the angle between the geomagnetic sensor output of the car's front direction and the geomagnetic north.

By refusing the quaternion output from the DMP in the MPU6050 sensor, the heading of the vehicle can be obtained. At the same time, using the MAG3110 geomagnetic sensor data to supplement and correct the motion attitude heading, a relatively accurate heading can be obtained. The final heading of the car can be achieved through a series type dual PID control as shown in Figure 2. From this block diagram, it can be seen that the heading is adjusted through an internal PID loop and an external PID controller that adjusts the motor speed. The dual series PID control loop ultimately determines the duty cycle of the four PWM waveforms, thereby determining the rotation rate of the four motors and achieving the heading of the car.

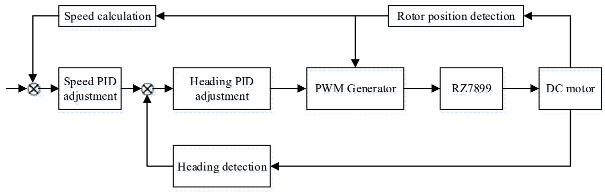

Figure 2. Series dual PID control block diagram

3. Detail Design

3.1 System Hardware Circuit Design

The hardware circuit of the system is mainly divided into a power supply section with 12V to 5V and 3.3V, a control section with STM32F4 microcontroller as the core, a car attitude data acquisition section composed of MPU6050 sensor and MAG3110 geomagnetic sensor, an external remote control communication section, and a motor drive section for the four wheels of the car. The structural composition between them is shown in Figure 3.

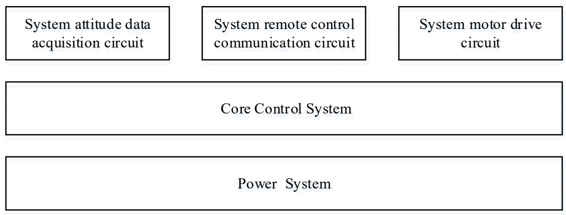

Figure 3. System hardware circuit structure composition

As shown in the above figure, the system power is converted from 12V to 5V and 3.3V respectively through two chips LM2596 and LM1117-3.3. These three types of power sources in the system supply power to the motor driver chip RZ7899, motor encoder, STM32F407 microcontroller, and system data acquisition sensor.

The core control part of the system is mainly composed of the STM32F407 microcontroller and its necessary peripheral circuits. The MPU6050 sensor circuit in the attitude data collection section is shown in Figure 4, and the MAG3110 geomagnetic sensor circuit is shown in Figure 5. The motor drive part of the system adopts the RZ7899 motor drive chip, and its peripheral circuit design is shown in Figure 6. The system remote control adopts the TTL level universal serial interface of STM32F407 peripheral and the Bluetooth serial universal interface of TTL level for interconnection. The circuit parts not provided in this article are all relatively simple general design circuit parts.

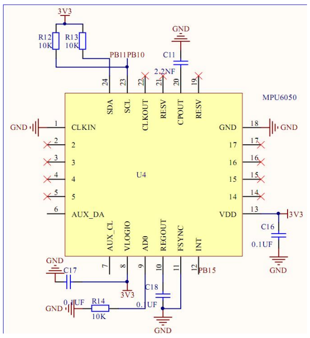

Figure 4. MPU6050 sensor circuit

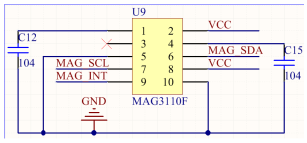

Figure 5. MAG3110 geomagnetic sensor circuit

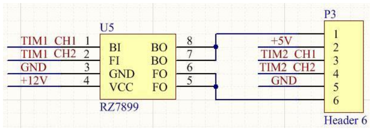

Figure 6. RZ7899 motor drive circuit

In Figure 6, channels 1 and 2 of TIM1 are connected to the BI and FI pins of RZ7899, and the motor forward, reverse, and speed are controlled through the duty cycle of the PWM of the two channels of TIM1. If TIM1 The mean (or duty cycle) of CH1 is greater than TIM1 When the mean (or duty cycle) of CH2 is equal to the forward rotation of the motor, then TIM1 The mean (or duty cycle) of CH1 is less than TIM1 When the mean (or duty cycle) of CH2 is reached, the motor reverses. At the same time, initialize the TIM2 timer to encoder mode and read the direction and speed of the motor through channels 1 and 2 of TIM2.

3.2 System Software Programming

The overall design flowchart of the system software is shown in Figure 7. All program functions, including initialization of each functional module, quaternion reading, geomagnetic angle reading, system motion attitude calculation, and motor control PWM waveform duty cycle assignment, are implemented in Keil. Finally, a hex file is generated and loaded into STM32F407 to achieve heading control of the four-wheel drive intelligent vehicle. In software programming, it is necessary to port the inv provided by Invensense company_ mpu_ dmp_ motion_ Driver. c and inv_ The mpu. c file and its corresponding header file. In this standard file library, there is a software functional interface that specifically implements the output of quaternions. Users do not need to be very concerned about how the raw data of three-axis gyroscopes and three-axis accelerometer sensors are fused into quaternions.

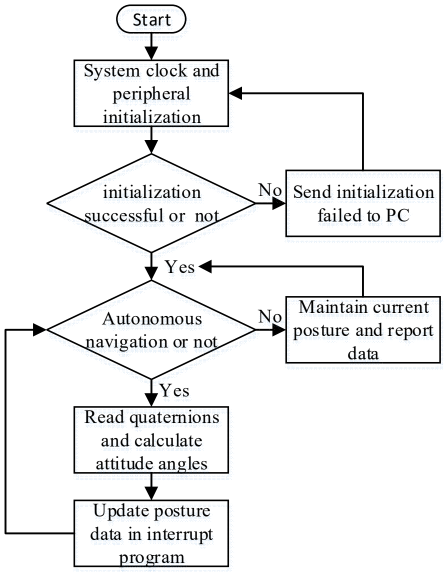

Figure 7. System software flowchart

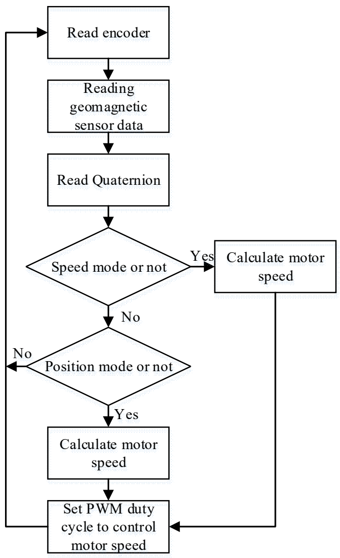

Figure 8. interrupt service routine

Figure 8 is the software interrupt service subroutine of this system. STM32F407 detects the INT signal generated by MPU6050 through an external interrupt pin. When the INT signal is high, STM32F407 reads the quaternion output from the sensor, determines whether the microcontroller is in speed mode or position mode, and obtains the current heading of the car through Kalman filtering. The speed of the four motors is adjusted to complete the entire process of the car's heading control.

4. Conclusion

The system is designed based on the above methods, and after installation, debugging, and software dual PID parameter tuning, the four-wheel drive intelligent car system runs 50 meters in a straight line according to the same set of PID parameters at 0.5 m/s, 0.8 m/s, and 1.2 m/s, respectively. In order to more clearly and intuitively display the process of combined navigation controlling the car during operation, a GPS positioning module is added to the intelligent car. And the collected position data was displayed on the trajectory in MATLAB, as shown in Figure 9. Through the trajectory display diagram, it can be clearly seen that the control results of the combined navigation on the small car when it deviates from the heading. It also proves that this set of PID parameters is the best for controlling the small car at 1.2 m/s, followed by 0.8 m/s, and the control effect at 0.5 m/s is the worst.

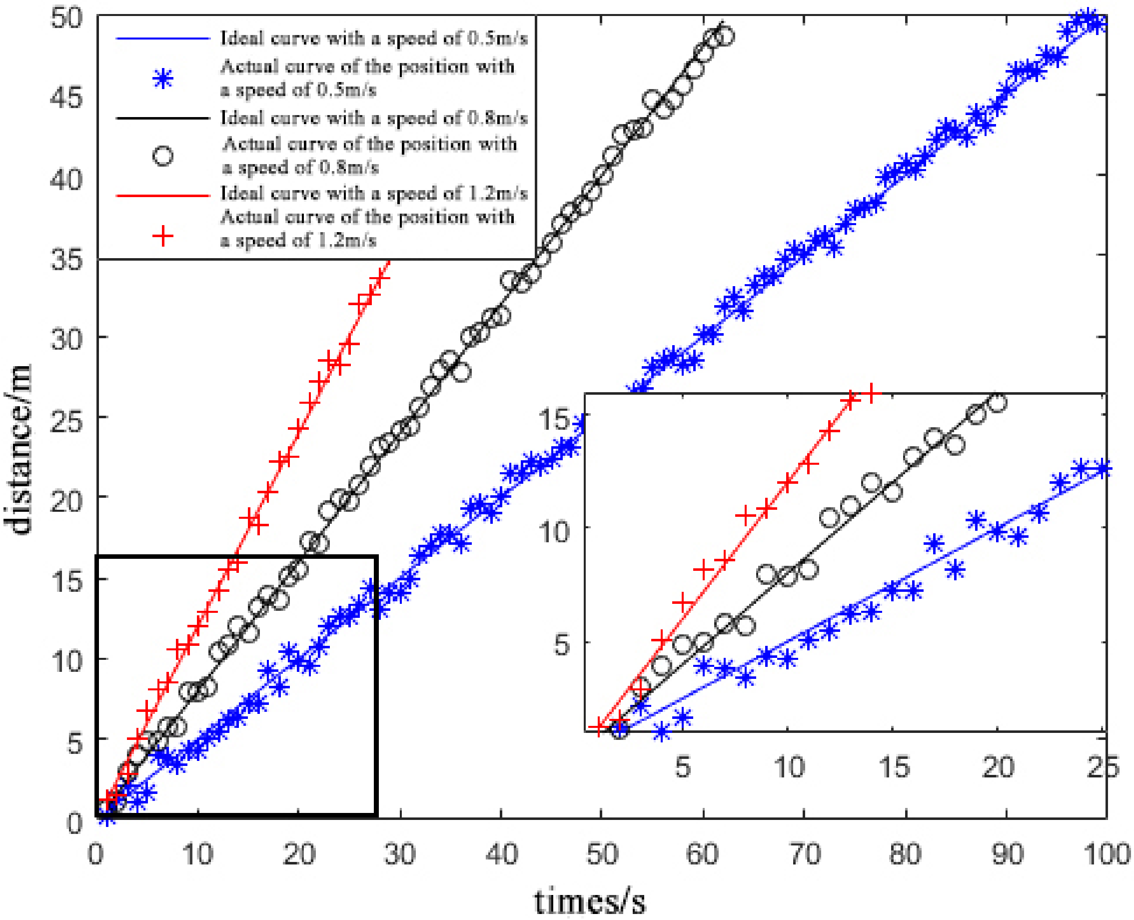

Figure 9. Comparison of GPS fixed point trajectories of the car at three different speeds

Acknowledgments

Using the STM32F407 microcontroller as the control core, MPU6050 and MAG3110 sensors as data acquisition methods, the integrated navigation control system is achieved by fusing quaternions obtained from three-axis gyroscopes and three-axis accelerometers, combined with geomagnetic heading angle as heading assistance, using DMP tools and series dual PID to meet the goal of smooth linear operation of 4WD intelligent vehicles. However, through comparison with cars without navigation control, it was found that the system, due to the addition of navigation control, slows down the forward speed of the car, adjusts the optimal PID parameters at different speeds, and maintains long-distance navigation accuracy, which is worth further improvement.

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