Design of Two-wheeled Self-balancing Vehicle System

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Abstract

With the increasing environmental problems, two-wheeled balanced car will be widely used in urban traffic in the future due to its excellent performance and low carbon environmental protection. From the analysis of the control system of the whole two-wheeled self-balancing car, it has instability and multiple control variables, so it has high academic research value.Based on the design scheme of two-wheeled self-balancing car, this paper abstracts it into a first-order inverted pendulum, carries out force analysis and establishes a mathematical model. Secondly, considering the function of the self-balancing car, this paper completes the hardware construction of the system. STM32F103C8T6 is selected as the controller, and MPU6050 with integrated gyroscope and accelerometer is used to realize vehicle attitude detection. On the basis of hardware design, this paper adopts PID control to realize the upright, forward and backward motion and steering functions of the two-wheeled self-balancing car. Finally, the system debugging of the two-wheeled self-balancing car is carried out. The car can be upright on power without external force, and it can quickly adjust its posture and restore to the balanced upright position when moderate external force disturbance is added. When the corresponding instructions are issued, the car can complete a series of actions such as forward, backward and steering.

Keywords

Two-wheeled Self-balancing; Gyroscope; Attitude Detection; PID Control.

1. Introduction

In terms of structure, the two wheel self balancing trolley is a single axle two wheel vertical robot [1]. It has a wide range of applications, not only limited to civil transportation, but also can be flexibly applied to military and industrial production. For example, the two wheeled mine sweeping vehicle used in military is improved on the basis of two wheeled self balancing vehicles, which can play a key role in military operations [2]. From the analysis of the control system of the whole two wheeled self balancing robot, it is equivalent to a first-order inverted pendulum system, so it is unstable, has multiple control variables, and has strong coupling and nonlinear characteristics [3]. At this stage, the research and development of automatic control principle is progressing day by day, new control algorithms emerge in endlessly, and the fields covered are also expanding. However, due to the lack of a suitable control platform, researchers can not achieve a deeper level of development and Research on control algorithm simply through software level simulation. Therefore, researchers need to find a stable, robust and controllable control experimental platform. The two wheel self balancing trolley is an ideal experimental platform in line with the above characteristics, and its structure is simple, and the control platform is easy to build. Scientific research workers can easily realize the development and debugging of new control algorithms through this platform [4]. Therefore, the design of two wheeled self-balancing trolley system has a very high academic research significance.

2. Overall Design Idea Diagram

2.1 Overall Design

The block diagram of the two wheel self balancing trolley system is shown in Figure1. The system includes the main control MCU, accelerometer, gyroscope, photoelectric encoder, motor drive module, DC motor and PC. In this design, STM32F103 is selected as the main controller. The current body posture and real-time motion of the car are obtained through the accelerometers and gyroscope sensors carried on the car body. The angle and acceleration data obtained are analyzed and processed through STM32 chip, and the PWM signal is output to control the motor.

At the same time, the photoelectric encoder detects the speed of the DC motor, obtains the PWM value and feeds it back to the MCU for negative feedback control[5]. The two wheel self balancing trolley mainly controls the rotation of the wheels through two groups of motors placed in parallel to drive the car body to complete the vertical, speed adjustment and control the steering of the car body. The Bluetooth module is used to receive the command signal from the mobile phone to complete the manual control of the car's straight travel and steering; Use the ST series burner to complete the debugging and downloading of the program.
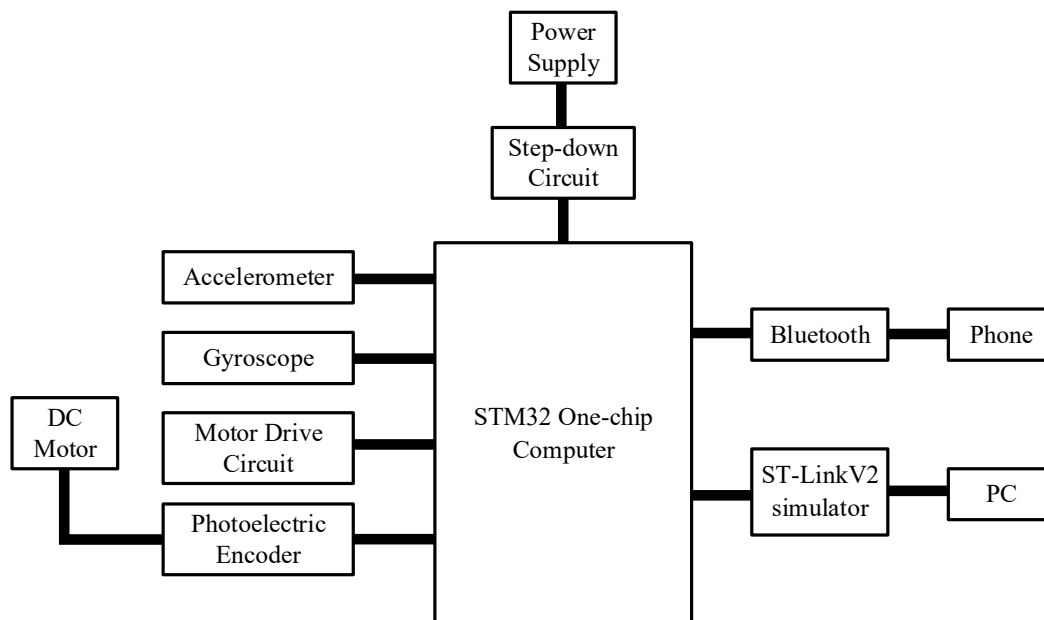

Figure 1. System block diagram of two-wheeled self-balancing vehicle

2.2 Control Chip Design

Combined with the requirements of the design itself and the cost of the overall hardware construction and other objective factors, this design selects a STM32F103C8T6 chip produced by Italy France semiconductor as the core of data processing. This 32-bit chip based on arm has powerful functions. It is equipped with Cortex-M3 core with strong processing speed, which can meet the basic requirements of daily development and data processing of this design. This processor has a working frequency of up to 72Hz. It is also equipped with a flash memory unit of up to 64K, which can realize repeated erasure of data. It uses 2v-3.6v power supply. Support rich peripheral interfaces, including SDIO, I2C, USART, etc. It has two most popular burning methods, SWD and JTAG, and 112 fast I/O, so it can meet various user needs; It is equipped with four 16 bit timers, and each timer has four special channels, which can be used for the input of encoder, so it can well realize the control of motor and encoder in this design; The design of dual I2C communication interface facilitates the use of mpu6050 motion processor.
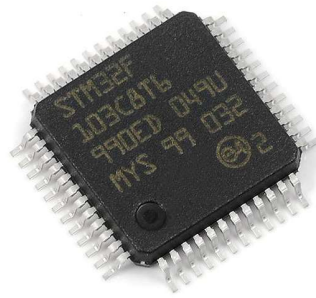
Figure 2. STM32F103C8T6 Chip

2.3 Gyroscope and Accelerometer

MPU6050 is the first 6-axis motion processor in the world. It is equipped with a 16 bit ADC three-axis MEMS gyroscope sensor, a MEMS accelerometer with signal conditioning function and a DMP digital motion processor supporting expansion. MPU6050 can connect with other sensors through the I2C serial communication interface. The DMP on the chip can read data from gyroscopes and accelerometers, and complete data integration through internal algorithms. If a three-axis magnetometer is loaded on the peripheral, the nine axis data fusion output can be realized[6].

The module is equipped with a 1024 byte FIFO memory, which can centrally store data and greatly reduce the power consumption of the whole system. I2C or SPI interface is used to realize the communication connection between registers, and SPI interface can realize high-speed data transmission. The module also has a built-in temperature sensor that can detect the working temperature at any time, which improves the safety of the whole module. The whole module adopts leadless packaging, which can withstand an external impact force of nearly 10000 grams.

MPU6050 module integrates accelerometer and gyroscope. In this design, three axial acceleration values can be obtained by using accelerometer, and three axial angular velocity values can be measured by using gyroscope. But what this design calls in the program is the data of attitude angle, namely pitch, yaw and roll. Therefore, the original data can be collected through the DMP module to convert the original data into quaternions. Quaternion can be converted into attitude angle by processing with the system's own algorithm . The physical hardware diagram of the module is shown in Figure 3.
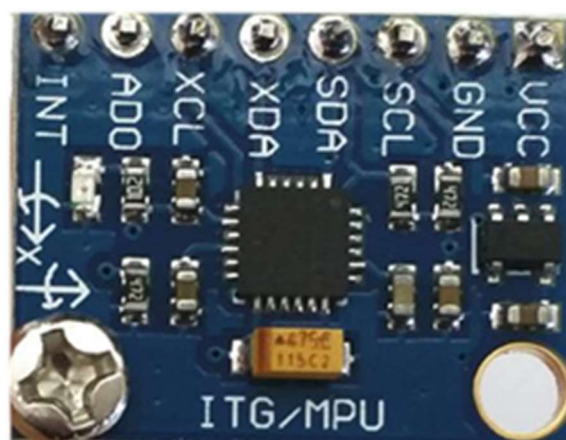

Figure 3. Gyroscope and Accelerometer

2.4 Motor Drive Module

TB6612FNG is a drive module for DC motor. It is produced by Toshiba company. It has a high current H-bridge circuit structure and can generate two outputs at the same time to control two motors Similar devices are L298N, which are basically the same. However, in comparison, TB6612FNG

does not contain heat consumption and peripheral diode freewheeling circuit, so it does not need additional heat sink, and the peripheral circuit structure is relatively simplified. It can drive the motor only by connecting the power filter capacitor, which is conducive to reducing the size of the components. At the same time, TB6612FNG has a frequency up to 100kHz, which can meet the requirements of this design for PWM signal input frequency. The physical hardware diagram of this module is shown in Figure 4.
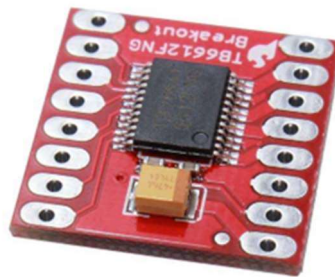

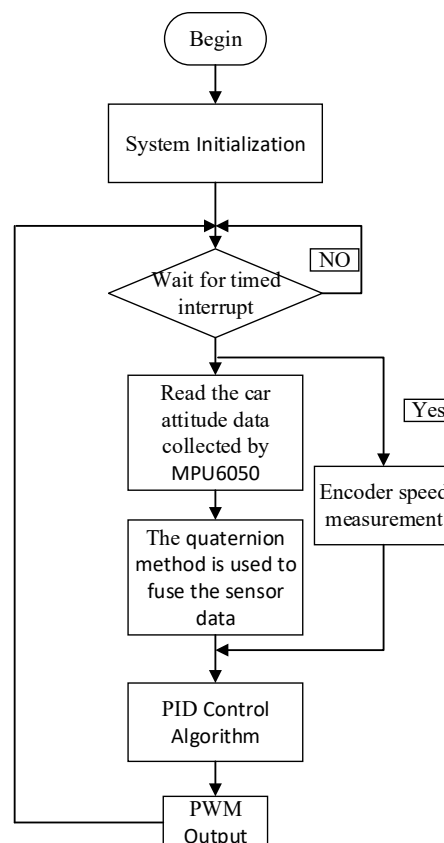**Figure 4.** Motor drive module

2.5 Control System Design

Figure 5. Overall control flow chart

The implementation method is to initialize the gyroscope and accelerometer. Then MPU6050 performs a self-test, places the data obtained by the gyroscope and accelerometer in the FIFO memory, and updates the data in the FIFO memory. Set the measurement data range of gyroscope and accelerometer respectively, and set MPU6050 clock. Change the mode of MPU6050 to slave mode, connect with STM32 MCU through I2C bus, and finally read the angle information.

Encoder speed measurement is realized by scanning high level through timer. When the timer function is enabled, it starts to scan and identify the level of the encoder interface. Whenever a high

level appears, the timer adds one to its counter value, and stores the accumulated data in the count register. Finally, by obtaining the accumulated value in the count register, the current speed value of the self balancing trolley can be measured.The core part is the PID control program design of the trolley, which is divided into three links: upright, speed and steering. Through the PID control, the trolley can be powered on and upright to realize the functions of straight steering.

3. System Testing and Analysis

3.1 Serial Port Debugging

In this design, the burner used in this design supports two burning methods. In order to facilitate the burning of the program, this design selects the burning method of SWD, and only four pins need to be connected to complete the download of the program. Connect the 3v3 pin of St link V2 with the VCC pin of the minimum board, and connect CLK with DCLK, GND with GND, IO with DIO in turn. At this time, insert the burner into the USB port on the PC side, and the corresponding green LED indicator on the burner and the minimum board will light up at the same time. Double click to open the Keil mdk5 software installed on the PC, open project, click options for target 1, and select debug. Select the mode in the upper right corner as the st link used in this design, and click setting. In the next interface, it can be found that the ID of the smallest board used in the design is displayed in the SW device, indicating that the design has successfully completed the SWD mode connection of the burner, and the self-balancing trolley system can be debugged and the program can be downloaded. The software interface of serial port connection is shown in Figure 6.
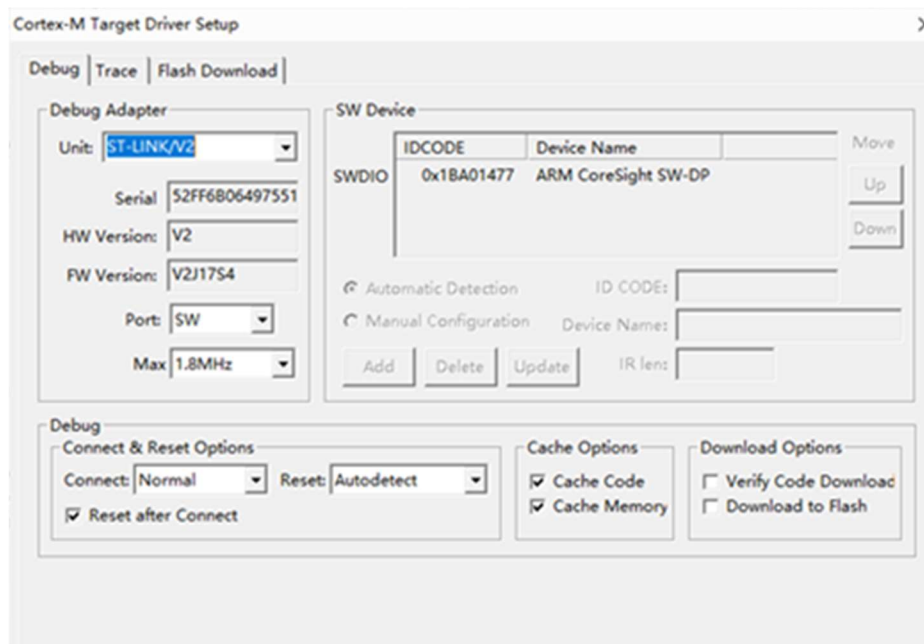

Figure 6. Serial port debugging software interface

3.2 Physical Testing

Hardware debugging is mainly divided into three aspects: (1) inspection of system schematic diagram. By checking the schematic diagram, compare whether the pins of each module are marked correctly and whether the wiring of each module is correct. (2) Check the hardware circuit. Use the multimeter commonly used in the laboratory to detect the welding circuit of the main control board and the base to see if there is a short circuit caused by the wrong connection of the welding points. Focus on checking whether the positive and negative electrodes of the battery box are connected correctly to prevent the reverse connection of the power supply from burning the circuit board. The inspection process is shown in Figure 7. (3) Power on inspection. Install the battery, turn on the power supply

to power on the balance trolley and check whether the indicator lights of each module are on, so as to prevent problems inside the module from affecting the software debugging.
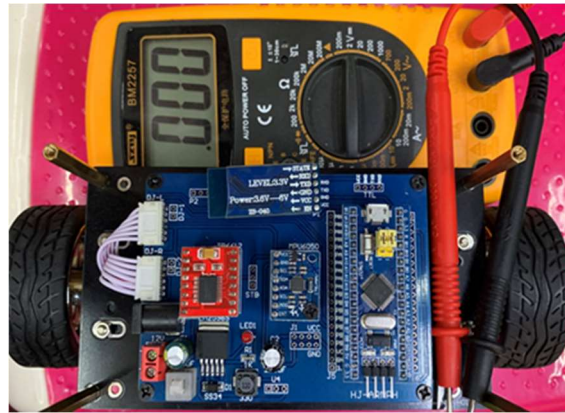

Figure 7. Check the circuit board with a multimeter

After burning the software program of the system into the microcontroller system, the power is turned on for physical debugging. After a series of debugging such as device welding, program writing, software debugging, and physical testing, the hardware system is connected to the power supply and the power switch is pressed, and the initial LCD screen displays the results as shown in Figure 8. The key of the two wheel self balancing trolley system designed this time is the vertical ring, which is the basis for the trolley to realize straight travel and steering. The whole system uses PID control algorithm. For the vertical ring, PD control is used to adjust the angle. The adjustment step of this design should be to adjust P first and then D. adjusting the KP value can enable the trolley to overcome external forces, that is, overcome the resultant force on the trolley to keep the trolley upright; The Kd value is adjusted to overcome the self inertia of the car, reduce the shaking of the car body, and make the whole upright more stable.
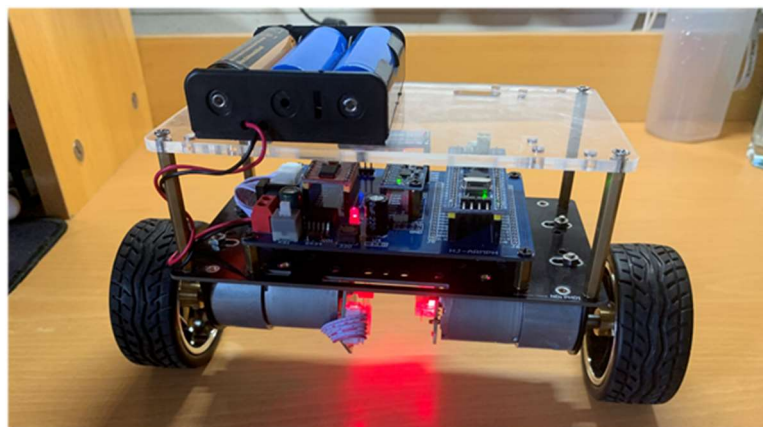

Figure 8. Two-wheeled self-balancing trolley is powered on vertically

In this chapter, the self balancing trolley system is debugged from hardware, serial port, vertical ring, speed ring and steering ring. The core of this design is to adjust the parameters of the control program. The approximate method is to control one of the coefficients to change other values, and observe the motion state of the trolley until the trolley reaches the best control effect.

4. Conclusion

In this design, STM32 single chip microcomputer is used as the controller to complete the data processing of each sensor signal, and realize the adjustment of the self balancing system's own attitude. The system is equivalent to a first-order inverted pendulum system. It has the characteristics of instability, multiple control variables, strong coupling and nonlinearity. Through this platform, the development and debugging of new control algorithm are realized. This design has very high academic research significance.

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