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System Design of Quadrotor UAV based on Embedded Development

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Abstract: This paper introduces a micro quadrotor uav based on STM32F106ZET6 single chip microcomputer. The main hardware circuit includes minimum system, dc motor drive, NRF24L01 wireless communication based on 2.4ghz, six-axis attitude acquisition and human-computer interaction module. By means of wireless communication module, various attitude of airframe is transmitted back to the ground, and the flight attitude of uav is controlled in real time by remote control. In the software algorithm, the attitude collection array is solved by quaternion method and rotation matrix to obtain the flight attitude of the fuselage. Then, the cascade PID algorithm is adopted to minimize the system error, so as to achieve the purpose of accurate data processing and realize the stable flight of uav.

Keywords: STM32 single chip microcomputer; NRF24L01 wireless communication; Attitude solution; Cascade PID; Motor drive.

1. Introduction

Relying on convenient human-computer interaction function, UAV(Unmanned Aerial Vehicle) technology involves a wide range at present. In terms of transportation, it can assist the traffic police and other departments to monitor road safety and solve the hidden dangers of road safety. In the face of unpredictable danger, drones can also be used for real-time exploration and material rescue to avoid human injury. In agriculture, automatic irrigation and planting services can be realized, saving manpower. In landscape shooting, various heights and postures can be changed to meet the requirements of various shooting angles. Based on the above user requirements, this paper designs an ARM cotex-m3 kernel STM32F106ZET6 single-chip microcomputer, which is more efficient in reading and writing data and adopts cascade PID algorithm to improve the adaptive ability of uav in the natural environment. The micro quadrotor uav is designed from the aspects of mechanical structure, circuit design and software control. Based on the traditional algorithm, the quaternion method and cascade PID are used for optimization[1].

2. The Total Design Scheme

Four rotor UAV is developed on the basis of the traditional propeller helicopter, a new type of structure through four power size is the same and equal distance symmetrical distribution of motor and fixed on the motor radius and structure are the same blade to cooperate with each other, to achieve the six degrees of freedom on any changes of flight attitude and position, belongs to the classic underactuated systems. At present, there are "+" and "×" quadrotors with two different mechanical structures. The"×"type system requires the coordinated operation of four motors at the same time to achieve flight stability, which requires too high accuracy of the control algorithm and is difficult to achieve. Therefore, most "+" type systems are adopted at present. The rechargeable 3.7v dynamic lithium battery is used to provide a stable voltage of 3.3v and 5V for each module. The height, Angle, speed and PID parameters of the uav flight are displayed dynamically through the OLED display. The test data is transmitted to the OLED display on the remote control through the NRF24L01 wireless communication module to complete human-computer interaction.

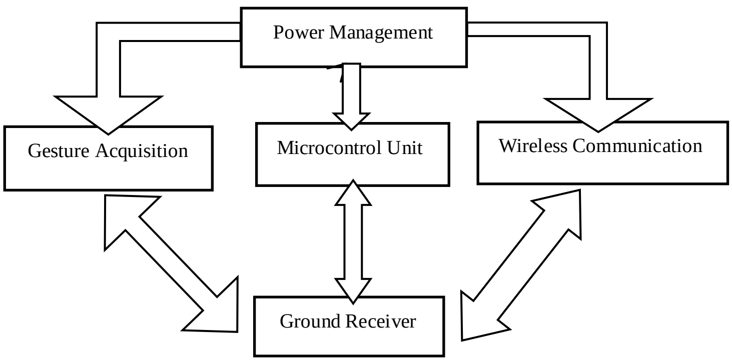

Figure 1. The total architecture of UAV

3. The System Circuit Design

3.1 Microcontrol Unit

As a powerful core microprocessor with high reading and writing speed, STM32 MCU is powered by 3.3v. It cannot work alone. It must be composed of crystal oscillator clock, reset circuit, power supply and serial port download interface to work as the minimum system unit and provide multiple input and output. This series of single-chip microcomputer has 112 GPIO ports, 512 bytes FLASH, 64 bits RAM, 3 SPI and 2 IIC bus interface, data processing speed, high efficiency, advanced design of timer fully meet the needs of the project.In this experiment, 8MHZ crystal oscillator was selected to provide system clock for the core unit.

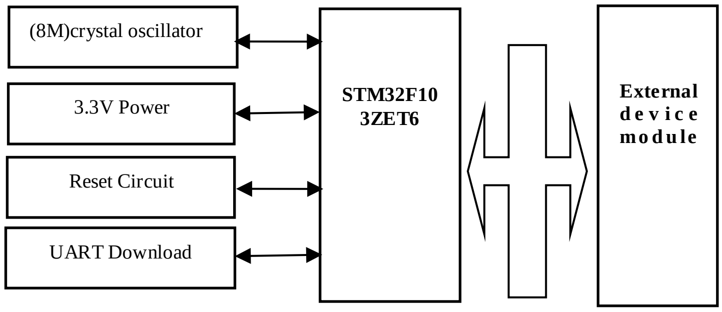

Figure2. The microcontrol unit

3.2 The Power Management Module

As the energy port of the whole system, it is necessary to provide a stable and effective voltage for each module. In this case, we choose the dynamic lithium ion battery that can be recharged to provide a stable 3.7v. Since the attitude acquisition and wireless communication modules are powered by 3.3v, it is necessary to reduce the 3.7v battery voltage to 3.3v through XC6204. In order to power the serial port and OLED module, the 3.3v module must be changed into 7.2v by boosting the LM2940 module, and then the voltage is reduced through TPS7350.

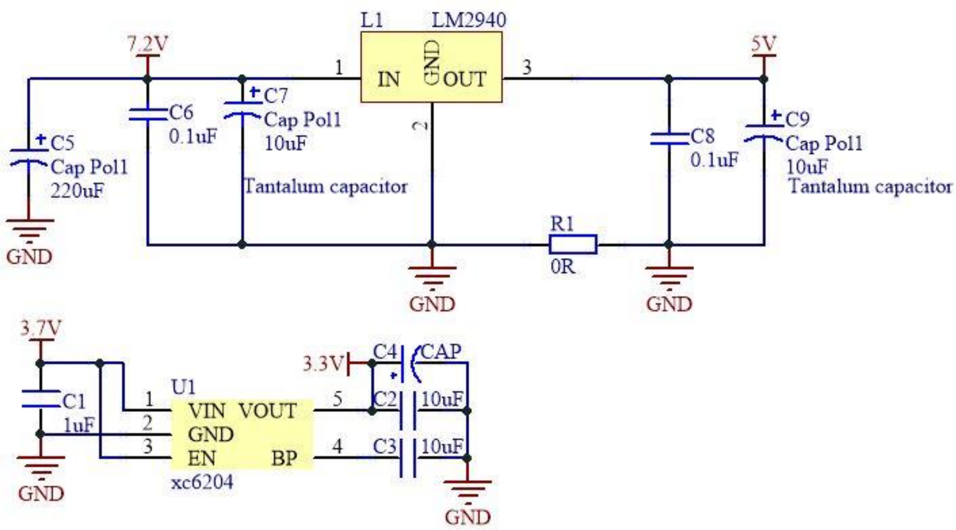

Figure3. The circuit of power management module

3.3 Attitude Acquisition Module

In order to obtain real-time pitch, yaw and roll in the process of unmanned aerial vehicle (uav) in flight of flight attitude, we decided to choose set three-axis accelerometer and three-axis gyroscope as one of the six axis attitude MPU6050 chip, the chip by 3.3v power supply, can effectively eliminate in the case of a separate installation error due to two axes are not completely consistent, thus cause angle measurement error, which is convenient for data normalization processing and fusion. Moreover, the MUP6050 has a slave IIC interface, which is convenient to connect the digital compass and realize the master-slave combination, especially can share a transmission data line with the microprocessor's IIC interface saving and the acquired attitude calculation data can be more accurate and efficient.

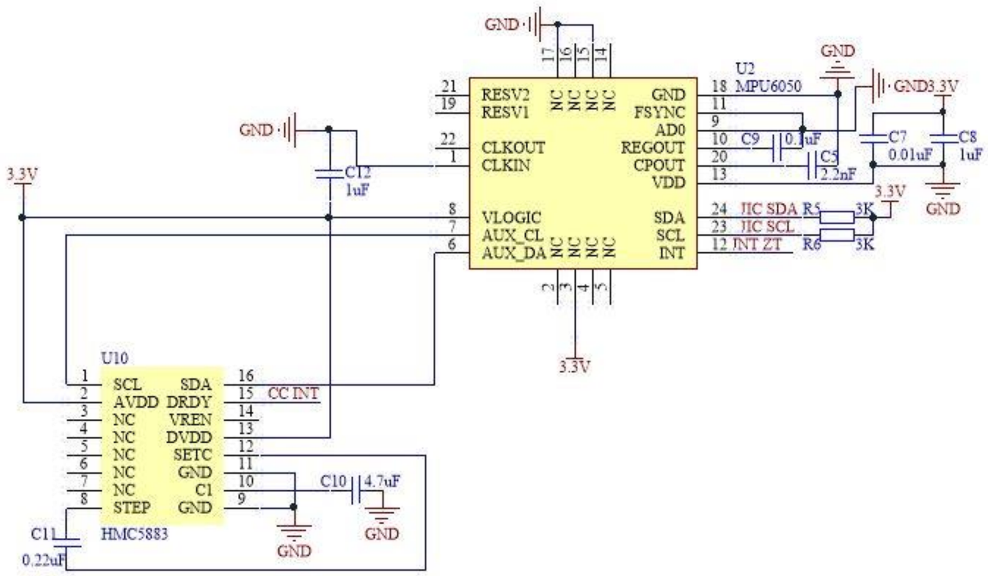

Figure 4. The Circuit of Attitude Acquisition Module

3.4 The Wireless Communication Module

In order to achieve the data transmission between the body and the ground receiver[2], we chose NRF24L01 chip as the wireless communication chip, which is most widely used in the field of communication and transmission. It is powered by 3.3v and can be directly connected to the single-chip pin to achieve high-speed full-duplex synchronous communication. Its transmission frequency band is 2.4GHZ, which has the advantage of high speed and low energy.

3.5 The Motor Drive Module

The structure of brushless motor is simple, which can be controlled by the driver to change the DC signal into three-phase alternating current depend on the motor speed and steering and its circuit structure is relatively complex, which will increase the load of the micro-uav. After the actual measurement, it is found that there is a big deviation between the actual output of the motor and the theory. The structure of the brushless motor is relatively complex and the change of internal current is realized by the coordinated operation of the brush and the commutator. The motor speed is only related to the current in the hardware circuit and the single-chip microcomputer is more convenient to control with smaller error. Under the 3.7v power supply, it can work normally and meet the requirements of current and speed, so we finally choose the brushed-hollow cup motor. The electric current driving method is the first thing with consideration. When testing the motor speed, it can be found that there is a threshold effect. Once the motor speed is raised to a certain threshold, the motor cannot speed up. Moreover, the triode current no longer changes linearly, which may result into distortion. In fact, the driving current can be regarded as generated by the charging and discharging process of parasitic capacitance between gate and drain, gate and source. In the instantaneous state of charging, the capacitor can be regarded as a short circuit, which will generate a relatively large current.

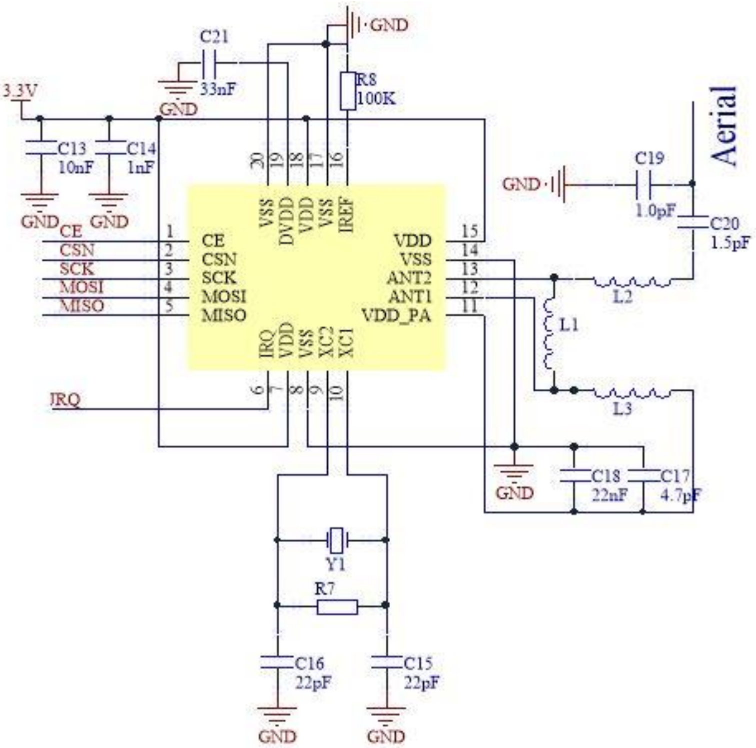

Figure5. The circuit of wireless communication module

3.6 The Human-computer interaction module

In order to facilitate real-time monitoring and modification of system parameters, realize communication with PC terminal, and adapt to flight under different altitude, air pressure and wind speed, buttons, OLED screen display, buzzer alarm module and USB port download module are designed on the fuselage[3].

4. Software programming

4.1 PID and Cascade PID Control Algorithm

After collecting the current attitude data, we use PID algorithm to optimize the data. The traditional PID algorithm is to eliminate the error through the error generated by the system, the error of the past and the current error by proportional differential integral weight to eliminate the error value. But the error value of this method is difficult to obtain accurately, and the weighted coefficient is difficult to weigh. Therefore, we adopted the three-stage cascade PID control algorithm. By controlling the Angle to control the speed, constitute the "velocity-angle-angular velocity", the speed quantity into the angle quantity, then the angle quantity into the angular velocity quantity, from the outside to the inside of the three-stage cascade control system. The specific implementation method can be as follows: firstly, when adjusting the cascade control system, the inner loop is used as the secondary regulator, and the purpose is to introduce the auxiliary variable to stabilize the principal variable. So we need to adjust the angular velocity ring firstly. Given a target angular velocity of 0, that is the output of the angular ring is 0, increase the *P* value, move the fuselage back and forth with your hands until you feel obvious resistance, and then increase the *D* value until the resistance weakens and feels relatively gentle. On this basis, increase the *P* value again to complete the debugging of the angular speed ring. Secondly, adjust the angle ring, set the Angle of the target angle as the mechanical zero point, gradually increase the *P* value until the fuselage jitter, then increase the *D* value, until the jitter disappeared, finally increase a little *P*, that is to complete the debugging of the angle ring. The advantage of cascade system is to accelerate the response speed of the system and the parameter range is large, which is easy to adjust. In addition, due to the existence of auxiliary loop, the control time constant of the system is shortened and the anti-interference of the system is improved. The attitude angle fitting in the debugging process is shown in the Figure 6 as follows.

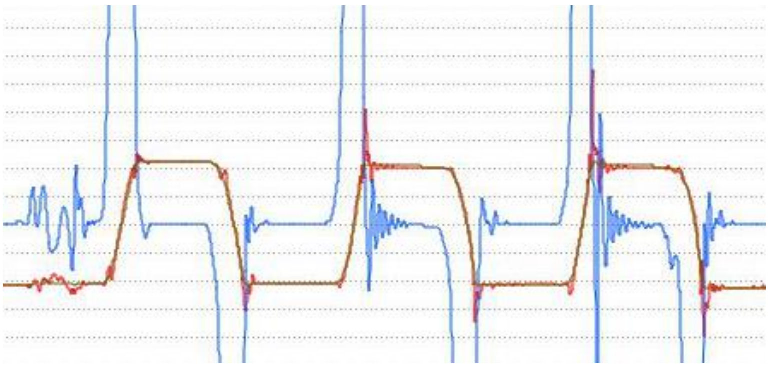

Figure 6. Four-rotor UAV with attitude angle fitting variation

4.2 Attitude Algorithm

MPU6050 directly obtains the angle quaternion data through its own DMP module and the classical quaternion attitude solution algorithm, which simplifies the operation of large amount of data and filtering, and then sends back the data via the IIC bus to the MCU. The quaternion method avoids the complex requirements of trigonometry in the original euler angle calculation, and the rotation attitude of the fuselage is expressed by four basic elements. The incremental rotation is obtained by using the mapping relationship between the direction cosine matrix and the coordinate axis, and the attitude angle can be obtained after fusion. In the attitude angle data processing we mainly use the complementary filtering method to eliminate the cumulative effect of signal acquisition and noise interference. The complementary filtering method and kalman filtering method have the same idea. The main filter accelerometer in the instantaneous state of all directions of the motor mechanical vibration of the noise acceleration, as well as the gyroscope over time cumulative integration of the temperature drift error[4]. Therefore, the data obtained by the accelerometer in the case of continuous time integration is highly reliable, while there is a large error in the instantaneous state, that is, a large inclination error will be generated in the case of high frequency.In the process of integrating for a long time, the low frequency gyroscope will produce a large deviation error due to the zero drift. Complementary filtering is to combine the advantages of two sensors to suppress the effect of accelerometer at high frequency and increase the proportion of low frequency, that is, low frequency inhibits high frequency. On the contrary, the effect of gyroscope at low frequency is increased while that at high frequency is suppressed. The optimal Angle can be obtained by selecting appropriate weighting coefficient and combining with complementary filter and serial PID.

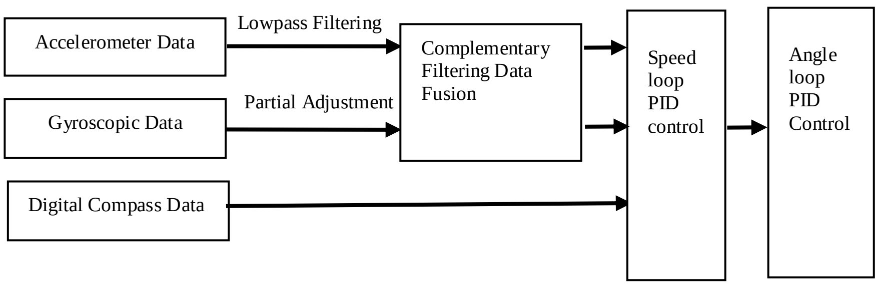

Figure 7. The flow of attitude algorithm

4.3 The Protocol of Wireless Communication

The communication method choosed is SPI communication, which supports the communication between a host and multiple slave machines, and determines which slave machine is currently used by slice selection signal line NSS. SCK clock signal line determines the rate of data transmission. Only one bit of data is transmitted in each clock cycle and it is only valid in the descending edge. The Enhanced Shock Burst TM mode is selected for the mode of transceiver, which is a low-energy data transmission protocol that can be written at a low speed and transmitted at a high speed with strong anti-noise interference ability[5]. When changing the mode of reading and writing, only the last bit in the 30-bit configuration word is modified accordingly.

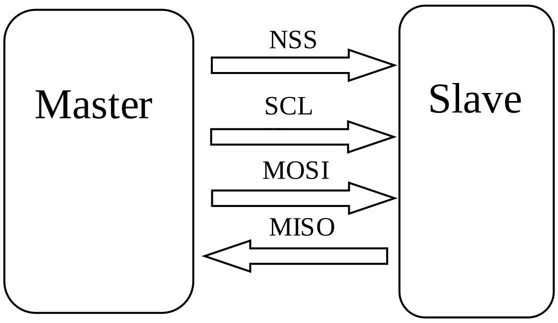

Figure 8. The protocol of wireless communication

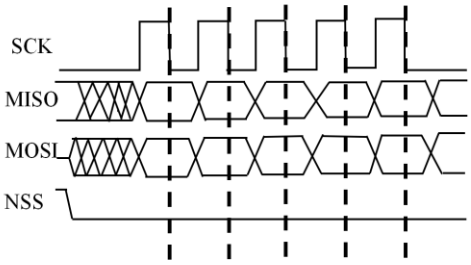

Figure 9. The simulation results

5. Conclusion

The hardware scheme designed in this paper is proved to be feasible in practical operation. The altitude value obtained from the six-axis sensor combined with the digital compass is converted into the actual data value by attitude calculation, namely quaternion method. Effective combination of complementary filtering method and cascade PID, filter all kinds of interference term, as far as possible to reduce the error value. Under natural conditions, the micro-quad-rotor UAV can complete various attitude changes and the obtained data values also achieve the effect of smooth change. In the process of uav flight, it can also realize real-time data reception and exchange with ground base station or remote control and make quick response, which indicates that the designed micro-quadrotor uav can meet various control and flight requirements.

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