

Research and Design of Flight Control System for Small Four Rotor Aircraft

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Abstract

Four-rotor vehicle is very popular in the current research. STM32F103 is selected as the core of four rotor autonomous vehicle control in this paper. Arm cortex m3 series products are used as the processor core. The real-time attitude measurement task of the vehicle is detected and calculated by mpu6050 sensor. After NRF24L01 wireless communication or Bluetooth control of the aircraft, the final detected attitude is compared with the ideal attitude, and PID control hollow cup 720 motor is used to drive the four rotor aircraft to complete the flight control.

Keywords

Four axis aircraft; mpu6050; STM32; PID algorithm.

1. Introduction

The four-rotor UAV (unmanned aerial vehicle) has played a bigger role in military and civilian use, at present, UAV can conduct aerial photography, prospecting, blasting, mine sweeping, emergency search in civilian use, etc., and it can also be used as an entertainment tool. UAV is widely used in military use. The four-rotor vehicle is widely used in life; the following are its advantages and uses. [1]

- (1) The size of four-rotor vehicle is small and it can be used in many places where it is narrow and inconvenient, such as the detection of pipelines, caves, and other places.
- (2) The four-rotor vehicle can be combined with various high-end electronic products to obtain more widely used products.
- (3) In some work scenarios that endanger people's life or property safety, UAV can be used for low-altitude operations, such as personnel search and rescue after earthquake, and UAV can avoid additional damage caused by aftershock to the army and people.
- (4) The four-rotor UAV can operate for a long time, and can greatly increase the work efficiency while ensuring that the line is not burned.
- (5) The structure of the four-rotor aircraft is very simple and the price is also economical.

There are many types of UAV, four-rotor aircraft that can be controlled autonomously, and four-rotor aircraft that are remotely controlled by radio (as shown in Fig.1).



Fig.1 four-rotor unmanned remote aircraft

2. Attitude Measurement System

The real-time attitude measurement of this design is collected and measured by the MPU6050 sensor. One attitude tracking method of acceleration and magnetic field compensation of measurement unit that considers three-axis gyroscope, three-axis accelerometer and three-axis magnetometer integration is used. In the proposed method, quaternion and translational acceleration and magnetic disturbance related to body rotation together included in the state vector.

The purpose of compensation is to make the coordinate system directly considered as a rigid body coordinate system on a certain basis; its difference value is fixed or 0, which is convenient for measuring results. Based on this, a new rotation matrix is obtained by modifying the matrix calculation before compensation, and a new quaternion matrix is obtained. The calculated quaternion attitude is the real flight attitude. The attitude of the four-rotor includes three position quantities x , y , z in the three-dimensional coordinate center, and the attitude amount along the three axes can be calculated by the rotation angle.



Fig.2 MPU6050 sensor

As a detecting device, the MPU6050 sensor can detect measured information, and the sensed information can be detected, and then the perceived signal is converted into an electrical signal or other form of required signals for output to control according to its unique law. (As shown in Fig.2) The MPU6050 can measure the three-axis angular rate of the body and measure the three-axis acceleration of the body. There are many unexpected phenomena in the measurement process, so it is necessary to combine the accelerometer with the gyroscope to get a more accurate value.

3. Attitude Acquisition Module

This paper uses the MPU6050 sensor, which combines the three-axis gyroscope, three-axis accelerometer and digital motion processor, and conduct interface with many non-inertial digital sensors on its auxiliary I2C port. The on-chip 1024-byte FIFO buffer allows the system processor to read sensor data in burst, FIFO buffers the complete data set, the timing requirements of the system processor is reduced by allowing the processor to read FIFO data burst. Then enter into the low-power mode when the MPU collects more data, which helps to reduce system power consumption. With a separate VLOGIC reference pin, the MPU-6050 uses three 16-bit ADCs for the gyroscope and accelerometer to convert the measured analog quantities.

The MPU-60X0 consists of three independent vibrating MEMS rate gyroscopes, which can detect the rotating X, Y and Z axis. When the gyroscope rotates around any sensing axes, the Coriolis Effect will cause capacitive sensor detects vibration. The generated signal is amplified, demodulated, and filtered to produce voltage that is proportional to the angular rate. This voltage uses a separate on-chip digitized 16-bit analog-to-digital converter (ADC) to sample each axis. The full-scale scope of the gyroscope sensor can be digitally programmed to ± 250 , ± 500 , ± 1000 or ± 2000 degrees per second (dps). The ADC sample rate is programmable from 8,000 samples per second to 3.9 samples per second, and the user can select a low-pass filter to achieve large-scale cutoff frequency. The embedded digital motion processor (DMP) is located within the MPU-60X0 and unloads the computation of the motion processing algorithm from the main processor. In general, motion processing algorithms should operate at a high rate (usually about 200 Hz) to provide accurate results with low latency.

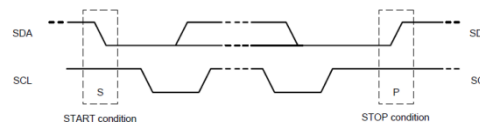


Fig.3 sequence diagram of I²C communication protocol

4. PID Control Algorithm

PID is a closed-loop control algorithm, P, I, D are proportional, integral, and differential control algorithms, respectively. The proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. The PID controller continuously calculates the error value as the difference value between the required set point and the measured process variable, and calculates according to the proportional, integral and derivative term (sometimes expressed as P, I and D, respectively), their names are the controller types. The functional block diagram of PID analog control system (as shown in Fig.4) is as follows:

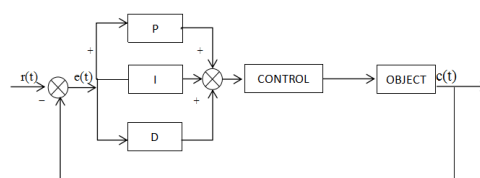


Fig.4 functional block diagram of PID analog control system

In order to solve the flight control problem of the four-rotor UAV, the transfer functions of the pitch, roll and yaw channels are established by coordinate transformation and attitude calculation of the four-rotor UAV. The PID controller is used to control the flight attitude of the four-rotor UAV. The PID controller can effectively realize the control of the four-rotor UAV,

which greatly reduces the steady-state error of the UAS, and it improves the stability of the whole UAV system, it has certain reference value and guiding significance for the research on stability of UAV system in the future.

When designing the aircraft, the pitching motion of the aircraft should be considered first, followed by the lateral rolling motion of the aircraft, finally, the plane translational motion of the aircraft is considered. Formula (1) is a matrix relationship between translational motion and angular motion.

$$\begin{bmatrix} u1 \\ u2 \\ u3 \end{bmatrix} \Rightarrow \begin{bmatrix} \varphi \\ \theta \\ \psi \\ \cdot \\ \varphi \\ \cdot \\ \theta \\ \cdot \\ \psi \end{bmatrix} \Rightarrow \begin{bmatrix} x \\ y \\ z \\ \cdot \\ x \\ \cdot \\ y \\ \cdot \\ z \end{bmatrix} \quad (1)$$

The conversion process of attitude angle and corresponding transformation process of coordinate system (Fig.5).

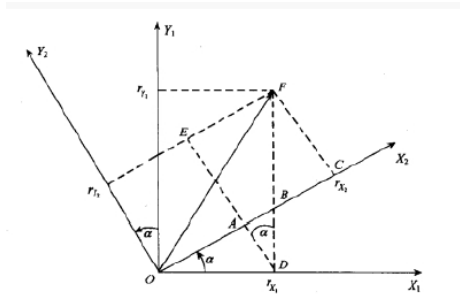


Fig.5 rectangular coordinate system and the corresponding transformation diagram of the attitude angle in transformation process

When the coordinate system rotates α angle along the same direction, the corresponding relationship is as follows:

$$r_{x2} = r_{x1} \cos \alpha + r_{y1} \sin \alpha \quad (2)$$

$$r_{y2} = r_{y1} \cos \alpha + r_{x1} \sin \alpha \quad (3)$$

$$r_{z2} = r_{z1} \quad (4)$$

The above correspondence is expressed in the form of matrix as follows:

$$r^1 = \begin{bmatrix} r_{x1} \\ r_{y1} \\ r_{z1} \end{bmatrix} \quad (5)$$

$$r^2 = \begin{bmatrix} r_{x2} \\ r_{y2} \\ r_{z2} \end{bmatrix} \quad (6)$$

$$c_1^2 = \begin{bmatrix} \cos \alpha & \sin \alpha & 0 \\ -\sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (7)$$

A direction cosine matrix can be derived from the above formula, through which the rotation direction is expressed.

$$\begin{aligned}
C_n^b &= \begin{matrix} b & 2 & 1 \\ C_2 & C_1 & C_n \end{matrix} \\
&= \begin{bmatrix} \cos \alpha & \sin \alpha & 0 \\ -\sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & \sin \theta \\ 0 & -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} \cos \psi & -\sin \psi & 0 \\ \sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \\
&= \begin{bmatrix} \cos \gamma \cos \psi + \sin \gamma \sin \psi \sin \theta & -\cos \gamma \sin \psi + \sin \gamma \cos \psi \sin \theta & -\sin \gamma \cos \theta \\ \sin \psi \sin \theta & \cos \psi \cos \theta & \sin \theta \\ \sin \gamma \cos \psi - \cos \gamma \sin \psi \sin \theta & -\sin \gamma \sin \psi - \cos \gamma \cos \psi \sin \theta & \cos \gamma \cos \theta \end{bmatrix}
\end{aligned} \tag{8}$$

Euler angle differential equation is used to solve:

$$\begin{bmatrix} \dot{\gamma} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \frac{1}{\cos \theta} \begin{bmatrix} \cos \theta & \sin \gamma \sin \theta & \cos \gamma \cos \theta \\ 0 & \cos \gamma \cos \theta & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \omega_{EBx}^b \\ \omega_{EBy}^b \\ \omega_{EBz}^b \end{bmatrix} \tag{9}$$

The attitude estimation algorithm only introduces quaternion method. Quaternion can be regarded as a four-dimensional space. Quaternion is composed of real number and imaginary number. And the square of imaginary numbers is equal to 1. There is no singularity in its expression for quaternion, and its structure is much simpler than that of matrix. Quaternion can accurately describe the corresponding physical quantities when the rigid body rotates.

5. STM32F103 Single-chip Microcomputer

This paper uses the STM32F103 enhanced processor, its GPIO port can be connected with many peripherals, in most four-rotor or balance car, STM32 is the best choice for central processing, it is fully functional, powerful, low power consumption, safe and convenient to use, low cost and low market price.

The STM32 single-chip microcontroller has seven 16-bit parallel I/O ports; they are PA, PB, PC, PD, PE, PF, and PG, respectively. Each GPIO port of the STM32F103 processor has two 32-bit configuration registers (GPIOx-CRL and GPIOx-CRH); two 32-bit data registers (GPIOx-IDR and GPIOx-ODR); one 32-bit position/reset register (GPIOx-BSRR); one 16-bit reset register (GPIOx-BRR); one 32-bit lock register (GPIOx-LCKR). Each pin of the IO port can be configured to many operation modes by software. Each used pin function must be configured before running the program, if the multiplexing function of some pins is not used, they can be configured as commonly used GPIO port.

6. Conclusion

This paper discusses research status of four-rotor aircraft at home and abroad at present, which focuses on the attitude system and the acquisition of attitude module, PID control method is used, STM32 is used to achieve control, so as to make four-rotor aircraft, and its flight effect is better.

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