

Design of a Four-Rotor Aircraft based on Cortex-M4

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Abstract: In this paper, we present a controller design on mini aircraft with four rotors from its theory to implementation. The dynamic model is gained by means of Large-scale transformation Algorithm of Quaternion to Euler Angle. We apply Cortex-M4 inner core microcomputer as a processor; get angle information from inertial sensor and altitude information from ultrasonic. By using sliding-mode control, six dimensions of the aircraft get under control. In the meantime, flight information will be preserved in SD card. The controller assures its reliability combining with embedded real time processing system RT-thread. Position machine programmed in C# could monitor the aircraft and modify its parameters by human.

Introduction

A mini four-rotor aircraft has many advantageous characteristics including high mobility, good adaptability to different situations, low cost and being capable of taking off and landing vertically. The ability to hover is necessary and beneficial for operations in confined space, both indoors and outdoors. In addition, the rapid progress of techniques on sensors, drivers and processors made it more effective for four-rotor aircrafts being applied to more and more areas, especially in some certain dangerous occasions.

Flight controller mostly adopts single chip microcomputers as its major controlling chip because mini aircrafts need high controlling frequency to handle various complex circumstances. But in the same time this leads to some boundedness including limitation of peripheral resources and low operating rate. This work seeks to take advantage of low energetic consumption processor STM32F4291G based on high speed core Cortex-M4. It has rich peripheral resources and comparatively high operating rate, and its combination with real time embedded operating system RT-thread increases the portability of code. We will introduce hardware structure and software process of our designed mini aircraft in the following sections.

Controlling system hardware structure

The hardware design of a four-rotor aircraft mainly contains a core-board, inertial sensor, ultrasonic wave sensors, wireless transmission, SD memory card, electrical machine and driver module. The system framework is shown in Fig.1

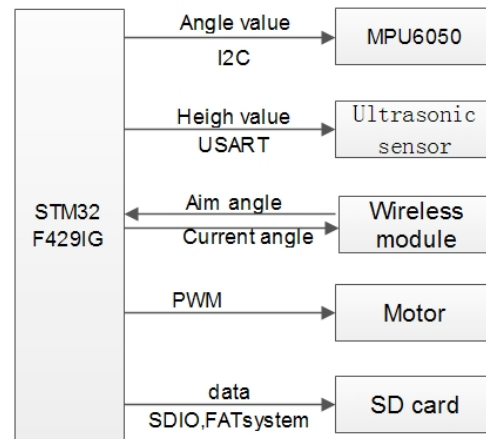


Fig1: System framework

Core board

In this work, flight controlling core-board use singlechip STM32F429IG as the Micro Controlling Unit, it has been designed for very high frequency operations of up to 180 MHz with 2M-byte flash code memory and 256K-byte SRAM. Moreover, its rich of peripheral resources such as 168 fast I/Os, 17 timers, 4 USARTs, 6 SPIs, 3 I2Cs, 2 CANs, 2 SDIOs, single float point unit can help to calculate floating number, which is certainly satisfied for flight controller.

Inertial sensor

We adopted inertial sensor MPU6050 for its inserted triaxial accelerometer and three-axis gyroscope. It maximizes the dynamic range to $\pm 16g$ of triaxial accelerometer and ± 2000 degree of three-axis gyroscope. When comes to this part, the solution was to read original angles' data through I2C bus, and then to apply quaternion algorithm and complementary filter algorithm to get accurate position angle. But during the experiment we find it not necessary to take complementary filter algorithm into consideration, instead we could use sensor's inserted Digital Motion Processor. It can not only overcoming environmental disturbance but also save calculating space for CPU.

Altitude sensor

Altitude sensor use US-100 ultrasonic distance to measure module, covering the range from 2cm to 4.5cm. By reading the distance data through serials and combining the current attitude angles, we get the vertical distance between aircraft and ground.

Wireless transmission

To get communication between aircraft and upper computer, wireless transmission is of great help. In the process, aircraft take the order from human and in return it sends back important data for preservation.

Motor driver

It is always important about the choice of electrical machines and drivers in the aircraft for they provide necessary power. We choose MOS tube SI2302 to get output PWM from single chip, with which we can change on-off radio and alter electrical machines' rotate speed.

SD card

The system use microcontroller's SDIO bus and FAT file system to store necessary data, such as PWM value, altitude value, angles. Next, we can analyze the bug in the process using the data.

Software process

The controlling system uses RT-thread embedded operation system in real time. Firstly, initialize the

necessary peripheral resources, and then set inertial sensor MPU6050 to DMP module. It shall create three threads containing position analysis and controlling thread, real time modification thread and SD card memory thread. The specific process is the same as Fig2.

Position analysis and controlling

The system initializes a 10ms timer interrupt. Each interrupt function gives position analysis and controlling thread a semaphore to activate this thread. It reads quaternion q_0, q_1, q_2, q_3 dealt by DMP through inertial sensor MPU6050. After that, transfer received quaternion to Euler angles by conversion formula. The formulas are:

$$\phi = \arctan\left(\frac{2(q_2q_3 + q_0q_1)}{q_0^2 - q_1^2 - q_2^2 + q_3^2}\right) \quad (1)$$

$$\theta = \arcsin(-2(q_1q_3 - q_0q_2)) \quad (2)$$

$$\psi = \arctan\left(\frac{2(q_1q_2 + q_0q_3)}{q_0^2 + q_1^2 - q_2^2 - q_3^2}\right) \quad (3)$$

Once get the Euler angles, we use

sliding-mode control to do the following analysis. The output U_1, U_2, U_3, U_4 are calculated by the followed formulas[5]:

$$U_1 = \frac{m}{\cos\phi \cos\theta} (g - \alpha_7^2 z_7 - k_7 \text{sign}(s_8) - k_8 s_8) \quad (4)$$

$$U_2 = \frac{1}{b_1} (-a_1 \dot{\theta} \dot{\psi} - a_2 \dot{\theta} \Omega_r - \alpha_1^2 z_1 - k_1 \text{sign}(s_2) - k_2 s_2) \quad (5)$$

$$U_3 = \frac{1}{b_2} (-a_3 \dot{\phi} \dot{\psi} - a_4 \dot{\theta} \Omega_r - \alpha_2^2 z_3 - k_3 \text{sign}(s_3) - k_4 s_3) \quad (6)$$

$$U_4 = \frac{1}{b_3} (z_5 - \alpha_3^2 z_5 - k_5 \text{sign}(s_4) - k_6 s_4) \quad (7)$$

In the formula, $k_1, k_2, k_3, k_4, k_5, k_6$ are constant, sign is sign function and[5]:

$$z_1 = \phi_d - \phi \quad (8)$$

$$z_3 = \theta_d - \theta \quad (9)$$

$$z_4 = \dot{\theta} - \dot{\theta}_d - \alpha_3 z_3 \quad (10)$$

$$s_4 = \psi - \psi_d - \alpha_3 z_3 \quad (11)$$

$$s_3 = \dot{\theta} - \dot{\theta}_d - \alpha_2 z_3 \quad (12)$$

$$s_8 = \dot{z} - \dot{z}_d - \alpha_7 z_7 \quad (13)$$

$$z_5 = \psi_d - \psi \quad (14)$$

$$z_7 = z_d - z \quad (15)$$

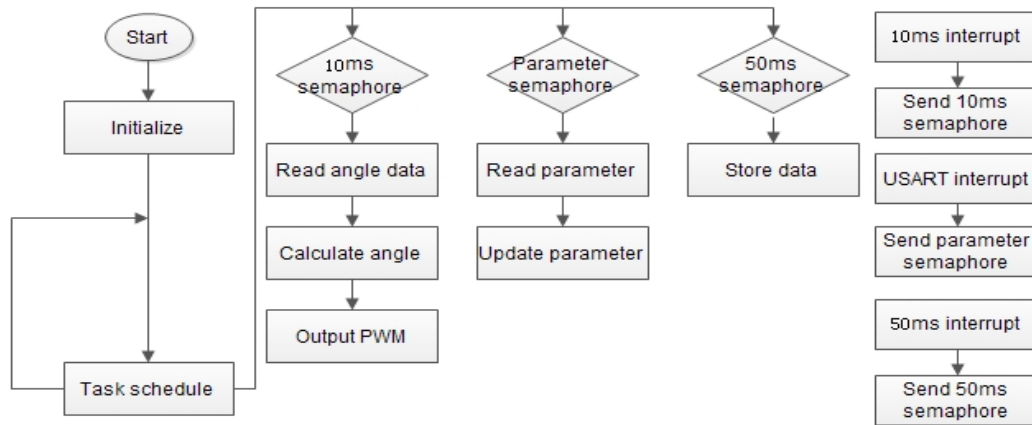


Fig.2 software process

Real time modification

The aircraft has many parameters need to be modified. It is of great difficulty to modify them every time by reloading. That is the reason why we create this thread to modify parameters in real time. The system gives a serial of orders to the aircraft through self-developed upper computer software in order to trigger its serial port break. In return, the built-in function will send a semaphore to modification thread as feedback. This thread can modify the parameters according to the relevant orders in the stated protocol.

SD card memory

The controlling system takes advantage of SDIO peripheral resource and FAT file system to help store important flight data into SD card. When the aircraft is going to take off, controlling system initializes a 50ms-timer port break, and this timer interrupt function would send a signal to activate this thread so as to collect flight data and surrounding information, better for upper period data analysis.

Experimental results

Just change angle in one dimension, keeping others remaining the same, and read the data of inertial sensor through a transfer serial port. The result just like Fig.3. When flight angle changes, the corresponding output changes as well.

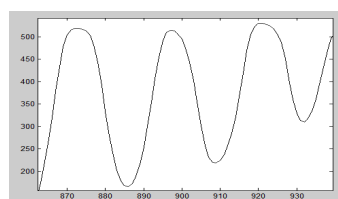


Fig.3 angle output

In the opposite, we send a target position signal through serial port to see if aircraft would react correspondingly and get the result shown in Matlab. As is seen in Fig.4, dotted line stands for target angel curve while full line stands for reality curve. When adjusting to the target angle, aircraft could respond within very short time.

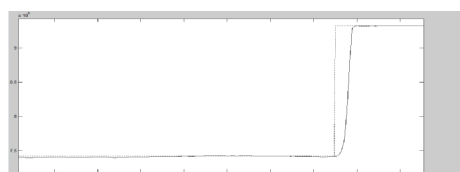


Fig.4 angle response curve

Summary

The four-rotor mini aircraft designed in this paper succeeded in steadily controlling in four dimensions including pitching, rolling, yawing and hovering. With well self-developed upper-computer software and embedded real time processing system RT-thread, it is of good result to control the aircraft's position in real time and provides the system with good extensibility for secondary development use. This determines it can be applied to some confined space where GPS is not available like undermine.

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