# An anti-collision four-axis UAV design based on PID fuzzy controller

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**Abstract**. The hardware of the four-axis unmanned aerial vehicle (UAV) is based on ARM SCM32f103, and the hardware is designed and manufactured independently. The UAV has the characteristics of high reliability, good stability and strong resistance to damage. The circuit of the UAV includes a gyroscope accelerometer module, an infrared module, a Bluetooth serial port module, a barometer module, and a PWM output module. In terms of control algorithms, a four-axis motion model was established using MATLAB/SIMULINK, and an optimal algorithm was derived for model simulation calculations. That is, the PID fuzzy controller is designed and the fuzzy controller is used to precisely control the speed of the motor. The four-axle UAV judges the damaged propeller through the abrupt change of attitude of the four-axle UAV and enters the fault handling mode. For different destruction situations, the four-axle UAV use the existing undamaged paddles to make the UAV still stable in the sky and landing slowly to protect the UAV, even if one paddle, two paddles, or three paddles are damaged.

## 1. Introduction

Nowadays, UAV applications can be seen everywhere. From military to commercial to civilian use, the four-axis UAV covered extremely broad field. Owing to the increasing frequency and the increase in the number of uses of four-axle UAV, UAV's safety issues appeared. When the four-axle UAV flying, the propeller often stalls or rotates abnormally due to a fault, which may lead to the UAV's losing stability and crashing, and will break the machine and even hit people, causing great losses. In this regard, this paper focuses on the issue of the crash of a propeller due to the failure of a propeller during the flight of a UAV. In order to prevent the four-axle UAV from crashing due to the failure of the propeller during the flight, this paper proposed the concept of anti-crash four-axis UAV. When a failure occurs, the UAV starts to rotate in the air in this way that is designed by a specific algorithm, in which it does not crash directly. It will eventually fall slowly according to a certain angle, which just could be completed by the unbroken propeller.

The design of anti-crash four-axis UAV can be divided into two parts. The first part is the design and improvement of the four-axis UAV algorithm. Combined with the current UAV flight algorithm, the improvements of the problem of simulating the possible propeller failure is carried out to detect specific failure propellers, entering the mode of processing damage. For different modes, the UAV could be protected by controlling the remaining propellers to control the slow and smooth landing of anti-crash four-axis UAV. The second part is to construct the hardware experimental platform, which including to designation the circuit schematic of the UAV and PCB, completion of the component selection, welding of circuit board, writing and debugging of code.

## 2.  Construction of the hardware experiment platform

The construction of the experimental platform is mainly based on the four-rotor racks purchased online and control board designed autonomously. The circuit is mainly based on SCM32F103C8T6 [1]. There are attitude detection sensor MPU-6050 module, height sensor MS5611 module, motor control PWM module, USB and Bluetooth serial communication module, memory module, and infrared remote control module. The STM32F103C8T6 uses a high-performance ARM® CortexTM-M3 32-bit RISC core, Operating frequency is 72MHz, a rich set of enhanced I/O ports and peripherals connected to two APB buses to fully meet the experimental requirements. The main sensors for the experiment are the MPU-6050 module for attitude detection and the MS5611 module for height.

*2.1.  Designation of the attitude detection chip MPU-6050 circuit*

The MPU-60X0 integrates a 3-axis MEMS gyroscope, a 3-axis MEMS accelerometer, and an expandable digital motion processor DMP. Gyroscopes and accelerometers use three 16-bit ADC respectively to convert the measured analog quantities into exportable digital quantities. In order to track fast and slow motions accurately, the sensor's measurement range is user-controllable. The gyroscope's measurable range is ±250°, ±500°, ±1000°, ±2000°/second(dps), and the accelerometer's measurable range is ±2, ±4, ±8, ±16g. There are I2C and SPI interface, this article uses the I2C interface to connect the main chip [2-3].

The external circuit of the MPU-60X0 is structured simply. its power supply can be taken from the range of 2.5V ± 5%, 3.0V ± 5%, or 3.3V ± 5%, this article directly connected to VDD (3.3V) and with a 0.1uF capacitor filtering. In addition, the MPU-6050 has a pin of VLOGIC that is used to provide the logic level for the I2C output. This article also directly connects to VDD (3.3V).
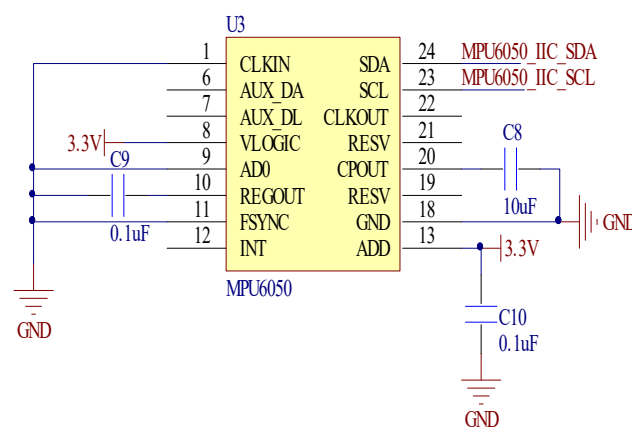


Figure 1. Design drawing of the attitude detection chip MPU-6050 circuit.

*2.2.  Designation of height determination circuit*

The MS5611-o1BA barometric pressure sensor is a new high resolution pressure sensor from MEAS (Switzerland) with a resolution of up to 10cm. The sensor module includes a high linearity pressure sensor and an ultra-low power 24-bit Σ analog-to-digital converter. There are two types of serial interfaces: SPI and I2C. The I2C or SPI communication interface is selected by adjusting the voltage of the PS pin. Considering that the I2C only requires one clock line and one signal line, due to which board space can be saved. Therefore, this article uses a serial I2C interface [4-5].

This design uses the I2C mode. The I2C programming is easy to implement, and the communication speed meets the chip requirements. The I2C only has two wires to facilitate PCB traces. MS5611_IIC_SCL is connected to PB14 pin of STM32F103C8T6, and MS5611_IIC_SDA is connected to PB15 pin of STM32F103C8T6 to obtain the data acquired by MS. The specific circuit is shown in figure 2.
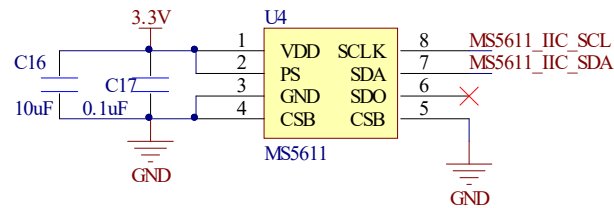
Figure 2. Design drawing of height detection sensor MS5611.

## 3. Algorithm design and improvement

### 3.1. Improvements in motor control

The traditional PID controlling of the motor motion uses a closed-loop control strategy. Due to the direct load on the motor generated by the disturbance, the controlling of the motor is difficult to satisfy the system's rapid response needs. Because the fuzzy control has a wide range of application and a certain robustness to the time-varying load, the motor servo control system is a system that requires fast response and can realize dynamic adjustment in a very short time. This paper designs a PID fuzzy controller and uses a fuzzy controller to control the speed of the motor to achieve precise control of the motor. The basic structure of the fuzzy controller is shown in figure 3.
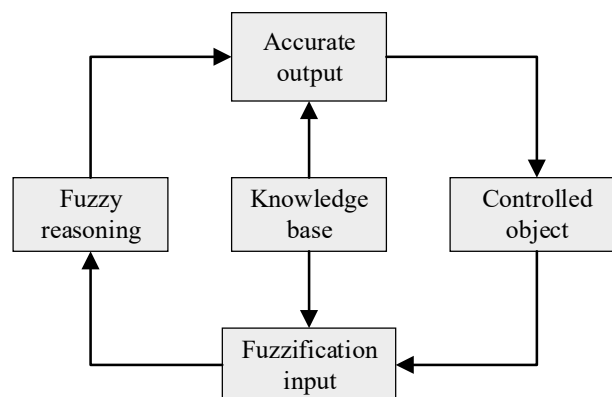


Figure 3. Basic structure of fuzzy controller.

From the structure chart of fuzzy control, we can see that the input and output of the controller are accurate. The fuzzy control algorithm itself is a fuzzy quantity, which requires the conversion between the precise quantity and the fuzzy quantity in the process of implementing the algorithm.

In this paper, a standard fuzzy controller is designed. The input/output domain is {-3, -2, -1, 0, 1, 2, 3}. Language variables are all 7 language values: NB, NM, NS, ZE PS, PM, PB, respectively, represent negative big, negative median, negative small, zero, positive small, median, and positive big. The membership function of the input parameters e, ec uses a Gaussian curve. Output value This text carries on the inquiry according to the corresponding fuzzy rule, then uses the center of gravity method to defuzzify, obtains the accurate output quantity [6].

### 3.2. Four-axis UAV power model

In order to simplify the model, it is assumed that the high-bandwidth motor is used for the four axes, and the angular velocity of the motor is not affected by the movement of the device itself, and the angular acceleration of the paddle is negligible. Assume further that $I^P \ll I^B$, then $I^P \dot{\omega}$ can be ignored. From practical considerations, the angular momentum of the paddle can't be ignored, compared to the angular

momentum of the four-axis body. At the same time, it is assumed that the four axes are uniformly symmetrical rigid bodies [7-10].

Can be reduced to the following formula

$$M = \frac{dL}{dt} = I^B \dot{\omega}^B + \omega^B \times \left( I^B \omega^B + \sum_{i=1}^{4} I^P \left( \omega^B + \omega^{Pi} \right) \right) = \tau_f + \tau_d \tag{1}$$

In the formula:

$$I^B \dot{\omega}^B = \begin{bmatrix} I_{xx}^B \dot{\omega}_x & I_{yy}^B \dot{\omega}_y & I_{zz}^B \dot{\omega}_z \end{bmatrix}'$$

$$\omega^B \times (I^B \omega^B + \sum_{i=1}^{4} I^P (\omega^B + \omega^{Pi})) = \begin{bmatrix} (I_{zz}^T - I_{yy}^T)\omega_y \omega_z + I_{zz}^P \omega_y \omega_T \\ (I_{xx}^T - I_{zz}^T)\omega_x \omega_z + I_{zz}^P \omega_x \omega_T \\ (I_{yy}^T - I_{xx}^T)\omega_x \omega_y \end{bmatrix} \tag{2}$$

Among them, $I_{xx}^T = I_{xx}^B + 4I_{xx}^P$, $I_{yy}^T = I_{yy}^B + 4I_{yy}^P$, $I_{zz}^T = I_{zz}^B + 4I_{zz}^P$, $\omega_T = \omega_1 + \omega_2 + \omega_3 + \omega_4$.

In actual flight, the four-axis roll angle and pitch angle are basically stable. The process is very short even if it changes. It is assumed that the damping moment in these two directions is zero, and only the damping in the direction of yaw angle $\tau_{f_z}$ is considered. In order to simplify the model, it is assumed that the size of $\tau_{f_z}$ is proportional to the yaw rate $\omega_z$, and the proportional coefficient is a constant $\kappa_f$ Then

$$\tau_f = \begin{bmatrix} 0 & 0 & -\kappa_f \omega_z \end{bmatrix}' \tag{3}$$

The moment force of a four-axis propeller is proportional to the lift of the propeller, and the proportional coefficient is $\kappa_\tau$, and the lift of the propeller is proportional to the square of the propeller angular velocity, and the proportional coefficient is $\kappa_\tau$. The expression is as follows:

$$\tau_i = (-1)^{i-1} \kappa_\tau f_i \tag{4}$$

$$f_i = \kappa_d \omega_i^2 \tag{5}$$

Then, the four equations of simultaneous equations can be obtained four-axis attitude equations:

$$\begin{cases} I_{xx}^B \dot{\omega}_x = \kappa_d(\omega_2^2 - \omega_4^2) - (I_{zz}^T - I_{yy}^T)\omega_y \omega_z - I_{zz}^P \omega_y(\omega_1 + \omega_2 + \omega_3 + \omega_4) \\ I_{yy}^B \dot{\omega}_y = \kappa_d(\omega_3^2 - \omega_1^2) - (I_{xx}^T - I_{zz}^T)\omega_x \omega_z - I_{zz}^P \omega_x(\omega_1 + \omega_2 + \omega_3 + \omega_4) \\ I_{zz}^B \dot{\omega}_z = -\kappa_f \omega_z + \kappa_\tau \kappa_d(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2) \end{cases} \tag{6}$$

From Eulerian kinematics equation:

$$\begin{cases} \omega_x = \dot{\varphi}\sin\theta\sin\psi + \dot{\theta}\cos\psi \\ \omega_y = \dot{\varphi}\sin\theta\cos\psi - \dot{\theta}\sin\psi \\ \omega_z = \dot{\varphi}\cos\theta + \dot{\psi} \end{cases} \tag{7}$$

When the roll angle, pitch angle, and yaw angle change at small angles in the equilibrium position, there are $\theta = \pi/2$, $\varphi = 0$, and $\psi = 0$. Then the simplified model of the center-of-mass motion can be simplified. Assuming that the speed of the four axes in the air is not large, the air resistance f can be ignored.

$$\begin{cases} m\ddot{x} = \kappa_d(\cos\psi\sin\theta\cos\phi + \sin\psi\sin\varphi)(\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) \\ m\ddot{y} = \kappa_d(\sin\psi\sin\theta\cos\varphi - \sin\varphi\cos\psi)(\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) \\ m\ddot{z} = \kappa_d\cos\theta\cos\varphi(\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) - mg \end{cases} \tag{7}$$

## 4. Troubleshooting

Design the fault detection function and put a 5ms timer interrupt. Once the fault is detected, quickly determine the failed motor, cut off the ESC output, and control the remaining motor to maintain the stability of the UAV. The processing idea is as shown in figure 4.
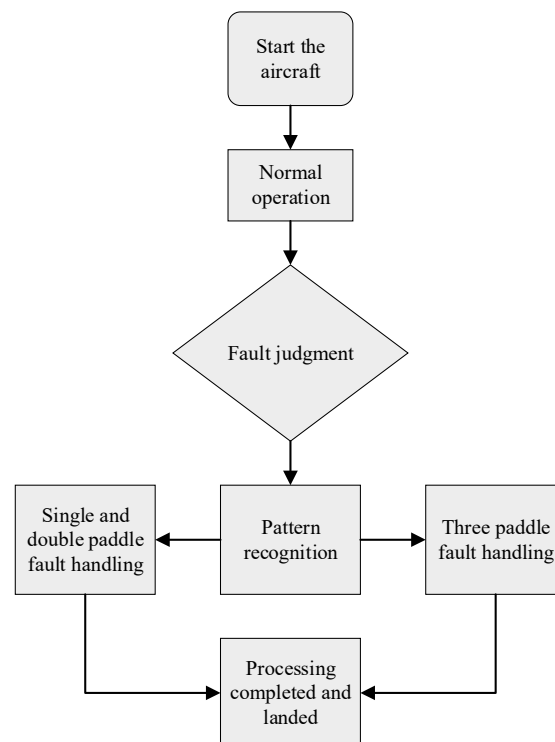
Figure 4. Basic structure of fuzzy controller.

The refinement of specific parameters is tested according to the experimental platform built. After testing and adjusting the parameters, the four rotors can detect bad propellers and can also land slowly.

## 5. Conclusion
Aimed at the crash of the propeller due to the failure of the propeller during the flight of the UAV, the problem was investigated. In order to prevent the four-axle UAV from crashing due to the failure of the propeller during the flight, the concept of anti-crash four-axis UAV was proposed. When a failure occurs, the UAV starts to rotate in the air in a way that is designed by a specific algorithm, so that it does not crash. The UAV will eventually fall slowly according to a certain angle. This process only needs the unbroken propeller of the UAV.

## References
[1]   Yang Wei, Xiao Yiping. Design of LCD Display System Based on STM32F103C8T6 Microcontroller[J]. Microcomputer and Applications, 2014, 33(20): 29-31+34. [2017-10-06]. DOI:10.19358/ J.issn.1674-7720.2014.20.010
[2]   Huang Zhiwei, Xu Sunan, Wei Yi, Tang Ying. Multi-sensor fusion attitude detection of STM32[J]. Journal of Huaqiao University(Natural Science), 2015, 36(04): 422-426. [2017-10-06 ].
[3]   Deng Limin, Guan Shengqi, Wu Yongqiao, Cai Caicai. Research and application of MPU6050 signal acceptance and processing[J]. Internal Combustion Engine & Attenuation, 2016, (12): 129-130. [2017-10-06]. DOI: 10.19475/j.cnki.issn1674-957x.2016.12.056.
[4]   Cui Wei, Deng Sheng, Dai Hangyang, Zhang Yang, Yang Taibo. SPI Interface Design for MS5611 [J/OL]. Science & Technology Innovation Report, 2017, 14(01): 31-33+35. (2017 - 03-08)[2017-10-06].
[5]   Pan Yinsong, Liu Tiangang, Ma Zezhong, Liu Zhihua. Design of a Small UAV Height Detection System Based on MS5611 [J]. Electronic Measurement Technology, 2015, 38(07): 22-26. [2017-10-06].

[6]   Ye Yunyue, Lu Kaiyuan. PID control and fuzzy control of linear motor [J]. Chinese Journal of Electrical Engineering, 2001, (03): 11-15. [2017-10-06].

[7]   YAO Tingting. Design and research of control algorithm for quadrotorcraft[D]. Dalian Maritime University, 2015.

[8]   Huang Xiliu. Design of a four-rotor unmanned helicopter flight controller[D]. Nanjing University of Science and Technology, 2010

[9]   Xin Xu. Design and implementation of four-rotor UAV control system [D]. Nanjing University of Science and Technology, 2017.

[10]  Li Jun, Li Yuntang. Dynamic Modeling and PID Control of a Four-rotorcraft[J]. Journal of Liaoning Technical University(Natural Science Edition), 2012, 31(01): 114-117.