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Adaptive Control of Quadrotor UAV Based on Arduino

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Abstract –This paper mainly studies the control of the sensors of the quadcopter unmanned aerial vehicle (UAV) based on the serial-stage PID controller. Firstly, by modeling the dynamic model of the drones, the control method of the quadcopter unmanned aerial vehicle is illustrated. After that, the design requirements for the parameters and precision of the sensors and executors needed in this design are put forward, and the device comparison is carried out. Finally, a system design scheme with four brushless DC motor speed control is given, and the scheme is tested.

Keywords – Adaptive control, manned aerial vehicle, circuit design, Arduino

I. INTRODUCTION

The four-rotor drone is used as a small, flexible, lightweight, portable underdrive system [1]. While rotary-wing drones do not require theoretical knowledge, such as overly complex aerodynamics compared with fixed-wing drones. They are less stringent than conventional helicopters in terms of blade and pitch. However, due to its multivariable, strong coupling characteristics, the real-time control is difficult.

Four-rotor unmanned aerial vehicle (UAV) achieves space six degrees of freedom movement through the distribution of control amount. However, due to the large vibration of the multi-motor operation, the large-angle maneuvering is often caused and serious misalignment of sensor data, the use of high-quality sensor components will significantly increase the overall cost increased. In addition, the higher requirements are also put forward for the multi-motor multi-propeller control parameters of the system also put forward. These factors limit the development of high-rotor drones.

Currently, the manufacturers have designed new flight control panels for in-flight executors and sensor failures. For example, CAUV adds a backup sensor in its own flight control board. The probability of accidents reduced during drone flights by improving the performance of hardware facilities. In fact, for a drone, it’s not just hardware that matters, its core control system is also important. At present, several mainstream open source flight controls all use PID control algorithm to achieve the attitude and trajectory control of drones. The typical representative is PX4, whose software code system is relatively simple and clear. Therefore, based on the traditional PID control theory, a more adaptable UAV flight control system can not only reduce the probability of accidental crash during UAV flight to a certain extent, but also improve the control effect, reduce the hardware requirements of existing UAV, and provide a new way of thinking for low-cost civilian UAV [2-3].

In this paper, the motion model of the four-rotor drone aircraft control system is established by Newton-Eura method, and the control system is designed for attitude controller, low-cost combination navigation and four-rotor drone brushless DC motor. The original data of the attitude controller is processed by Kalman filtering to get the estimate of the current state, and the current position information of the drone is read by low-cost combined navigation. Based on the serial PID controller, a system design scheme with output of four brushless DC motor speed control is designed and is used in the actual system.

II. MATHEMATICAL MODEL OF QUADROTOR UAV

The dynamic model of the four-rotor unmanned aerial vehicle control system is established by Newton-Eura method, as shown in Fig. 2. In the two coordinate systems, the four-rotor drone is controlled by the rotation of the four rotary wings, in which the motors M1 and M3 rotate clockwise at the angle speed of s1 and s3 respectively, generating thrust f1 and f3, respectively. At the same time, the other two motors (M2 and M4) rotate counterclockwise at the adverb velocity of s2 and s4, generating thrust f2 and f4, respectively.

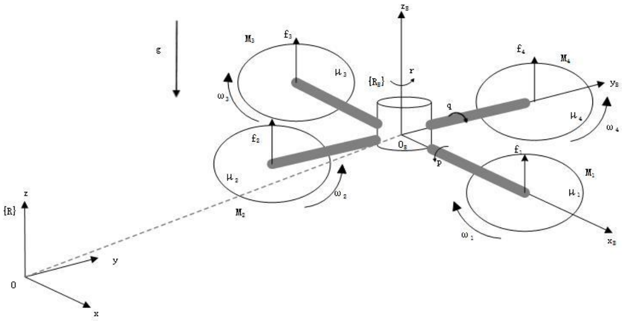

Fig. 1: Dynamic model of quadrotor UAV

In order to control the aircraft, it is necessary to define a spatial reference coordinate system and an ontology coordinate system fixed to the aircraft. The relative relationship between the two coordinate systems describes the motion state of the aircraft [4]. In Fig.1, $Oxyz$ is the Inertial coordinate system and $O_Bx_By_Bz_B$ is the Body frame. The origin of the body coordinate system is fixed to the mass of the drone [5].

$p_o^I=[x\ y\ z]^T$ is used to represent the position of the origin O_B of the Body frame in the inertial system, $v_o^I=[x\ y\ z]^T$ is used to represent the velocity vector of the drone at the inertial coordinates, and $v_o^B=[u\ \ v\ \ w]^T$ is used to represent the speed vector under the Body frame. The three horns ϕ, θ, Ψ represent the direction of the Body system relative to the inertial coordinate system, and the angle velocity vector $\omega_B = [p\ q\ r]^T$ indicates the momentary adverb velocity of the axes of the ontology coordinate system. Among them, the rolling angle ϕ is the angle between the symmetrical plane of the drones and the lead vertical plane containing the shaft, the angle when rolling to the right is positive, the pitch angle θ is the angle between the body axis Ox_B and the horizontal Oxy plane, the head of the drone is positive, the deflection angle Ψ is the angle between the projection OxB and axis on the body axis Oxy and the horizontal OxB plane, and the angle of the drone when the right is deflected.

Vector v_o^B of the Body coordinate system is known, and vector v_o^I in the inertial coordinate system can be expressed as:

$$v_o^I = Rv_o^B \qquad (1)$$

To find the conversion matrix R, the right-handed rules (in the order in which the $z \to x \to y$ rotates) are used. OX_1, OY_1, OZ_1 and OX_2, OY_2, OZ_2 are the transition axes at rotation, multiplied by the corresponding matrix generated by each rotation, and the transformation matrix R of the Body coordinate system to the inertial coordinate system is:

$$R = \begin{bmatrix} C_\theta C_\psi & C_\psi S_\theta S_\phi - C_\phi S_\psi & C_\phi C_\psi S_\theta + S_\phi S_\psi \\ C_\theta S_\psi & S_\theta S_\phi S_\psi + C_\phi S_\psi & C_\phi S_\theta S_\psi - C_\psi S_\phi \\ -S_\theta & C_\theta S_\phi & C_\theta C_\phi \end{bmatrix} \qquad (2)$$

where S(.), C(.), and T(.) represent sin(.), cos(.) and tan(.), respectively.

Since R is an orthogonal matrix, it is satisfied $R^{-1} = R^T$.

Thus, the positional motion equation writes the components in the form of:

$$\dot{x} = uC_\theta C_\psi + v(C_\psi S_\theta S_\phi - C_\phi S_\psi) + w(C_\phi C_\psi S_\theta + S_\phi S_\psi) \qquad (3)$$

$$\dot{y} = uC_\theta S_\psi + v(S_\theta S_\phi S_\psi + C_\phi C_\psi) + w(C_\phi S_\theta S_\psi - C_\psi S_\phi) \qquad (4)$$

$$\dot{z} = -uS_\theta + vS_\phi C_\theta + wC_\theta C_\phi \qquad (5)$$

Similarly, the motion equation for Cape Eura is:

$$\begin{aligned} \dot{\phi} &= p + qS_\phi T_\theta + rC_\phi T_\theta \\ \dot{\theta} &= qC_\phi - rS_\phi \\ \dot{\psi} &= \frac{1}{C_\theta}[qS_\phi + rC_\phi] \end{aligned} \qquad (6)$$

$$v_c^I = Rv_c^B = R(v_o^B + \omega^B \times r_g^B) \qquad (7)$$

III. DESIGN OF CONTROL SYSTEM FOR QUADROTOR UAV

A. Mega2560

Arduino Mega 2560 is a micro control board based on ATmega2560. It has 54 digital input or output ports (15 of which can be used as PWM output), 16 analog input ports, 4 UART serial ports, 16 MHz crystal oscillator, USB connection port, battery interface, ICSP head and reset button. This type of Arduino can just connect the computer with USB or a voltage transformer.

B. Hardware Design

The design uses the Arduino Mega2560 as the core control board, the MPU6050 sensor to control the stability of the UAV attitude, and the VL53L0X sensor to achieve the drone height [6]. By sensing the displacement changes of the aircraft on the X, Y and Z axes, each motor is controlled to compensate for the power to maintain the balance of the entire aircraft. The overall design of the hardware circuit is shown in Fig. 2.

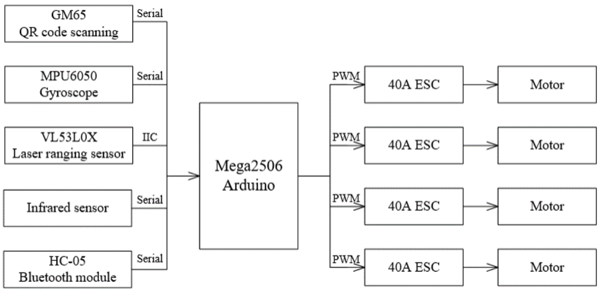

Fig. 2: Overall design scheme of hardware circuit

The gyroscope used in this design is mpu6050, which is an integrated 6-axis motion processing component. Compared with the multi-component scheme, it avoids the problem of the time axis difference between the combined gyroscope and accelerator, and reduces a lot of packaging space.

In this design, the angle and angular velocity of UAV can be obtained by transmitting the information from gyroscope to MCU [7-8]. Therefore, in the design of hardware circuit, the output interface and level conversion device are designed to obtain information and provide energy to the gyroscope. The hardware circuit schematic design of gyroscope module is shown in Fig. 3.

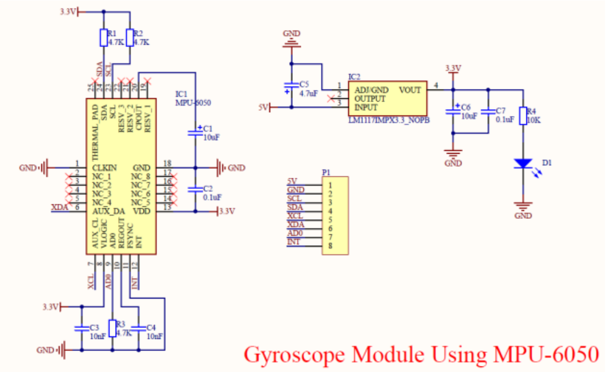

Fig. 3: Schematic design of Gyroscope module

ESC (Electronic speed control) module adjust the speed of the motor according to the control signal [9]. The EMC module in this design uses a mega8l MCU chip, two independent level conversion circuits, three-phase power inverter circuit and multi-point voltage detection [10]. It takes 11.1V voltage as power supply input, and external MCU gives 5V control voltage and PWM control signal. The internal MCU peripheral circuit of EMC module is shown in Fig. 4.

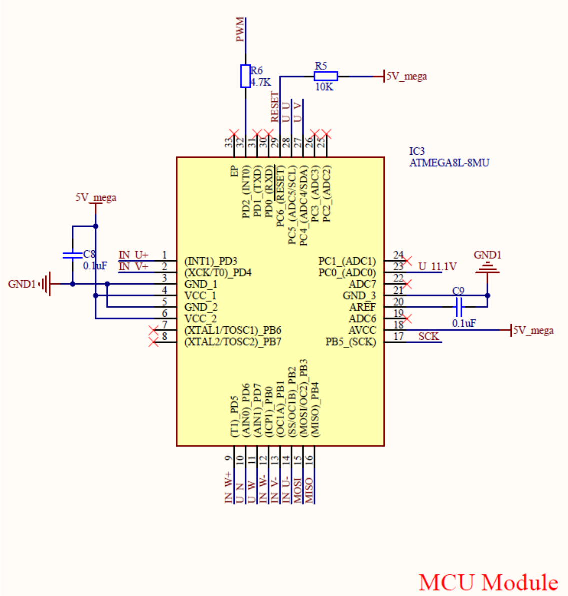

Fig. 4: Schematic design of MCU peripheral circuit in ESC module

The design scheme of the level conversion furnace is shown in Fig. 5. The energy source is an external battery, which is supplied through the plug.

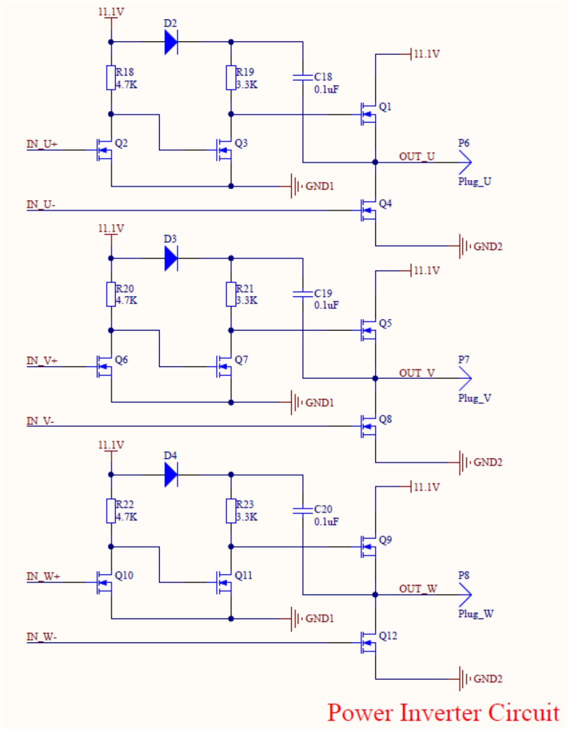

Fig. 5: Schematic design of power inverter in ESC module

In order to ensure the control of the circuit, it is necessary to detect the phase voltage, neutral point voltage and supply voltage in real time and send them to the internal MCU. Due to the large voltage, it is necessary to divide the voltage through the resistance to the MCU.

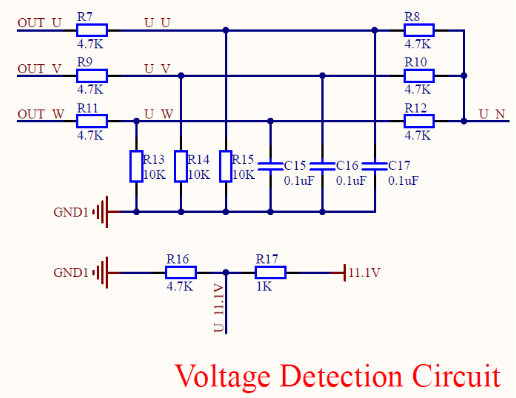

Fig. 6: Schematic design of voltage detection circuit in ESC module

The ESC module proposed above needs to use four groups in the design of the quadrotor UAV in this paper.

C. Software Design

In the program design, the serial PID type adaptive control is essentially two PIDs string together, divided into inner ring and outer ring PID [11]. Single-stage PID input is the actual angle, feedback is angle data, string-level PID foreign ring input feedback is also angle data, inner ring input feedback is aching velocity data. The executor can indirectly control the angle of the difference, that is, the adverb velocity, so as to achieve the goal of indirectly controlling the physical amount of the target, so that the four axes can still maintain the stability of the system when the attitude changes dramatically. The control block diagram is shown in Fig. 7.

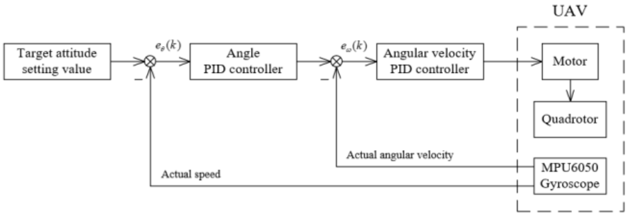

Fig. 7: Block diagram of cascade adaptive PID control system

The control logic and calculation method of outer loop PI and inner loop PID are given in Fig. 8.

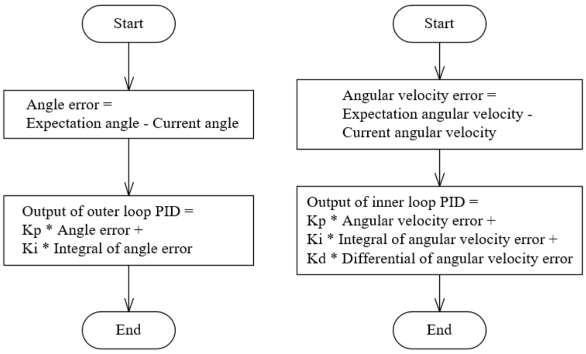

Fig. 8: Control logic diagram of outer loop PI and inner loop PID

IV. SIMULATION AND EXPERIMENTAL VALIDATION

A. Simulation Results

Based on MATLAB/Simulink, the simulation validation is carried out. The simulation result of the motor speed is shown in Fig. 9, showing that the reference speed can be effectively tracked.

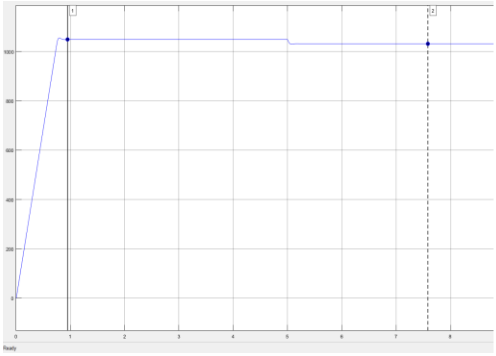

Fig. 9: Speed waveform

B. Experimental Results

Based on the designed scheme, this design is realized by 3D printing material structure and self-designed circuit system. This design uses a set of brackets, a control unit, a gyroscope, an infrared sensor, a ranging sensor, a two-dimensional code scanner, four electronic speed control, four motors and four propellers. The physical figure is shown in Fig. 10.

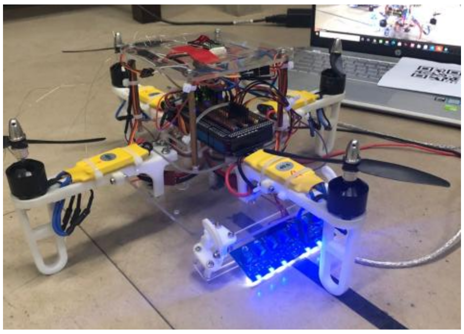

Fig.10. A picture of quadrotor UAV

Fig.11 shows the simulation result of the motor speed, showing that the reference speed can be effectively tracked even when the load is changed.

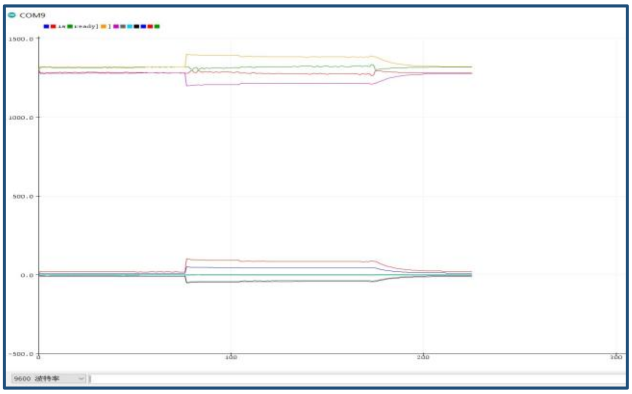

Fig. 11: Experimental waveform of speed.

V. CONCLUSION

The simulation and experiment results verified that the four rotor UAV proposed in this design has the anti-jamming and low-cost advantages. The circuit design applied in this design can not only be used in the example of quadrotor UAV, but also provide a reference scheme for other equipment which need to use gyroscope and electronic speed control.

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