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The Research of Control Technology for Four-rotor Aircraft Based on STM32

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ABSTRACT: The four-rotor aircraft is different from the traditional helicopter. The four-rotor aircraft by changing the speed of the propeller implements various flight movements. According to the characteristics and dynamical features of four-rotor aircraft, this paper mainly studied an attitude control technology of the four-rotor aircraft based on STM32. The three-axis gyroscope and triaxial acceleration sensor of MPU6050 collect the original data, and the data is transmitted to the main controller by I2C. The data with noise is processed by the filter. The stability control problem for the flight attitude of the four-rotor aircraft is solved by using quaternion attitude algorithm, PWM and PID.
KEYWORD: Four-rotor Aircraft; Attitude Control; Gyroscope; Quaternion; PID

1 INSTRUCTIONS

In recent years, with the development of embedded technology, sensor technology and modern control theory, the four-rotor aircraft has developed toward the direction of multi-purpose and high performance. It has many advantages, such as small size and weight, low altitude, low cost and good safety. The research of the four-rotor aircraft system relates to theory and technology of many subjects and fields which provide the theoretic evidence and the new test method. According the research of the four-rotor aircraft dynamics, control algorithm and control system development, the new unmanned aerial vehicle can be designed to meet different conditions.

2 THE STRUCTURE OF THE FOUR-ROTOR AIRCRAFT

The four-rotor aircraft is mainly composed of rock, motor, propellers and control circuit. The electric parts include the control circuit board, electronic governor, battery, communication module and sensor module. The electrical connection is shown in Figure 1.

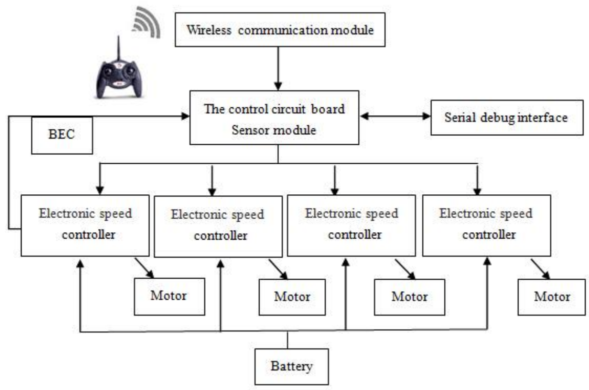

Figure 1. The electrical connection.

3 THE FOUR-ROTOR AIRCRAFT FLIGHT CONTROL SYSTEM

3.1 *The information acquisition of the four-rotor aircraft attitude*

MPU6050 is a 6 axis motion processing components. MPU6050 incorporates 3 axis gyroscopes, 3 axis accelerators, and can be connected by I2C ports of other accelerator, magnetic sensors, or other Digital Motion sensor processing hardware acceleration.

In digital output axis 6 or 9 shaft rotation matrix, quaternion, Euler Angle format data fusion of calculus.

MPU6050 will receive the aircraft attitude information from I2C, at the same time; the internal registers can be operated by I2C interface.

3.2 *The earth frame and supporter frame*

We define two coordinate system, Earth frame and Supporter frame. Both are right-handed coordinates. θ is the pitch angle, ψ is the yaw angle, γ is the roll angle(Bortz 1971). The earth frame and the supporter frame are shown in Figure 2.

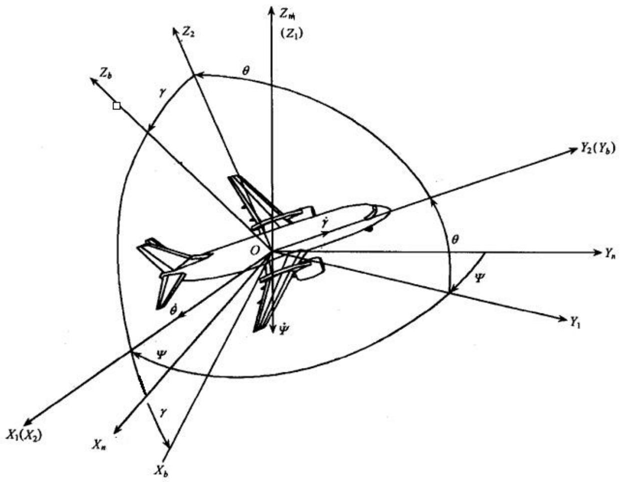

Figure 2. Earth frame and Supporter frame.

3.3 *Quaternion attitude algorithm*

Calculate quaternions initial value. Before we calculate the initial value of quaternion, we need to know the initiatory attitude Angle. We can get the data through accelerometer and electronic compass. And the data is fed into Formula 1 to obtain the initial value of quaternion (Dam 1998).

$$Q = q(X)q(Y)q(Z) = \begin{bmatrix} w \\ a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \cos\frac{j}{2}\cos\frac{\theta}{2}\cos\frac{\gamma}{2} + \sin\frac{j}{2}\sin\frac{\theta}{2}\sin\frac{\gamma}{2} \\ \cos\frac{j}{2}\sin\frac{\theta}{2}\cos\frac{\gamma}{2} + \sin\frac{j}{2}\cos\frac{\theta}{2}\sin\frac{\gamma}{2} \\ \cos\frac{j}{2}\cos\frac{\theta}{2}\sin\frac{\gamma}{2} - \sin\frac{j}{2}\sin\frac{\theta}{2}\cos\frac{\gamma}{2} \\ \cos\frac{j}{2}\sin\frac{\theta}{2}\sin\frac{\gamma}{2} - \sin\frac{j}{2}\cos\frac{\theta}{2}\cos\frac{\gamma}{2} \end{bmatrix} \quad (1)$$

Take each shaft angular velocity into Formula 2 to correct quaternion(Jeremy 2011).

$$\begin{bmatrix} \dot{w} \\ \dot{a} \\ \dot{b} \\ \dot{c} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 0 & -\omega_{nbx}^{b} & -\omega_{nby}^{b} & -\omega_{nbz}^{b} \\ \omega_{nbx}^{b} & 0 & \omega_{nbz}^{b} & -\omega_{nby}^{b} \\ \omega_{nby}^{b} & -\omega_{nbz}^{b} & 0 & \omega_{nbx}^{b} \\ \omega_{nbz}^{b} & \omega_{nby}^{b} & -\omega_{nbx}^{b} & 0 \end{bmatrix}\begin{bmatrix} w \\ a \\ b \\ c \end{bmatrix} \quad (2)$$

The attitude matrix is the orthogonal matrix. When calculating quaternion, we are inevitably to cause round-off error and truncation error, which cause the attitude matrix into non-orthogonal matrix. Quaternion normalization method can eliminate the impact. We can use the formula 3 to translate informal quaternions Q= $[q_0\ q_1\ q_2\ q_3]T$ into normalized quaternion Q'= $[q_0'\ q_1'\ q_2'\ q_3']T$.

$$q_i' = \frac{q_i}{\sqrt{q_0^2 + q_1^2 + q_2^2 + q_3^2}} \quad (3)$$

Solve the attitude Angle by using C_n^b. See formula 4 below:

$$\begin{cases} \theta = \sin^{-1}(t_{23}) \\ \gamma = \tan^{-1}(-t_{13}/t_{33}) \\ \psi = \tan^{-1}(-t_{21}/t_{22}) \end{cases} \quad (4)$$

where t_{ij} is the row i column j element of C_n^b.

The quaternion attitude algorithm flow diagram is shown in Figure 3.

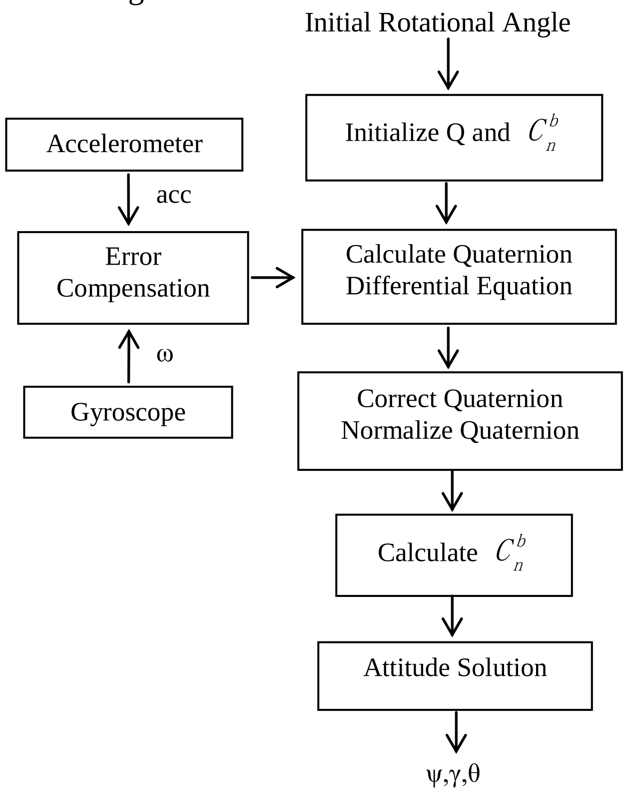

Figure 3. Quaternion attitude algorithm flow diagram.

The value domain of arcsin() is from $-\pi/2$ to $\pi/2$. The value domain of arctan () is from $-\pi$ to π. Conversion may be incomplete from -2π to 2π. So this result needs to be redressed. The angle can be modified according to according to the previous moment angle. $\theta'(k)$ is the angle at k moment. $\theta(k)$ is the angle, which is redressed at k moment. For the roll angle and yaw angle, the correction formula is shown in Formula 5. For the pitching angle, the correction formula is shown in Formula 6. Calculate $\theta(k)-\theta(k-1)$ respectively, the minimum error is to correct the current Angle.

$$\begin{cases} \theta(\mathrm{k}) = \theta^{'}(\mathrm{k}) \\ \theta(\mathrm{k}) = \theta^{'}(\mathrm{k}) + \pi \\ \theta(\mathrm{k}) = \theta^{'}(\mathrm{k}) - \pi \\ \theta(\mathrm{k}) = \theta^{'}(\mathrm{k}) + 2\pi \\ \theta(\mathrm{k}) = \theta^{'}(\mathrm{k}) - 2\pi \end{cases} \tag{5}$$

$$\begin{cases} \theta(\mathrm{k}) = \theta^{'}(\mathrm{k}), \theta(\mathrm{k-1}) \in (-\frac{\pi}{2}, \frac{\pi}{2}) \\ \theta(\mathrm{k}) = \pi - \theta^{'}(\mathrm{k}), \theta(\mathrm{k-1}) \in (\frac{\pi}{2}, \frac{3\pi}{2}) \\ \theta(\mathrm{k}) = 2\pi + \theta^{'}(\mathrm{k}), \theta(\mathrm{k-1}) \in (\frac{3\pi}{2}, 2\pi) \\ \theta(\mathrm{k}) = \pi - \theta^{'}(\mathrm{k}), \theta(\mathrm{k-1}) \in (-\frac{3\pi}{2}, -\frac{\pi}{2}) \\ \theta(\mathrm{k}) = -2\pi + \theta^{'}(\mathrm{k}), \theta(\mathrm{k-1}) \in (-2\pi, -\frac{3\pi}{2}) \end{cases} \tag{6}$$

At the same time, when angle is from one segment to another segment, it is necessary to judge and process it accordingly (Hoffmann 2011). The segment schematic is shown in Figure 4.

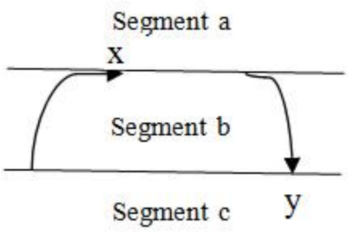

Figure 4. The angle in different segment.

When θ'(k) is in segment b and near x, θ(k) is calculated in accordance with the correction formula of segment b. And judge the difference between θ(k), θ(k-1) and θ(k-2), if the value is great contrast, we should calculate θ(k) in accordance with the correction formula of segment a.

3.4 *The four-rotor aircraft attitude control*

The most traditional PID control is widely used in industrial control. The equipment is controlled by means of the proportional, integral and differential. It is mainly suitable for linear and time-invariant systems. And PID has been widely used in industrial control. PID is a feedback controller, it will compare the collected data against the reference data and then use the error to calculate the new output value, keep controlled system as far as possible in the vicinity of a reference value. According to the emergence rate of historical data and the deviation, PID controller can adjust the output value, which ensures the accuracy and stable operation of the system(Miller 1983). Analog PID control system block diagram is shown in Figure 5.

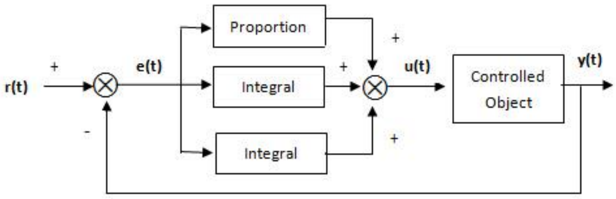

Figure 5. Analog PID control system block diagram.

In the digital control system, to discretize t to get digital PID controller expression is Formula 7:

$$u_k = K_p\left[e_k + \frac{T}{T_1}\sum_{j=0}^{k} e_j + \frac{T_D}{T}\left(e_k - e_{k-1}\right)\right] \tag{7}$$

Using the output of k times sampling minus the output of the k-1 times sampling, we can get the incremental PID controller. It is shown in Formula 8.

$$\Delta u_k = u_k - u_{k-1} = K_p[\mathrm{e}_k - \mathrm{e}_{k-1} + \frac{T}{T_1}\mathrm{e}_k + \frac{T_D}{T}(\mathrm{e}_k - 2\mathrm{e}_{k-1} + \mathrm{e}_{k-2})] \tag{8}$$

Only to know the value of e_k, e_{k-1}, e_{k-2}, we can calculate the output of PID controller. There is no accumulated error and is advantageous for the MCU to achieve. See the C code below:

```
int32_t pid_iterate (const float input[3],float output[3])
{
      const param_t *p = param_getRamParam();
      for(int i=0;i<3;i++)
      {
           float p_o=input[i] * p->xyz_pid[i].p;
           pid_accumulate[i] += input[i] *
                                p->xyz_pid[i].i;
            float i_o = pid_accumulate[i];
            if(i_o<-0.1)
                   i_o = -0.1;
            if(i_o > 0.1)
                   i_o = 0.1;
            float d_o = (input[i] - pid_pre[i]) *
                          p->xyz_pid[i].d;
            output[i] = p_o + i_o + d_o;
            pid_pre[i] = input[i];
      }
      return 0;
}
```

4 SIMULATION AND EVALUATION

In accordance with the above analysis, we have compiled the M function program based on MATLAB and compared the calculation result with the test data. The simulation of quaternion attitude algorithm is shown in Figure 6.

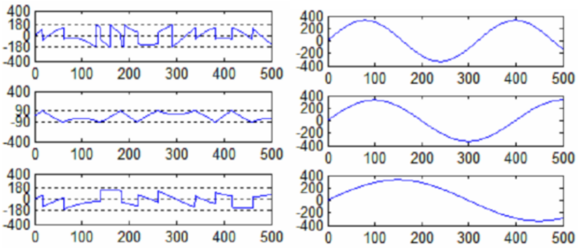

Figure 6. The simulation of quaternion attitude algorithm.

Compare the above two figures, the simulation results show that this algorithm is successfully implemented the transformation process.

5 CONCLUSION

This paper puts up an attitude detection system for the four-rotor aircraft, which is based on quaternion and the kalman filtering, and completes the improved variable parameter PID control algorithm. Finally a large number of tests indicate that the flight controller system can achieve stable attitude control for four-rotor aircraft, the performance reaches the expected goals.

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