Design of Attitude Control System for Four Rotor UAV

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Abstract. This paper designs the quadrotor aircraft, and the software algorithm is the core. The software structure mainly uses the quaternion to Euler angle algorithm as the core to carry out the real-time attitude calculation of the aircraft, and supplemented by the cascade PID controller algorithm to stabilize, accurately and quickly respond to the RF signal. In this paper, the final goal of stable flight is achieved by solving the flight attitude algorithm.

1. Introduction
The flight controller connects the hubs of the various sections as the core components of the four-rotor. The main function of the flight controller is similar to the human brain. The real-time data acquired by each sensor is collected into the chip, and the attitude angle is obtained by the algorithm of quaternion Euler angle change, and then according to the remote command received by the wireless receiver. For comparison, the obtained difference is then subjected to PID control calculation output, and finally these outputs are converted into PWM signals, and at the same time, different target postures and positions of the respective motors reaching the target are controlled.

The core algorithm of the quadrotor involves the initialization of the main program including each module, the solution of the pose, and the cascade PID control.

2. Four-rotor flight attitude algorithm definition
Attitude concept: The relative relationship obtained by the difference between the coordinate system of the quadrotor body and the geographical coordinate system is used to settle the current posture. Of course, the detection is mainly caused by the acceleration error caused by the vibration of the aircraft and the error caused by the gyroscope integral, so the obtained result is not particularly accurate. Therefore, as long as we can eliminate this error, we can get an accurate flight attitude.

The core of the attitude of the aircraft is the angle of rotation of the body. Usually an object has four ways to indicate its rotational position in space:

a). Matrix representation: suitable for use in transformed vectors.
b). Euler angles indicate that the angle in space is most intuitive and the state of the object.
c). Axis angle representation: Suitable for the derivation of geometric formulas.
d). Quaternion representation: Applies to spatial combination rotation. Therefore, since the quadrotor requires a large and frequent use of the combined rotation and transformation vectors in the attitude calculation, the quaternion is used to record the data pose in the data settlement, and the vector is transformed by the matrix and then converted into Europe. Pull the angle and then input it into the subsequent PID algorithm, as shown in Figure 2.

![Figure 2. Quaternion to Euler angle flow chart](image)

3. Four-rotor flight attitude algorithm

The flight attitude of the aircraft is the so-called real-time flight state of the aircraft. It can be defined by the coordinate system of an object itself and the angular positional relationship between the spatial reference coordinates. The three attitude angles we represent include roll, pitch, and yaw.

There are also many ways to describe the pose. The most commonly used are the quaternion, Euler angle and direction cosine matrix. Our design uses a quaternion with a wide range of applications and a small amount of computation to describe the real-time attitude of the aircraft.

The data of the attitude of the four-rotor aircraft studied in this paper is mainly derived from the attitude calculation process of the MPU6050 sensor as shown in Figure 3.

![Figure 3. Attitude solution flow chart](image)

4. Cascade PID control algorithm

The role of PID in the quadrotor system is to achieve a stable, accurate and fast response. Stability: When the aircraft is in the air, it encounters external interference. After a period of time, it can return to its stable state again. P and I reduce the stability of the system, and D improves the stability of the system. When the system is stable, it will exist. Steady state error, resulting in drift. Among them, P
and I improve the steady-state accuracy, and D has no effect on the accuracy. Fastness: The system measures the speed of response in response to dynamic instructions that require a transition period.

Among them, P and D improve the response speed, and I reduce the response speed.

The definition of PID control is: usually multiply the error coefficient $K_p$ by the error $e(t)$ to eliminate the current error of the aircraft; the integral term coefficient $K_i$ multiplied by the integral of the error $e(t)$ is used to eliminate the accumulation of historical error; the differential term coefficient $K_d$ Multiplying the differential of the error $e(t)$ is used to eliminate the error variation, that is, to ensure that the error is constant. In summary, the proportional link P control mainly eliminates the current error and belongs to the core position in adjusting the entire flight control system. The integral link I control is to eliminate the static error existing in the previous proportional link control margin and prevent the error accumulation. The final differential link D control has a smaller proportion in the entire control system, just to increase the degree of system damping to prevent the response speed from being too fast and cause strong vibration of the system, based on which to enhance system stability.

The main purpose of PID control is to calculate the angular velocity measured by the quaternion converted Euler angle and the MPU6050 sensor. The function is to pass the proportional (P), integral (I), and differential (D) pairs before outputting the signal to the motor. The controlled object is controlled to make it more stable. We use the Euler angle as the outer loop, the period is controlled to 5MS; the angular velocity is the inner loop, and the period is 2.5MS. The set value of the remote control is used as the input value of the outer ring. The set value of the inner loop is the output value of the outer loop.

When describing the control algorithm at the same time, we use two nouns to define the attitude of the aircraft: the desired attitude and attitude error. The former refers to the target posture specified by the remote controller. The latter represents the difference between the desired pose and the current instantaneous pose. Therefore, the basic meaning of the control algorithm is to make the attitude of the aircraft smoothly approach the target posture and reduce the error in the shortest possible time. The flight attitude requires a quick update to keep the aircraft stable, the update speed is maintained at 1000 Hz, and it also causes a large error in order to reduce the delay generated by the entire system.

![Figure 4. MPU6050 Cascade PID Structure](image)

In the cascade PID control algorithm, the two control systems can control more variables than the control system of one controller. Yes, the aircraft has more stability and is more adaptable. The outer ring controls the overall direction adjustment of the aircraft, so that the aircraft quickly responds to the remote control given signal to the corresponding position. The inner ring controls the fine tuning of the aircraft to make it more stable.

5. Data filtering algorithm

After the quadrotor aircraft obtains the attitude data through the inertial measurement unit, it also needs to separately filter the data acquired by the accelerometer and the gyroscope.

The accelerometer in the inertial measurement unit MPU6050 measures the inclination of the whole aircraft. Relatively speaking, its dynamic response is slow, and all the low-frequency signals are generated. The main source of noise is the vibration of the body itself, so in order to reduce the noise interference. The low frequency model can be kept intact by suppressing high frequencies.
The gyroscope in the inertial measurement unit MPU6050 has accurate data response and fast speed, and the inclination can be measured after integration. However, as time progressed, there was a problem of zero drift of data. Here, sliding window filtering is chosen to solve the problem of zero drift. The sampling period has a value of 20, and each 20 data is shifted back by a weighted average to reduce the error caused by drift.

Therefore, the two types of combined filtering methods are used to obtain a more accurate signal.

A). IIR low pass filtering algorithm

```c
void Calculate_FilteringCoefficient(float Time, float Cut_Off)
{
    ACC_IIR_FACTOR = Time / (Time + 1/(2.0f*Pi*Cut_Off) );
}

void ACC_IIR_Filter(struct _acc *Acc_in, struct _acc *Acc_out)
{
    Acc_out->x = Acc_out->x + ACC_IIR_FACTOR*(Acc_in->x - Acc_out->x);
    Acc_out->y = Acc_out->y + ACC_IIR_FACTOR*(Acc_in->y - Acc_out->y);
    Acc_out->z = Acc_out->z + ACC_IIR_FACTOR*(Acc_in->z - Acc_out->z);
}
```

B). Window sliding filter algorithm

```c
void Gyro_Filter(struct _gyro *Gyro_in, struct _gyro *Gyro_out)
{
    static int16_t Filter_x[Filter_Num], Filter_y[Filter_Num], Filter_z[Filter_Num];
    static uint8_t Filter_count;
    int32_t Filter_sum_x=0, Filter_sum_y=0, Filter_sum_z=0;
    uint8_t i;
    Filter_x[Filter_count] = Gyro_in->x;
    Filter_y[Filter_count] = Gyro_in->y;
    Filter_z[Filter_count] = Gyro_in->z;

    for(i=0;i<Filter_Num;i++)
    {
        Filter_sum_x += Filter_x[i];
        Filter_sum_y += Filter_y[i];
        Filter_sum_z += Filter_z[i];
    }
    Gyro_out->x = Filter_sum_x / Filter_Num; Gyro_out->y = Filter_sum_y / Filter_Num;
    Gyro_out->z = Filter_sum_z / Filter_Num;
}```
Filter_Num;
Filter_count++;
if(Filter_count == Filter_Num)
    Filter_count=0;
}

6. Summary
The four-rotor UAV control system uses a matrix conversion algorithm from quaternion to Euler angle and a cascade PID control algorithm. It mainly includes the calculation of the real-time attitude of the aircraft in the air and the control of the output signal. Finally, the communication between the upper computer and the lower computer is realized.

References
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