Mobile Attitude Transmission and Aircraft Control Strategies Based on WIFI

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Abstract. Four rotor aircraft controlled by remote controller has obvious disadvantages which including high cumulative error, and poor portability and low dynamic response and those decrease the user's sense of substitution and result in poor touch experiences. This paper proposes a set of control strategies and applies them in flight control and mobile phone terminal. Firstly, STM32 is used to solute the attitude of aircraft by DMP based on MPU6050 and communicates with the Smartphone by wireless WIFI communication module based on ESP8266. Secondly, the attitude solution of Smartphone is calculated by JAVA development kit and the adjusted Euler angle will be sent to flight control terminal so as to follow the phone attitude. Simulation and the actual test results show that our proposed strategies have good stability and portability.

Keywords: STM32 · ESP8266 · MPU6050 · Quaternion · Attitude algorithm

1 Introduction

It is not portable to use remote control of carrier attitude in the conventional method. The smartphone device is used as a remote control device, which has good touching experience, high portability and practicability, and supports magnetic, gravity and gyroscope sensors. It can control the micro-four-wing aircraft through mobile phone attitude. In order to achieve attitude transmission, flight control board need to configure the WIFI module.

Attitude calculation is one of the most important technologies in the field of flight control, which is widely used in aeronautics and astronautics, industrial robots and other popular fields. It is the key technology of inertial navigation system [1]. In order to accurately calculate the attitude information of the carrier, it is necessary to fuse the data of various sensors to achieve the purpose of complementary advantage. In this paper, the board of flight control integrates the MPU6050 to solve the carrier attitude. Using smart phones integrated magnetic sensor, gravity sensor, the remote control solves the carrier attitude through the Android API, and transfer Euler angles to the flight control side through the WIFI, In order to achieve the purpose of mobile phone control carrier attitude.

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2 System Framework and Hardware Design

2.1 System Framework

The hardware of the system includes mobile phone as remote control and flight control board. STM32 microcontroller connects the gyroscope(MPU6050) through the IIC interface to complete the attitude sensor data collection. The original data is processed by the main control processor to generate quaternions, which is converted into Euler angle [2, 3]. The STM32 is connected to the ESP8266 via the LVTTL serial interface. Set it to COM-AP mode to accept smart phone attitude data. The raw data (acceleration, gyro) as well as the attitude sensor data can be sent through the UART serial communication to the host computer for analysis (Fig. 1).

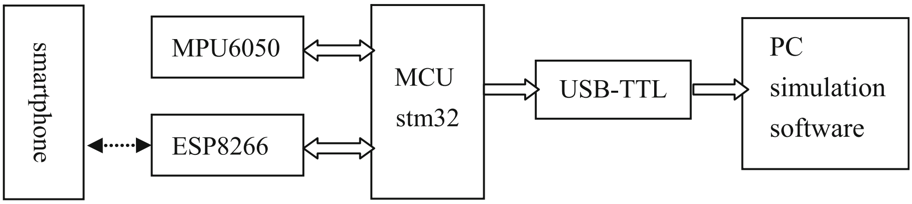

Fig. 1. System architecture

2.2 Hardware Design of Flight Control Board

The STM32F407 communicates with the attitude sensor MPU-6050 by GPIOB interface of the PB8/PB9. Communication using iic protocol. PC0 of STM32F407 connects MPU6050 interrupt request, AD0 connects low level. Thus, the access address of the MPU 6050 is 0x68. The pins TXD, RXD, and RST of the ESP8266 module are connected to PB11, PB10, and PF6 of the MPU. The hardware connection is shown in Fig. 2.

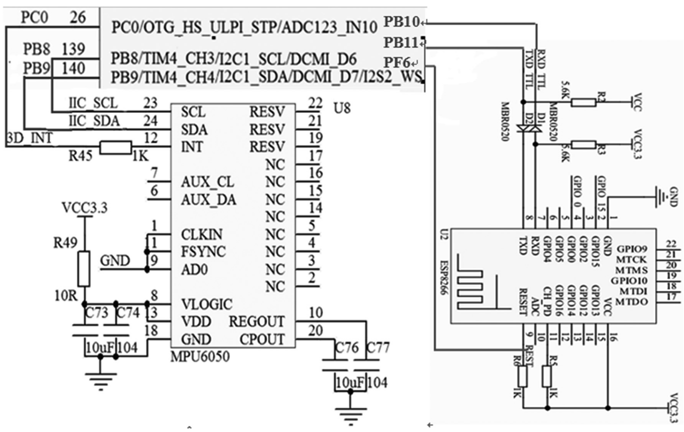

Fig. 2. The hardware connection diagram of flight control board

3 System Software Design

3.1 Smartphone Attitude Estimation

When using orientation and movement sensors in Android, two coordinate systems are defined: the global coordinate system, and a device coordinate system. Both coordinate systems are illustrated in Fig. 3. Euler angle(azimuth/yaw, pitch, roll angle) is formed between the device coordinate system and the global coordinate system, when the Smartphone attitude change [4]. The Android platform provides two sensors that let you determine the position of a device: the geomagnetic field sensor and the orientation sensor. the orientation sensor is a synthetic sensor that calculates rotation angle of the global coordinate system with respect to the device coordinate system using the accelerometer, the magnetometer, and possibly the gyroscope if available. [5] We can use these sensors to calculate the Euler angle, the specific steps are as follows:

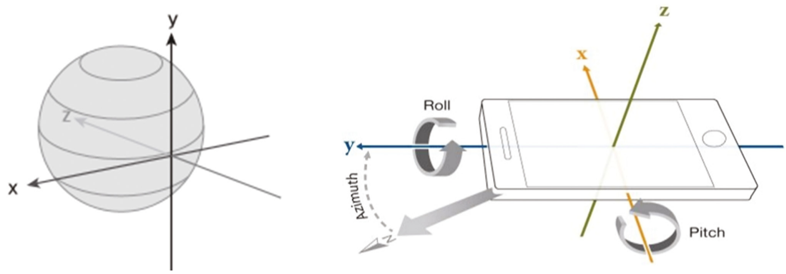

Fig. 3. Coordinate system

Step 1: Create a sensor manager and a sensor listener and instantiate it.
Step 2: Regester and monitor the geomagnetic sensor and the gravity sensor. When the sensor data change, callback the SensorEventListener, and obtain the real-time change data through the SensorEvent.
Step 3: A rotation matrix can be obtained from getRotationMatrix() or getRotationMatrixFromVector(), using the geomagnetism sensor and gravity sensor to generate the attitude rotation matrix. ns). [5]
Step 4: The rotation matrix can then be passed to function getOrientation() to get the orientation (azimuth, pitch, and Roll).

3.2 Design of WIFI Data Transmission Strategy

Establishing TCP communication in wireless local area network. The flight control terminal server is established in a wait state, waiting for the mobile phone client connection. When a client request is received, the server generates a message to the client. In the client, smart phone use the constructor to create the connection to server through the IP address and port.

Wireless WIFI module ESP8266, used to receive smart phone gesture and control data. In order to ensure the reliability of data transmission, you need to customize a set of transmission protocols to prevent interference by other signals. As shown in Table 1:

Table 1. Transfer protocol

Function	Header	Type code data		End of message
Flight control signal	MH	00-10	XXXXXX	ME
phone attitude	MH	11	XXXX XXXX XXXX	ME

The "MH" in the transport protocol represents the protocol header. "ME" represents the protocol tail, and is used to determine the start and end of a data transmission. There are two types of code: "00" that remote control command data, "01" that control the attitude data. The valid data of the attitude data are 12 bits, which are 4 Roll angle data, 4 Pitch angle data and 5 Yaw angle data.

3.3 The Software Design of STM32 Flight Control Board

STM32 as the control part of the whole system, the algorithm through Keil MDK5 Integrated development tools to achieve. The main idea of the flight control program is to initialize the MCU (serial port, interrupt, timer, IIC, etc.), wireless module, MPU6050 initialization after power on. Flight control system interrupted every 0.5 ms,

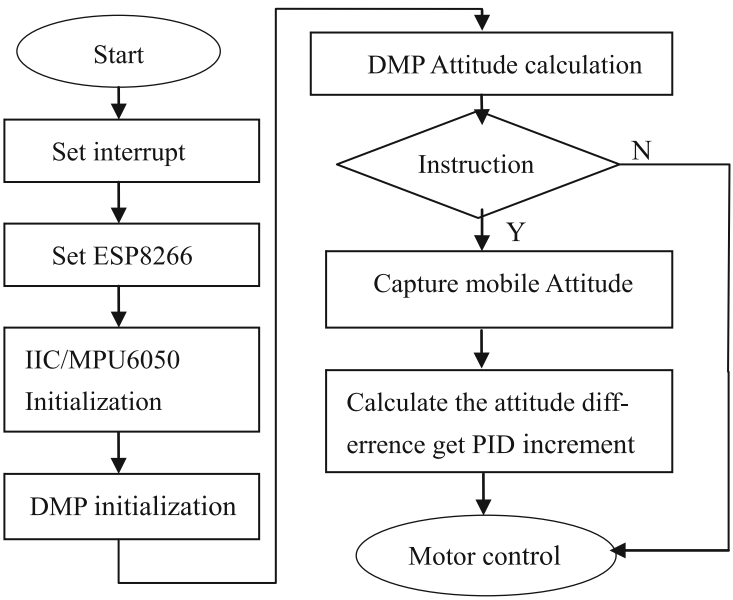

Fig. 4. Control flow chart

each interrupt will check once the wireless module data reception, to ensure that the flight control information is real-time. The raw data of the system acceleration, angular velocity of the IMU is read once every two milliseconds to complete the quaternion attitude calculation. In order to simulate the flight controller and mobile terminal, STM32 relies on timer interrupt to perform sampling, and send the data to PC via RS232 serial port. Real-time display MPU6050 and the phone's sensor status curve, and display 3D pose. Figure 4 shows the overall control flow.

(1) *Attitude solving algorithm based on DMP*

MPU6050 is used to realize the attitude calculation of the carrier, which not only simplifies the code design, but also reduces the burden of the MCU. The MCU does not need the attitude solving process, so it has more time to process other events and improve the system real-time. The main processes include MPU6050 initialization and DMP attitude calculation.

MPU6050 comes with a digital motion processor (DMP), and InvenSense provides a MPU6050 embedded motion-driven library. We can convert our raw data directly into quaternion, and Finally, Euler angles are calculated, yaw, roll and pitch are obtained. After DMP processing, MCU can directly read out the number of quaternion and the corrected gyro data, acceleration data from the FIFO cache of MPU6050. It is very important to convert quaternion to the Euler angle in the process of Attitude calculation. In 3D graphics, the commonly used method to solve the problem of coordinate system rotation direction cosine method and Quaternion method [6]: method of direction cosine calculation to obtain three angle data of attitude. Assume that the rotation angles around the x, y, and z axes are θ, ϕ, ψ, the rotation matrix such as formula (1), therefore, Transformation of reference coordinate system to the carrier coordinate system can be achieved by the product of these three independent transformations, $R_Z\psi R_Y\theta R_X\phi = A$ [7], as shown in the formula (2)

$$R_X\phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \quad R_Y\theta = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix}$$
$$R_Z\psi = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$A = \begin{bmatrix} \cos\psi\cos\theta & \sin\psi\cos\theta & -\sin\theta \\ \cos\psi\sin\theta\sin\phi - \sin\psi\cos\phi & \sin\psi\sin\theta\sin\phi + \cos\psi\cos\phi & \cos\theta\sin\phi \\ \cos\psi\sin\theta\cos\phi + \sin\psi\sin\phi & \sin\psi\sin\theta\cos\gamma - \cos\psi\sin\phi & \cos\theta\cos\phi \end{bmatrix} \tag{2}$$

The calculation of attitude matrix with direction cosine method, no Equation degradation problem, but needs to solve 9 differential equations, so the real-time performance is bad and the calculation is large. Quaternion method needs to obtain rotation axis and rotation angle. Compared with the direction cosine attitude matrix differential equation, the computational cost is obviously reduced [8].

The representation of the quaternion is given in Eq. (3). The reference coordinate system rotates a corner θ. The direction of the rotation axis is determined by the imaginary part of the number of four elements. The value ($\cos\alpha$, $\cos\beta$, $\cos\gamma$) indicates the direction cosine value between the axis of rotation axis N and the reference coordinate system.

$$q = \lambda + p_1 i + p_2 j + p_3 \tag{3}$$

$\lambda = \cos\frac{\theta}{2}$, $p_1 = \sin\frac{\theta}{2}\cos\alpha$, $p_2 = \sin\frac{\theta}{2}\cos\beta$, $p_3 = \sin\frac{\theta}{2}\cos\gamma$. The quaternion can be transformed into attitude matrix A by using the trigonometric formula

$$\mathrm{A} = \begin{bmatrix} p_0^2 + p_1^2 - p_2^2 - p_3^2 & 2(p_1 p_2 + p_0 p_3) & 2(p_1 p_3 - p_0 p_2) \\ 2(p_1 p_2 - p_0 p_3) & P_0^2 + p_2^2 - p_1^2 - p_3^2 & 2(p_2 p_3 + p_0 p_1) \\ 2(p_1 p_3 + P_0 p_2) & 2(p_2 p_3 - P_0 p_1) & p_0^2 + p_3^2 - p_1^2 - p_2^2 \end{bmatrix} \tag{4}$$

$$\phi = \arctan\left(\frac{A(2,3)}{A(3,3)}\right); \psi = \arctan\left(\frac{A(1,2)}{A(1,1)}\right); \theta = \arcsin(A(1,3)) \tag{5}$$

According to the formula (2), the formula (4) gets the Euler angle formula of the quaternion formula is as follows: [9]:

$$\phi = \mathrm{arctan}((2 \times \mathrm{p2} \times \mathrm{p3} + 2 \times \mathrm{p0} \times \mathrm{p1})/(\mathrm{p}_0^2 - \mathrm{p}_1^2 - \mathrm{p}_2^2 + \mathrm{p}_3^2)) \tag{6}$$

$$\psi = \mathrm{atan2}(2 \times (\mathrm{p1} \times \mathrm{p2} + \mathrm{p0} \times \mathrm{p3})/(\mathrm{p}_0^2 + \mathrm{p}_1^2 - \mathrm{p}_2^2 - \mathrm{p}_3^2)) \tag{7}$$

$$\theta = \mathrm{asin}(-2 \times \mathrm{p1} \times \mathrm{p3} + 2 \times \mathrm{p0} \times \mathrm{p2}) \tag{8}$$

Thus, a calculation formula for roll ϕ, yaw ψ, and pitch θ is obtained. Pitch accuracy: 0.° range: −90.0 DEG +90.0 DEG <—>; roll angle and heading angle accuracy: 0.1° range: −180.0 DEG +180.0 DEG <—>, through Dmp_get_data (float *pitch, float *roll, float *yaw) attitude.

(1) *ESP8266 settings and software design*

ESP8266 module connects the WIFI device phone as a wireless WIFI hotspot. We need to configure the ESP8266 for the COM-AP mode. According to the different application scenarios the mode includes 3 sub models: TCP server, TCP client, UDP. Work mode can be configured with AT instructions. [10, 12] Serial Wireless AP WIFI mode, TCP server configuration, as shown in Table 1.

The bottom driver of STM32 mainly includes the sending and receiving of AT instruction, the module state detection, the acquisition of IP/MAC and the establishment of TCP connection, as well as the data transmission and reception of the mobile phone and module (Table 2).

Table 2. Esp8266 work mode configuration

Send instructions	Effect
AT + CWMODE = 2	Set the module WIFI mode to AP mode
AT + CWSAP = "ESP8266", "12345678", 1, 4	Set the AP parameters of the module: SSID is ESP8266, password is 12345678, channel number is 1, and the encryption mode is WPA_WPA2_PSK
AT + CIPMUX = 1	Turn on multiple connections
AT + CIPSERVER = 1,8086	Turn on SERVER mode, set the port to 8086
AT + CIPSEND = 0,25	Sending 25 byte packets to ID0

4 Related Testing

4.1 WIFI Related Testing

WIFI communication test mainly include the communication between the PC and the aircraft and the communication between the mobile phone APP and the aircraft. Test method: In the test, first connect the aircraft as WIFI hotspots, and then enter a set account password. Connection is successful, after successful connection, PC or APP is required to open the TCP client, connected to the aircraft's TCP server. The server IP address is 192.168.4.1, port 8086. We can send remote frame data to aircraft after the connection is established. The mobile phone attitude data use the serial debugging assistant to simulate, mobile phone use the existing network assistant APP. Simulation of the Euler angle of smart phone is as shown in Fig. 7. The red curve represents roll; yaw is the gray curve; the blue curve is pitch.

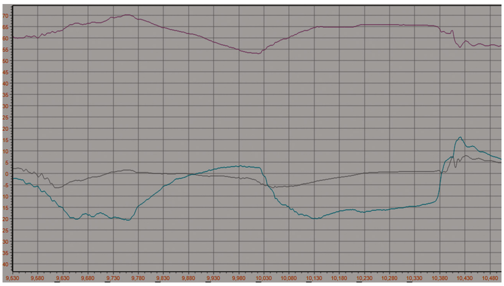

Fig. 7. Simulation of the Euler angle of smart phone (Color figure online)

4.2 Flight Attitude Testing

In order to observe the changes of MPU6050 data in real time and evaluate the performance of the algorithm, this paper uses the serial communication to send the sensor data and the Euler angle data generated by the algorithm to the host computer. The usart1_niming_report function is used to package data, calculate the checksum, and then reported to the PC software; mpu6050_send_data function for the original data to the accelerometer and gyroscope, waveform display for sensor data. The usart1_report_imu function is used to display the frame, flight control, real-time 3D display MPU6050 attitude sensor data, etc.

Figure 8 shows the original data of MPU6050 (three axis acceleration, three axis gyroscope). The waveforms show that the data are unstable and there is noise. Figure 9 shows the filtered Euler angle (pitch, roll, yaw) after a continuous sampling of the data waveform. Test results show that the DMP attitude solution can effectively suppress the noise and obtain the stable and smooth data.

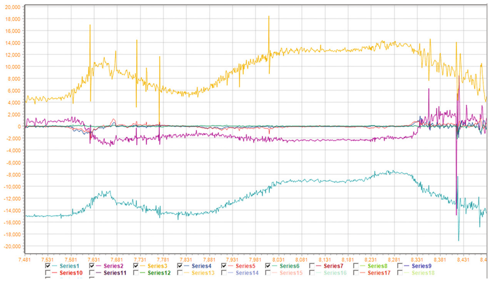

Fig. 8. waveform of the original data of gyroscope

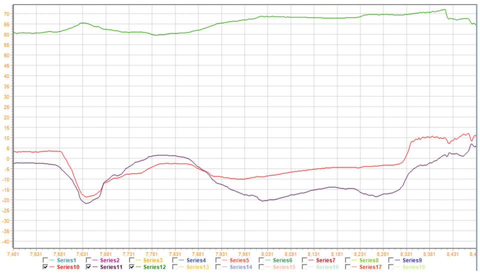

Fig. 9. attitude waveform of gyroscope

5 Conclusions

In this paper, the attitude solution of mobile phone based on the JAVA development kit is realized, and the smartphone's Euler angle is transmitted to the flight control side. Flight control board uses DMP of MPU-6050 gyroscope to achieve the carrier attitude calculation. Experimental results show that the proposed approach not only has low noise but also has high dynamic response. The system can meet the requirements of the aircraft attitude control system. However, the MPU-6050 itself does not have a fusion magnetometer, so the carrier in the yaw angle has accumulated error, the system can further expand the three-axis magnetometer to compensate for the shortcomings.

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References

1. Zhang, R.H., Jia, H.G., Chen, T., et al.: Analysis of Attitude of Strapdown Inertial Navigation System Based on Quaternion Method. Editorial Office Optics Precis. Eng. **16**(10), 1963–1970 (2008)
2. Zhang, Y.: Proficient in the STM32F4 (library function version), pp. 13–14. Beihang University press (2015)
3. Huang, W.K., Wu, F.J.: The development of actual combat guide robot volume, pp. 95–97. Machinery Industry Press (2014)
4. Wang, Z.P., Tang, X.H., Wang, Y.F.: Research on attitude recognition technology of aircraft based on MEMS accelerometer. Piezoelectric Acoust. Opt. **29**(2), 224 (2007)
5. Milette, G., Stroud, A.: Professional Android Sensor Programming, pp. 87–97. Tsinghua University Press (2013)
6. Guo, L.L., Zhao, H.: The spatial coordinate conversion algorithm of the accelerometer data of the mobile phone in the mobile phone is applied. Comp. Appl. **36**(02), 301–306 (2016)
7. Wang, X.P., Zhang, T.G.: Strapdown inertial navigation technology, 2nd edn. National Defence Industry Press (2007)
8. Sun, D., Tian, Z., Han, L.: Simulation on quaternion calculate attitude angle of the strapdown inertial navigation system. J. Projectiles Rockets Missiles Guidance **29**(1), 51–54 (2009)
9. Zhao, J.J., Chen, B., Yang, L.B.: Geodetic coordinate transformation algorithm based on four element number and its implementation. Comput. Eng. Appl. **49**(4), 202–205 (2013)
10. Molloy D.: Wireless Communication and Control. Exploring Raspberry Pi, pp. 535–575 (2016)
11. Liu, X.H., Li, J.B.: Four rotor attitude control system based on STM32. Comput. Meas. Control **22**(3), 762 (2014)
12. Rudinskiy, M.: ECE 4999 Independent Project: Wi-Fi Communication Using ESP8266 & PIC32 Mikhail Rudinskiy Completed for Dr. Bruce Land