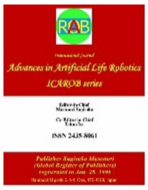
SUGISAKA
MASANORI

Journal of Advances in Artificial Life Robotics
Vol. 1(1); June (2020), pp. 17–21
ON LINE ISSN 2435-8061; ISSN-L 2435-8061
https://alife-robotics.org/jallr.html



Research Article

A Design of the Intelligent Aircraft based on STM32

Fengzhi Dai[1,2], Hongbo Hao[1]
[1]Tianjin University of Science and Technology, China
[2]Tianjin Tianke Intelligent and Manufacture Technology CO., LTD, China

ARTICLE INFO

Article History

Received 23 October 2019
Accepted 01 July 2020

Keywords

Aircraft
Man-machine interaction
Wireless transmission
PID

ABSTRACT

With the chip STM32f767 igt6 (M7 series) as the core, the designed aircraft will finally realize the intelligence by using the optimized attitude algorithm (cascade PID and single-stage PID share the optimized control), omni-directional ultrasonic radar detection barrier collision prevention technology, long-distance wireless transmission technology (to realize the timely transmission of images recognition), navigation technology (the Beidou and GPS double positioning system to realize more accurate positioning), voice recognition technology, man-machine interaction technology, and wireless local area network technology. The experiment shows the result.

1. Introduction

1.1. Research background

In the inspection of the expressway, the UAV (Unmanned Aerial Vehicle) is used to conduct the inspection of the high-speed section. It is possible to carry out the first-time processing of various emergencies, and truly grasp the road conditions of the expressway in real time. Also in the field of forest fire prevention, various sensors and line electronic devices are not easy to be installed, so the application of the UAV can immediately monitor the situation of the forest [1].

Another advantage of the four-rotor UAV is its small size. Unmanned aircraft can autonomously fly in the air and finish certain tasks. Compared with the ordinary aircraft, it is simple and low cost, and it is easy to be maintained and manufactured. UAV can be used for real-time battlefield investigation, target positioning, and unit tracking in military. It can also be used for survivor rescue and all kinds of scientific experiments because it can carry a variety of scientific equipment.

1.2. Innovation of the design

The designed aircraft has the functions of voice interaction, image recognition, and it has stereo radar. The main control core STM32F767 is the first aircraft designed for M7 in China. M7 has high processing speed, excellent running effect and stable performance. It can carry a variety of smart sensors, and have multiple peripheral interfaces to support IIC, USART communication external device mounting and large-size screen display.

1.3. The main work

The control algorithms, software and hardware are designed. In this paper, the communication protocols used by various quad-rotor aircrafts are analyzed in depth and optimized for program design.

According to the current mainstream algorithm of quadrotor, the attitude control is optimized.

This paper analyzes the fusion algorithm that uses multiple types of sensors to achieve flight movement control.

Corresponding author's E-mail: daifz@tust.edu.cn, URL: www.tust.edu.cn

2. Principle and Modeling of Four-rotor Aircraft

2.1. Four-rotor dynamics analysis

First, the four-rotor aircraft has a cross shape with the four arms. In flight, there are generally two states, X-shaped or cross-shaped. The aircraft is equipped with an imaging device. The principle is to realize the action of the aircraft through the angle between the aircraft and the horizontal plane. First of all, the quadrotor has a cross shape and has four arms.

Generally, there are two states when flying, which are the X-type and cross-type. The angle between the arm and the forward direction is 45 degrees, and the adjacent arms are perpendicular for each other. The arms coincide with the forward direction, and two adjacent vertical arms are crossing [2]. The four-rotor aircraft is usually equipped with camera. The X type is often used in flight. It is mainly used to realize the movement through the angle between the aircraft and the horizontal plane, so it is relatively simple [3].

2.2. Four-helical mathematical modeling

The four-helical aircraft is a nonlinear, multi-variable, highly coupled, under actuated system. The motion state of the aircraft has 6 degrees of freedom, and there are only 4 inputs. The idealized model is assumed as follows.

2.2.1. DC motor modeling

The phase voltage of each winding of the three-phase brushless DC motor is composed of the winding induced potential and the copper wire's own resistance. Therefore, the following voltage balance equation can be used for each voltage.

$$U = IR + L\frac{\mathrm{di}}{\mathrm{dt}} + E \tag{1}$$

Then the three-phase DC state equation is

$$\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} \dot{i}_a \\ \dot{i}_b \\ \dot{i}_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{2}$$

The equivalent circuit diagram of the three phase brushless motor is shown in Fig.1.

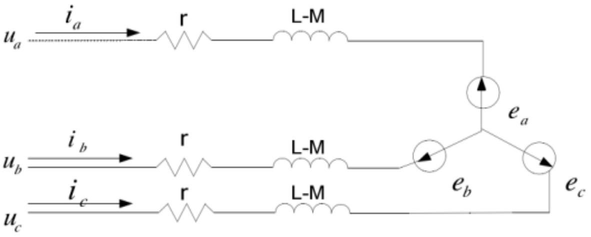


Fig.1 Equivalent circuit diagram of three-phase brushless motor

2.2.2. The torque equation

The current magnitude and electromagnetic torque of a phase brushless motor are proportional to the flux.

$$P = T_e \omega = \sum_x i_x e_x \tag{3}$$

The equation of motion of the motor is

$$T_e = T_L + J\frac{d\omega}{dt} \tag{4}$$

2.2.3. The aircraft model

The four-rotor has six flight states: rising, descending, forward, backward, leftward and rightward. In order to stabilize the hover, it is necessary to detect the angle between the four motors and the horizontal plane.

The aircraft uses the quaternion and Euler angles in 3D stereology to represent the angle of rotation, and the calculation formula uses a 3D Cartesian coordinate system, as shown in Fig.2.

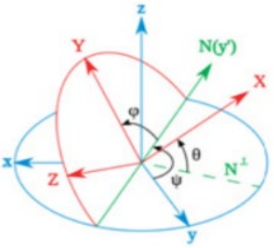


Fig.2 3D Cartesian coordinate system Definition of quaternion

$$q = \begin{bmatrix} \mathrm{w} & \mathrm{x} & \mathrm{y} & \mathrm{z} \end{bmatrix}^T \tag{5}$$

$$|q|^2 = w^2 + x^2 + y^2 + z^2 = 1 \tag{6}$$

Conversion of Euler angles to quaternions:

$$q = \begin{bmatrix} w \\ x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos(\phi/2)\cos(\theta/2)\cos(\psi/2) + \sin(\phi/2)\sin(\theta/2)\sin(\psi/2) \\ \sin(\phi/2)\cos(\theta/2)\cos(\psi/2) - \cos(\phi/2)\sin(\theta/2)\sin(\psi/2) \\ \cos(\phi/2)\sin(\theta/2)\cos(\psi/2) + \sin(\phi/2)\cos(\theta/2)\sin(\psi/2) \\ \cos(\phi/2)\cos(\theta/2)\sin(\psi/2) + \sin(\phi/2)\sin(\theta/2)\cos(\psi/2) \end{bmatrix} \tag{7}$$

Quaternion is converted to Euler angle:

$$\begin{bmatrix} \varphi \\ \theta \\ \psi \end{bmatrix} = \begin{bmatrix} \arctan(\frac{2(wx+yz)}{1-2(x^2+y^2)}) \\ \arcsin(2(wy-zy)) \\ \arctan(\frac{2(wz+xy)}{1-2(y^2+z^2)}) \end{bmatrix} \tag{8}$$

3. Aircraft scheme design

3.1. Overall scheme

The aircraft modules used in this paper include M7 series control cores, attitude sensors, intelligent interactive equipment, wireless remote control equipment, obstacle avoidance equipment, positioning equipment, and upper computer display equipment.

3.2. Equipment selection

This paper selects the frame (F450), motor (B2212 brushless motor), ESC (SimonK ESC), NRF24L01 wireless module, ESP8266 WIFI module, voice recognition module LD3320A, ultrasonic module HC-SR04, OV5640 camera module, GPS Beidou dual positioning Module S1216, attitude sensor MPU6050 AK8975.

4. Hardware scheme design

4.1. Overall design

After the component selection is completed, the overall circuit is designed accordingly. Each module has its own communication method, and each module occupies different internal resources to the core control board according to different design schemes.

4.2. STM32F767 minimum system design

The system includes a hardware reset circuit for testing the system; the Jlink download interface is used to download programs and online testing. The SDRAM external expansion circuit uses the W9825G6KH chip to expand the 256K memory capacity to 32M, which enhances the demand for memory of each program. The FLASH chip used in the FLASH external circuit is MT29F4G08, which adds 512M of storage space to the main control [4]. It can be used to store pictures and key information.

4.3. Power supply

The system contains 5V to 3.3V regulated power supply, which mainly supplies power to 3.3V modules and core STM32F767 chips. In order to prevent the voltage from being too high, the voltage regulator is used to stabilize the voltage.

4.4. Module Interface Circuit

As each module transmits information through digital signals, the common interfaces are IIC, UART, and motor interface, voice interface, camera interface, etc.

5. Software scheme design

5.1. Single-level PID control algorithm

The PID (positional, incremental and differential) algorithm of the input-output response is used and the parameters are adjusted to make the output response reach an ideal state. The positional PID is related to the error of the whole past, and the integral link is used. The incremental PID is only related to the error of the first two beats, and the output is the control increment.

The single-stage PID is more suitable for the linear system. When the output and the control are linear, the single-stage PID method can get better results, but the four-axis is not a linear system.

5.2. Cascade PID control algorithm

As a result, it is difficult to obtain good control effect by the single-stage PID. In order to achieve the ideal control effect, the cascade PID is introduced [5]. It is divided into the inner loop and outer loop. The input and feedback of the outer loop are angle data, while the input and feedback of the inner loop is the angular velocity data, which is quickly adjusted according to the expected speed.

The outer loop is the input to the inner loop according to the angular deviation, and the inner loop determines how much the speed should be operated according to the angular deviation.

Generally, we only use the PI control in the outer loop. Proportion corrects the aircraft from the deviation angle to the desired angle. Integration eliminates the angular static difference.

In the inner loop, we adopt the PID control. Proportion corrects the yaw angular velocity of the aircraft to the desired value. Integration eliminates the static acceleration difference. And the different coefficient makes the correction faster.

6. Testing and conclusion

The design realized the stable flight of the aircraft. It detected the environmental parameters and realized the function of human-computer interaction. It also provided more convenient control through the remote control of the mobile phone, and supported the real-time one-megapixel image transmission. It can record and take pictures and support the GPS/Beidou global positioning and synchronize positioning in real time in Google Earth. The accuracy of positioning information also improves gradually with the accumulation of time [6].

Google Earth is a simulated Earth that contains information about various roads and buildings on the entire earth. Supported by the Google Earth, the location of the aircraft is shown in Fig.3 and the Google Earth interface is shown in Fig.4.

Fig.3 Aircraft position

Fig.4 Google earth

Acknowledgements

The research is partly supported by the Project of Tianjin Enterprise Science and Technology Commissioner to Tianjin Tianke Intelligent and Manufacture Technology Co., Ltd (19JCTPJC53700). It is also supported by the Industry-University Cooperation and Education Project (201802286009) from Ministry of Education, China.

References

1. Hongbo Hao, Fengzhi Dai, Haokang Wen, Jichao Zhao, Qianqian Zhang, Research on the Intelligent Aircraft Design based on STM32, *Proceedings of the 2020 International Conference on Artificial Life and Robotics*, Oita, Japan, 2020.1.13-16, pp. 628-631.
2. C. H. Lo, E. H. K. Fung, Y. K. Wong, Intelligent Automatic Fault Detection for Actuator Failures in Aircraft. *IEEE Transactions on Industrial Informatics*, 2009, 5(1): pp.50-55.
3. J. Escareno, S. Salazar-Cruz, R. Lozano, Embedded control of a four-rotor UAV, *Proceedings of 2006 American Control Conference,* Minneapolis, USA, 2006.
4. Yuan Gao, Yiqing Liu, Integrated Circuit IO Characteristic Intelligent System, *Proceedings of 2020 5th International Conference on Computer and Communication Systems*, Shanghai, China, 2020, pp. 895-899.
5. Ming-Hao Hung, Li-Sun Shu, Shinn-Jang Ho, Shiow-Fen Hwang, Shinn-Ying Ho, A Novel Intelligent Multiobjective Simulated Annealing Algorithm for Designing Robust PID Controllers, *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 2008, 38(2): pp. 319-330.
6. Lina He, Maorong Ge, Jiexian Wang, Jens Wickert, Harald Schuh, Experimental Study on the Precise Orbit Determination of the BeiDou Navigation Satellite System. *Sensors*, 2013, 13(3): pp.2911-2928.

Authors Introduction

Dr. Fengzhi Dai

He received an M.E. and Doctor of Engineering (PhD) from the Beijing Institute of Technology, China in 1998 and Oita University, Japan in 2004 respectively. His main research interests are artificial intelligence, pattern recognition and robotics. He worked in National Institute of Technology, Matsue College, Japan from 2003 to 2009. Since October 2009, he has been the staff in Tianjin University of Science and Technology, China, where he is currently an associate Professor of the College of Electronic Information and Automation.

Ms. Hongbo Hao

She is a first-year master candidate in Tianjin University of Science and Technology, majoring in pattern recognition, principle of automatic control, engineering mathematics and other important control disciplines. Her research area is about deep learning and image processing. During her study, she has published several research paper