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Review of the Application of Open Source Flight Control in Multi-rotor Aircraft

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Abstract

With the development and progress of modern science and technology, it is only a matter of time for UAV to enter the public life. However, autopilot is still the key equipment that puzzles the development of UAV. With the development of open source flight control technology, this problem has been solved in a breakthrough, which has laid the foundation for UAV products to enter public life. Because of its flexibility and VTOL, autonomous flight, multi-rotor aircraft are widely used in military, agricultural and industrial fields. This paper reviews the application of open source flight control based on multi-rotor aircraft. First of all, introduce the development of open source flight control. Then, combined with the research status of open source flight control technology, this paper introduces several common open source flight control and analyzes its advantages and disadvantages. After that, through the in-depth analysis of the application of scholars in multi-rotor aircraft based on open source flight control in recent years, the tasks that have been completed are pointed out. And further put forward the tasks that we should continue to complete and the possible problems and difficulties in technical research. Finally, the development trend and prospect of open source flight control technology in UAV application field are discussed.

Keywords

UAV; Multi - rotor Aircraft; Open Source Flight Control.

1. Introduction

The reliability of flight is considered to be one of the main obstacles to UAV integration. This is not an easy topic given the unknown factors of the system, environment and possible failures. According to us, the flexibility required for such solutions requires an open architecture, so a large number of open source flight controls based on MEMS sensors have emerged.

Open source flight control is an automatic flight controller project (Open Source Auto Pilot) based on open source idea, which includes open source software and open source hardware. The software includes firmware and ground station software in flight control hardware. Fans can not only participate in the development of software, but also participate in the development of hardware, not only can buy hardware to develop software, but also self-made hardware, so that people can freely enjoy the development results of the project.

2. Development of open source flight control

The development of open source flight control can be divided into three generations:

The main characteristics of the first generation flight control are modular and scalable capabilities. Open source flight control systems, based on Arduino or other similar open source electronic platforms, extend to connect various MEMS sensors to take off smoothly. As shown in Fig. 1.

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Fig. 1 First Generation Flight Control System

The main characteristics of the second generation flight control are two high, that is, high integration and high reliability. Most of the open source flight control systems have their own open source hardware, development environment and community. In order to improve the reliability, the lODOF sensor, the main control single chip microcomputer, and even the GPS and other devices are all integrated on a circuit board. The full digital three-axis MEMS sensor is used to form an attitude system (IMU), which can control the aircraft to complete the autonomous flight, and can also install a radio station to communicate with the ground station, which has the function of a complete autopilot. Such flight control can also support a variety of unmanned equipment, including fixed-wing aircraft, multi-rotor aircraft, helicopters and vehicles, and has a variety of flight modes, including manual flight, semi-auto flight and full-auto flight, its functions are close to commercial autopilot standards. as shown in Fig. 2.

Fig. 2 Second Generation Flight Control System

The third generation open source flight control system will be innovated in software and artificial intelligence. It adds advanced flight functions such as cluster flight, image recognition, autonomous obstacle avoidance and automatic tracking flight, and develops towards the direction of machine vision, cluster and platform development process. as shown in Fig. 3.

Fig. 3 Third Generation Flight Control System

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3. Research status of open source flight control

Flight control according to whether to open the source code is divided into open source flight control and commodity flight control. With the development of commodity flight control more and more hot, more and more manufacturers, open source flight control projects are also favored by domestic and foreign aviation model enthusiasts and researchers because of their unique participation and high scalability. These open source projects have a very important influence in the field of flight control. At present, most open source projects are still in the development stage and are being updated and modified in real time, see Table 1.

Table 1. Comparison Table among Open Source Flight Controller Hardware Platforms

Hardware Accessories	APM	Pixhawk	KK	MWC	PPZ
processor	Mega2560	Stm32f407	Mega168	Mega328	Stm32f105
gyroscope	MPU6000	L3GD20H	ENC03	IDC650	MPU6000
accelerometer	MPU6000	LSM303D	-	LIS3L02	MPU6000
geomagnetic pole	HMC5834	LSM303D	-	HMC5883	HMC5883
barometer	MS5611	MS5611	-	BMP085	MS5611

The following introduces some representative open source flight control in recent years.

3.1 Arduino flight control

The famous open-source hardware project Arduino is the beginning of development of open-source flight control, is the earliest open-source flight control. Developed by Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, David Mellis and Nicholas Zambetti in 2005 at the Italian Institute of Interactive Design. Arduino has first built a flexible open source hardware platform and development environment for electronic development enthusiasts, where users can obtain the design documents of the hardware from the official Arduino website, adjust the circuit boards and components to meet their actual design needs.

Arduino can view the source code and upload the code written by themselves through the Arduino IDE software. Arduino IDE use the Arduino language based on the C language and the C++ language, which is very easy to master. And Arduino IDE can run on the three major operating systems of Windows, MacOS and Linux.

As the platform is gradually accepted by enthusiasts, electronic expansion modules of various functions emerge in endlessly, the most complex of which is the flight controller integrated with MEMS sensors. For better flight control design source code, Arduino companies decided to open their flight control source code, they opened the way to open source flight control. The famous open source flight control WMC and APM are direct derivatives of Arduino flight control, and still use the Arduino development environment to develop.

3.2 APM flight control

APM is the abbreviation of ArduPilotMega, which is a very easy to assemble and use control platform, is one of the most powerful open source self-driving instrument on the market [1].

APM is the most mature open source hardware project today, and is a flight control product launched in 2007 by the DIY UAV Community (DIY Drones). APM, based on Arduino's open source platform, improves on multiple hardware, including accelerometer, gyroscope and magnetometer combined inertial measurement unit (IMU). Due to its good custom ability, APM quickly spread among model aircraft enthusiasts worldwide.

APM flight control can support multi-rotor, fixed-wing, helicopter and unmanned vehicle and other unmanned equipment, has become a mature benchmark of open source flight control. APM flight control supports four, six and eight rotor products for multi-rotor, and can effectively increase the stability of the aircraft after connecting the external GPS sensor, and complete the rich flight modes

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such as autonomous take-off and landing, autonomous route, fixed height, fixed point and so on. APM can also connect external ultrasonic sensors and optical flow sensors to achieve fixed height and fixed-point flight indoors.

The Mission Planner ground station can be used to match the APM self-driving instrument. The communication between Mission Planner and APM self-driving instrument is carried out by USB or wireless data transmission station. Through Mission Planner, we can see each parameter value in the flight process in real time, including attitude angle, attitude angular velocity, flight control system parameters, system output, GPS data, flight mode and so on. The mode change and flight control parameters can be debugged during the experiment, as well as the recording and playback of flight log.

3.3 PX4 and Pixhawk flight control

PX4 is a common open source project based on software and hardware, The aim is to provide a low-cost, high-performance high-end self-driving instrument for academic researchers, interested enthusiasts and industry groups. this research project originated from the Pixhawk project of the computer vision and geometry science research laboratory at the federal university of technology in zurich. PX4FMU self-driving module runs an efficient real-time operating system (RTOS), Nuttx provides a portable operating system interface (POSIX) type of environment. software can be updated using USB bootloader. PX4 communicate with ground stations through MAVLink agreements, compatible ground stations have QGroundControl and Mission Planner, software all open source and comply with BSD protocols.

Pixhawk flight control is an upgraded version of PX4 flight control, which was launched in 2014 by 3DR United APM Group with PX4 Group, with PX4 and APM two sets of firmware and corresponding ground station software. The company is the highest hardware product in the world and the hottest product among enthusiasts. Pixhawk has the operation frequency of 168 MHZ, and Breakthrough adopts the single chip Cortex-M4 which integrates the hardware floating-point operation core as the main control chip. Built-in two sets of gyroscope and accelerometer MEMS sensors, which complementary correction each other, three-axis magnetic field sensor and can be connected with a three-axis magnetic field sensor, at the same time can be connected with one master and one standby two GPS sensors, automatic switching in case of failure.

Based on the core and floating-point algorithm of its high speed operation, Pixhawk using the most advanced fixed height algorithm, the altitude of the aircraft can be fixed within 1 meter only by barometer. It supports not only all multi-rotor types, but also aircraft with irregular structures, like trirotor and H4 products. It enables the aircraft to have a variety of flight modes, supporting fully autonomous routes, key points around, mouse guidance,“FollowMe” to tail flight and other advanced flight modes, and can complete autonomous tuning.

The openness of Pixhawk flight control is very good. All hundreds of parameters are open to players to adjust, and it can also be fly after simple debugging based on the basic mode. Pixhawk integrates a variety of electronic maps, and enthusiasts can choose according to the local conditions.

3.4 KK(KKMultiCopter)flight control

KK fly control is an open source fly control project originated from South Korea, and the first widely accepted multi-rotor fly control. In the early stage of open source fly control development, the emergence of the fly control is a shock [2] to the whole multi-rotor industry. The flight control can only use three low-cost uniaxial gyro, combined with a simple four-channel remote control equipment, to control the common three, four and six rotor vehicles. The vehicle uses an 8-bit micro processor chip. Great results in short-distance flights. However, in the control process are involved, more artificial factors, higher requirements for fly controllers, and the maneuver ability is poor. In addition , the aircraft can provide relatively few control codes, and for some enthusiasts, it can be studied and developed accordingly .

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MEMS (Micro-Electro-Mechanical System) has been developing rapidly in recent years. As a result, some enthusiasts began to fuse some magnetic, acceleration and other sensors on the flight device to measure attitude, but also to improve the flight stability of the aircraft.

3.5 MK(Mikrokopter)flight control

Germany MK open source flight control, the device uses 8-bit microprocessor chip, the choice is Atmel series. the main structure of the aircraft is high complexity relative to the KK four-axis. in addition, many sensing devices are added, such as magnetic force, angular velocity and acceleration. these sensors are mainly used in attitude estimation and navigation, with rich interfaces, and PCB board technology is used to add functional [3]. In addition, the motion performance of the aircraft is relatively stable and can even be controlled by traditional air model remote control equipment. In addition, the flight control system adopts modular design and has good reference.

3.6 MWC(MultiWiiCopter)flight control

Flight control is based on the Arduino IDE development environment to design. Designed initially by French model enthusiasts Alex control his own three-axis aircraft. After being transformed and expanded by enthusiasts all over the world, it now supports, in addition to the common four, six, eight rotors, the biggest feature is to support many strange aircraft types, such as three rotors, Avatar aircraft (BIcopter avatar style), Y4 multi-rotor (where the two axes are up and down opposite), powerful and easy to use. MWC support is extremely rich in sensor types and supports a wide range of external devices and flight modes, which makes MWC flight control firmware one of the popular multi-axis open source flight control in foreign countries. Of course,MWC also have shortcomings, compared with other open source firmware such as APM, the biggest deficiency of MWC is that there is no better ground station support.

3.7 Paparazzi(PPZ)flight control

Paparazzi (PPZ) is the first software and hardware all-open source project, began in 2003, the development goal is to establish a flexible and powerful open source flight control project. A major feature of the PPZ is that the open source flight control scheme includes ground station hardware, including various modems, antennas and other equipment, in addition to common flight control hardware, flight control software and ground station software. Functionally, PPZ are close to a small drone system.

The open source project also features a ubuntu operating system that integrates all of the ground station software and development environment under the system, officially called the Live CD. A CD plus flight control hardware can complete all the work from development to use.

PPZ current most popular hardware version is Paparazzi (PPZ) Lisa/ MV2.0. He hardware has a large number of extended interfaces and uses extendible separate IMU sensor boards. This was also a popular practice in early open source flight control, which IMU hardware is continuously upgraded as the sensor is upgraded.

The key feature of the PPZ system is the use of infrared sensors and flight attitude inertial measurement sensors to provide powerful and accurate attitude estimates so that the aircraft can automatically adjust the flight state without manual ground control calibration. The controller only needs to set tasks for the aircraft on the ground station, and the rest is left to the aircraft itself. All the flight control, navigation, attitude adjustment, task execution and other work are fully completed by the flight control board. Of course, the ground personnel can also switch freely between the automatic control and manual control at any time.

4. Application of open source flight control in multi-rotor aircraft

4.1 Related applied research

During the past few decades, community and research projects have developed several open source UAV platforms (hardware, software, or both) to test and implement various UAV application [4]. In

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2001, Meszaros [5] studied the UAV aerial survey system based on open source software and hardware, a simple and low-cost scheme was proposed, that is, to build an autonomous aerial survey aircraft that can meet the needs of high-resolution aerial photography, and is very useful in the field of photogrammetry. Based on the commercial remote-controlled model aircraft, the open source GPS/IMU system (MatrixPilot) was used to realize the semi-automatic or automatic stabilization and navigation of the model aircraft according to the predetermined trajectory, and a field survey experiment was carried out using the above system: aerial survey of an undiscovered relic. In 2010, Chao et al. [6] introduced the small or micro UAV automatic control system, describing the radio control system from hardware and software, some open source autopilot systems, and compared several typical autopilot from sensors, observation channels and controllers. In 2012, Lim et al. [7] studied the open source project of quadrotor UAV systems, introduced the analysis of quadrotor UAV and its avionics, sensors, attitude estimation and control algorithms , and compared its additional features. In 2014, Chen Zijie et al. [8] studied the implementation of high reliability multi-rotor controller based on PX4. A high reliability flight control system composed of redundant switching device and fall warning device is designed to replace the existing single flight control system to improve the reliability of UAV and reduce the probability of crash. And minimize the loss of life and property after the crash. In 2016 ,Sabikan et al. [9] proposed an open source project (OSP) platform for autonomous UAV flight, which can be used in any outdoor application or even for experimental purposes. In 2019, Lv Kai [10] according to the real-time attitude data of multi-wing UAV, proposed an architectural design and test method of the open-source flight control test platform. At the same time, aiming at the preflight detection requirements of APM and pixhawk type open source flight control UAVs, we design and realize the precise step size control of multi rotor UAV throttle channel input through computer keyboard and mouse. Compared with manual control of multi rotor UAV throttle channel through remote control, the control is more linear, accurate and smooth, It makes the preflight detection of UAV more convenient. In 2019, Huang Xun [11] proposed a new tandem twin rotor UAV that can be used in narrow space flight, designed the corresponding mechanical structure and experimental prototype, and realized the system control by modifying the open source APM flight control. Finally, a real flight test was carried out successfully to verify the feasibility of this kind of UAV, It has reference value for UAV industry to develop and manufacture this kind of UAV which is easy to use in small space.

4.2 In-depth analysis of relevant applied research

UAV flight control system is the core system for UAV to complete the whole flight process, such as take-off, air flight, mission execution and safe landing. In fact, it is similar to a professional pilot controlling the aircraft [12,13]. For UAV, flight control system is undoubtedly the core technology. The key of the flight control system is mainly concentrated in three modules: sensors, airborne computer and servo actuator, and completes the stability and control of UAV attitude, mission equipment management and emergency control. Multi rotor aircraft is a kind of aircraft that can take off and land vertically, and has the advantages of relatively simple structure, small volume, light weight, easy operation, convenient take-off and landing, strong concealment, etc., which is widely used in military and civil fields such as search and rescue, aerial photography, traffic patrol, pesticide spraying and reconnaissance [14]. Therefore, this paper summarizes the application research of open source flight control based on multi rotor aircraft.

With the continuous development of open source flight control, the research literature on open source flight control is also increasing. By comparing the open source flight control used by scholars in the research of multi rotor aircraft in recent years, the development of open source flight control is further understood, and the application research of open source flight control in multi rotor aircraft is summarized.

It can be found from a large number of relevant literature that in the application research of multi rotor aircraft, most scholars choose pixhawk flight control to control the aircraft, and a few scholars

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choose open source flight control such as APM or PPZ to control the aircraft. Let's take a look at these selected open source flight control systems.

4.2.1 PPZ flight control

PPZ is the originator of open source flight control, especially PPZ is famous for its powerful algorithm and high stability. There are many versions of PPZ. MCU adopts ST and NXP solutions. In reference [15], the method of paparazzi project is described: the complete integrated design of hardware, software and fuselage forms a powerful and reliable system, which is verified by analysis method and thousands of flights. In reference [16], the authors use the Paparazzi open source autopilot system to reduce the integration of low altitude UAVs. In order to ensure safety, we need to achieve this integration through airspace management and UAS reliability. From the perspective of UTM, paparazzi provides functions to simplify traffic congestion management, such as dynamic geofencing, trajectory communication and collision avoidance. In the case of paparazzi software, part of the code has been officially proved, and the stable version has thousands of hours of flight time. Paparazzi also provides a unique set of functions (as open source software) to realize the security integration of low altitude UAS in G airspace.

If researchers follow PPZ's full open source hardware and software design and compatible hardware list, find a carrier and make appropriate adaptation, they can quickly launch their own products. But it should be noted that because PPZ is open source, competitors can also launch similar homogeneous products, so how to make their own characteristics outside the aura of PPZ is often the most important consideration for these researchers.

4.2.2 APM flight control

In reference [12], the author chose APM autopilot to design a low-cost and high-precision quadrotor flight control system. The flight control system has different functions for quad rotor helicopter in different control modes. Through the outdoor flight experiment, it can be seen that the stability control of quadrotor helicopter can be well completed in hovering mode. And it can easily view the attitude and position information in the flight process, which provides a good flight experimental platform for the follow-up research of quadrotor helicopter control.

As the most mature open source hardware project, APM flight control is widely selected by users. However, after the development based on Arduino, APM flight control has gradually transferred to Px4/Pixhawk platform, adopting the scheme of dual ST MCU, redundant power supply and sensor to meet the more demanding requirements and functions in the future.

4.2.3 Pixhawk flight control

In recent years, the research of autonomous obstacle avoidance, cluster formation, machine vision [17] and ground station system has become a hot issue in the field of UAV. With the development of image recognition, active following, path planning [18] and other technologies and theories, scholars have made more and more in-depth research on UAV. Pixhawk flight control has low cost of ownership, Good stability and high safety are widely used to control UAV.

Pixhawk is a low-cost, high-performance autopilot. It inherits the advantages of APM and Px4 and improves on them. Summarizing the research literature on the autonomous obstacle avoidance system of multi rotor aircraft based on pixhawk flight control [19-22], we can see that scholars have completed the analysis of the flight control system operation process, compilation process, uORB, rcS, flight control law, etc. on the basis of previous research results, but there are still difficulties in the research system, That is, the analysis of pixhawk flight control system with APM: copter flight control stack, which is related to whether an effective obstacle avoidance flight system can be successfully developed. In addition, when the small UAV encounters obstacles in autonomous flight, the flight control system can not make corresponding attitude and heading adjustment in time. It is suggested to add some ultrasonic or laser ranging on the basis of external or pixhawk board to solve the obstacle avoidance problem of UAV. In the literature of pixhawk flight control in the field of cluster formation [23-27], we can understand that the formation flight of multi rotor aircraft is a

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relatively complex engineering task, and there are many problems to be solved in practical application, that is, not only the control, communication and data fusion problems in the flight process of single multi rotor aircraft, but also the formation control, communication and data fusion problems Formation around obstacles, formation trajectory planning and other practical problems [28]. Multi rotor aircraft formation flight has a broad research prospect, which involves many disciplines and cross fields, and is difficult to study. In the relevant literature of pixhawk flight control in the field of ground station system design [29-35], it is mainly based on pixhawk flight control to study the function of each module of UAV Ground Station, and design and implement several functional modules according to the actual needs. The main problems are as follows: first, the communication efficiency between the ground station and UAV is poor, and the follow-up research can improve the communication protocol to improve the communication efficiency. Second, the positioning effect will have an impact on the track planning and flight, and the commonly used GPS positioning accuracy is not high, so DGPS can be added in the follow-up research to improve the positioning accuracy. Third, the security is not high. In the process of using SQLite database, the problem of data backup is not considered. In reference [36-38], the problem that pixhawk flight control microprocessor is difficult to carry out large-scale operation is solved. Researchers combine obroid processor with pixhawk flight control, and carry out secondary development, so that the UAV can achieve autonomous obstacle avoidance, visual navigation, online planning and other mission functions.

5. Development trend and Prospect of open source flight control technology

To sum up, pixhawk is the mainstream of flight control technology in various application fields, and its technology is relatively mature. The application of other advanced flight control technology in UAV flight control presents the situation of multi-point flowering. With the development of market demand in military and civil fields, combined with the current research hotspot and development trend of multi rotor flight control, it can be judged that pixhawk flight control is the future development trend of flight control technology for multi rotor aircraft.

Open source flight control system is more obvious, involving a wide range of applications. After this literature review, I think that there are several aspects to be completed for the research of open source flight control

(1) In the literature, the successful development of four rotor UAV Simulation Platform can greatly shorten the development cycle of flight control system and reduce the development cost. However, with the continuous development of UAV technology, it is bound to put forward higher requirements for the accuracy, stability and adaptability of flight control system. Moreover, the simulation platform designed in the literature is only for the test of some complex environmental factors. In view of the complexity and diversity of the real environment, the research of simulation platform still has a lot of room for development. This is a mutual promotion process, so it is necessary to develop simulation platform in the research of flight control system.

(2) With the rapid development of open source flight control in various fields, the serial port resources of flight control board may be more and more tense, so we can carry out secondary development for the CAN bus interface of flight control board, realize the communication between flight control board and data acquisition module, and liberate the serial port resources.

(3) The open source platform limits the hardware conditions, making the related research and development have to rely on the open source flight control system architecture, which leads to the lack of flexibility of the related research process.

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