DOI: 10.54254/2755-2721/2026.KA29638

Key Technologies and Application Strategies of Unmanned Aerial Vehicles

Muxi Li[1], Haocheng Sun[2*]

[1]Tianjin Farragut International School, Tianjin, China
[2]International Division of Hefei 168 High School, Hefei, China
**Corresponding Author. Email: outlook_A34D5B025FF721DF@outlook.com*

Abstract. Unmanned aerial vehicle technology is widely used in modern society. It plays an important role in amusement and production. This paper will focus on the four important modules of an unmanned aerial vehicle, power and control system, the Navigation and path planning system, for a research review. The power system of an electric drone contains electronic motors, electronic speed regulators, and batteries. The power system of a hybrid UAV includes three types: series connection, parallel connection, and hybrid connection. In addition, there is another way--fuel cells. The flight control system of a UAV always has a gyroscope, rudder, throttle, elevator, and barometer. But the UAV navigation relies on visual navigation, inertial navigation, and the global navigation satellite system. Besides, path planning is achieved by two mainstream modeling methods--structured light and multi-view. The application and requirements of these modules vary because of the different levels of the drone. The research can provide a report on the latest unmanned aerial vehicle technology.

Keywords: Multi-rotor aircraft, power system, navigation system

1. Introduction

With the development of society, quadcopters have unique advantages in an increasing number of fields, and it is difficult to find substitutes for them. The era of the Internet of Everything is approaching. With the rapid development of communication technology and intelligent control technology, the application scope of drones is becoming broader, and people's demand for using drones is also increasing day by day. The consumer market for drones is opening up rapidly. It is not difficult to predict that in People's Daily lives in the future, civilian drones will provide more convenience and assistance. The industrial chain of civilian unmanned aerial vehicles (UAVs) is gradually improving, and large-scale production has been basically achieved. The future market size is huge and the commercial value is very significant. It is precisely for this reason that the research on quadcopter UAVs has very good market foresight.

A drone is a type of aircraft that can receive instructions or fly autonomously through wireless technology under unmanned conditions. Since 1907, research on multi-rotor aircraft has begun to sprout abroad, due to the relatively low level of computer and electronic technology at that time.

DOI: 10.54254/2755-2721/2026.KA29638

Multi-rotor aircraft have not yet been widely applied. Since the 21st century, many institutions and schools at home and abroad have conducted extensive research and application of quadcopters in their respective fields, constantly exploring various technologies and algorithms of quadcopters to develop more quadcopters that meet people's needs. Moreover, as the current research direction mainly focuses on small and micro aircraft, embedded technology, as an important branch of microelectronics technology, also plays a significant role in it. Since the 21st century, many institutions and schools at home and abroad have conducted extensive research and applications on quadcopters in their respective fields, constantly exploring various aspects of technologies and algorithms of quadcopters to develop more quadcopters that can meet people's needs. Moreover, as the current research direction mainly focuses on small and micro aircraft, embedded technology, as an important branch of microelectronics technology, has also played an important role. With the rapid development of hardware manufacturing technology, the micro-systems, sensors, processor chips, and control theories of quadcopter drones have ushered in a brand-new era. At present, commercial quadrotor helicopter models are the main form for studying quadrotor unmanned aerial vehicles (UAVs), with a focus on aspects such as modeling, control, and planning. This paper, based on the scientific issues of UAVs, aims to systematically review the research progress of key technologies such as the power system, flight control system, navigation system, and path planning of UAVs. It analyzes their application status and technical challenges, and provides references for future research directions. It also conducts a review of some research work on the power system in relation to the power system, flight control system, navigation, and path planning of UAVs.

2. The power system and flight control system of Unmanned Aerial Vehicles

2.1. First section power system

2.1.1. Electric Unmanned Aerial Vehicles

At present, the mainstream UAV use electric motors as their main power source. Its power system usually includes: electronic motors, electronic speed regulators and batteries [1].Electronic motor is one of the most important parts of the whole power system. Its main function is to transfer electrical energy into mechanical energy and provide power for the entire unmanned aircraft. At present, the motors used in UAVs include brushless motors commonly used in multi-rotor systems, and permanent magnet synchronous motors are also widely applied in UAVs. Their main advantages are more reliable and high energy density [2,3].

Furthermore, another important power component of electric unmanned aerial vehicles is the electronic speed controller. It can convert the direct current from the battery into different pulse modulation (PWM) signals to control the rotational speed of the motor, thereby achieving various actions of the UAV. It can be regarded as the nerve of the UAV. As a result, the energy conversion efficiency of this device can affect the energy consumption level of the drones and thereby have an impact on the flight duration of the UAV. It can be divided into these kinds below:4 - in - electric speed controller, open cooling system electric and passive cooling electric speed controller. Among these, the overall performance of Four-in-one electric speed controller is significantly better than the other single electronic speed controller [4]. Besides, the electric speed controller can also protect the circuit and reduce damage to the motor and batteries in abnormal situations.

Batteries, as energy storage devices, are the energy core of UAVs and are used to maintain the operation of the UAV itself and its load. However, due to the current technological limitations, the battery life of UAVs is generally short, ranging from half an hour to tens of minutes [1]. At present,

DOI: 10.54254/2755-2721/2026.KA29638

lithium-based batteries are mainly used in drones. Although they have a relatively high energy density and can withstand higher current loads [5], their battery capacity is limited. Moreover, batteries with higher energy density are still under development. Therefore, the current method to increase the endurance of drones is often to establish an automatic battery replacement system at the drone's home port [5,6].

The power system of an electric unmanned aerial vehicle mainly consists of these components: the battery provides energy, the electric speed controller controls the rotational speed, and the motor outputs power [3]. The combination between them is shown in figure 1.

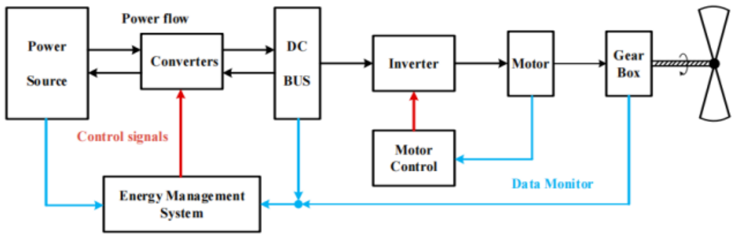

Figure 1. Schematic diagram of the power system for electric UAVs

2.1.2. Hybrid Unmanned Aerial Vehicles

Hybrid drones combine fuel power and electricity to increase the drone's endurance and meet environmental protection requirements. It can mainly be classified into three categories: series hybrids, where the engine directly drives the battery and the electric motor, parallel hybrids where both the internal combustion engine and the electric motor provide power for the propeller, and hybrid systems, where the internal combustion engine can drive the rotor and generate electricity for the electric motor [7]. Due to its low energy consumption and high efficiency, hybrid systems are very suitable for use in medium and large-sized aircraft [3].

In addition, the currently relatively novel hybrid unmanned aerial vehicles mainly combine fuel cells and batteries. Because it can ignore the limitations of the Carnot cycle, its driving range will be greatly increased. At the same time, with the assistance of the battery, stability will also be improved to enable the unmanned aerial vehicle to operate normally in complex air conditions [8]. Not only that, but energy management can also be used to extend the service life of each battery [8].

2.2. Flight control system

At present, the main control of UAVs is through the Real-Time Operating System (RTOS). The flight control system mainly includes the flight management system, mission control module, safety module, communication control component, and monitoring system [9]. Among them, the flight management system directly controls each flight component to control its flight attitude. For multi-rotor UAVs, it is to adjust the rotational speed of each rotor for control [10]. For fixed-wing UAVs, it is the combined control of aerodynamic control surfaces and engine thrust. The task control module is the software center of the unmanned aerial vehicle (UAV), used to issue instructions to the flight management system. Meanwhile, the safety system and monitor ensure the safe flight of the aircraft [9]. Additionally, the communication control component is also a crucial part of the flight control system. Its main role is to receive ground flight instructions, collect, process and send flight data for reference and reporting [10].

DOI: 10.54254/2755-2721/2026.KA29638

In the flight control system of multi-rotor drones, hardware usually requires gyroscopes, rudders, throttles, elevators, barometers and ailerons [11]. Gyroscopes also play an important role in navigation, which will not be elaborated here. It will be mentioned in detail later. The main function of the elevator is to generate pitch moments to change the attitude and flight altitude (rotation around the lateral axis), and during normal flight, it can also maintain flight stability, such as counteracting external disturbances like air currents. In contrast, the rudder is used to generate lateral force and yaw moment to control direction and turning (turning around the vertical axis), as well as to correct deviations, etc. In the latest small rotorcraft drones, there are also extensive applications of micro-electromechanical systems and cameras. For instance, in the micro-drone AR. Drone, miniature sonar, inertial measurement units (IMU), and other devices are employed [12].

Unlike multi-rotor drones, fixed-wing drones also require flaps, pitot tubes, damping control systems, etc. to ensure the aircraft's wind resistance and flight attitude [13], and prevent stalling. The pitot tube mainly provides the main data of the drone's aerodynamic performance, thereby maintaining flight stability. The damping control system can prevent flight oscillation, enhance stability, and avoid loss of control caused by external airflows, etc [13].. In addition, the elevators and rudders of rotorcraft drones, as well as sensors for altitude and angular velocity, are also present on fixed-wing drones.

3. Navigation and path planning of Unmanned Aerial Vehicles

3.1. Navigation system of UAV

The navigation system of UAV mainly contained: Global Navigation Satellite System (GNSS), inertial navigation and visual navigation etc. The joint work of them can locate the drones and plan the next path with path planning module together at the same time. However, the navigation systems of different types of UAVs vary. For small civilian UAVs represented by Parrot's AR. Drone, their main navigation is a combination of visual navigation and inertial navigation [12]. It can even be easily controlled on mobile phones and tablets by displaying the real-time images sent back [12]. Visual navigation is not only highly reliable but also cost-effective for small machines, making it very suitable for mass production and attracting price-sensitive users in the market [14].

Moreover, visual navigation and inertial navigation can also ensure the normal flight of drone when the GNSS is failure to function. Due to the unreliability and susceptibility to interference of civilian GNSS systems, visual navigation is even applied in some higher-end models to enhance security.

Inertial navigation system (INS) is an important navigation technology through measuring self-motion state to positioning, velocity measurement, and orientation. The IMU inertial measurement unit is its core component, consisting of two important sensors: the gyroscope and accelerometer mentioned earlier, and some may also include a magnetometer [15].The main function of an accelerometer is to measure the linear acceleration of an object in three directions. It often determines the direction and magnitude of the acceleration by means of the inertial force of the inertial mass block and physical deformation. The gyroscope is used to measure the angular velocity of three orthogonal axes to confirm the flight conditions of the aircraft, such as pitch or yaw. Its fundamental principle is the conservation of angular momentum or the Coriolis force. Traditional mechanical gyroscopes navigate by the direction of the rotor axis, while MEMS micro-electronic gyroscopes rely on the Coriolis force, which means that when an object moves in a straight line in a rotating system, it is subjected to a force perpendicular to the direction of motion and the rotation axis. Modern gyroscopes calculate the rotational angular velocity based on this.

DOI: 10.54254/2755-2721/2026.KA29638

In addition, GNSS remains an important navigation method for drones. It uses satellites as reference points and relies on triangulation ranging and distance measurement for positioning and navigation. This will not be elaborated on here.

3.2. Unmanned Aerial Vehicle path planning system

Both of UAV path planning system and the navigation system are the core modules of the autonomous flight of drone. They can guarantee the normal safety flight of drone. In simple terms, the navigation system focuses on positioning and overall direction, correcting flight status, while the path planning system concentrates on how to avoid obstacles in the current short-distance path and provides reference paths.

The path planning system mainly utilizes the starting and ending point coordinates, such as longitude and latitude or three-dimensional spatial coordinates, to achieve tasks while also optimizing goals, such as the shortest path or the least energy consumption. At the same time, it also needs to control the UAV based on its performance constraints (ceiling, minimum turning radius, etc.) or the limitations of the environment it is in such as obstacles, no-fly zones, etc. as well as the limitations of the mission. Therefore, the core of a path planning system lies in algorithms and modeling. It is necessary to automatically transform the environment into images and add nodes (i.e., locations), which are interconnected to find paths. Therefore, for the path planning of UAVs, the most crucial part is three-dimensional modeling to reflect the position of the UAV and its surrounding conditions. Thus, high-definition and accurate modeling is of great significance. And all of these need to be based on the input images, which all require pictures taken by unmanned cameras. However, it is not the case that the more photos there are, the more accurate the modeling will be. In fact, too many photos may even cause difficulties in the storage of drones [16]. Therefore, more efficient modeling methods have become the main research direction of UAV path navigation planning.

At present, the more mainstream 3D reconstruction methods include SFM structured light method and MVS multi-view stereo method [16]. The main principle of structured light method is to actively project a specific structured light pattern and then record and analyze the deformation that occurs through a camera to calculate the three-dimensional coordinate position. This approach features high modeling accuracy, fast reconstruction speed, and low requirements for the computing power of drones. However, it relies on active projection and requires not only cameras but also projectors, and it is not effective for large objects and high-reflectivity materials. On the contrary, multi-view stereo modeling is more effective for large objects. Its basic principle is to restore the original three-dimensional structure through two-dimensional images from different perspectives and the parallax principle. Although its modeling accuracy is relatively low, it is sufficient for use in unmanned aerial vehicles. However, it takes a longer time and requires higher computing power. Therefore, both of these modeling methods have their advantages and disadvantages. Generally speaking, structured light can be used for high-precision path planning in small areas, while the multi-view stereoscopic method is more suitable for applications in larger areas such as unmanned aerial vehicle mapping.

4. Classification of UAVs and the application of various systems on different UAVs

Overall, according to the flight mode, the UAVs can be classified into multi-rotor, fixed-wing, unmanned helicopters, unmanned airships, and bionic flapping-wing aircraft [3]. If classified by

DOI: 10.54254/2755-2721/2026.KA29638

application, they can be divided into consumer-grade drones, industrial-grade drones and military drones. Due to the different application scenarios, the usage of each part also varies.

Consumer-grade drones only need to meet the needs of daily shooting and entertainment. Their main features are small size and light weight. Such drones are mainly rotorcraft drones. Dji, AR. Drones and others are the main representatives. The power source is basically lithium-based batteries. Generally, each battery has a battery life of about 30 minutes. The battery life can be extended by replacing the battery. Navigation mainly relies on GNSS satellite navigation and some simple offline navigation methods such as visual navigation, which not only enables autonomous flight under normal circumstances but also ensures that the driver can quickly take over control in case of emergencies.

Industrial-grade drones have a wide range of applications, often including high-altitude mapping or express delivery, etc. Their size and load capacity requirements are much higher than those of consumer-grade drones. Take the latest Chinese transport drones as an example, their take-off mass has exceeded one ton. Most of these drones are fixed-wing or multi-rotor, and a considerable number are a combination of both types. It is mainly powered by the hybrid system, which makes the range longer and the power more abundant, so as to have greater load capacity and maneuverability. Due to the need to perform complex tasks in various environments, its navigation and path planning system is more reliable. It often adds inertial navigation and other methods on the basis of satellite navigation to avoid the unreliability of civilian satellite navigation affecting the implementation of tasks. At the same time, it has greater computing power and stronger modeling capabilities, and mainly uses multi-view stereoscopic modeling as the path planning method.

In addition, there are military UAVs. Due to the extremely special and complex environment in which they are used, as well as the extremely high requirements for reliability and significant importance, the requirements for each system of such UAVs are even higher. It mainly relies on fixed-wing and hybrid systems to ensure high maneuverability, so as to survive on the battlefield. The navigation system is also a combination of military GNSS and multiple integrations such as inertial navigation, visual navigation and terrain matching, ensuring that there is still a backup navigation method that can operate when one navigation system fails, guaranteeing its stability and reliability.

5. Conclusion

This article reviews some key technologies of UAVs, including power systems, flight control systems, navigation systems and path planning systems, and analyzes the differences in their applications among different types of UAVs. In general, navigation and path planning are controlled, while power and flight control are responsible for execution. The navigation system makes decisions on the overall main direction, and the path planning system determines the next action of the UAV based on the surrounding environment. The two form a closed loop.The power system ensures flight, while the flight control system adjusts the flight posture. They complement each other. These discoveries not only provide a systematic summary of the technology development of unmanned aircraft, but also point out the direction for future research.

Authors contribution

All the authors contributed equally and their names were listed in alphabetical order.

DOI: 10.54254/2755-2721/2026.KA29638

References

[1] Bláha, L., Severa, O., Goubej, M., et al. (2023). Automated drone battery management system—Droneport: Technical overview. Drones, 7(4), 234.
[2] Bristeau, P. J., Callou, F., Vissière, D., et al. (2011). The navigation and control technology inside the ar. drone micro uav. IFAC Proceedings Volumes, 44(1), 1477–1484.
[3] Conte, G., & Doherty, P. (2008). An integrated UAV navigation system based on aerial image matching. 2008 IEEE Aerospace Conference (pp. 1–10). IEEE.
[4] Fujii, K., Higuchi, K., & Rekimoto, J. (2013). Endless flyer: A continuous flying drone with automatic battery replacement. 2013 IEEE 10th International Conference on Ubiquitous Intelligence and Computing and 2013 IEEE 10th International Conference on Autonomic and Trusted Computing (pp. 216–223). IEEE.
[5] Maboudi, M., Homaei, M. R., Song, S., et al. (2023). A review on viewpoints and path planning for UAV-based 3-D reconstruction. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 16, 5026–5048.
[6] Malyshev, B. A., Troshin, P. A., Zanegin, S. Y., et al. (2024). Research of electronic speed controllers designs and functional for unmanned aerial vehicles. 2024 IEEE 25th International Conference of Young Professionals in Electron Devices and Materials (EDM) (pp. 1150–1155). IEEE.
[7] Rangarajan, M. (2018). Unmanned aerial vehicle flight control system (U.S. Patent No. 10, 001, 776). U.S. Patent and Trademark Office.
[8] Valencia, A., Cando, E., et al. (2021). Propulsion sizing correlations for electrical and fuel powered unmanned aerial vehicles. Aerospace, 8(7), 171.
[9] Xia, Y., Han, W., Ren, S., et al. (2025). Unmanned aerial vehicle (UAV) power system test device design and research. Journal of Mechanical Design, (7), 115–121.
[10] Xu, Q. (2021). Design and realization of the four rotor unmanned flight control system. Computer Knowledge and Technology, (36), 173–174.
[11] Yu, Q., Shi, Z., & Wang, L. (2024). Design of flight control system for quadrotor unmanned aerial vehicle based on RTOS. Dazhong Science and Technology, 26(6), 26–30.
[12] Zhai, R., Zhou, Z., Zhang, W., et al. (2014). Control and navigation system for a fixed-wing unmanned aerial vehicle. AIP Advances, 4(3).
[13] Zhang, B., Song, Z., Zhao, F., et al. (2022). Overview of propulsion systems for unmanned aerial vehicles. Energies, 15(2), 455.
[14] Zhang, G., & Hsu, L. T. (2018). Intelligent GNSS/INS integrated navigation system for a commercial UAV flight control system. Aerospace Science and Technology, 80, 368–380.
[15] Zhang, Z. (2018). Design of hybrid power system for fuel cell multi-rotor unmanned aerial vehicle, Zhejiang University.
[16] Zong, J., Wang, Y., & Mao, J. (2016). Design and performance analysis of hybrid power system for multi-rotor UAV. Journal of Aerospace Science and Technology, 4, 25.