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Analysis of the Current Status of UAV Power Sources

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Abstract: UAVs have been applied in various industries and fields, and have an indispensable role. UAV power system is the key to the normal work of the UAV, this paper focuses on the summary introduction of lithium-ion battery, internal combustion engine, solar energy, fuel cell and hybrid power of the working principle, domestic and international research status, key technologies, advantages and disadvantages, part of the classification and application of the power system, and UAV power of the future development and outlook and so on.

Keywords: Unmanned Aerial Vehicle, power source, lithium ion battery, internal combustion engine, solar power, fuel cell, hybrid power, status analysis.

1. A Brief Analysis of Drones and Their Common Dynamics

Unmanned aircraft A "drone" is an unmanned aircraft manoeuvred by radio remote control equipment and its own programmed controls, or operated by an on-board computer. on-board computers They are fully or intermittently operated autonomously and have been in development for over a century. Compared to manned aircraft, drones are more flexible in control and operation, smaller in size, cheaper in cost, adaptable to many different complex environments, and have a high survivability[1]. In the military context, UAVs are classified as target aircraft. For military use, UAVs are classified as target and reconnaissance aircraft. For civilian use, drones are used in Aerial photography agriculture Agriculture and Surveying and Mapping Disaster Relief Disaster relief Disaster Relief Express Transport, power inspection, monitoring Infectious Disease and Observation Wildlife and other fields have applications[2].

As the "heart" of a UAV, the power system of a UAV is the most fundamental guarantee for the UAV to complete various flight tasks. The endurance and load capacity of the current UAV power source has put forward a serious test, the existing UAV has fuel power, lithium battery power, fuel cell power and other major power supply modes [3]. At present, most civil UAVs still use internal combustion engines as power, with methanol or petrol as fuel. Internal combustion engines are noisy, vibrate violently and emit gases that pollute the environment when working [4]. The internal combustion engine is noisy, vibrates violently and emits gas that pollutes the environment. In small electric UAVs, lithium batteries are most widely used. However, Li-ion batteries have a small energy density and cannot meet the requirements of long range UAVs for high energy density power supplies. Solar-powered UAVs do not need additional energy supplementation terminals, and the technology is more mature and reliable, but the flight process is heavily dependent on external weather conditions[5]. Fuel Cells Fuel cells have high energy density and are suitable for small power long time discharge; however, they have low power density and are not suitable for high power short time discharge[6]. Fuel cells have higher energy density, suitable for small power long time discharge.

2. Lithium Ion Battery

The migration and chemical reaction of lithium ions is the core principle of lithium-ion batteries, which are widely used in electronic products, electric vehicles, energy storage and other fields by virtue of high energy density, long cycle life, lightweight and other advantages. Small, miniature drones are driven by batteries, in the commercial battery, lithium-ion battery is currently the highest specific energy energy storage power supply, is expected to occupy a dominant position[7]. Li-ion battery is currently the highest specific energy storage power supply, and is expected to dominate. Commonly used lithium batteries are Li-MnO_2 primary batteries, lithium-chlorosulfonyl batteries, lithium-sulfur dioxide batteries and polymer lithium-ion batteries[8]. The lithium-ion battery is expected to dominate the market in the future.

The many advantages of lithium-ion batteries have made them an indispensable means of energy storage in modern electronic devices and energy fields. Lithium-ion batteries have an operating voltage of 3.7-3.8V, which is three times higher than that of nickel-cadmium and nickel-metal hydride batteries. High specific energy, the actual specific energy can be achieved is about 555Wh/kg, that is, the specific capacity of the material can reach more than 150 mAh/g (3-4 times of nickel-cadmium batteries, nickel-metal hydride batteries 2-3 times), about 88% of the theoretical value. Charge and discharge can usually reach more than 500 times, or even more than 1000 times, lithium iron phosphate can reach 8000 times. For equipment with low discharge current, the battery life can exponentially increase the competitiveness of the equipment. Lithium-ion batteries do not contain cadmium, lead, mercury and other environmental pollutants, the new lithium-ion batteries are harmless to the human body, no memory effect, good safety. The self-discharge rate of lithium-ion batteries after 1 month of storage at room temperature is about 2%, much lower than 25-30% of nickel-cadmium batteries and 30-35% of nickel-metal hydride batteries.

However, lithium-ion batteries still have a lot of problems that need to be solved today. Unlike other batteries, the capacity of lithium-ion batteries declines slowly depending on the number of uses and temperature. This degradation can be in the form of reduced capacity or increased internal resistance. Because this degradation is temperature dependent, it is more likely to occur in electronic devices that operate at higher currents. Replacing graphite with lithium titanate appears to extend service life. There is also the issue of recycling rates, with about 1 per cent of new products leaving the factory needing to be recycled for various reasons. When overcharging, excess embedded lithium ions are permanently fixed to the lattice and cannot be released again, thus shortening battery life. When over-discharging, the electrodes may de-embed too many lithium ions, leading to lattice damage, which shortens battery life.

3. Internal Combustion Engine Power (i.e. Gasoline and Diesel)

The working principle of oil-activated UAVs (i.e., internal combustion engine-powered UAVs) is similar to that of manned vehicles, and mainly consists of an engine, a fuel system, a transmission system, an aerodynamic system, a rudder control system, a remote control system and other components. In an oil-powered UAV, the engine uses fuel as fuel and releases energy through combustion to drive rotating propellers or transmission gears, hydraulics and other equipment to provide power to generate thrust and push the airframe into normal flight.

At the beginning of the twentieth century, aircraft engines were almost exclusively piston engines. After the Second World War, the era of the gas turbine began as turbojet, turboprop, turboshaft and turbofan engines were developed in response to the expansion of aircraft applications and the increase in aircraft mass, lift, speed and durability[9]. The gas turbine era began. Currently, about 80 per cent of medium- and long-endurance low- and medium-altitude UAVs are powered by internal combustion engines.

The advantages and disadvantages of oil-activated drones depend largely on the scenario of use and needs. Oil-activated drones generally use internal combustion engines, which can carry more fuel, resulting in a longer flight time and an executable range. The engines usually have a higher power output, which allows them to carry more payload, such as cameras, sensors, etc.; it also gives them a higher flight speed and climb rate, which makes them suitable for rapid response and mission execution. Oil-operated engines are a more mature and common technology, with maintenance and parts more readily available.

Oil-powered drones also have many limitations compared to electric drones. The thermal efficiency of conventional engines is only about 40 per cent, making it difficult to increase efficiency to higher values, and drones are inefficient as they only use a small portion of the operating area of a fuel engine[10]. The engine of an oil-powered drone produces a very small amount of energy. The engines of oil-powered drones make a lot of noise, which can affect the use scenario. The emission of exhaust gases can pollute the environment. The machine is more costly to maintain and service the drone due to more complex mechanics. Oil-operated engines produce greater vibration and instability, which can affect the stability of the entire flight system if left unchecked.

4. Solar Powered

4.1. Generation and development of solar-powered drones

Solar cells use the photoelectric effect of semiconductor materials to convert solar energy into electricity. Depending on the type of material, solar cells can be classified as silicon solar cells, amorphous silicon solar cells, copper indium gallium selenide (CIGS) solar cells and chalcogenide solar cells[11]. The solar cells can be divided into silicon solar cells, amorphous silicon solar cells, copper indium gallium selenide (CIGS) solar cells and calcite solar cells. As early as the mid-20th century, attempts were made to develop aircraft that could use solar radiation as a source of propulsion. The power system of a solar-powered aircraft consists of solar panels, DC motors, propellers and controllers. Due to the low energy density of solar radiation, the aircraft must have a large area of solar cells to generate enough energy.

The development of solar-powered drones officially began on 4 November 1974, and the world's first solar-powered drone, the Sunrise I, made its maiden flight in September 1995, with a body weight of 12.25 kg, a total of 4,096 silicon solar cells, and 450 W of solar power, and a flight time of 20 minutes at an altitude of 100 m. The Sunrise I is the first solar-powered drone in the world. . The "Pathfinder" project, developed by NASA and launched in September 1995, has a larger wingspan than a conventional aircraft and is powered by a combination of solar cells and batteries. The solar-powered UAV was designed to fly at an altitude of 15.4 kilometres and had a total weight of 252 kilograms. 2001 saw the launch of the Helios UAV, which had a wingspan of 75.3 metres, a solar-powered power generation capacity of 40kW, and 14 brushless DC motors controlling 14 wing propellers. The aircraft reached an altitude of 29.43 kilometres, marking another step forward in the development of solar-powered unmanned aerial vehicles, and in July 2010, the new solar-powered unmanned aerial vehicle Zephyr 7 completed a 336-hour continuous test flight, which at the time was the longest single flight ever recorded. "The Westwind's solar-powered UAV tested a new power system that uses a combination of lithium-ion batteries and solar panels rather than a single power source.

China's first "Soarer" UAV, developed by Professors Yong Zhao and Xiaoyang Li and their team, is an important milestone in China's solar UAV industry. "With a length of 1.25 metres and a wingspan of 1.88 metres, the Soarer can fly at an altitude of between 1,000 and 1,500 metres. There are 120 monocrystalline silicon solar cells on the wings, a thin protective layer of GPPS on the wings, and a special nickel-metal hydride battery for energy storage[12]. In 2002, the Zhuhai New Aeronautical Concept R&D Centre launched the "Green Pioneer" solar UAV research project, which is a technical demonstration of the aerodynamic design of a solar-powered "composite wing". The UAV adopts an aerodynamic composite wing design with solar panels on both the upper and lower wing surfaces. "The Green Pioneer completed its first 1/4-scale demonstration flight in 2002 and its 1/2-scale demonstration flight at the end of 2003[13]. The Green Pioneer

4.2. Key technologies for solar-powered drones

(1) Overall layout

Solar-powered UAVs are often designed with a large aspect ratio to achieve a high lift-to-drag ratio, which allows for more solar panels to be mounted on the upper surface of the wing, and also reduces energy consumption by reducing drag while maintaining the weight of the UAV.

(2) Framework

In order to reduce energy consumption, solar-powered drones are lighter than conventional drones, but still have high strength. Currently, frames and housings are mainly made of lightweight non-metallic materials, while the main support structures are usually made of carbon fibre composites. Carbon fibre composites are not only lightweight, but also have high specific strength, specific modulus, fatigue and corrosion resistance, as well as good processability.

(3) Solar-powered drones for night navigation

Owing to the lack of sunlight at night, in order for a solar-powered UAV to fly continuously day and night, the excess electricity generated by solar power during the day must be stored in an energy storage system (e.g., lithium batteries) that can be used for night flights. Night flights of UAVs should be conducted in a different flight mode than during the day. In order to save energy, night flight is usually a combination of unpowered gliding and powered flight. Solar-powered UAVs have excellent gliding capabilities due to their high wing aspect ratio and lightweight design[14].

5. Fuel Cell Power

5.1. Hydrogen fuel cell UAV generation and development

Fuel cell consists of proton exchange membrane, catalytic layer, cathode, anode and collector plate. According to different electrolytes, fuel cells can be divided into alkaline fuel cells, phosphate fuel cells, molten carbonate fuel cells, proton exchange membrane fuel cells, solid oxide fuel cells and direct methanol fuel cells. Among them, proton exchange membrane is currently the most mature, fastest developing and most applied fuel cell technology[15]. Among them, proton exchange membrane is the most mature, fastest developing and most applied fuel cell technology.

The United States is at the forefront of the application of fuel cell technology in the field of UAVs. As early as 2004, the U.S. Air Force Research Laboratory initiated the Fuel Cell Power Project, which aimed to replace the traditional small electric UAV power system with fuel cells and apply fuel cell technology to long endurance UAVs[6]. The project was launched in 2004 by the U.S. Air Force Research Laboratory. In the same year, Uche C. Ofoma, Chivey C. Wu and other researchers at the University of California began to work on the development of a fuel cell UAV, and they completed the initial design of the UAV and the selection of a fuel cell power system. By 2006, Christopher Herwerth and others carried out a detailed design of the aircraft and computer simulation experiments, selecting a 550W fuel cell and metal hydrogen storage cylinders to develop an all-composite flying prototype with a wingspan of 5.5 metres and a total mass of 9 kg. Subsequently, the power system was tested and the first flight was successfully conducted.

The U.S. Navy has been working on the development of fuel cell long endurance UAVs through collaboration with Georgia Tech and others, completing the development of the Ion Tiger UAV in 2009 and setting a record for a hydrogen fuel cell powered UAV flight time of 26 hours and 1 minute, and then breaking its own record in 2013 with a continuous flight of 48 h. The U.S. Navy has been working on the development of fuel cell long endurance UAVs through collaboration with Georgia Tech and others[16]. In 2013, it broke its own record by flying continuously for 48h. The aircraft is powered by a 550W fuel cell, which is four times more efficient than an internal combustion engine of similar power and can provide seven times the power of a battery of the same weight. 4,000 feet above the desert in southern California. Powered by four high-efficiency electric motors and fuel cells on its maiden flight, the drone was designed to fly for seven days at 65,000 feet.[13] It is designed to fly for seven days at 65,000 feet.

5.2. Hydrogen fuel systems for UAV applications

The hydrogen fuel cell system mainly consists of hydrogen storage tank, hydrogen fuel cell, lithium battery, motor and propeller.

When the power demand is certain, the overall performance of the aircraft is mainly affected by the power-to-weight ratio and efficiency of the hydrogen fuel cell system, including the power-to-weight ratio of the hydrogen fuel cell, the power-to-weight ratio of the electric motor, the energy density of the lithium battery, the mass ratio of the hydrogen storage system, and the energy conversion efficiency of the hydrogen fuel cell and other important parameters[17]. The main influence of the hydrogen fuel cell system is the power-to-weight ratio and the efficiency.

For the safety of fuel cell UAVs, the main concern is hydrogen safety. Firstly, hydrogen is highly buoyant and diffuses quickly, so in an open space, hydrogen leaks spread quickly, reducing the risk of explosion. Unlike other fuels, the only by-product of hydrogen combustion is water, which does not produce harmful fumes and dust or pollute the environment. In addition, the hydrogen flame has a low emissivity and the temperature does not rise very high around it.

It is important to note that the UAV operates in open space, and even in the event of a collision, safety remains high because the hydrogen storage system is made of carbon fibre composite materials that can withstand higher pressures. In addition, due to the faster diffusion rate of hydrogen, the hydrogen will not gather, reducing the risk of catching fire. Finally, in the design of the fuel cell UAV, the control system is able to quickly cut off the hydrogen supply if a malfunction occurs to ensure safety[18].

6. Hybrid

6.1. Hybrid electricity

With the continuous development of UAV technology, the application fields and frequency of use of UAVs will gradually expand. Compared with traditional drones driven by internal combustion engines, purely electric drones have many advantages, such as lower noise, rapid power output response, higher system reliability, etc[19]. However, the development space of electric UAVs is limited due to the limited battery capacity. In complex terrain areas such as mountains, forests, and islands, the requirements of altitude and flight distance make pure electric drives no longer able to meet the needs of long flights and carrying large loads. Hybrid oil-electric UAVs can effectively solve the range problem by modifying the fuel tank according to the demand, as long as there is enough fuel. At the same time, with long-distance mapping technology, the detection range can reach more than 100 kilometres, thus enabling the execution of wide-area, long-distance aerial surveillance and survey missions. In addition, hybrid oil-electric UAVs can easily cope with harsh environments such as high temperature, low temperature, gusty winds and heavy rain, and their adaptability far exceeds that of purely electric or purely fuel-powered UAVs.

The main purpose of hybrid power is to effectively switch between the working motor and engine of the UAV to ensure that the propellers are always in working condition. When the engine is connected to a generator, the electricity generated can be used to charge the battery or directly drive the motors for work[20].

In 2015, the German company Airstier managed to develop and build a brand new drone called the Yeair. The drone itself weighs only 4.9 kg, but it is able to carry a payload of up to 5 kg and is able to fly up to a maximum cruising speed of 100 kilometres per hour. According to the developers, the Yeair drone offers excellent reliability and safety. Even if one of the engines fails or there is a delay in response, the other engines will ensure a safe landing. It also has excellent wind resistance and can operate even in strong winds.

In November 2016, Beijing Ruishen Aeronautical Science and Technology Co. Ltd. successfully developed a fuel-electric hybrid power system called H2.The H2 hybrid power system weighs about 5.2 kg and has a stabilised output of 1.8 kW, with a maximum power of 2 kW. The system can achieve more than 2.5 hours of flight time on 3.7 litres of petrol and is suitable for multi-rotor drones with a maximum take-off weight of 18 kg, thus compensating for the shorter flight time of electric multi-rotor drones. In addition, it can be used for vertical take-off and landing fixed-wing drones to extend their mission flight time and improve mission fulfilment efficiency.

In December 2017, Elroy Air, a San Francisco, California-based drone company, announced the successful development of a vertical take-off and landing fixed-wing drone called the Aluminum Falcon. The drone is capable of transporting up to 68kg of cargo in a single flight and has a range of up to 480km. Its modern airframe design, air traffic management system and embedded on-board camera, as well as advanced equipment such as LIDAR, allow it to be used in a variety of industries [21].

Also in December 2017, Quaternium UAV Europe unveiled their self-developed quadcopter drone "HYBRiX.20", which set the current record for the longest flight time of a rotor drone, which can fly for up to 4 hours and 40 minutes unloaded. The HYBRiX.20 has a maximum take-off weight of 20 kg, a payload of 2.5 kg, a cruising speed of 50 km/h and a maximum speed of 80 km/h. The HYBRiX.20 is also temperature-resistant. In addition, it excels in temperature adaptability, being able to fly in environments ranging from minus 10 degrees Celsius to minus 45 degrees Celsius, and maintains a flight time of more than 2 hours even when fully loaded [22].

6.2. Solar, fuel cell and battery hybrids

With the continuous development of solar cell and fuel cell power systems, they have each made significant progress in addressing energy and environmental issues. However, pure solar cell power systems sacrifice some of the strength of the aircraft structure, especially the wing structure, and therefore their operating environment is limited to the stratosphere, where the airflow is relatively calm. The pure fuel cell power system is also limited by the hydrogen storage capacity, the power-to-weight ratio of the whole fuel cell system, and the poor dynamic characteristics of the fuel cell, which also cannot support the UAV for a long time flight. Therefore, the hybrid power system becomes a low-cost and effective means to achieve long flight duration. Such hybrid systems can optimise the use of energy according to the needs of the mission, which is expected to increase the flexibility and availability of UAVs, especially for applications that require long-duration flights or missions in remote areas.

Back in 2010, the Illinois Institute of Technology of the United States of America proposed a hybrid energy system solution aimed at improving the long endurance performance of UAVs. The scheme combines solar cells, rechargeable batteries and rechargeable fuel cells (which produce hydrogen through the electrolysis of water). During the day, the solar cells serve as the primary energy source, while charging the batteries and electrolysing water. At night, it is powered by the fuel cells at a fixed power output, and if that is insufficient, the batteries provide electrical support. The researchers performed computer simulations of take-off, cruise and landing, which theoretically met the design requirements. However, this required an average conversion efficiency of 26.8 per cent for the solar panels, which has not yet been achieved in reality. In addition, the simulation assumes constant loads, which change in real flight, and has not yet considered the quality of the overall system. Although this is only a future scenario that is not yet mature, it provides useful ideas for the future direction of long endurance UAVs.

In 2012, Bohwa Lee of the Korea Aerospace Research Institute (KARI) conducted research on a hybrid UAV propulsion system based on a pure fuel cell-powered UAV that had already been successfully flown, with the addition of a solar cell and a storage battery. The researcher developed mathematical models of solar cells, storage batteries and fuel cells, and used actual flight data from pure fuel cell UAV flight records for numerical simulations. This hybrid propulsion system was designed by directly adding solar modules and storage batteries on top of the fuel cell system, without considering the coupling relationship between the propulsion system and the UAV system, as well as without an in-depth study of the inter-matching relationship between the various power sources and power systems.

Therefore, with the above analyses, hybrid UAVs will become a research hotspot and frontier area in the field of UAVs, with a broad research space [23]. The research of hybrid UAV will be a hotspot and frontier area in the field of UAV, with a broad research space.

7. Concluding Remarks

In recent years, the UAV power system has also gradually developed in the direction of wide field and diversification, and the optimisation for electric and oil-operated UAVs is also in progress. How to design a lighter weight power system, how to improve the range, and how to reduce the energy consumption while meeting the starting and working conditions of UAVs will also be the research hotspot in the direction of UAV power.

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