International Journal of Robotics and Automation, Vol. 34, No. 5, 2019

ANALYSIS OF POWER SOURCE OF MULTIROTOR UAVs

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Abstract

Multirotor unmanned aerial vehicles (UAVs) have found wide applications in practice with the rapid development of multirotor UAV technology. But limited by the energy density of conventional Li batteries, the battery life is short, which has become a bottleneck restricting the development of multirotor UAVs. Therefore, the power source of multirotor UAVs is urging to be improved. This paper introduces the application of fuel cell, fuel power, solar cell and hybrid power in multirotor UAVs and some innovative technologies of lithium–ion battery in recent years and also looks forward to the future development of various power sources of multirotor UAVs.

Key Words

Multirotor UAV power source, fuel cell, hybrid electric power, lithium battery innovation

1. Introduction

As the unmanned aerial vehicle (UAV) technology grows mature gradually, the UAV industry has witnessed a swift development because the manufacturing cost has fallen dramatically, and the application of UAVs has been expanded in combination with other components. An aerial work platform has been set up for them and has been used to do lots of aerial work in place of human. UAVs have a broad market and have been widely applied to the fields of agricultural plant protection, aerial survey, geological exploration, power inspection, forest fire prevention, fire control and disaster relief and so on. Among them, the multirotor UAVs, with their simple structure and low-maintenance cost, occupy the majority of share in the field of civil UAVs. The multirotor UAVs in the market mainly use lithium battery as the main power source, but regardless of mature technology and availability, their battery life is only 20–30 min, and the charging time is too long. As the multirotor UAV cannot carry a heavy lithium battery with large capacity, it needs to reduce the takeoff weight as much as possible. In practical use, the battery needs to be recharged or replaced frequently. At the same time, limited by energy density, lithium battery has become a fatal shortcoming in the development of multirotor UAVs. It is impossible to make a big breakthrough in short time, and it is urgent that the technical problem should be solved in the development of multirotor UAVs in various countries. Therefore, to settle the problem in multirotor UAVs' flight endurance, we have to find other ways.

2. Fuel Cell Power Source

2.1 Principles and Techniques

The fuel cell is a power generation device that converts the chemical energy of fuel into electric energy by redox reaction primarily via oxygen or other oxidants. There are four main types of fuel cells: PEMFC (proton-exchange membrane fuel cell), phosphoric acid fuel cell, molten carbonate fuel cell and solid oxide fuel cell [1]. What is generally applied to multirotor UAVs is the PEMFC fuel cell, the basic working principles of which include [2] the following:

1. Anode semi-reaction: Hydrogen atoms enter the battery pack through the gas guide tank at the flow field plate of the anode terminal, pass the diffusion layer to the anode catalyst reaction layer and then are oxidized into hydrogen ions (namely protons) through the reaction with the anode catalyst and release electrons, *e.g.*:

$$H_2 \rightarrow 2H^+ + 2c^- \tag{1}$$

2. Under the action of electrical penetration, hydrogen ions, together with the water molecules, pass the exchange membrane to the cathode catalyst reaction layer at the other end. Free electrons are collected via the conductive plate, and for the sake of potential difference, flow to the cathode conductive plate through the circuit connected to the conductive plate, and are converted into the current and generate electric power. Electrons are finally transferred to the cathode catalyst reaction layer by the cathode conductive plate.

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Recommended by Prof. Anmin Zhu
(DOI: 10.2316/J.2019.206-0330)

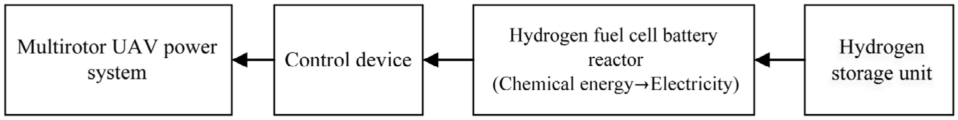

Figure 1. Working process of multirotor UAVs supported by fuel cell power source.

3. Cathode semi-reaction: Hydrogen ions, electrons and oxygen transported by the cathode flow field plate produce water through the cathode catalyst at the cathode catalyst reaction layer, *e.g.*:

$$\frac{1}{2}O_2 + 2H^+ + 2c^- \rightarrow H_2O \tag{2}$$

As the oxygen supplied to the cathode plate can be obtained from the air, electricity can be provided continuously as long as the anode plate is continuously supplied with hydrogen, the cathode plate with air and water (vapour) is carried away in time. As hydrogen fuel cells do not store energy, they are technically called hydrogen generators.

Figure 1 is the working process of the multirotor UAVs supported by fuel cell power source. The hydrogen fuel cell power reactor obtains hydrogen from the hydrogen storage device, converts the chemical energy into electricity, supplies the motor of the UAVs and drives the UAVs' power system.

In the hydrogen fuel cell, the density of hydrogen is known as 101.325 kPa, the calorific value is $q = 283$ kJ/mol and the molar mass of the gas in the standard condition is 22.4 L/mol. The joule conversion formula is

$$1\,\text{kW h} = 3.6 \times 10^4\,\text{J} \tag{3}$$

The heat generated by hydrogen complete fuel at room temperature is

$$Q = \frac{V_{H_2} \times P_{H_2} \times q}{VM \times 3.6 \times 10^4} \tag{4}$$

where V_{H_2} is the volume of hydrogen bottle and P_{H_2} is the pressure.

Assuming that the conversion efficiency of fuel cells is η, the energy generated by the final conversion is

$$Q_f = Q \times \eta \tag{5}$$

The energy output is directly proportional to the volume, pressure and conversion efficiency of the hydrogen bottle.

UAVs supported by hydrogen fuel cells are not only green and environment-friendly but also work at a low operating temperature and are of low noise and easy to maintain. They represent one of the directions of the UAV power sources.

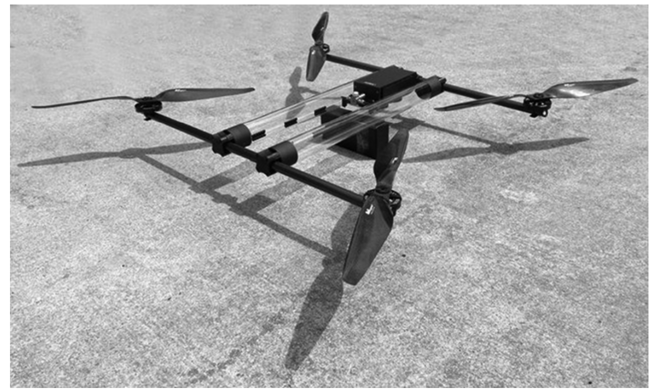

Figure 2. HUS's Hycopter supported by hydrogen fuel cells.

Figure 3. MicroMultiCopter Aero's HYDrone-1800 UAV supported by hydrogen fuel cells.

2.2 Current Research

In May 2015, Singapore HUS (Horizon Unmanned Systems) developed the world's first multirotor UAV Hycopter, which used hydrogen fuel cells [3]. As shown in Fig. 2, the UAV used hydrogen fuel cells developed by its sister company Horizon Energy Systems [4]. It can fly for 4 h unloaded. Hycopter fuel cells can convert hydrogen into electricity for the use of motors and other electronic devices.

Figure 3 is the HYDrone-1800 [5]–[7] launched by China MicroMultiCopter Aero in April 2016, which was the world's first hydrogen-fuelled multirotor industrial UAV, supported by hydrogen fuel cells. Its flight endurance is more than 4 h.

In 2018, Gang *et al.* made the proposal of a portable electric power device which was based on $NaBH_4$ PEMFCs in [8]. The hydrogen generator in the device uses 20 wt% of

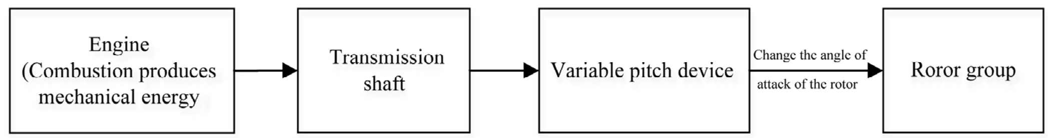

Figure 4. Workflow of multirotor UAVs with fixed speed with variable propeller distance.

$NaBH_4$ as a catalyst and produces hydrolytically 5.9 L/min pure hydrogen to support 500 W fuel cell pack, with 211 W h/kg energy density. Such cells have seen excellent applications in UAVs.

2.3 Development Trend

Hydrogen fuel cells, with slower performance degradation and less hydrogen refilling time, obviously outperform conventional lithium batteries in battery life. Different from fuel-powered UAVs, hydrogen fuel cells only emit pure water without any air pollution, and the noise is little. But the source of hydrogen is a problem, and the cost is very high, no matter it is obtained from electrolyzing water or from natural gas or water gas. At the same time, hydrogen is also a flammable and explosive gas. If used improperly or in adverse conditions, it may explode. It contains potential safety hazards.

The power calculation formula is

$$W = \mathrm{N\,m} \times \mathrm{rpm} \times \frac{2\pi}{60} \tag{6}$$

where N m is torque and rpm is speed.

Then the final output energy is

$$Q = W \times t \times \eta \tag{7}$$

The output energy is directly proportional to torque, speed and conversion efficiency.

At present, hydrogen fuel cells for multirotor UAVs cannot be mass produced, but it indicates one of the directions of batteries for multirotor UAVs.

3. Fuel Power Source

3.1 Principles and Techniques

The fuel power has been widely used in fixed-wing UAVs and helicopter UAVs. They have excellent flight endurance and can carry a large load. However, due to the slow response and complexity of the fuel engine, it finds few applications in multirotor UAVs at present. The fuel-powered multirotor UAVs mainly depend on two technologies: fixed propeller distance with variable speed and fixed speed with variable propeller distance.

3.1.1 Fixed Propeller Distance with Variable Speed

Fixed propeller distance with variable speed is the same as the traditional power-driven UAVs, in which each propeller is independently and directly driven by an engine. The pitch of each propeller is fixed. The tension value of each propeller is adjusted by changing the rotation speed of the engine so as to obtain different angular velocity and acceleration, and thus to adjust the position, speed, attitude and altitude of the flight.

3.1.2 Fixed Speed with Variable Propeller Distance

The workflow of multirotor UAVs with fixed speed and variable propeller distance [9] is shown in Fig. 4. The power device is fixed on the rack of the unmanned aerial equipment, in such a way that it is connected with each rotor set correspondingly and flexibly, the power device and each rotor set can be mechanically transmitted. The combustion power plant is pre-injected with comburent to generate mechanical kinetic energy, driving the rotor in each rotor set connected with the power device to rotate. A variable pitch device, composed of main shaft, slide block, steering gear, torque arm and the like, lies between the rotor set and the drive shaft. The variable pitch device is used to adjust the output power by changing the angle of the rotor wing and also the lift of the rotor wing. The rotating speed of the rotor remains unchanged. The vertical, roll and steering motions are realized by changing the pitch of the rotor.

3.2 Current Research

In April 2016, China Zhuanglong Technology exhibited the world's first fuel-powered directly driven multirotor UAV DZ310 named also 'DaZhuang' [10], [11], as shown in Fig. 5. 'DaZhuang' is driven by a gasoline engine and adopts a multiple directly driven scheme featuring fixed propeller distance with variable speed [12]. It has flight endurance of up to 4 h, with effective load of 60 kg.

In November 2016, China Ewatt launched a fuel-powered multirotor UAV featuring variable propeller distance named EWZ110 at the Zhuhai Airplane Exhibition, as shown in Fig. 6. Its power system is a two-cylinder two-stroke engine with a maximum endurance of 120 min, a maximum payload of 20 kg and a maximum takeoff weight of 40 kg, breaking the limitations of the power system of most multirotor UAVs.

3.3 Development Trend

The most prominent advantage of a multirotor UAV is simple to operate, but the response of the fuel-powered multirotor UAV is slow, the mechanical structure is too complicated and it may suffer too many uncertainties and thus are more demanding for stability. Meanwhile, the fuel is flammable and explosive, and the safety requirements

Figure 5. ZhuangLong DZ310 fuel-powered multirotor UAV (featuring fixed propeller distance with variable speed).

Figure 6. Ewatt's EWZ-110 fuel-powered multirotor UAV (featuring fixed propeller distance with variable speed).

are higher during flight. However, the fuel-powered multirotor UAV still has certain advantages. For example, although the structure is more complicated than that of the electricity-powered multirotor UAV, it is still simpler than the traditional helicopter UAV, with lower unit cost, longer flight endurance and higher effective load. Therefore, in the long run, fuel power source represents the trend of industrial-level agricultural plant protection multi-rotor UAVs [13].

4. Solar Power Source

4.1 Principles and Techniques

The solar cell is a kind of photovoltaic semiconductor wafer that uses sunlight to generate electric power directly and converts optical energy directly into electric energy through photoelectric or photochemical effect. Refer to Fig. 7 for the workflow. According to fabrication materials, it is divided into silicon semiconductor battery, CdTe (cadmium-telluride) thin-film battery, CIGS (copper-indium-gallium-diselenide) thin-film battery, dye-sensitized thin-film battery, organic material battery *etc.* Silicon

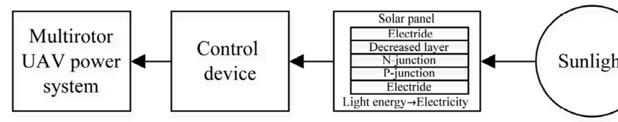

Figure 7. Workflow of solar-powered multirotor UAVs.

cells include monocrystalline silicon cells, polycrystalline silicon cells, amorphous silicon thin-film solar cells and so on. The paramount parameter for solar cells is conversion efficiency. According to the track chart of maximum efficiency improvement for the solar cell laboratory released by National Renewable Energy Laboratory (NREL) in April 2017, currently, among the silicon solar cells developed in the laboratory, the highest efficiency of monocrystalline silicon is 27.6%, that of polycrystalline silicon is 21.9%, that of CIGS thin-film cells is 23.3%, that of CdTe thin-film cells is 22.1% and that of amorphous silicon thin-film cells is 14.0%. The efficiency of components which have been put into mass production in fact is as follows: 16–18% for monocrystalline silicon, 15–17% for polycrystalline silicon and 6–8% for amorphous silicon thin-film batteries [14].

The key technologies of solar-powered UAVs shall be able to first, collect effectively solar energy and convert it into electricity efficiently; second, to sustain the energy supply at night when the sunlight is weak [15]. Solar energy has been widely tested on fixed-wing UAVs, such as the Facebook Aquila UAVs and the 'Mozi' solar-powered UAVs developed by China 811 Research Institute, which relies on photovoltaic cell components on the wings to achieve long-term and high-altitude flight.

The energy generation formula of solar cells is

$$Q = P \times S \times T \times \eta \tag{8}$$

where P denotes sunshine intensity, S denotes sunshine area, T denotes sunshine time and η denotes conversion efficiency.

It can be seen that the energy generated by solar cells is directly proportional to the intensity of sunshine, the area of sunshine, the time of sunshine and the conversion efficiency.

Solar energy is rarely used in multirotor UAVs, because the limited size of multirotor UAVs makes it impossible to carry sufficient solar cell components. And in practical use, multirotor UAVs are less applied in high-altitude flight, for it is more difficult to effectively collect solar energy. At present, individuals, colleges and universities are keen at experimenting and developing solar-powered multirotor UAVs.

4.2 Current Research

Figure 8 is a solar-powered quadcopter developed by students of Queen Mary University of London in 2013. It is completely powered by solar energy although the quadcopter can only fly for a short time.

At Hong Kong Autumn Electronics Fair held in October 2015, China Shenzhen Qianhaidashenghao UAV Technology Co., Ltd. displayed a multirotor UAV with solar

Figure 8. A solar cell-powered UAV developed by the Queen Mary University of London.

Figure 9. A solar cell-powered UAV developed by Qianhaidashenghao.

panels, as shown in Fig. 9. It is reported that the UAV mainly depends on programming to solve the problems in solar energy supply, and its flight endurance can be extended to 58 min.

In recent years, perovskite thin-film solar cells represented by CH3NH3PbI3 have attracted wide academic attention in the photoelectric field [16]. The conversion efficiency is 22.1% at present, and that of CdTe solar cells is equal to that of CIGS solar cells. However, because inorganic–organic hybrid perovskite and devices are vulnerable to environmental considerations such as moisture, UV, oxygen and temperature, their stability is the core factor influencing their application. If the stability problem can be solved well, perovskite solar cells shall change the industry of solar cells. If the problems mentioned earlier can be solved well, solar energy shall find wider applications in multirotor UAVs.

4.3 Development Trend

As the most abundant and inexhaustible, green and environment-friendly energy, solar energy is a promising power source solution. However, its greatest drawback is that at present, its generation efficiency is very low, and a multirotor UAV cannot carry solar panels covering a large area. Therefore, solar energy does not see too many

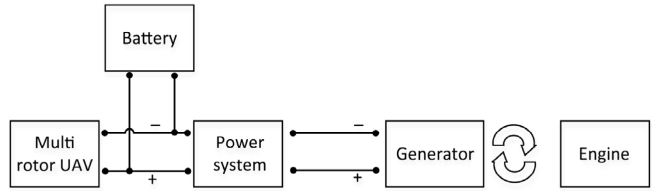

Figure 10. Workflow of gas–electric hybrid multirotor UAVs.

Figure 11. MYBRIX.20 hybrid multirotor UAV developed by Quaternium.

prospects in its application to multirotor UAVs. In other words, it does not represent a main development trend of multirotor UAV in the near future.

5. Oil–Electric Hybrid Power

5.1 Principles and Techniques

The workflow of an oil–electric hybrid power [17] is shown in Fig. 10. By starting the control circuit, it supplies the electricity in the rechargeable battery set to the brushless DC (direct current) motor, so that the permanent magnet direct-current brushless motor drives the fuel engine and starts the fuel engine by ignition. As the fuel engine starts by ignition, it starts the control circuit and then cuts off the power supply from the rechargeable battery set to the brushless DC motor. At the same time, the fuel engine drives the brushless DC motor to generate power which can be used to the recharge rechargeable battery set. The power output end of the brushless DC motor or the rechargeable battery set is also the power output interface of the power supply device. Compared with the battery as the power supply device alone, the gas–electric hybrid power as the power supply device has higher energy density which can reach up to 1,000–1,500 W h/kg.

5.2 Current Research

In December 2017, MYBRIX.20, an oil–electric hybrid multirotor UAV, was developed by Quaternium, as shown in Fig. 11. The UAV achieved a flight time of 4 h and 40 min during the test flight. MYBRIX.20 has a generator set based on a two-stroke engine that can charge the UAV batteries during flight.

TailWind (as shown in Fig. 12), a gas–electric hybrid UAV developed by Skyfront, has set a flight record of 4 h and 34 min in December 2017.

Figure 12. TailWind hybrid multirotor UAV of Skyfront.

Figure 13. Concept map of Tesla Drone.

5.3 Development Trend

At present, the oil–electric hybrid power has been widely applied and vigorously promoted in the automobile industry, and it has become an important trend of automobiles, which can be an important reference for the development of the power source of multirotor UAVs. The multirotor UAVs relying on gas–electric hybrid power as the power source have longer flight endurance than those relying merely on electric power and have a simpler structure and fewer emissions than those relying on fuel power. However, the power of such UAVs comes from the engine and the motor. Once one of them does not work well, the vehicle shall be out of control. So it is necessary to enhance its reliability. To sum up, the multirotor UAVs driven by gas–electric hybrid power have great prospects. They represent an important trend of the power sources of multirotor UAVs.

6. Other Power Sources

Figure 13 is the concept map of 'Tesla Drone', a UAV prototype launched by American Tesla in September 2015. The UAV is equipped with a 10,000 mA h battery and can fly for 60 min on a single charge for about 20 min. But the product is still a concept.

At present, as the new energy power technology is not yet mature, to improve the lithium battery technology it represents a directly effective way.

6.1 Graphene Battery

Graphene is a honeycomb two-dimensional planar structural molecule in which carbon atoms extend outward through sp2 hybridization. Due to its high load factor mobility [18], ultra-high theoretical surface area [19] and wide electrochemical window [20], how to apply graphene materials including the anode materials in lithium batteries [21], has been widely studied in recent years.

In December 2015, Shanghai Institute of Silicic Acid of Chinese Academy of Sciences, in cooperation with Peking University and University of Pennsylvania in the United States, successfully developed a high-performance and super-capacitor motor materials – nitrogen-doped orderly mesoporous graphene [22]. The material has an excellent electrochemical energy storage property and can be used as a 'super battery' for electric vehicles: 7 s recharging enables it to run for 35 km.

In 2016, Shanghai Graphene-king, a subsidiary of China Tunghsh, developed lithium battery anode materials from composite materials of reduced graphene oxide layered metal phosphate. It features multiplier performance and cyclic stability, and its specific capacity is improved when charging and discharging under high current density. The battery can work at $-30°C$ to $80°C$ and be recharged for about 3,500 times. Its charging efficiency is 24 times that of ordinary rechargeable batteries.

Graphene batteries feature the advantages of large storage capacity, short charging time, long service life, light weight and high stability. However, at present, the high cost of materials and the difficulty in processing make the mass production of them impossible.

6.2 Nanowire Battery

Nanowire battery is a lithium–ion battery invented by Cui Yi *et al.* of Stanford University [23]. The stainless steel anode covered with silicon nanowire replaces the conventional graphite anode. When the battery is recharged, positively charged lithium ions trap electrons in the current and move to the anode. When the battery discharges, the lithium ions release the electrons that are originally trapped, emit electric power and return to the cathode through conducting resin. The anode of a conventional battery consists of a very thin layer of carbon atoms, and it takes six carbon atoms to store a lithium ion. Silicon, by contrast, has huge potential for a single atom that can store four lithium ions, enhancing the energy density of the anode to a large extent and reducing the mass of the entire battery. In Cui Yi's experiment, a large swath of silicon nanowires were grown on a stainless steel substrate, and then ordinary electrolytes and electrodes were added to make a simple battery. A silicon anode stores power 10 times more than a conventional graphite anode.

Nanyang Technological University of Singapore has invented a new battery based on nanotubes [24], which can be recharged by 70% within 2 min and has a service life of up to 20 years. Conventional lithium–ion batteries cannot be recharged fast, primarily for safety considerations with graphite electrodes. An electrolyte membrane is formed on the surface of the electrodes as they work, slowing the movement of lithium ions. But the Nanyang Technological University replaced graphite with titanium dioxide nanotube gel which can accelerate the chemical reaction and thus shorten the charging time. But because of the complex process and high cost, it will take time for the technology to become widespread. At the same time, a cathode that can also store more charges is needed to make a lithium–ion battery 10 times as powerful as

Table 1
List of Power Sources of Multirotor UAVs

		Advantages	Disadvantages	Prospect	Safety	Cost to Use
Traditional lithium battery		Mature technology and convenience in purchase	Limited by energy density and short flight endurance	Medium	High	Low
Fuel cell power source		High energy conversion efficiency and little pollution	Problems in the source and storage of hydrogen; hydrogen is flammable and explosive	Medium	Medium	High
Fuel power source		Long flight endurance and high effective load	Slow response and complicated mechanical mechanism	High	Low	Medium
Solar cell power source		No pollution, inexhaustible energy source and no space limitation	Low conversion efficiency and the UAVs cannot carry solar cell plates which over a large area	Low	High	High
Oil–electric hybrid power		Low gas consumption and little pollution	High in price and complicated in structure	High	Medium	High
Others	Grapheme battery	High charge capacity, fast recharging, light in weight and long service life	High cost	–	High	–
	Nanowire battery	Little capacity loss from charging and discharging, long service life and fast recharging	Great technical difficulties	–	High	–
	Lithium–air battery	High energy density and high energy conversion efficiency	Great technical difficulties	–	High	–

conventional ones. However, because the weight and volume of the silicon nanowire anode have been greatly reduced, manufacturers will be able to put more cathode materials into the original space so as to store more charges.

6.3 Lithium–Air Battery

Lithium–air battery [25] is a metal air electrochemical battery. The anode is made of lithium metal, while the cathode material is the oxygen in the air. During discharging, the lithium metal at the anode is oxidized, and the oxygen at the cathode is reduced, thus generating electric current in the external circuit. The most prominent advantage of lithium–air battery is its high energy density. At present, the energy density of lithium–ion batteries is about 200 W h/kg, while that of existing lithium–air batteries have reached 500 W h/kg. Theoretically, the limit of energy density of lithium–air battery is 11,400 kW h/kg [26], being close to the energy density of gasoline (13,000 W h/kg), and there is a great space for improvement. At present, the main problems in achieving long-term endurance of secondary lithium–air batteries can be summarized as SEAS [27], namely stability, efficiency, applicability and safety. Stability mainly includes the stability of carbon-based positive electrode and non-proton electrolyte in the superoxide ion environment. Efficiency is primarily about improving the energy utilization efficiency and output power of the battery. Applicability refers to how to enable the secondary lithium oxygen battery to work directly in the air, that is to evolve from the secondary lithium–oxygen battery to the secondary lithium–air battery. Safety is to avoid burning and explosion in battery systems using organic electrolyte after the diaphragm is punctured by lithium dendrites emerging during repeated charging and discharging.

In November 2015, Clare Grey, professor of chemistry at the University of Cambridge in the United Kingdom, and her team overcame the technical difficulties in the development of lithium–air batteries. According to a research paper published in Science [28], Grey's team has overcome some practical problems in the technology – especially in chemical instability. Researchers used lithium hydroxide instead of lithium peroxide as the raw material for lithium–air batteries. Lithium–air batteries use graphene as the electrode to become more stable and efficient. It can be recharged for more than 2,000 times, and the energy efficiency is about 93%. This breakthrough may lead to 'supercells' that can be used in multirotor UAVs, which could greatly expand their flight endurance and dramatically improve the economic benefits of circuit storage. However, the lithium–air battery is still under investigation. At present, the charging and discharging levels of the lithium–air battery are still very low. It may take more than 10 years to apply the lithium–air battery technology on a large scale.

7. Summary

Short flight endurance has become a barricade in the development of multirotor UAVs, and also one of the urgent problems to be solved. The following conclusions are drawn through the comparison with the existing new power sources shown in Table 1.

Fuel cells are not a mature technology for multirotor UAVs. For hydrogen fuel cells, the cost of hydrogen is too high. In addition, hydrogen is flammable, explosive and difficult in storage and transportation. They cannot be applied on large scale or form an industrial chain. However, regardless of one direction of the power supply of multirotor UAVs, it deserves greater attention and investment which shall help overcome existing technical difficulties.

The fuel-powered multirotor UAVs mainly have two technical solutions: fixed propeller distance with variable speed and fixed speed with variable propeller distance. The former means that each propeller is independently and directly driven by an engine. A UAV needs to carry more than one engine, so it is demanding for the UAV's load and engine. The latter relies on the pitch device to change the angle of attack and pitch of the aerofoil. Its mechanical mechanism is complicated and it demands stability. The fuel-powered multirotor UAVs have huge advantages over the traditional electric multirotor UAVs in flight endurance and effective load, which represents the trend of multirotor UAVs for the purpose of agricultural plant protection.

Solar cells, limited by the load and flight height of multirotor UAVs, will not become the development of direction of multirotor UAVs at present. However, after the technical problem of low generation efficiency of solar cells has been solved, especially the perovskite thin-film solar energy represented by CH3NH3PbI3, solar cells shall also have great prospects.

The oil–electric hybrid power combines the advantages of electric power and fuel power, greatly extending the flight endurance and improving the stability. It shall be an important development trend of the power source of multirotor UAVs.

The lithium battery technology is mature and will remain the main power source of multirotor UAVs for a long time in the future, but it is urgently needed to improve the lithium–ion battery technology. Currently, graphene materials, nanowire battery technologies and lithium–air batteries have all seen breakthroughs, but they are still under investigation.

Different power sources of multirotor UAVs have their own advantages and disadvantages. But it is researchers' ultimate goal to develop a power source which offers longer flight endurance, huger power and less weight so as to provide UAVs with more power support and enable them to fly a longer time.

Acknowledgement

This study is jointly funded by the National Natural Science Fund of China (No. 61673285) and Found Project of Science and Technology Department in Sichuan Province – Research and implementation of the medium and small civilian UAVs airworthiness monitoring platform and key technology (2018JZ0066). Research project on technical road map of key industries in Chengdu – Technical Road map of unmanned aerial vehicle industry in Chengdu (2016-YJ01-00009-JH). The innovation team project of the Sichuan Provincial Education Department – Application and research of rotor unmanned aerial vehicle in industrial field (17TD0001). Application Foundation Project – Hierarchical Construction and Attribute Reduction of Uncertainty Measurement in Neighborhood System (2019YJ0203).

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