Key technologies of laser power transmission for in-flight UAVs recharging

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Abstract. UAVs have played important roles in many fields. However, due to the insufficient energy of electric UAVs, the future development has a major obstacle. This problem can be solved by laser power transmission. This paper summarizes the research results at abroad and domestic, introduces the work flow of the whole system, discusses the key technologies and puts forward the prospect.

1. Introduction

In 1987, the small UAV "Pointer" was developed by Aero Vironment, and evaluated by the “Jane's Defence Weekly”. Although there are some shortcomings, its potential is enormous [1]. The small electric UAVs have become a research hotspot. The main development directions of the UAVs are low cost, light, small, high altitude and long endurance, etc. [2]. It manifests small electric UAVs still be an important direction for the development of UAVs, which also has a higher demand for the energy supply. It depends on increasing the airborne battery capacity or in-flight recharging to extend its flying endurance for small electric UAVs. However, increasing airborne battery capacity will increase the UAVs’ weight and reduce the UAVs’ effective pay-load. The existing recharging mainly relies on charging after landing, but the UAVs’ damage often occurs in the takeoff and landing process. Laser wireless charging can solve this problem.

2. Research status

At present, the laser wireless charging system is widely researched in some countries, such as Japan and the United States, etc.

In 1997, Yugami H carried out the ground experiment of laser power transmission [3]. It was observed that the laser affected by atmospheric changed for a long time. The performance of various types of lasers and photovoltaic (PV) panels were compared. This experiment provided references for the subsequent research. In 2006, the laser energy was used to power a robot by Kinki University. The kite and the helicopter powered by laser beam were also done in this experiment [4]. The kite continuously and stably flew more than an hour. It proved that it is possible to apply the laser power transmission technology in recharging UAVs.

In 2011, “Feasibility of Laser Power Transmission to a High-Altitude Unmanned Aerial Vehicle” was issued by the Rand Corporation [5]. According to the report, it was feasible to recharge the UAV by laser beam based on the existing technology. In 2012, it was successful to make the “Stalker” UAV powered with the laser charging system flying more than 48 hours by Lockheed Martin Space Systems Company and LaserMotive.
Chinese also had corresponding studies of the laser power transmission, but mostly in the theoretical research and experimental stage. There is currently no overall feasibility of the experiment. In 2007, a device using light energy was designed by Wang J P\cite{6}. In 2013, the American laser power transmission experiment for in-flight UAVs was introduced by Li X Q. Difficulties and prospects were analyzed for the UAVs powered by laser beam\cite{7}.

3. The system structure
The overall structure of the UAV laser wireless charging system includes three major parts: ground-based equipment, data link and airborne equipment, as shown in figure 1.

![Figure 1. The diagram of the laser wireless charging system.](image)

The ground-based equipment includes the power supply circuit for lasers, lasers, the laser cooling system (not required), laser beam shaping elements, optical trackers and sensors, control circuits and the beam direction device. The main work is positioning and aiming at the optical antenna of the airborne equipment, powering the whole system and lasing.

The data link refers to the transmission process of the laser and the communication signal in the atmosphere. The request of data link is unimpeded. It needs to consider the effect of atmosphere for the laser beam energy and beam quality.

The airborne equipment composes optical trackers and sensors, the optical antenna, PV panels, the cooling system for PV panels (not required) and the power management circuit. The main function is sending the position of the UAV or aiming error to the ground-based equipment, and converting the laser energy to the electrical energy for powering equipment.

4. The work flow
The work flow includes ten steps, as shown in figure 2. Two optical trackers and sensors of the ground-based equipment and the airborne equipment establish a connection for real-time communication, and transmit the aiming error to the control circuit of the ground-based equipment in the whole charging process. The control circuit makes beam direction device to aim at the optical antenna. Starting the power supply circuit for the laser, the laser beam goes through the beam direction device to the airborne optical antenna, and be received by the PV panels. The laser energy is transferred to the electric energy by the PV panels. The power management circuits distribute electric energy to the battery, other equipment and the motor.
Figure 2. The work flow chart of laser power transmission for in-flight UAVs recharging.

5. Key technologies and difficulties

The most important evaluation criterion for the system is the overall conversion efficiency of the electro-optical-to-electrical process [9]. The factors that affect the overall conversion efficiency are the tracking and aiming, the electro-optical conversion efficiency of the laser and the output beam quality, the effect of the atmosphere on the laser beam, the conversion efficiency of the PV panel, the maximum power point tracking and the power management circuit.

5.1. The tracking and aiming

The tracking and aiming research is a difficult spot, because the electric UAV is small and flexible, which makes the UAV tracking requires a lot. Aiming error will decrease the using efficiency of laser beam and the conversion efficiency of PV cells. Therefore, it is necessary to design the high precision tracking and aiming system with UAVs as a cooperation target.

5.2. The laser

It is important for improving the overall conversion efficiency that the laser has the high electro-optical conversion efficiency and higher beam quality, where the laser diode has the highest conversion efficiency, reaching 55% ~ 60% [9]. So, it was used in the laser power transmission system. Most of the laser beam have a large divergence angle, and gently it is a class of Gaussian spot. The system requires decreasing the divergence angle to save the laser energy, and designing the structure of array-photovoltaic to match a class of Gaussian spot.

5.3. The laser transmission

Laser transmission in the atmosphere will produce linear and nonlinear effects. Linear and nonlinear effects will decrease the aiming accuracy and the beam quality, which reduces the overall conversion efficiency.

5.4. The PV panel

At present, commercial PV cells have low conversion efficiency, generally 20%. If the beam quality is poor, the conversion efficiency of PV panels will be significantly reduced, and PV panels may even be burned out. According to the beam quality, it is necessary to design a reasonable structure of array-photovoltaic.

5.5. The maximum power point tracking algorithm

There is a nonlinear relationship between the output power and voltage of PV panels. There is also a maximum power point. Due to the uneven illumination, there are many extremes in output characteristic curve of the PV panel. It is necessary to use the maximum power point tracking technology for improving the efficiency of PV panels. But traditional maximum power point tracking methods, such as perturbation observation, incremental conductivity method and open-circuit voltage
method, are proposed for uniform illumination conditions, and not applicable to the present. Therefore, it is urgent to research a maximum power point tracking technique for uneven illumination.

5.6. The power management
The function of the electric energy management circuit is distributing the electric energy to the storage battery, other equipment and the motor. If the power supplies the equipment or the motor, it only needs to design the step-down rectifier circuit. But charging the battery will need to consider the way of charging and so on. The existing charging methods are constant current charging, constant voltage charging, constant current-constant voltage charging, variable current intermittent charging, fast charging and intelligent charging. A suitable charging mode matching the laser wireless charging system is needed.

6. Summary
In this paper, after a short state-of-the-art review on the laser power transmission, the system structure and charging process model are proposed for small electric UAVs recharging, and the key technologies and problems are presented. Improving energy conversion efficiency from the aspects of laser selection, tracking and aiming control, the array-photovoltaic structure, charging mode and power management is important.

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