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Design and Motion Analysis of Intelligent City Terminal Distribution Energy-Saving Logistics UAV

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Abstract

In order to solve the problem of low efficiency of rural terminal distribution, a new type of rural terminal distribution energy-saving logistics UAV is designed. The UAV uses solar energy and gasoline as fuel, while the hybrid power system provides power. The particularity of solar photovoltaic panel is expounded. The working principle of six-rotor UAV is analyzed in detail. According to the characteristics of rural logistics terminal distribution, the airframe, landing gear, intermediate warehouse and decoupling device of logistics UAV are designed. The three-dimensional solid modeling of logistics UAV is completed by using three-dimensional software. The kinematics simulation analysis of logistics UAV is carried out, and the blade and decoupling device are put into operation. The dynamic analysis shows that the structure design is reasonable and meets the design requirements.

Keywords:*Village, terminal distribution, energy-saving, motion simulation, dynamics analysis.*

I. INTRODUCTION

The development of logistics in rural areas is relatively backward, and the efficiency of commodity circulation is not high, which has brought inconvenience to the production and life of rural residents. Due to the characteristics of rural logistics and current logistics distribution methods, the efficiency of existing rural logistics is still relatively low. Most of the distribution methods that use rural stores as self-pickup points still maintain the traditional operation mode, which has the problems of small network coverage and high distribution costs. We need to overcome this problem in order to better serve the rural public. Therefore, the new type of drone transportation has become a new choice for rural logistics. UAVs deliver fast upon receipt of delivery instructions, they can act quickly according to the instructions and directly airdrop the express delivery materials to the designated places, transporting daily necessities purchased online for remote rural areas, and improving the delivery efficiency.

Domestic and foreign scholars have also carried on the thorough research regarding rural logistics terminal distribution and have obtained massive achievement. Bertrand David points out that a large number of labor cost accounts for too much of logistics distribution cost as a whole, and puts forward that no one can use self-service distribution to replace the traditional manpower distribution

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modein the process of logistics distribution[1]. Rene Chalon proposed a location model of rural logistics center based on the vague intuitionistic TOPSIS theory, and verified the effectiveness and feasibility of the method by examples[2]. By using the idea of analytic hierarchy process, Wang Jie and others compared and analyzed the rural logistics terminal distribution mode of e-commerce enterprises, and combined with vague comprehensive evaluation method to obtain customer satisfaction. This paper analyzes the advantage of different distribution modes of e-commerce enterprises in rural terminal logistics distribution[3]. By means of data comparison and examples, Wu Yongxin analyzed why UAV can solve the shortcomings of rural e-commerce logistics and the development prospect of UAV in rural e-commerce logistics market. It is suggested to solve the existing problems from three aspects: logistics UAV technology, logistics operation and policy supervision system, cooperating with each other to promote the application of logistics UAV in rural e-commerce logistics market in China[4]. According to the rural environmental conditions, this paper designs a rural terminal distribution energy-saving logistics UAV. Through the analysis of various logistics and distribution tasks, the special structure design of the UAV is carried out with the three-dimensional modeling. Through kinematics simulation and dynamics analysis, the structure of the UAV is optimized.

II. PRINCIPLE OF LOGISTICS UAV

Flight Principles of Logistics Drones

In this paper, the rural terminal logistics distribution UAV is designed as a six-rotor UAV. Compared with the fixed-wing aircraft, the six-rotor UAV is more flexible. It can change the attitude of the aircraft by controlling the speed of each motor, and can execute rotation, tilt, yaw, longitudinal drive and so on, so accordingly the UAV can perform a variety of tasks[5]. The motor layout of the six-rotor UAV is shown in Figure 1.

Rotational motion: when the six-rotor UAV receives the command to rotate to the right, the G2, G3 and G4 motors increase speed, and the G1, G5 and G6 motors decrease speed, as a result the UAV rotates to the right. When the logistics UAV receives the command to rotate to the left, the G2, G3 and G4 motor decreases speed and the speed of the other motors increase synchronously.

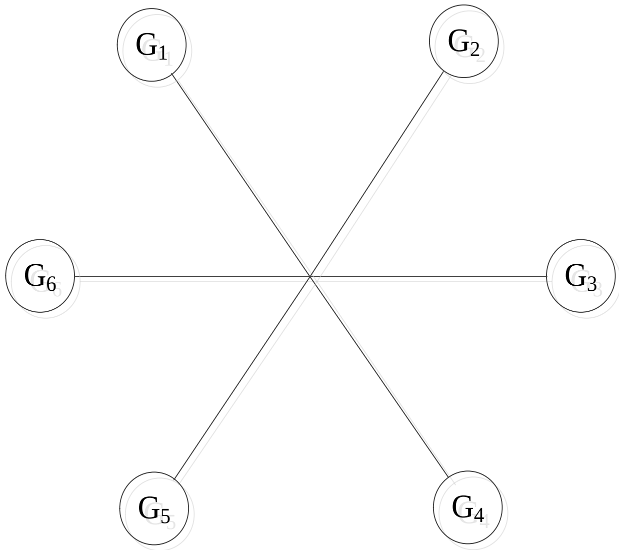

Fig 1: Arrangement of six-rotor UAV

Tilt motion: when the six-rotor UAV receives the downward tilt command, the speed of the G1 and G2 motor decreases, the speed of the G4 and G5 motor increases, and the speed of the G3 and G6 motor remains unchanged thus the UAV will make a downward tilt motion; Similarly, when the six-rotor UAV receives the upward tilt command, the G1 and G2 motor increase the speed, the G4 and G5 motor speed decreases, and the G3 and G6 motor speed remains the same, as a result the UAV will execute the upwards tilt command.

Yaw motion: when the six-rotor UAV receives the right yaw command, the motor speed of the G1, G3 and G5 increases and the G2, G4 and G6 motor speed decreases, so the UAV yaws to the right. When the G1, G3 and G5 motor speed decreases

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and the G2, G4 and G6 motor speed increases, the UAV yaws to the right.

Longitudinal motion: when the six-rotor UAV receives the rising command, the speed of the six motors increases and the UAV rises rapidly; similarly, when the six-rotor UAV receives the drop command, the speed of the six motors decreases and the UAV drops its height.

Working Principle of Hybrid Systems

In this paper, the new logistics UAV adopts series hybrid power system, as shown in Figure 2. Engine directly drives the generator to generate electricity, the battery is controlled by a control unit in order to charge, the chemical energy of fuel is converted into electric energy, then transferred from battery to motor, controlling the UAV by a variable speed mechanism, and then electric energy is converted into mechanical energy[6]. The series hybrid system can improve the utilization rate of fuel, reduce fuel consumption which can reduce fuel cost, prolong the life of UAV, and as a result improve the efficiency of terminal distribution using logistics UAV[7,8].

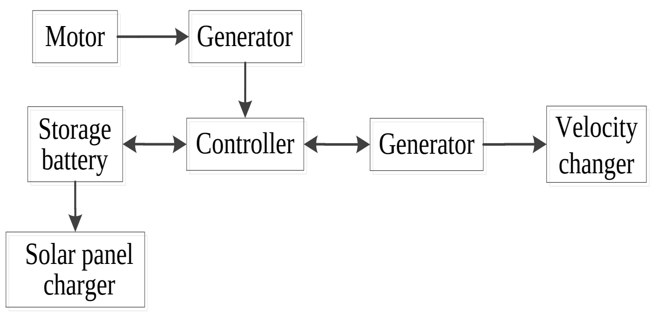

Fig 2: Series hybrid power system

Working Principle of Solar Photovoltaic Panel

Solar photovoltaic panels are used as energy sources for solar charging systems in UAVs, converting solar energy into potential energy through the photoelectric volt effect of semiconductor materials. The basic structure of solar photovoltaic panels is a large area of P-N junction. The sunlight irradiates on the P-N junction of the semiconductor, P electrons in the region move to the N region under the action of the electric field, and the holes in the region drift to the P region to form the photogenerated current from the N region to the P region. The photogenerated carriers drift and accumulate to form an electric field opposite to the thermal equilibrium junction electric field. qV also produces a forward junction current opposite to the photogenerated current direction to establish a stable potential difference between the two ends of the P-N junction, that is, photogenerated voltage [5].

III. STRUCTURE DESIGN OF LOGISTICS UAV

By SolidWorks 3D modeling operation, the parts of the new logistics UAV are modeled, including the body, central storage, landing mechanism and the hook device.

Body Design

The logistics UAV load is very heavy thus needs to be accurately calculated to select a motor, electronic velocity adjuster and propeller blade compatible with the result. Part of the thrust generated by the motor enables the UAV to maintain a hovering state, and another part of the force is required to complete the roll, pitch, yaw, longitudinal and other movements to ensure that the motor can respond quickly and that the battery voltage changes so that the UAV will not fall. At the beginning of the design, the approximate take-off weight of the UAV is estimated. The parameters of the selected equipment for the logistics UAV are shown in Table 1, and the 3D modeling of the arm is shown in Figure 3. The weight is added to the total weight of the UAV as a load. When the UAV is empty, the overall mass of the UAV has reached 8160 g, and when 10 kg of express goods are added, the overall weight is about 18 kg, which has exceeded the ideal weight we calculated. If the motor takes off at full load, the output current of the motor should be about 20 A. It can be seen that this

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is the reasonable output of the motor, so the model of the motor meets design requirements[9].

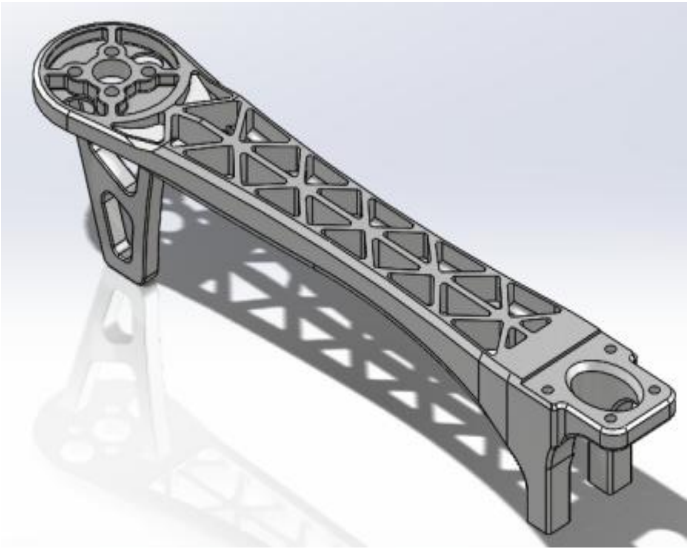

Fig 3: Three-dimensional Modeling of Arm

Table1. Performance parameters of logistics UAV

Type	Value	Type	Value
Pull force by motor(g)	4300	Motor wight(g)	160
Max capacity factor by motor(W)	792	Propeller wight(g)	50
Max flight weight(kg)	25	Drop device wight(kg)	2.5
Max load(kg)	13.5	Lithium battery capacity(mah)	22000

Central Storage

The airframe central storage is the core component of the logistics UAV structure. We select light and sturdy carbon fiberboard as its main material. The fiberboard is hollowed out to provide space, which is beneficial to the installation of the flight control system and the arrangement of the wire. The six arms are evenly distributed on the central warehouse and connected with screws. Solar photovoltaic panels and the body's central storage can be connected by aluminum columns, which can increase the connection strength [10]. The battery mounting plate and the central bin of the body are connected by nuts, and the battery mounting plate is placed in the upper position of the central bin. If the battery needs replacement, only the upper carbon fiberboard needs to be opened and the battery can be replaced quickly.

Landing Gear

Landing gear is when the UAV lands on the ground, the weight of the whole logistics UAV will be concentrated on it, so the landing gear must be strong enough and have better shock absorption ability and can protect the UAV from damage caused by the vibration when landing. The decoupling device is placed in the center of the landing gear, and its center of gravity should be perpendicular to the center of gravity of the UAV to ensure that it flies normally. Ground landing gear is made of hollow aluminum frame, which reduces the overall weight of logistics UAV as much as possible. The bottom of the landing gear which makes contact with the ground and can be wrapped with sponge, which can effectively increase the UAV's shock absorption capacity [11]. The three-dimensional shape of the landing gear is shown in Figure 4.

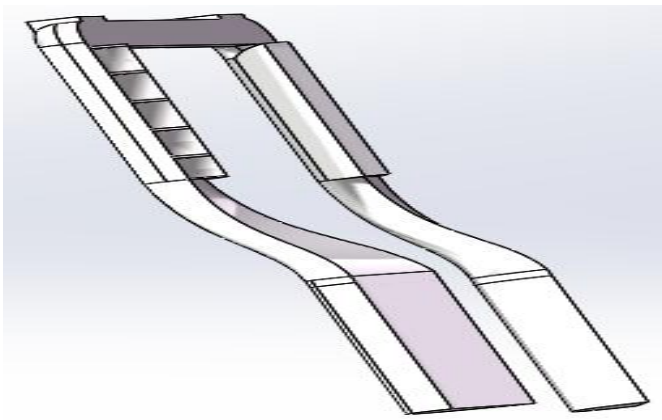

Fig 4: Three-dimensional modeling of landing gear

Decoupling Launch System

The decoupling device is installed at the bottom of the UAV, when the items need to be mounted, they are mounted in the locking slot of the mounting seat, after the logistics UAV receives the command,

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the electric motor controls the active eccentric shaft, and then makes the slider move, locking the item firmly in the end. When the logistics UAV arrives at the delivery site, it will slide open the slider and deliver the materials according to the order. The three-dimensional modeling of the decoupling device is shown in Figure 5.

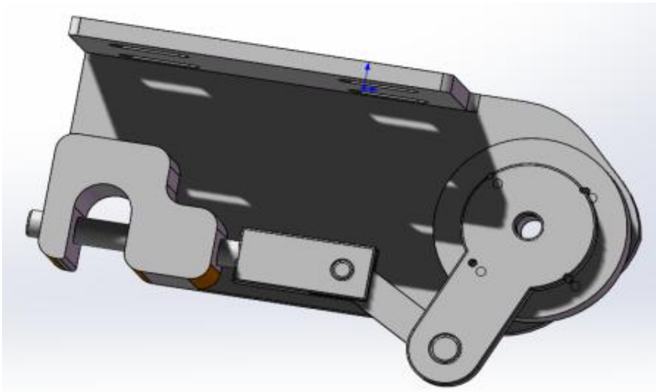

Fig 5: Three-dimensional modeling of placement device

The three-dimensional software is used to assemble the parts of the logistics UAV. The final assembly drawing is shown in Figure 6.

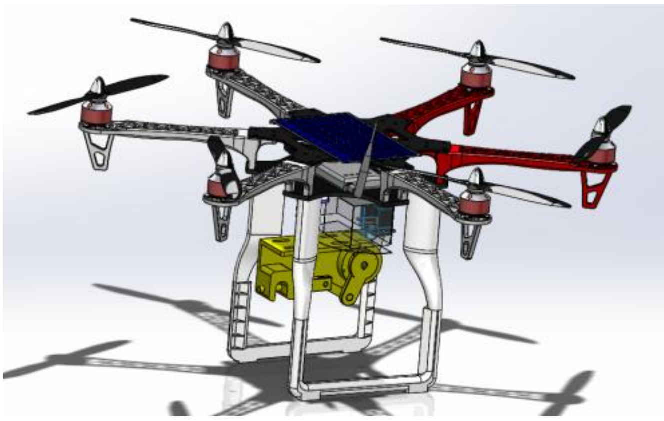

Fig 6: 3D Assembly map of logistics UAV

IV. STRUCTURE DESIGN OF LOGISTICS UAV

Through the motion simulation function of the SolidWorks, the path trajectory optimization diagram of the new logistics UAV designed in this paper is obtained, as shown in Figure 7 [12]. The rotor force curve, as shown in Figure 8; the mass center position curve, as shown in Figure 9; the linear displacement curve, as shown in Figure 10; the linear velocity curve, as shown in Figure 11; the linear acceleration curve, as shown in Figure 12; five sets of data in total.

(a)Selection (b)Transportation (c)Delivery

Fig7: Path trajectory optimization

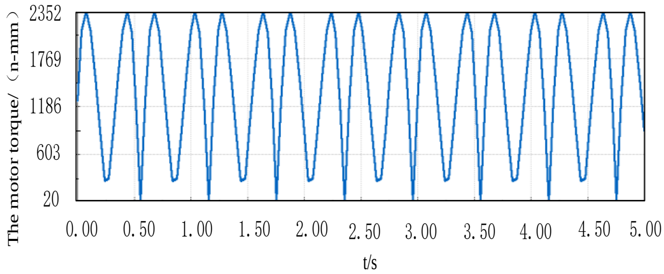

Fig8: Force curve

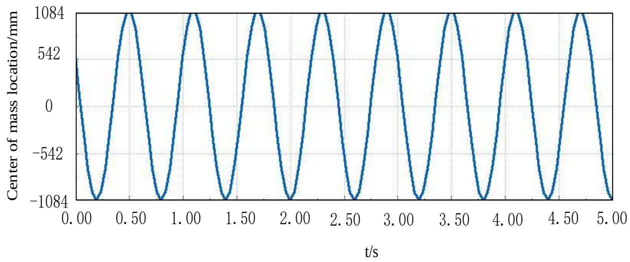

Fig9: Mass center position curve

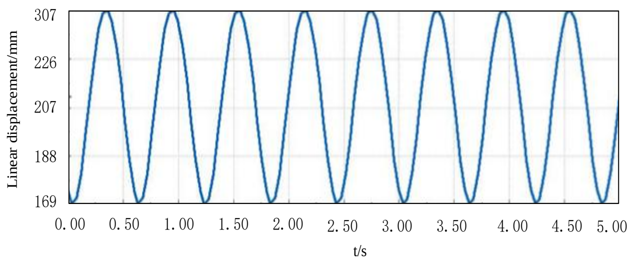

Fig10: Linear displacement

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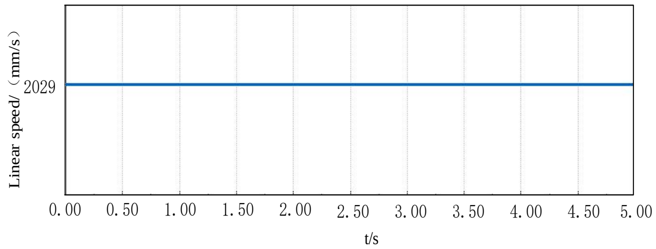

Fig11: Linear velocity curve

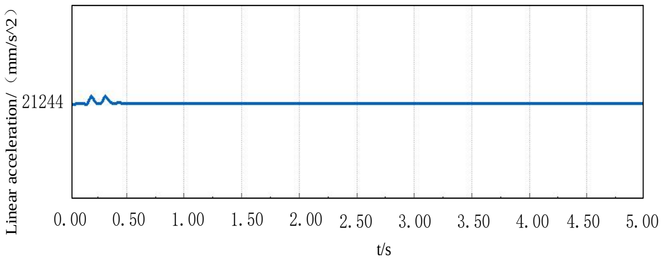

Fig12: Linear acceleration curve

Through the rotor mass center position curve and linear displacement curve generated by SolidWorks, it can be found that the rotor center of mass position and linear displacement have peaks, troughs and periods, similar to the change position of the sine graph, and the periodic changing force moment is M-shaped due to damping and other reasons. Through the linear velocity and linear acceleration curve of the rotor generated by SolidWorks, it can be found that the linear velocity of the UAV remains constant during the delivery, and the linear acceleration fluctuates slightly within 0-0.5s. It should be the UAV receiving the command resulting in the quick reaction of the motor causing the fluctuation in the latter 0.5 seconds, but the overall is relatively flat, which shows that the significant reliability of the mechanism is relatively good.

V. DYNAMIC ANALYSIS OF LOGISTICS DRONE

The dynamic analysis of the UAV decoupling launching device was conducted by Ansys to verify whether the launching device can bear the load required by the design.

The blades of the UAV are made of 45 steel, and its mechanical properties are shown in Table 2.

Table2.Mechanical properties of propeller

Density (kg/m^3)	Modulus of elasticity (GPa)	Poisson ratio
7800	200	0.3

The mesh is calculated by using tetrahedral high-order element Solid87. The final mesh number is 74414 and the number of nodes is 115456. It can be seen that most of the mesh quality is greater than 0.6, which meets the simulation requirements. The four waist-shaped holes are fixed and restrained, and a tensile force of 500N is applied to the cross section of the stressed rod.

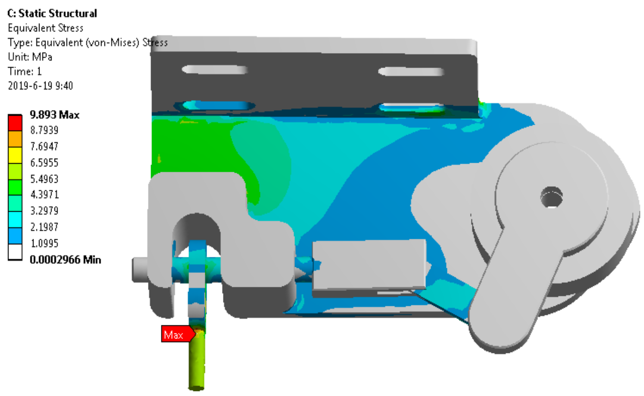

Fig13: Modal modes of blades

As shown in Figure 13, the maximum stress is 9.9MPa, which is located at the root of the stress rod, which is much smaller than the yield strength of the material. It can be seen that the decoupling device has a stable structure and can bear the load required by the design.

VI. CONCLUSION

This paper designs an energy-saving logistics drone for rural end distribution. The research of a new type of logistics drone based on the six-rotor effectively solved the problems that the materials could not be delivered in time, the drone's short lifespan, and the low amount of material load. The details are as follows:

By investigating the relevant content of the logistics drone, the flying principle of the drone is analyzed, and a hybrid power system that uses solar energy and gasoline as fuel is designed.

In order to realize the operation of logistics terminal distribution in the rural logistics environment, the overall structure of the UAV is designed, including the UAV body design, rotor design, conveying device design, etc., and kinematics analysis is carried out.

Combining the three-dimensional model in this paper, through three-dimensional software simulation, accurate theoretical data and curves can be obtained to verify whether the design scheme is correct and reasonable, and through dynamic analysis to verify that the structural design meets the design requirements.

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