Design and analysis of retractable structure of new quadrotor landing gear

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Abstract. With the development of equipment level, the requirements for the compact-ness and light-weight of UAV become more and more stringent. In order to solve the problems such as the weight and large volume of the landing gear of the existing four-rotor aircraft, this paper developed a new four-rotor unmanned helicopter landing gear retractable structure based on the existing landing gear. The release process and retraction of retractable structure of the new landing gear are described, and its motion form and attitude are introduced in detail. In this paper, the stress of high strength flexible rope during landing gear releasing and re-tracting is analyzed, and the mathematical model is established. Adams software is used to simulate and analyze the force state of the landing gear leg when the rope is pulling at a constant speed. The results of the dynamic simulation and mathematical model are consistent, that is, the maximum force when retracted to 90° is about 30N (for a single wing). Finally, the finite element simulation software Ansys Workbench was used to carry out strength checking and deformation analysis of the wing, and the rationality of the designed me-chanical structure was verified. The research results of this paper provide a certain basis for the development of landing gear of four-rotor unmanned helicopter.

1. The introduction
In recent years, aerospace technology has received more and more attention and development, among which Unmanned Aerial Vehicle (UAV) has attracted more and more attention, and has been classified as "flying camera". It has been widely used in both military and civil fields, and has attracted much attention. Therefore, UAV has become an important research direction in the space field. In the military field, UAVs play an important role, and are often used for weapons factory monitoring, strategic reconnaissance, enemy territorial reconfirmation and homeland defense. According to flight principle and dynamic model, UAV is classified as follows:
One of the most common types of VTOL, (Vertical take-off and Landing) aircraft is quadrotor UAV. Due to its features of free hovering in the air and flexible takeoff and landing, it can be adapted to the flight conditions of various speeds and various flight profiles, so it can perform relatively difficult missions. As the landing gear of four-rotor UAV is relatively special compared with other types of UAV, with the development of equipment level, the traditional simple landing gear has gradually been unable to meet the needs of scientific researchers began to focus on the continuous innovation and development of landing gear structure.

The four rotor aircraft landing gear basically has two kinds of structure forms one is the traditional four corners fixed landing gear. Its advantage is the device is simple and low cost, but with the development of the four rotor aircraft, people growing demand for below add Pan-Tilt. Those kind of the landing gear can appear the stationary gear view shade and interference, due to its large size at the same time, also not easy to avoid obstacles in the air. Is another kind of structure can be folding the gear, using multiple sets of motor control frame and each foot, and ropes in flight up to Pan-Tilt zero interference, but this kind of structure of the gear size and weight are larger and larger gear weight significantly increases the difficulty to adjust air plane pose, increase the workload of flight control system.

In view of this, this paper proposes a new four-rotor landing gear retractable structure with small volume and light weight, which maximizes the requirement of non-interference of the cradle head and keeping reasonable flight counterweight. Its structure and performance were studied from the aspects of mechanical structure, force analysis and checking, dynamic simulation analysis, etc.

2. Mechanical structure and operating principle

The principle of the new four-rotor landing gear retractable structure presented in this paper is shown in Figure 1. It is mainly composed of servo motor, high-strength flexible rope, lightweight pulley, torsion spring, landing gear leg, limit column and other components.
1. Servo motor mounted inside the central control chamber 2. Landing gear legs
Light pulley 4. High strength flexible pull rope 5. Limit column
FIG. 2 Three-dimensional diagram of structural principle

As shown in FIG. 2, the landing gear is powered by a servo motor mounted inside the central control chamber of the rack, which simultaneously drives four landing gear legs to complete the releasing and retracting action of the landing gear.

In each state, the movement form and attitude of the landing gear retractable structure are as follows:

1) When the quadrotor is at rest, a certain amount of pretension exists in the torsional spring inside the landing gear legs to ensure that the landing gear legs are in a vertical state to support the fuselage.

2) An Angle sensor is installed at the end of the servo motor for closed-loop position control. After the quadrotor takes off, the servo motor pulls the landing gear leg to the horizontal position through high-strength flexible pulling rope to overcome the torque of the torsional spring, and locks the motor when it is in place, so as to maintain the retract state of the landing gear.

3) By controlling the reverse of the servo motor, the landing gear leg is returned from the horizontal position to the vertical position under the action of the torsion spring, so as to realize the expansion of the landing gear.

4) After the landing gear leg returns to the vertical position, it is limited by the limit column, and at
the same time, the pre-tightening force of the torsion spring keeps it in the vertical state. At this time, the flexible rope is in the free state, which also reduces the servo motor and rope fatigue, and improves the service life.

This type of landing gear releasing and retracting structure is based on the existing four-rotor frame, and the four landing gear legs are pulled simultaneously by a single servo motor, which realizes the synchronous retracting and expanding of the landing gear, reduces the number of components and the weight of the whole machine, and improves the reliability and the system power and weight ratio.

3. Force calculation and mathematical model establishment

It can be seen from the previous section that the strength of the flexible pull rope overcomes the torque of the torsional spring to pull the landing gear leg from the vertical position to the horizontal position, and the strength and direction of the pull rope are always changing. The tension force of the rope will directly affect the servo motor selection and the deformation of the quadrotor landing gear as a whole.

In order to analyze the stress of high strength flexible rope during landing gear retracting and releasing, a mathematical model is established in this section, which is helpful to consider the reliability of landing gear structure and the feasibility of the scheme.

1) Force analysis

The following is the force analysis of the drawstring during the landing gear leg retract, corresponding to Figure 2. The state and Angle of the radio frame at any time can be simplified as Figure 3. Segment AB is the height difference between the landing gear legs and the rotating shaft of the landing gear light pulley; segment AC is the horizontal position difference between the landing gear legs and the rotating shaft of the landing gear light pulley; segment BD is the equivalent force arm of the torsion spring at any time; segment BE is the length of the landing gear legs.

![FIG. 3 Schematic diagram of undercarriage movement and force state analysis](image)

According to the geometric relationship of the analysis, it can be seen that:

$$\tan \lambda = \frac{AB}{AC}$$

Then, the length of BD segment and CD segment is:

$$BD = \sqrt{AC^2 + AB^2 \sin (\alpha - \lambda)}$$
$$= \sqrt{AC^2 + AB^2 (\sin \alpha \cos \lambda - \sin \lambda \cos \alpha)}$$
$$= AC \sin \alpha - AB \cos \alpha$$

$$CD = \sqrt{AC^2 + AB^2 \cos (\alpha - \lambda)}$$
$$= \sqrt{AC^2 + AB^2 (\cos \alpha \cos \lambda + \sin \lambda \sin \alpha)}$$
$$= AC \cos \alpha + AB \sin \alpha$$
The Angle can be calculated by formula (2)&(3):

$$\beta = \arctan \frac{|BE - BD|}{CD}$$

(4)

Since the landing gear legs are made of light materials, hollow structure and low mass, their weight is ignored here. According to the balance between the force of the high strength flexible drawing rope and the torsional spring torque, we can get:

$$F_L \cdot BE \cdot \cos \beta = N_0 + K \alpha$$

(5)

Among them, is the strength of the high-strength flexible pulling rope, is the pretension force of the torsion spring, and is the stiffness of the torsion spring.

2) Force analysis $\alpha < \lambda$

It is similar to the force analysis of time, except that the calculation method of $BD$ is different, so the drawing will not be repeated here. $\alpha > \lambda$

At that time, the length of BD segment is: $\alpha < \lambda$

$$BD = \sqrt{AC^2 + AB^2} \sin(-\alpha + \lambda)$$

$$= -\sqrt{AC^2 + AB^2} (\sin \alpha \cos \lambda - \sin \lambda \cos \alpha)$$

$$= -AC \sin \alpha + AB \cos \alpha$$

(6)

Similarly, the Angle can be calculated by formula (3)&(6):

$$\beta = \arctan \frac{|BE + BD|}{CD}$$

(7)

The corresponding values of the above parameters are shown in Table 1:

| Parameter | Value  | Parameter | Value  |
|-----------|--------|-----------|--------|
| AB        | 15mm   | $N_0$     | 20Nmm  |
| AC        | 80mm   | $K$       | NMM / 10 °|
| BE        | 57mm   | $\lambda$ | 10.6 ° |

According to formulas (1) ~ (7), Matlab is used for analysis, and the relation with the Angle can be obtained, as shown in Figure 4. According to the analysis, as the Angle of retracting and retracting of landing gear increases from $0^\circ$ to $90^\circ$, the force of high-strength flexible pull rope increases nonlinearly. At $0^\circ$, due to the existence of the torsional spring pretension, the tension force of the pulling rope has a sudden stress phenomenon, and the stress increases to the maximum at $90^\circ$, which is about 30N.
4. Dynamics simulation analysis

The principle of the releasing and retracting structure of the new four-rotor landing gear is introduced in the paper, and the mathematical model of the pulling force during the releasing and retracting process is established. This section is mainly based on Adams, a system dynamics modeling and simulation software, to simulate and analyze the dynamic characteristics of landing gear retractable and retractable structure.

As an application software of virtual prototype analysis, ADAMS can be used by users to carry out statics, kinematics and dynamics analysis of virtual mechanical system very conveniently. Therefore, the system simulation model is established in ADAMS, as shown in Figure 5A, which mainly includes:

1) Add pretension and linear torsional stiffness to the torsion spring;
2) Establish marking points at the tension of pulley and landing gear leg respectively;
3) Based on the marking point, add rope to simulate the pulling rope;
4) Add horizontal drive and speed (10mm/s) for the drawstring.

By setting the number and time of simulation steps, the traction force of the pull rope in the process of the traction landing gear leg moving from the initial vertical position to the horizontal retraction position is shown in Figure 5B. According to the analysis, during the retraction of the landing gear with the pull rope at a constant speed, the traction force increases continuously, and the change trend is similar to Figure 4. Moreover, there is a sudden force at 0s, and the maximum traction force at 6.8s is about 30N.
5. **Strength simulation analysis**

As the main load-bearing component, the four-rotor frame is used to conduct strength checking and deformation analysis with Ansys Workbench finite element simulation software in this section, so as to verify the rationality of the designed mechanical structure.

There are two forces in the four-rotor frame, one is the traction force of the pull rope at the contact point with the landing gear leg rotation shaft (Plane B in Figure 6), and the other is the tension rope pressure at the light pulley bracket connected to the frame (Plane C in Figure 6). The right side of the frame (i.e. the center of the quadrotor) is selected as the fixed surface (Side A in FIG. 6).

On the basis of setting boundary conditions, the frame is simulated and analyzed, and the stress cloud chart (As shown in FIG. 7) and the deformation cloud chart (as shown in FIG. 8) of the frame can be obtained. In the figure, red shows the position with the maximum stress or deformation.

As shown in FIG. 7, the maximum stress of the frame is 22.8mpa, and the maximum stress is located at the connection between the light pulley bracket and the frame, where there is a corner and the stress concentration phenomenon makes the stress greater. It can be seen from Figure 8 that the maximum deformation is 0.125um, which is very small and will not affect the flight control and the balance state of the quadrotor. Therefore, it can be considered that the stiffness and strength meet the requirements.

6. **Conclusion**

Aiming at the requirements of compact and lightweight quadrotor aircraft, a new four-rotor landing gear
A retractable structure is developed in this paper, which provides a new idea for the landing gear design of small and lightweight UAV. The main research results are as follows:

1. Based on the existing landing gear, a single servo motor drives the movement of four landing gear legs simultaneously through pulling rope, and uses fewer driving components and structural parts to complete the retracting and reextending action of the landing gear, reducing the volume and weight of the whole machine, and increasing the power and weight ratio.

2. A mathematical model and a dynamic simulation model are established respectively to discuss the variation of the pulling force of the landing gear leg under two states of uniform retraction and release of the landing gear leg and uniform pulling of the rope. The calculation and simulation results of the two methods are consistent. In addition, there is a sudden force in the initial state, and the maximum force when folded up completely is about 30N.

3. Ansys Workbench was used to conduct strength check and deformation analysis of the main load-bearing wing. The results showed that the strength met the requirements and the stiffness was reliable, which verified the rationality of the designed mechanical structure.

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