Research on Structural Design of Land and Space Inspection Robot

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Abstract. The quadrotor is an aircraft that can take off and land vertically, and it is often used for target search and tracking of tasks. In order to further enhance the flexibility and endurance of the drone, a land and air inspection robot is designed. The land and air inspection robot is combined by a drone and a smart car. While driving, if the obstacle is not the case, the robot uses the landline equipment, otherwise, the rotor is used. The motion simulation analysis is carried out through 3D modeling to achieve optimal mechanical design. Through flight design calculation, the self-anti-jamming flight algorithm is obtained. According to the actual measurement, the design of the land and air inspection robot can achieve the expected results, and it can be widely used in the inspection tasks of factory monitoring, anti-terrorism, search and rescue, forest fire prevention and other occasions.

1. Introduction
In recent years, China has gradually begun to apply UAVs in the military and civilian fields. According to the survey, there are mainly problems such as fast power consumption, short flight time and cost, which seriously restricts the scope of use [1]. Based on the above problems, a land and air inspection robot is designed and developed. The land and air inspection robot is mainly composed of a smart car and a four-axis rotorcraft. It uses an automatic driving system that operates autonomously in an unmanned mode. In actual operation, the robot's camera performs road surface detection, and when it is barrier-free, it moves according to the preset trajectory. When there are obstacles, the camera works with the gyroplane, and after crossing the obstacle, it continues to travel along the ground track. The land and air inspection robot has both land and air flight functions, and it can be used for forest fire prevention, transportation of medicines, mountain rescue, special monitoring and other occasions.

2. Machine design ideas
Based on the design principle of simple production, low cost, endurance performance and versatility, the land and air inspection robot designed and developed adopts the combination of automobile and four-axis drone as shown in Figure 1. The vehicle model structure includes chassis, dual motor, hub, steering gear, power supply and control system [2]; the four-axis unmanned aerial vehicle consists of a propeller, a frame, a camera, a stage, an automatic control system based on a single-chip processor, and an automatic obstacle avoidance system.
Figure 1. Structure design of land and air inspection robot.

2.1. Design function
The land and air inspection robot takes into account the land-based operation, which can drive the car's forward, backward and steering, and it can change the speed of the four propellers to achieve various actions, hovering, advancing, retreating and other flight operations\(^1\). It can be further promoted and applied in the fields of factory monitoring, anti-terrorism, search and rescue, forest fire prevention and so on.

Ground driving function: The car body driving motor drives the driving wheel, and the steering gear drives the steering mechanism. Through the control of single-chip computer, the car can move forward, backward and direction.

Air flight function: Single chip computer collects data of attitude detection sensors (gyroscope, accelerometer and magnetometer), integrates and analyses the attitude of the body, drives the speed of the propeller motor through the control algorithm, and then controls the lift of the four propellers to realize various flight actions, hovering, forward, backward, etc.

2.2. Design features
(1) Taking into account long-distance land travel and short-range flight over the air;
(2) Take-off adjustment, short attendance, high efficiency;
(3) Easy to maintain, low cost of use and maintenance;
(4) The overall size is small, lightweight and high efficiency;
(5) The working height is low, the drift is small, and it can be hovered in the air, without the need for a dedicated take-off and landing airport;
(6) The terrain requirements are low, the operation is not limited by altitude, and there is no problem at high altitudes;
(7) Environmental protection and meet the national energy saving requirements.

3. Key structural design
3.1. Fuselage design
For the design of flight fuselage, it is necessary to bear not only its own load, but also the weight of the vehicle model and the object carried. When flying, the aircraft needs to be provided with sufficient lift and continuously optimized for the components that can generate resistance during the design; the aircraft is required to have sufficient internal volume; the land driving mechanism adopts a smart car model, which is composed of a steering mechanism, a driving mechanism, a chassis and the like. The driving process is characterized by responsiveness and high stability, as shown in Figure 2.
3.2. Design of vehicle model chassis
As the key load-bearing parts of the system, the chassis is designed as shown in Figure 3, which is made of acrylic plate and has streamlined structure. Considering the gravity distribution of the whole vehicle, the chassis is designed with narrow front and back width, and the quality of the whole vehicle is reduced. The chassis threads are evenly distributed and have reserved holes for subsequent parts installation. Considering the problem of heat dissipation in the operation of the system, the heat dissipation holes are reserved.

3.3. Aircraft frame design
In this paper, the design of the land and air inspection robot is driven by a four-axis rotor, vertically lifted, and controlled by a single-chip microcomputer, as shown in Figure 4. The frame adopts a symmetrical hollow design, which can greatly reduce the air resistance of the land and air inspection robot during the ascent, and it can also make the machine weight type gather at the center point. The propeller support material is made of carbon fiber. In actual operation, the deformation is small and can be approximated as a rigid body.

4. Flight design calculation
4.1. Estimation of takeoff weight
For a general aircraft, Fuel consumption, which is generated during the flight, makes the total weight of the aircraft constantly changing. For an aircraft that uses electric energy as its main energy source, the general battery does not produce a quality change during use, so there is no such problem. For the land and air inspection robot of this design, the electric device is also used as the propulsion device of
the aircraft, so the flying weight of the aircraft during the flight is equal to the take-off weight. The take-off weight can be expressed as:

\[ W_T = W_S + W_{EF} + W_B + W_R \]  \hspace{1cm} (1)

In the formula: \( W_T \) is the total weight of take-off which is the flying weight during flight; \( W_B \) is the weight of the mission load which is the weight of the vehicle body, which is 0.5 \( W_T \) here; \( W_S \) is the weight of the structure of the body. Generally speaking, the weight of the body structure accounts for 25% to 35% of the total weight, and 0.2 \( W_T \) is taken here; \( W_{EF} \) is the weight of fixed equipment, mainly for power equipment components such as motor, electric control, flight control, propeller, etc., take 0.25 \( W_T \) here; \( W_R \) is the weight of the battery, and here the weight of the battery is 0.5kg. The take-off weight of the aircraft: \( W_T = W_B/(1-0.5-0.2-0.25) = 10kg. \)

In order to meet the design requirements as much as possible, and to make the aircraft body have higher structural strength, the initial conservative estimate of the aircraft’s design flight weight is 12.5kg.

4.2. Determination of the weight-to-weight ratio

The land and air inspection robot has no rigid requirements for the voyage and the static ceiling. The maximum speed is mainly related to the batteries and motors selected, so it is not considered. In order to make the operation simple and easy to install, the wing is not provided with a lifting device. In addition, since the aircraft uses vertical take-off and landing mode, the take-off distance is not considered. Therefore, the two main limiting conditions are: maximum flat flying speed and minimum flat flying speed.

4.2.1. Maximum flying speed

According to the basic equation of the same force and resistance of the aircraft:

\[ T = \frac{1}{2} C_D \rho V^2 S \]  \hspace{1cm} (2)

It can be concluded that the expression of \( V_{\text{max}} \) is:

\[ V_{\text{max}} = \sqrt{\frac{2 \left( \frac{P}{W_T} \right) \left( \frac{W_T}{S} \right)}{C_D \rho}} \]  \hspace{1cm} (3)

The maximum flattening speed is expressed as a function of power-weight ratio and wing load. The unit of \( P/W_T \) is W/kg, the unit of \( W_T/S \) is kg/m², and the drag coefficient \( C_D \) is based on experience 0.1. Because the flight altitude is relatively small, the density \( \rho \) is taken as the density at sea level, \( \rho = 1.225 \text{ kg/m}^3 \).

4.2.2. Minimum flying speed

Limited by the maximum lift coefficient \( C_{L_{\text{max}}} \), according to the basic equation of gravity equal to lift:

\[ W_T = L = \frac{1}{2} C_{L_{\text{max}}} \rho V_{\text{max}}^2 S \]  \hspace{1cm} (4)

It can be concluded that the expression of \( V_{\text{max}} \) is:

\[ V_{\text{max}} = \sqrt{2 \left( \frac{W_L}{S} \right) / \left( C_{L_{\text{max}}} \rho \right)} \]  \hspace{1cm} (5)

Among them, the maximum lift coefficient \( C_{L_{\text{max}}} \) of theoretical airfoil and actual airfoil will be different, conservatively estimated to be 1.

4.3. Technical parameters

| Table 1. Technical parameters of land-air patrol robot |
|------------------------------------------------------|
| **Model** | **Land and Air Patrol Robot** |
| Dimensions | 600x600x400mm |
5. Motion simulation
Simulations are performed using SolidWorks software to detect the fit of each component. Setting the gravity direction of body modeling, adding rotating motors on four propellers, adding fixed rotation angle rotating motors on the front wheel of the car model, setting linear motors in the cross-section direction of the car body, restricting the moving range of the model, and then completing the simulation by controlling the number of animation frames.

In flight mode, the design of land and air inspection robot can realize vertical lifting and air translation function, as shown in Figures 7, 8, and 9. In the horizontal flight state, the velocity, acceleration and sudden response curves of the land-air patrol robot are obtained.

![Figure 5. Propeller simulation.](image)

![Figure 6. Overall motion simulation.](image)

![Figure 7. Flight translation speed tracking response curve.](image)
In actual work, the land and air inspection robot operates autonomously in the unmanned mode. The visual sensor of the land and air inspection robot cooperates with the ultrasonic sensor for pavement inspection. When there is no obstacle on the road, the land and air inspection robot moves according to the preset trajectory; when the obstacle is detected, the land and air inspection robot stops at 100mm from the obstacle and is processed by the delay device. After about 2s, the propeller automatically rotates to make the car fly, during which the camera works together, and after landing over the obstacle, it gently descends and continues to follow the previous ground track.

6. Summary
This paper proposes a design method for both land and air operations robots by modeling the land and air inspection robots and motion simulation. Through the continuous optimization of the vehicle body travel mechanism, the front wheel steering mechanism, the propeller flight mechanism, etc., the quality of the vehicle system is uniform, the complexity of the electronic control system design is reduced, and the electromechanical organic combination is well achieved. After many experiments, the land and air inspection robot can operate autonomously in the unmanned mode to meet the design requirements. In the later research, according to the design concept provided in this paper, a kind of manned smart car with both land and air can be developed and used in the fields of rescue and mitigation of traffic congestion pressure.

References
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