Design and Connection Scheme of Quadrotor Drone Protective Shield

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Abstract. With the increasing global demand and expanding application fields of drones, the safety and durability of drones during flight has become particularly important in commercial competition. This study focuses on designing a protective shield specifically tailored for both commercial and personal drone use.So that the drone is not prevented from continuing to operate due to unexpected circumstances such as collisions or crashes.Utilizing a multidisciplinary approach, e.g., mechanics of materials, fluid dynamics,the structure of the protective shield is optimized through 3D modeling software (Creo) and simulated using Ansys to analyze stress distribution under various impact scenarios.to determine the difference between damage to a drone after a collision with the ground with and without a protective shield. Additionally, the design emphasizes the shield's detachability and modularity, facilitating maintenance and upgrades, and allowing for quick replacement to meet different mission requirements.And experimentally confirmed that the UAV protective cover has a significant effect on the protection of various parts of the UAV at a certain altitude.It is finally concluded that through the fine design of materials and structure, the protective cover can not only effectively mitigate the damage to the core components of the UAV from external impacts, but also improve the survivability of the UAV in harsh environments. Experiments and field tests show that the protective cover exhibits superior protection performance in a variety of scenarios, and has less impact on the flight performance and stability of the UAV.

Keywords: Drone, Protective Shield, Structure, Design

1 Introduction

With the progress of new materials, flight control and other technologies. The novel shape, simple structure, low cost, excellent performance and unique flight control of quadrotor UAVs have made them an international research hotspot and have been rapidly developed [1]. such as agricultural monitoring, logistics delivery, and disaster rescue, offering more convenient solutions [2]. Although researchers have attempted to extend the life of drones through various methods [3]. However, the increased use of drones has also led to a higher incidence of accidents. Drones are prone to mechanical

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failures, adverse weather conditions, or operator errors that may result in collisions with obstacles, leading to crashes from high altitudes due to loss of control. To ensure the safe operation of drones under various environmental conditions, especially in extreme weather or in the event of physical damage from high-altitude falls, this paper aims to design an efficient, lightweight, and highly functional protective shield for drones.

Researchers in the field of drone accident studies, based on the Fault Tree Analysis (FTA) model, have analyzed the risk of drone crash accidents and concluded that drones are inevitably affected by factors such as pilot error, inadequate pre-flight preparations, and environmental interference. If any of these factors are not adequately controlled, accidents are inevitable, resulting in property damage and personal injury [4]. Therefore, in the area of structural design, researchers have designed protective shields using mechanical principles to provide comprehensive protection for drones from all directions. The protective shield effectively prevents crashes caused by minor collisions due to operational mistakes, maximizing drone safety. When the propellers stop, it also provides a buffering effect, significantly reducing the damage to the drone before it falls. Nevertheless, the additional protective attachments may slightly decrease the drone's endurance, leading to shorter flight times [5]. Many researchers have attempted to reduce weight by designing blade guards composed of several protective shields to maximize the protection of the power blades. Although this reduces some weight, it cannot effectively protect other parts of the drone [6]. Consequently, some researchers have developed an overall structural design for the protective shield based on the rotational principle of a hemispherical shell. The spherical shell, being an openwork structure, is fixed to the arms of the quadrotor drone, protecting the drone body inside and preventing direct contact between the propellers and the external environment. The exterior is made of two carbon fiber hemispheres, allowing the drone to rebound or rotate upon collision, thus minimizing weight while maintaining flight stability and mitigating impacts with obstacles [7]. Additionally, some researchers have simulated the gyroscope structure principle when designing drone protection devices to achieve automatic control and protection of the drone. This approach significantly enhances the drone's exploration capabilities by reducing accident rates, thereby facilitating the execution of various complex tasks and minimizing losses in human and material resources caused by drone operations [8].

To ensure that drones can successfully complete various flight missions and avoid damage from collisions under hazardous conditions during flight, this paper proposes the design of a lightweight drone protective shield. This paper will elaborate on the function of drone protective shields in various environments and discusses the design and optimization of their structure and connections. Performance analysis and summarization will be conducted based on simulation results, and the future development directions will be discussed in the conclusion.

2 Design and Optimization of the Protective Shield Structure

2.1 Structural Design Plan

Structural Design Plan: Based on UAV dynamics [9], the weight m of a civilian quadrotor drone is approximately 1.2 kg. Its fall from a height of 6 meters can be simulated by taking the gravitational acceleration as $g=9.8m / s^2$. Under ideal conditions, neglecting air resistance, the falling speed of an out-of-control drone can be calculated using the free-fall formula:

$$h=1/2gt^2 \ t \tag{1}$$

and the speed formula:

$$v=gt \tag{2}$$

The falling speed immediately before the drone hits the ground is calculated to be 10 m/s. When the speed v' becomes 0, according to the impulse formula:

$$Ft=mv'-mv \ t \tag{3}$$

the impulse experienced by the drone upon impact with the ground is:

$$I=12N\bullet s \tag{4}$$

Under such significant impulse, a lightweight and impact-resistant protective shield is necessary to safeguard the fragile components of the drone.

In the design process, a spherical structure for the protective shield is designed to ensure comprehensive protection for the drone from all sides due to the unpredictable angles and directions of impacts on the drone. By attaching the protective shield to the top shell of the quadrotor drone, the internal vulnerable blades and arms are protected, preventing direct collisions with obstacles. The exterior of the protective shield consists of two mesh-like semi-elliptical spheres (as shown in Figure 1) connected by a central reinforced ring (as shown in Figure 2), resulting in the complete structure (as shown in Figure 3). The shield is 3D printed using ABS material (polymeric structural material), known for its durability, toughness, ease of manufacturing, and cost-effectiveness. Upon impending collision with an obstacle, the shield contacts the obstacle first, allowing it to rotate and rebound, thus preventing the drone's main body from impact and compression.

Furthermore, the shield is designed to weigh less than 50 grams, making its weight negligible compared to the drone's overall weight. This allows the drone to maintain its own payload limits [10]. The aerodynamic design of the protective shield also ensures that there is no excessive energy loss during flight, thus preserving the drone's endurance capacity.

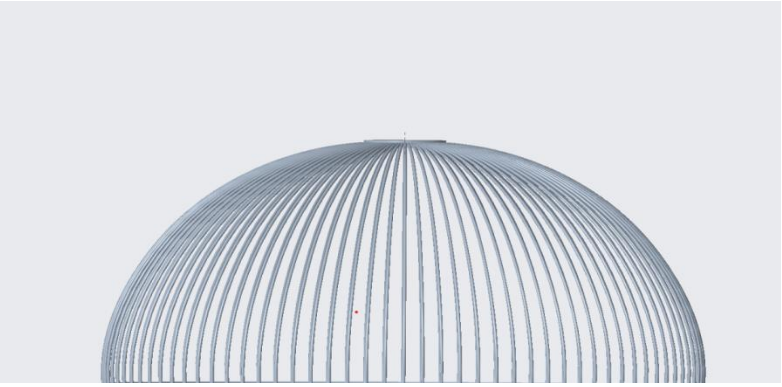

Fig. 1. Mesh-like semi-elliptical sphere

Fig.2. Reinforced ring

Fig. 3. Schematic diagram of the drone protective shield

2.2 Selection of the Protective Shield Connection Method

Selection of the Protective Shield Connection Method: To achieve simplicity and user-friendliness, a clip-on method is employed to attach the protective shield to the drone body (see Figure 4). The shape and size of the clip are precisely calculated to fit snugly into the drone's chassis, ensuring a tight connection and minimizing gaps. Made from high-polymer materials, the clip enhances connection strength and durability, capable of withstanding long-term wear and impact. The shield can be quickly and easily attached or detached by pressing the bottom of the clip, ensuring ease of use.

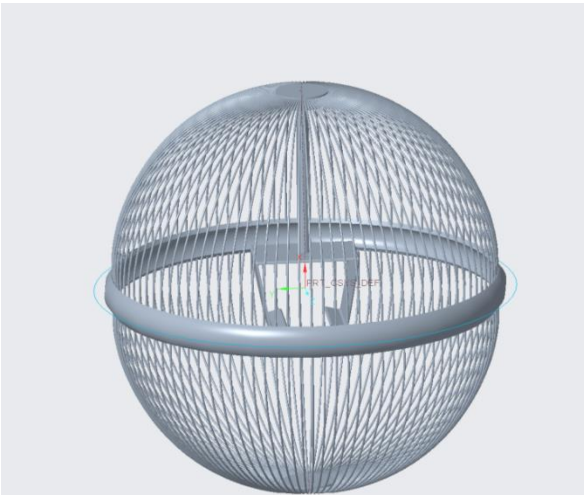

Fig. 4 Schematic Diagram of the Drone Protective Shield

2.3 Measures to Improve the Stability of the Connecting Rod

Measures to Improve the Stability of the Connecting Rod: The connecting rod, made of ordinary steel (45 steel), is designed to resist breaking upon impact. The protective shield's main body is connected to the top disc and clip using a long, hollow thin rod (depicted in Figure 5). In order to improve the stability of the connecting rod and minimize the overall weight of the drone protective shield, increasing the critical load Fcr of the compression rod is necessary according to the critical load formula.

$$F_{cr}=A\sigma_{cr} \tag{5}$$

When the area A is constant, the key to increasing the critical load is to enhance the critical stress σ_{cr}. The critical stress is defined as π squared multiplied by the elastic modulus E, divided by the slenderness ratio λ squared.

$$\sigma_{cr}=\pi^2E/\lambda^2 \tag{6}$$

This indicates that reducing the slenderness ratio λ will increase the critical stress σ_{cr}.

The slenderness ratio is given by:

$$\lambda=\mu l/i=\mu l\sqrt{A/I} \tag{7}$$

This indicates that increasing the moment of inertia I of the cross-section of the compression rod can enhance the critical stress σcr.

When the cross-sectional area remains unchanged, increasing the moment of inertia can be achieved by placing the material as far from the centroid as possible. Creating a long, hollow rod structure with perforations achieves high strength and stability, offering superior resistance to bending and compression, and lower sensitivity to vibrations and impacts. This contributes to the overall system's stability and is particularly beneficial for drones that need to carry a certain load without adding extra weight. Furthermore, hollow rods require less material, making them cost-effective. The support structure of hollow rods also requires minimal space, ensuring it does not affect the drone's operation.

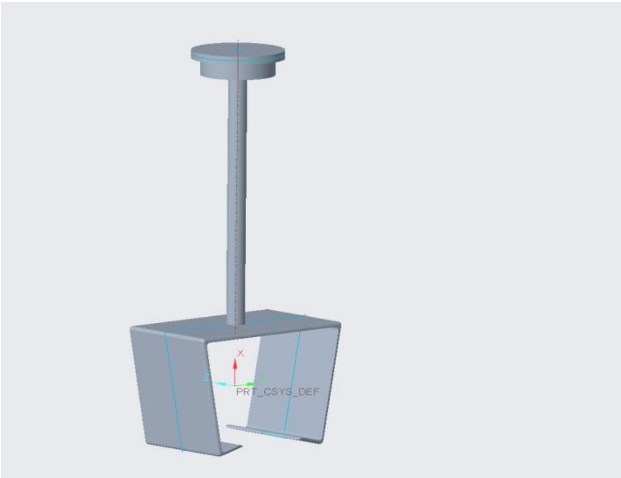

Fig. 5 Schematic Diagram of the Drone Connection Structure

3 Results and Discussion

3.1 Analysis of the Performance and Characteristics of the Designed Protective Shield

Analysis of the Performance and Characteristics of the Designed Protective Shield: The protective shield is made from high-polymer materials, which provide high strength and lightweight properties, while also being resistant to UV radiation, aging, and corrosion.

In terms of structural design, the clip of the protective shield uses a modular design, allowing it to be assembled with different models of drones. The installation is simple and quick, without affecting the drone's disassembly and maintenance. The design effectively absorbs impact energy, protecting the internal structure of the drone. Additionally, the protective shield is designed based on aerodynamic principles, with a streamlined shape that reduces air resistance, thereby improving the drone's flight efficiency and stability.

Regarding protective performance, the drone protective shield designed in this study can effectively resist harsh environmental conditions such as wind, sand, rain, and hail. In the event of accidental collisions, the protective shield safeguards critical components of the drone, such as sensors, cameras, and batteries, reducing the likelihood of damage to the drone.

3.2 Summary of Design Effects and Outcomes

Summary of Design Effects and Outcomes: By conducting simulations using Ansys (as shown in Figure 6 for the protected drone and Figure 7 for the unprotected drone), it can be observed that the stress experienced by the drone with a protective shield is approximately 1257.1 MPa, which does not significantly affect the rotors and blades. In contrast, without the protective shield, the stress from direct impact with the ground is around 11049 MPa, causing the rotors and blades to bend and break. The comparative analysis indicates that the presence of the protective shield significantly reduces the stress on the drone, preventing damage to critical components. This substantially increases the drone's survival rate during flight.

3.3 Discussion of Limitations

Discussion of Limitations: Although the protective shield provides unquestionable protection for the drone, its effectiveness is limited by the strength and performance of the materials. Under varying conditions of altitude and speed, the protective performance of the shield may be affected to some extent. According to simulations conducted using Ansys [11], when the drone's impact speed exceeds 20 m/s, the protective shield no longer offers significant protection (see Figure 8). In addition, the silk mesh-like structure, despite protecting the UAV in all directions, also obscures the sensor devices of the UAV itself to a certain extent, and the UAV needs to rely on visual recognition technology for navigation and target recognition when performing certain tasks. If the protective cover obscures the camera or sensors, the accuracy and efficiency of visual recognition is compromised, which may lead to navigation errors or target recognition failures [12].

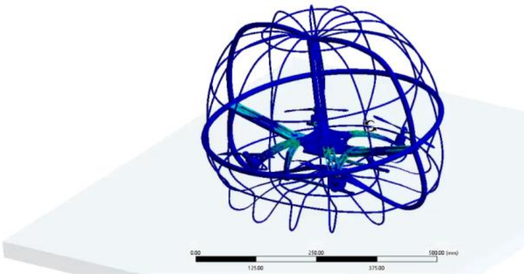

Fig. 6 Stress on Drone with Protective Shield Upon Ground Impact

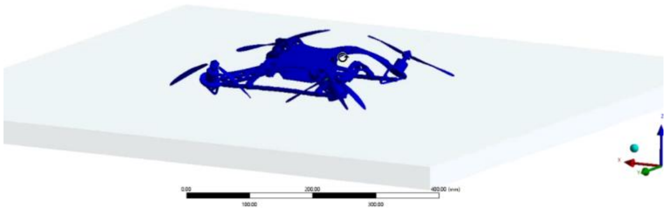

Fig. 7 Stress on Drone without Protective Shield Upon Ground Impact

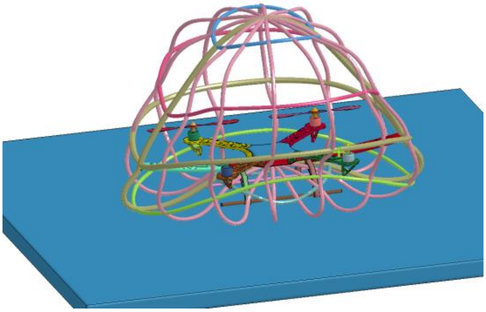

Fig. 8 Schematic of the drone at a speed of 20 m/s

4 Conclusion

This paper, based on current technological advancements, designs a protective shell for quadrotor drones. The design features simplicity, low cost, and effective defense against direct collisions with obstacles at certain speeds.Although the protective cover increases the weight of the UAV, experiments show that the protective cover has little effect on the flight performance of the UAV. By optimizing the design, a good balance is found between the weight of the protective cover and the flight stability, so that the UAV can still maintain good handling and endurance.Not only does it significantly improve the safety of UAVs in complex environments, it reduces the likelihood of accidental damage, which in turn reduces repair and replacement costs. More expand the application scenarios of UAVs, enabling them to be used in more complex and dangerous environments, such as rescue, exploration, monitoring and other fields. The additional safety provided by the protective cover makes the UAV more reliable and efficient in these missions. The design and successful experimentation of this protective cover provides valuable experience in the development of UAV protection technology. This will push UAV manufacturers to give more consideration to protective measures in their design and production, thus enhancing the technology level of the entire industry. In the future, the performance of the drone protective shield will be further explored using different materials to identify those capable of withstanding higher impact speeds. Materials with an excellent strength-to-weight ratio, such as carbon fiber, will be considered.

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