Analysis And Comparison Based on Multiple Uav Landing Gear Structures

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Abstract. In recent years, the application of UAVs has become increasingly widespread, involving increasingly complex scenarios and environments. To ensure the safe takeoff and landing of UAVs in various environments, the landing gear plays a crucial role as an important mechanism to support the UAV fuselage. This paper aims to summarize and compare the advantages and disadvantages of various UAV landing gear mechanisms, and to discuss the future development trends of landing gear. Through analyzing various types of landing gears such as retractable structure landing gears, modular landing gears based on habitat principle, inflatable float water landing gears, and bionic remora fish suction cups, it is found that retractable and automatic retractable simple structures are characterized by light weight, and that inflatable float structures can help UAVs complete landing and takeoff on the water more smoothly and safely when they are involved in water work. However, bionic landing gears have significant advantages regarding development convenience and adaptability to special environments. For example, a modular landing mechanism based on the principle of habitat can help UAVs complete the landing and take off of street signs, street lamps, and branches in multiple scenarios by utilizing a simple gripping hand design. The future development trend of landing gear design will mainly focus on lightweight, multi-environment adaptability, and modular replaceability. Modularized and replaceable landing gear design ideas will provide UAVs with more abundant and flexible options, reducing maintenance and replacement costs.

Keywords: UAV; landing gear; specialized environments.

1. Introduction

A UAV is an unmanned aerial vehicle operated by radio remote control equipment or self-contained programmed control devices. The use of UAVs reduces the risk of pilots operating in the air while offering the advantages of flexibility, adaptability, economy, and efficiency. The application field of UAVs is expanding and has become a hotspot for scientific and technological research today and in the future. The use of UAVs can reduce the risk of high-altitude and high-risk work, improve the quality and efficiency of work, and at the same time significantly reduce cost, such as in the fields of rescue, geologic disaster identification, and forest fire prevention [1-3]. Compared with the traditional way of working, the use of drone technology can respond to emergencies more quickly, more safely, and accurately understand the specific situation on the scene, and drones have the advantages of flexible route change, flexible monitoring and emergency deployment, etc. On the whole, the put into use of drone technology has promoted the development of most industries. The trend of increasing UAV applications means that there are more and more cases of special environments and complex terrains involved in UAV work in some fields, and these environmental conditions can have a greater impact on UAV takeoff and landing work.

In such diverse and complex terrain conditions, the issue of smooth takeoff and landing and the safety of UAVs is of paramount importance. The mechanical system of an aircraft's landing gear absorbs the load generated during landing and transfers a portion of it to the fuselage to dissipate a large portion of the impact energy. At the same time, the landing gear system also serves to maintain the stability of the vehicle during the ground phase and provides a safe distance between the fuselage and the ground to prevent damage to the UAV from direct contact with the ground [4]. As a key institutional component connecting the UAV fuselage with the ground, the UAV landing gear also plays a major role in providing stabilizing support and cushioning protection for the UAV fuselage. In addition, the landing gear allows enough space between the propeller and the ground, effectively minimizing airflow interference when the aircraft takes off and lands. Therefore, under the premise of not increasing the overall weight of the UAV and not affecting the flight status of the UAV, the design of the landing gear needs to be tailored to all kinds of complex terrains and environments to help improve the safety and stability of the UAV during takeoff and landing.

This paper aims to investigate the design principles of many different landing gear mechanisms and analyze the advantages and disadvantages of these landing gear mechanisms as well as adjustable ideas. At the same time, this paper lists the application scenarios and adaptable terrains of each type of landing gear and discusses the categorization. Finally, based on the results obtained from the analysis, this paper proposes the future development trend of UAV landing gear.

2. Various Landing Gear Mechanisms

2.1. Retractable structural landing gear

The retractable structure landing gear is based on the existing four-rotor landing gear through a single servomotor pulls the rope to drive the movement of the four landing gear legs at the same time to complete the retraction action of the landing gear, the structure is simple, and the materials used are extremely lightweight [5]. The principle of this landing gear retractable structure is shown in Fig. 1. It mainly comprises servo motors, high-strength soft ropes, lightweight pulleys, torsion springs, landing gear legs, limit columns, and other components. The servo motor installed in the central control room of the frame drives the landing gear No.2, and, at the same time, drives the other three landing gear legs, which cooperate to complete the release and contraction of the landing gear.

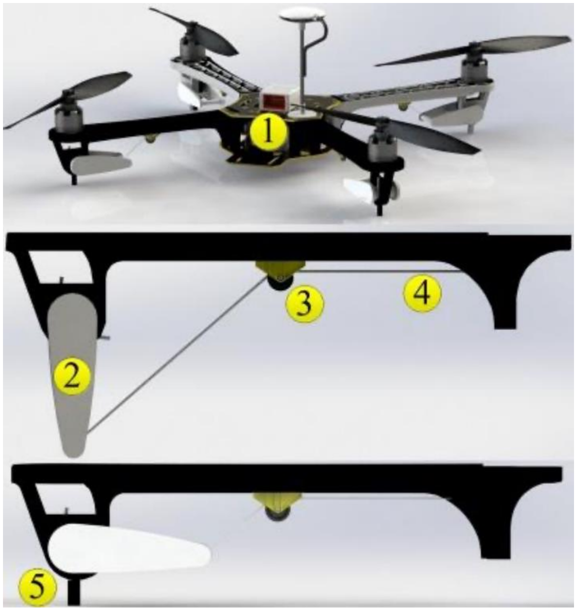

Fig. 1 Three-dimensional diagram of structural principle [5]

When the quadrotor is at rest, there is a certain amount of pre-tension in the torsion springs inside the landing gear legs to ensure that the landing gear legs are in a vertical position to support the fuselage. An angle sensor is mounted on the end of the servo motor for closed-loop position control. After the quadcopter takes off, the servomotor pulls the landing gear legs to the horizontal position through a high-strength flexible pull rope, overcomes the torque of the torsion spring, and locks the motors when they are in place to maintain the retracted state of the landing gear. By controlling the reverse of the servo motor, under the action of the torsion spring, the landing gear is returned from the horizontal position to the vertical position to realize the expansion of the landing gear. After the landing gear leg returns to the vertical position, it is restricted by the restriction column, and at the same time, the preload force of the torsion spring keeps it in the vertical state. At this time, the flexible wire rope is in a free state, reducing the fatigue of the servomotor and the wire rope, and improving the service life.

2.2. Automatic landing gear retraction

The automatic landing gear retraction and release can realize the single-input drive landing gear overall retraction and release [6]. The structure utilizes the spatial vertical combination of plane offset crank slider mechanism and flat face centric crank slider mechanism, and the crank of the plane offset crank slider mechanism is driven by the servo with constant angular velocity to oscillate in a certain range, so that the slider reciprocates along the guide rail, and then the plane centric crank slider mechanism converts the linear reciprocal movement of the slider to the oscillation of the crank, so as to realize the retracting and releasing motion of the landing gear support bar.

2.3. Passive perch landing structures for multi-rotor flying robots

Observing the passive perching landing structure of a multi-rotor flying robot [7], the landing mechanism structure is cleverly designed in such a way that it does not require additional brakes to achieve passive perching on the tip of a cylindrical object by simply using its own gravity. The structure consists of three fingers that passively close together when an object pushes the bottom of the vehicle upward, thus converting its own gravity into a gripping force. When the fuselage is lowered from the top of the cylinders and the bottom of the fuselage is pushed by the cylinders, a portion of the mechanism is weighted and the three fingers close. Sufficient gripping force is generated to support the weight of the airplane against the assumed diameter of the cylinders to hold the airplane in place even when the propeller is stopped. The two upper joints are fixed to the bottom of the fuselage and the cylinders are in contact with them. As the cylinders push upward on the bottom of the fuselage, the weight of the fuselage is applied to the center joint fixed to the side of the multi-rotor fuselage. Also, the mechanism can be used to support the plane's landing.

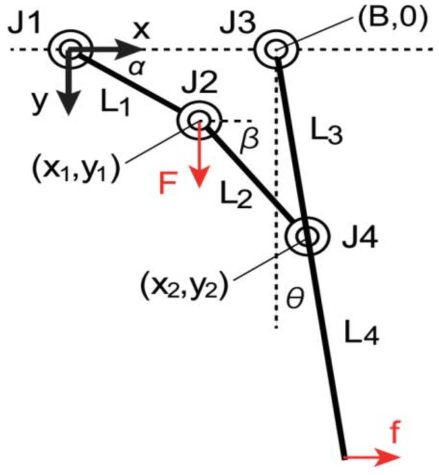

Fig. 2 Simplified model of the proposed perching mechanism, which converts the weight of the flying robot F into the grasping force f[7]

Fig. 2 illustrates the mechanism sketch model of the passive perching mechanism with a single finger, where the self-weight of the UAV is denoted as F. The whole joint is pushed downward by its own weight, while at the same time, the connecting rods L3 and L4 are rotated counterclockwise with the upper-right joint as the center of rotation. The lower end of this linkage can make contact with the cylindrical side surface of the target and provide the gripping force f. In this way, the proposed mechanism passively utilizes its own weight to achieve the perch without the use of additional actuators.

2.4. Inflatable Float Water Landing Structure

This type of mechanism system has a swimming ring-shaped float that can be inflated before landing and deflated after takeoff, utilizing an air pump system to control the float [8].

Inspired by past water landings, the structure uses a swimming ring-shaped inflatable float. With the use of a single plate float, the stability of the UAV for landing and takeoff from the water will be improved, while the deflatable float makes the UAV more controllable in somewhat windy conditions. Since there is only one air inlet on the inflatable float, a port connector was designed and to ensure that one of the air pump ports is always open to receive/distribute air when the other is running, two Y-valves were added to the ports as shown in Fig. 3. In the 3D structural model, 1, 2, and 3 illustrate the valves, air pumps, and valve switches.

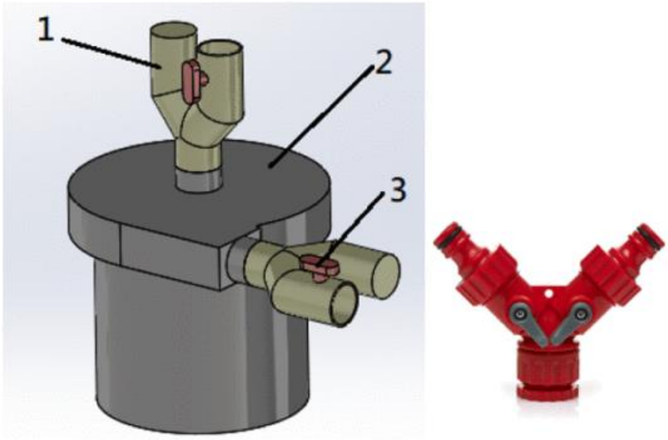

Fig. 3 SolidWorks 3D model and real y-shaped valve [8]

2.5. Multi-link bionic landing gear

Inspired by the foot and leg of locusts, dragonflies and other insects, and based on the bionic design concept, Ren et al [9] designed a bionic-legged landing gear. The multilink bionic landing gear has a certain loading capacity and can also meet the needs of stowage and folding. This landing gear adopts multiple legs of the same design, and the single leg adopts the configuration of a multi-link hybrid mechanism, as shown in Fig. 4. Inspired by the foot and leg of locusts, dragonflies and other insects, based on the bionic design concept, Ren et al [9] designed the bionic leg landing gear. The multilink bionic landing gear has a certain loading capacity and can also meet the needs of stowage and folding. This landing gear adopts multiple legs of the same design, and the single leg adopts the configuration of a multi-link hybrid mechanism, as shown in Fig. 4.

Fig. 4 Diagram of one-leg prototype [9]

The landing mechanism as a whole adopts four single legs to form the landing gear system (Fig. 5), and the four legs are symmetrically distributed with the same configuration and are mounted on the adapter plate. In order to facilitate the conversion and disassembly between the bionic legged landing gear and the original landing gear, the original landing gear mounting interface is retained, and the adapter disk is connected to the UAV with the original mounting interface, and rubber is added to achieve the purpose of shock absorption.

Fig. 5 Design form of bionic landing gear mechanism [9]

2.6. Modular landing gear based on roosting principles

As shown in Fig. 6, this is a modular landing gear designed by Hang et al [10] of Yale University based on the analysis of roosting habits of organisms such as birds and bats. This modular landing gear framework allows for stabilizing the UAV on various structures through perching and resting, improving the ability of the UAV to establish stable contact with the environment and roost while accomplishing tasks. Inspired and designed by a bird's claw, this type of perching landing gear is modularly mounted on the underside of the drone's fuselage, with components including servomotors, fingers, and a removable contact module.

For horizontal surfaces, the gripper module opens, and the stiff fingers are used as a landing skid, similar to a bird landing on a flat roof.

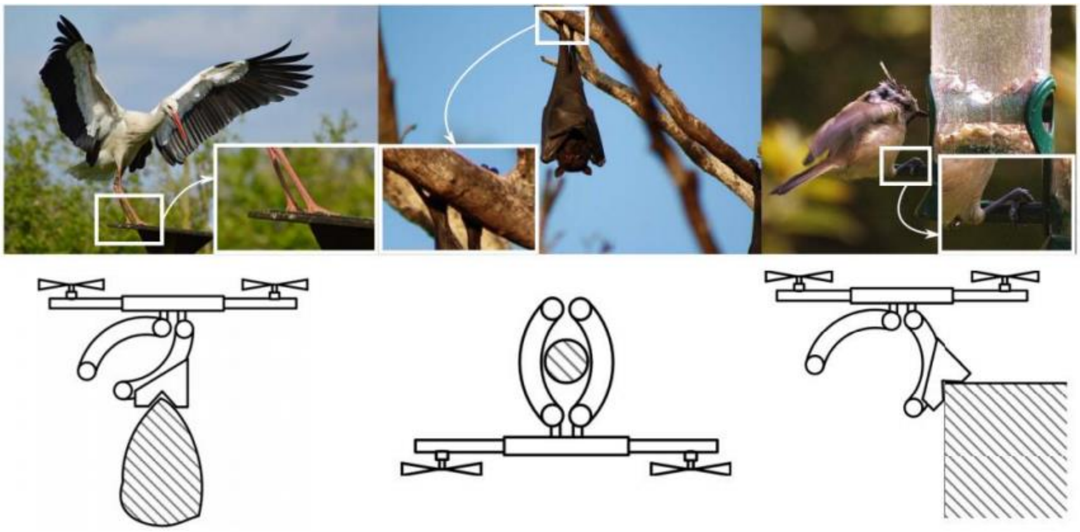

Fig. 6 Example of perching and resting actions in nature [10]

For cylindrical structures, the drone approaches from above and grabs the structure using the gripper module for suspension.

We rely on modularity for other types of structures, such as edges or corners of buildings, pillars, bars, or street signs, which gives us the flexibility to design and manufacture attachment modules to match a particular structure.

2.7. Bionic remora fish suction cups (landing gear-like)

The bionic remora suction cup design enables UAV adsorption on various surfaces in air and water, breaking the environmental limitations of conventional UAV landing gear [11]. The landing gear realizes trans-media adhesion and is able to stay on stationary surfaces or "hitchhike" on moving hosts, which greatly extends its working time and expands its monitoring area compared to remaining in a hovering state, providing new ideas for UAV operations.

Based on the morphological characteristics of the redundant adhesion mechanism of a biological Remora disc, the structure utilizes the basic principles of the Remora disc to realize an airborne-driven redundant biomimetic device, which employs a stacked fabrication method to integrate three functional layers into a single disc in order to realize three adhesion principles (redundancy, adaptive, and hydrostatic-enhanced adhesion).

3. Scenarios for each landing gear application

3.1. Retractable Landing Gear

This type of retractable landing gear has the advantages of being lightweight and small. However, due to its simple structure and low overall height, it has higher requirements for take-off and landing terrain. Therefore, it is usually suitable for more gentle ground. The take-off and landing of UAVs on complex or special terrain may be subject to greater environmental disturbances.

UAVs have a wide range of applications in agriculture, mapping, monitoring, traffic management, etc., and the lightweight and compactness of this landing gear structure can provide UAVs with greater flight flexibility and adaptability. For example, in the field of agriculture, UAVs can be used for crop spraying, fertilisation, and monitoring, and the retractable landing gear structure can make it easier for UAVs to take off and land in farmland, thereby improving agricultural productivity.

Secondly, this landing gear structure is also suitable for emergency rescue and disaster monitoring tasks. After a natural disaster, the UAV can be quickly deployed to the affected area for search, rescue and monitoring work. The lightweight and compact nature of the landing gear structure makes it easier for the UAV to take off and land in most terrains and environments, improving rescue efficiency and flexibility.

In addition, the landing gear structure can be used in scientific research and exploration missions. For example, the UAV can collect data and samples during scientific expeditions in extreme environments such as polar regions and oceans. The flexibility and adaptability of this landing gear structure allow the UAV to be better adapted to different scientific research tasks and provide scientists with more research tools and data support.

3.2. Multi-rotor flying robot passive perch landing structure

The passive perch landing mechanism design for multi-rotor flying robots has demonstrated its unique value and application prospects in several specific fields. In the area of infrastructure inspection and maintenance, this technology can provide engineers with a safer and more efficient way to inspect and maintain elevated facilities such as bridges, tunnels, wind turbines, and dams. Particularly where work at height is required, the landing gear provides reliable support, reducing reliance on personnel and minimising operational risk.

In terms of urban traffic management, the landing gear can be temporarily parked on various poles or lamp posts to monitor traffic flow, road conditions, and other information, providing real-time data support for urban traffic management departments.

3.3. Inflatable Float Water Landing Structure

The design of an inflatable float water landing structure is suitable for traditional water monitoring and rescue tasks and can play an important role in various application scenarios.

Firstly, in the field of marine resources exploration, the landing gear design can enable the UAV to accurately take off and land in the ocean, and realise the monitoring and exploration of marine organisms, seabed topography and marine meteorology. The UAV can easily cope with wave ups and downs and the effects of sea winds, providing reliable data support for marine resource development.

Secondly, in aquaculture management, the landing gear is designed so that the UAV can be easily flown over the water surface to monitor water quality conditions, fish growth and changes in the aquaculture environment of aquaculture farms. This helps farmers to manage their farms scientifically and improve aquaculture efficiency and production.

In addition, in marine scientific research, the landing gear design allows the UAV to carry out long-term observation and data collection in the ocean, providing real-time, high-precision data for marine ecosystem research. The UAV can cover a wide area of the ocean, helping scientists gain a deeper understanding of the marine ecosystem.

In addition, in terms of maritime transport monitoring, the landing gear design allows the UAV to conveniently cruise and monitor on the surface of the sea, monitor vessel activities, maritime traffic conditions and the condition of the waterway, and improve the safety and efficiency of maritime transport.

3.4. Multi-link Bionic Landing Gear

The multi-link bionic landing gear design is widely applicable to the application scenarios of multi-rotor UAVs. Firstly, it is suitable for mission execution under various rugged terrains. In mountainous areas, forests, deserts and other complex terrain environments, traditional fixed tripods are often unable to adapt to the irregularities of the terrain, while the landing gear structure is able to achieve a stable landing on uneven ground through its flexible design, ensuring the safe takeoff and landing of the UAV.

Secondly, the design of the landing gear structure is also advantageous for missions on sloping terrain. In mountainous and hilly areas, the terrain's inclination makes the traditional landing gear face the challenge of balance and stability. In contrast, the landing gear structure can enable the UAV to land safely on slopes and maintain a stable state through its adaptive and flexible support.

In addition, the landing gear design can also play an important role in applications that require landing in unknown environments, such as in exploratory missions, rescue operations, or military operations. UAVs may be required to perform missions in wild, urban, or other uncertain environments where terrain characteristics are often unknown and conventional landing gear is often inadequate. Through the design of bionic-legged landing gear, the UAV can better adapt to various unknown terrains and ensure the safety and stability of landing, thus improving the success and efficiency of the mission.

3.5. Modularised landing gear

Modular landing gear based on the principle of perching opens up many new application scenarios. Firstly, for missions that require observation from a fixed position for a long period, such as surveillance or gaze missions, the perch and rest functions bring significant advantages. They provide a greater field of view while maintaining good stability and reducing energy consumption. For aerial grabbing tasks, the perching capability allows the UAV to lift larger loads without rotor power, thus expanding the field of application. Additionally, drones can be used for high-altitude delivery of items without the need for continuous human operation. Regarding human-computer interaction, perched and resting UAVs can safely deliver items to persons located at high altitudes while reducing the risk of human interaction with the UAV.

3.6. Bionic Remora Fish Suction Cup Structure

The Bionic Remora Fish Sucker Structure exhibits a wide range of application scenarios and provides a unique capability for robots to perform tasks in both aerial and underwater environments. Firstly, the landing gear structure enables the UAV to park and attach outdoors, for example on the roof of a building, a sloping surface, or even a 45° inclined surface. This capability enables the UAV to perform outdoor surveillance and monitoring tasks, providing important technical support in security and environmental monitoring areas.

Secondly, the landing gear structure enables the UAV to perform a variety of tasks in an underwater environment, including underwater exploration, observation and sampling operations. The UAV can be quickly de-alerted from its standby state on the wall of a pool and attached to an underwater host, using propellers to align and securely attach it to the bottom surface of the host. This capability is important for marine scientific research, underwater resource exploration and other fields.

The landing gear structure also allows the UAV to attach to challenging surfaces such as narrow surfaces, damaged surfaces and even rocky surfaces in flowing water. This versatility allows the UAV to perform stably in a variety of complex underwater environments. Finally, the landing gear structure also provides significant support for the UAV's seamless transition between airborne and underwater environments. The UAV can achieve a stable transition between air and water while maintaining excellent attitude control and stability. This capability is important for application scenarios that require missions in different media, such as ocean observation and underwater exploration.

4. Discussion

4.1. Discuss and compare the characteristics of each landing mechanism

Observing retractable structural landing gears and auto-retracting landing gears, it can be seen that these mechanical structures usually use a single input to realize the overall attitude adjustment function. Due to their simple structure and general use of lightweight materials, this broad category of landing gear typically has the advantage of being lightweight overall and having less impact on the UAV's flight attitude or flight drag during flight. However, they are less capable of adapting to specific terrain environments and may not be able to perform smooth and safe takeoffs and landings in certain complex terrain.

In order to provide UAVs with the ability to land and take off in specific environments, designers have used special structural designs for landing gear or installed additional components to help UAVs land and take off in specific scenarios. For example, the passive perch landing mechanism of the Multirotor Flying Robot (MRF) is designed to allow the UAV to perch and land on columnar objects, and the inflatable float water landing mechanism is designed to provide the UAV with the ability to land and take off smoothly on the water surface during partial water work. These types of landing structures are designed to be more adaptable to specific environments than simpler types of landing gear structures, but there are problems with the overall weight of the UAV being too high due to the complexity of the structure or the components used, which may affect the flight endurance or increase the resistance to flight.

Referring to the multi-link bionic landing gear, modular landing gear based on habitat principle, and bionic remora fish suction cup type landing gear, most of the inspiration for the animal simulation design of this kind of landing gear comes from the animal posture when people optimize the landing and take-off maneuvers of UAVs, in order to better optimize the design of the landing gear structure for a specific environment. Inspired by the foot-standing posture of locusts, dragonflies, and other insects, the design of the multi-link bionic landing gear, the result of this bionic greatly improves the adaptability of the link-type landing gear to the landing terrain, which can help the UAV to land smoothly even on the ground with greater slopes. Comparing the modular landing gear designed according to the roosting habits of birds and bats with the passive roosting landing mechanism of the multi-rotor flying robot designed for cylindrical objects in the non-biomimetic case, it is easy to find that the former can be more adaptable to similar environments, for example, not only can it be adapted to cylinders, but also can be used for the roosting of vertical bodies with irregular cross-section. Meanwhile, comparing the listed inflatable float water landing mechanism with the bionic remora fish suction cup landing gear, it can be observed that this kind of design can be adapted to a wider range of conditions, and some of the designs have already realized cross-boundary qualitative success. In addition, most bionic landing gear designs have the advantage of modular installation, which allows users to add or remove parts in order to realize the landing and takeoff of the UAV in different environments.

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From the above comparative analysis of landing gears, it is not difficult to find that the design of landing gears in different environments is crucial, and the design of landing gears should be guided by adapting to as many environments as possible in order to cope with different environments, the modularized design scheme of UAV landing gears can be an important direction to consider.

4.2. Future landing gear design trends

Under the basic conditions of ensuring light weight and not affecting the flight attitude of the UAV, the design of the UAV's landing gear should try to realize the adaptability of take-off and landing in various environments. On the premise of not increasing the weight of the whole UAV, consideration can be given to adopting a modularized interchangeable landing gear design so that when dealing with different special geographic environments, the user can choose to assemble the corresponding landing gear, which can help realize the smooth takeoff and landing of the UAV. The modularized replaceable landing gear design will also reduce the coupling between the UAV and the bracket to a certain extent, making it easier to repair and replace the landing mechanism when it is damaged, which greatly facilitates the maintenance of the UAV. In the future, the innovative or optimized landing gear design can be directly applied to the UAV.

5. Conclusion

The landing gear is a key component of a UAV, and its design directly affects its take-off and landing performance and adaptability in various environments. After comparing the advantages and disadvantages of each landing gear and the scenarios in which they can be used, it can be seen that with the continuous development of UAV technology, the design of landing gears has also been continuously innovated and improved. Landing gear designs are diverse and innovative, including bionic and modular interchangeable designs. Bionic design is a design concept originated from nature, which improves the adaptability and flexibility of UAVs by imitating biological structures and movements. For example, a bionic landing gear can mimic the leg structure of an insect, enabling the UAV to better adapt to complex terrains and environments. This design enhances the UAV's ability to take off and land in special environments and improves its stability and safety. On the other hand, the modular interchangeable design provides greater flexibility and convenience for the UAV's landing gear. This design breaks down the landing gear into multiple modules, allowing users to select and replace different types of modules according to their specific needs to adapt to different environments and mission requirements. For example, in the case of needing to operate in different terrains, users can choose the appropriate landing gear module according to the terrain, thus improving the adaptability and versatility of the UAV.

In the future, the development trend of landing gear design will mainly focus on lightweight, multi-environment adaptability and intelligence. As UAV application scenarios continue to expand, the demand for landing gear is also increasing. Lightweight design can reduce the overall weight of UAVs and improve their flight performance and endurance; multi-environment adaptability design can enable UAVs to take off and land in various complex terrains and environments; intelligent design can enable UAVs to have the ability to identify and respond to the environment independently and improve their autonomous flight and mission execution capabilities.

Overall, the design of landing gear will continue to be orientated towards adapting to different environments, providing key support for the development of UAVs. As technology continues to advance and innovate, it is believed that future landing gear designs will be lighter, more flexible and intelligent, providing UAVs with a greater role in various application scenarios.

Authors Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

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