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# Research and Design of a Multifunctional Biomimetic Hedgehog

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**Abstract:** This paper explores the research and design of a multifunctional bionic hedgehog, aiming to develop a robot that can mimic the characteristics of hedgehogs in nature. Through in-depth analysis of the biological characteristics of hedgehogs, such as their unique spiny hair structure and adaptive behaviours, the research team designed a bionic robot that integrates multiple functions. The robot not only mimics the movement of a hedgehog, but also possesses advanced functions such as environment sensing, obstacle avoidance and self-protection. Advanced material science and robotics were used in the design process to ensure the durability and flexibility of the robot. This research provides new possibilities for future applications in search and rescue, exploration and environmental monitoring.

**Keywords:** Multifunctional Biomimetic Hedgehog; Spiny Hair Structure; Adaptive Behaviours.

## 1. Introduction

With the continuous development of science and technology, economic conditions are increasingly improved today, automated production has been an indispensable part of daily production. For example, in the military field of detection, collection of information processes, bionic robots have been widely used. Most of the existing robots are not easy to put, and it is necessary to design robots that are easy to put. In nature, hedgehogs are known for their unique survival strategies and adaptive behaviours. Hedgehogs can be curled up when encountering danger, and the overall size of the curled up hedgehog is smaller, which is easy to place, while the coat of hedgehogs can be used to defend against external enemies, and the height of hedgehogs when walking with the coat unfolded is lower, which is better to hide, and the prickly hairs covering its body is not only a defence mechanism, but also a key feature of its adaptation to a variety of environments [1]. Inspired by this biological phenomenon, this study is dedicated to the development of a multifunctional bionic hedgehog robot, as well as the design of a multifunctional bionic hedgehog based on the principles of mechanical design and electrical control, and the principles of bionics, aiming to mimic the biological characteristics and behavioural modes of hedgehogs, and designing robots capable of carrying out complex tasks by combining the latest advances in biology, materials science, and robotics with functions that include, but are not limited to, environment perception, mobility, and self-protection. In this paper, we will introduce in detail the design concept, technical realisation and potential applications of the bionic hedgehog robot, aiming to promote the further development of bionics in the field of engineering and technology.

Bionic robotics has experienced rapid development since the late 20th century. Early bionic robots focused on mimicking the basic movement patterns of animals, such as Boston Dynamics' BigDog, a quadrupedal robot that mimics the way a dog walks [2]. As technology progressed, the functionality and complexity of bionic robots continued to increase, such as MIT's Cheetah robot, which is capable of high-speed running, and Japan's ACM-R5 Mimuro Snake robot, which demonstrates the superior mobility of snake-like robots in complex terrain. These advances not only demonstrate the great potential of bionics in the field of robotics, but also lay the foundation for subsequent research. The biological characteristics of hedgehogs, as a small mammal, have been extensively studied. The hedgehog's prickly hairs are composed of keratinised cells, which are able to stand up quickly to form an effective defence barrier in the event of a threat [3]. In addition, the hedgehog's habit of moving at low speeds and being nocturnal provides an advantage for its survival in specific environments. Biologists have conducted in-depth studies on the behavioural patterns, physiological structures and ecological adaptations of hedgehogs, and these findings provide valuable biological data and theoretical foundations for the design of bionic robots.

Existing bionic robots have technically realised a variety of functions, such as environment sensing, autonomous navigation and complex action execution. For example, the RoboBee micro-robot mimics the flight mechanism of a honeybee and is able to fly stably in a breeze. However, despite the success of these robots in specific fields, they still have limitations in mimicking the unique biology of hedgehogs. Existing bionic robots tend to focus on the implementation of single functions and lack in-depth exploration of multifunctional integration and environmental adaptability. Despite significant progress in bionic robotics research, there is still a research gap in mimicking the biological characteristics and multifunctional integration of hedgehogs. The innovation of this study is to design a bionic robot that can mimic the structure of hedgehog's prickly hairs and adaptive behaviours, and integrate multiple functions, such as environment sensing, obstacle avoidance and self-protection. By combining advanced material science, sensor technology and intelligent algorithms, this research aims to fill the gaps in existing technologies and promote the application of bionic robots in complex environments [4]. In addition, this research will explore the potential applications of robots in the fields of search and rescue, exploration, and environmental monitoring, providing new directions for future technological development.

# 2. Materials and Methods

## 2.1. Design Concept of Bionic Hedgehog Robot

The design concept of this study is to create a bionic hedgehog robot that can move flexibly in multiple environments and perform complex tasks. The core of the design lies in mimicking the biological characteristics of hedgehogs, including their unique spiny hair structure and adaptive behaviours. By integrating advanced sensors, actuators and intelligent control systems, the robot will be able to achieve functions such as environment perception, autonomous navigation and self-protection. During the design process, we focus on the robot's multifunctionality and environmental adaptability, and strive to improve the robot's practicality and reliability while maintaining its biological similarity. The overall framework design consists of six modules: motion module, ultrasonic ranging module, energy storage and supply module, and control module, as shown in Figure 1.

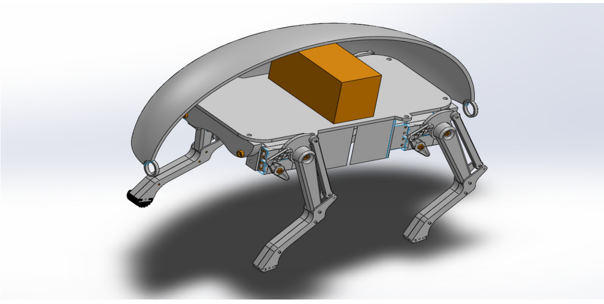

**Figure 1.** Overall framework design

## 2.2. Material Selection and Design of Bristle Structure

In order to realise the bionic effect of hedgehog's prickly hairs, we chose composite materials with good elasticity and abrasion resistance as the base material of the prickly hairs. The design of the bristles adopts a modular structure, where each bristle unit is able to move independently to simulate the reaction of a real hedgehog when it encounters a threat. In addition, the surface treatment of the bristles increases their impact resistance and self-cleaning ability, ensuring the durability and maintenance convenience of the robot in complex environments.

## 2.3. Selection of Sensors and Actuators

In order to equip the robot with the ability of environment sensing and autonomous navigation, we chose a variety of sensors, including infrared sensors, ultrasonic sensors, and vision cameras, to achieve comprehensive monitoring of the surrounding environment. For the actuators, we used high-torque micro-motors and flexible joint designs to ensure that the robot can achieve precise motion control and efficient energy utilisation.

## 2.4. Control System and Algorithm Development

The control system of the robot adopts a distributed architecture, which communicates with each sensor and actuator in real time through a central processing unit. For algorithm development, we introduced machine learning and path planning algorithms to enable the robot to autonomously adjust its behavioural strategies according to environmental changes. In addition, we have developed self-protection algorithms that enable the robot to quickly take defensive measures when it encounters obstacles or threats.

## 2.5. Manufacturing Process and Assembly Technology

In order to achieve efficient manufacturing and precise assembly of the bionic hedgehog robot, we adopted a modular manufacturing process. Each component is carefully designed to facilitate mass production and quality control. During the assembly process, we use precise positioning and fixing techniques to ensure accurate docking and stable operation of each component. In addition, we have developed an automated testing process to verify the robot's functions and performance indicators to ensure the reliability and consistency of the final product.

# 3. Experimental Design and Results

## 3.1. Experimental Platform Construction

In order to verify the design concept and technical implementation of the bionic hedgehog robot, we built a multifunctional experimental platform. The platform includes a test site that simulates a variety of terrains and environments, as well as a high-precision data acquisition system. The test site is designed with different obstacles and challenges, such as slopes, narrow passages, and simulated vegetation areas, to evaluate the robot's mobility and adaptability in complex environments. The data acquisition system, on the other hand, is equipped with sensors and camera devices to record the robot's trajectory, behavioural responses and performance parameters.

## 3.2. Performance Evaluation

During the functional testing phase, we conducted a comprehensive performance evaluation of the bionic hedgehog robot. The tests included the robot's movement speed, turning radius, climbing ability, and the defence response of the hedgehog. By comparing the robot's performance in different terrains and environments, we evaluated its locomotor agility, stability, and energy efficiency. In addition, we tested the robot's environmental awareness, including detection and avoidance of obstacles, and adaptation to light changes. To validate the robot's environmental adaptability, we conducted a series of environmental adaptation tests. These tests included operational tests under different temperature and humidity conditions, as well as performance evaluation under simulated extreme weather conditions (e.g., wind, rain). We also tested the robot's visual perception ability at night and in low-light conditions, as well as its stealth and mobility efficiency in complex vegetation environments. Through these tests, we aimed to assess the reliability and survivability of the robot in real-world applications.

## 3.3. Data Analysis and Discussion of Results

By analysing the experimental data in detail, we derived the performance of the bionic hedgehog robot in each test. The data analysis shows that the robot shows good mobility and environmental adaptability in a variety of simulated environments. In particular, the robot's autonomous navigation and obstacle avoidance abilities were significantly improved in complex terrain and low-light conditions. In addition, the robot's spiky defence mechanism showed effective protection when encountering shocks. Based on these results, we discuss the potential advantages and possible improvement directions of the robot in practical applications, providing valuable references for future research and development.

# 4. Discussion

In the process of designing a multifunctional bionic hedgehog robot, we faced several technical challenges. Among them, how to accurately mimic the structure and movement mechanism of hedgehog's prickly hair is a major challenge. To solve this problem, we used high-precision 3D printing technology and customised composite materials to achieve flexibility and durability of the prickly hairs. In addition, the robot is challenged with autonomous navigation and environment awareness, and we improved its performance by integrating multiple sensors and developing advanced algorithms. With these innovative solutions, we successfully overcame the technical barriers in the design and realised the robot's versatility and environmental adaptability. Experimental results show that the bionic hedgehog robot exhibits excellent performance in a variety of test environments. The robot's mobility and obstacle avoidance capabilities were verified in complex terrains, while its spiny defence mechanism effectively protected the robot's critical components in the event of an impact. These results demonstrate the validity of our design concept and show the potential of the robot in real-world applications. Through further data analysis, we found that the robot's energy efficiency and stability maintained a high level under different environmental conditions, which provides a solid foundation for its application in a variety of tasks.

Compared with existing bionic robots, our multifunctional bionic hedgehog robot demonstrates unique advantages in mimicking biological features and multifunctional integration. For example, our robot focuses more on ground mobility and environmental adaptability than a micro-drone that mimics insect flight. Compared to a snake robot, our design focuses more on versatility and utility while mimicking specific biological traits. Through this comparison, we can see that although each bionic robot has its specific application scenarios, our design has significant advantages in terms of comprehensive performance and application potential. The multifunctional bionic hedgehog robot has a wide range of potential application scenarios, including search and rescue missions, environmental monitoring, scientific exploration, and educational displays. In search and rescue missions, the robot's small size and flexible mobility allow it to enter small spaces and perform search and rescue tasks. In the field of environmental monitoring, robots can be used to test air quality, water quality or soil composition, especially in hard-to-reach areas. In addition, robots can be used as a research tool to help scientists better understand the ecology and behaviour of hedgehogs. Market analyses show that the demand for bionic robots in the education, entertainment and professional services markets will continue to grow as the technology matures and the cost decreases, providing a broad prospect for future commercial applications.

# 5. Conclusion and Outlook

In this study, a multifunctional bionic hedgehog robot was successfully designed and implemented, which is capable of mimicking the biological characteristics and behavioural patterns of hedgehogs and exhibits excellent performance in a variety of environments. By integrating advanced sensors, actuators and intelligent control systems, the robot achieves multiple functions such as environment sensing, autonomous navigation and self-protection. The experimental results verify the effectiveness of the robot's mobility flexibility, obstacle avoidance ability and stinging defence mechanism in complex terrains. These results not only demonstrate the potential of bionics application in robotics, but also provide valuable experience and data for future research and development.

Despite the remarkable progress made in this study, there are still many aspects that deserve further exploration. Future research could focus on the following areas: firstly, further optimising the energy management system of the robot to improve its range and energy efficiency. Second, developing smarter algorithms to enhance the robot's ability to make autonomous decisions and adapt to complex environments. In addition, explore the possibility of robots in more application scenarios, such as agricultural monitoring and disaster early warning. Finally, strengthen the cross-fertilisation with biology research to draw more design inspirations from nature and promote the technological innovation of bionic robots. The technological development of multifunctional bionic hedgehog robots is expected to have a profound impact on several fields. In the field of search and rescue and rescue, the application of robots will improve the efficiency and safety of rescue, especially in humanitarian assistance after disasters. In environmental monitoring and scientific exploration, robots will be able to access areas that are difficult for humans to reach for data collection and ecological research. In addition, with the popularisation of the technology and the reduction of costs, bionic robots are also expected to play a role in the fields of education, entertainment and family services, bringing convenience and fun to people's lives. In the long run, the development of bionic robots will push forward the progress of robotics technology, promote the development of human-robot interaction and intelligent systems, and contribute to the future progress of science and technology and social development.

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