

Design and Optimisation of Bionic Frog Hind Limbs

Yongyi He

School of Mechanical Engineer, Hangzhou Dianzi University, Hangzhou, China

20011112@hdu.edu.cn

Abstract. With the deepening of human exploration of the Earth, more and more survey tasks are being carried out in unstructured environments. Biomimetic robots that can replace humans in completing related tasks under harsh conditions have gradually become a hot topic in robot development. Therefore, developing a biomimetic robot with a wide range of activities, strong mobility, excellent obstacle crossing ability, and rapid avoidance response has important theoretical research significance and broad application prospects. This paper focuses on frogs as the research object, research is conducted from the perspective of institutional design, aiming to design a frog like jumping robot with strong obstacle crossing ability and good environmental adaptability. In terms of overall structural design, a M-shaped structure based on linear bearings was proposed to ensure the stability of the robot during takeoff and landing; In terms of leg structure design, C-shaped flexible springs are used to integrate the calf, ankle joint, and foot into one, which can play a buffering role when the robot lands; In terms of transmission structure design, Propose to control the compression cycle of the jumping leg through a cam to achieve continuous jumping of the robot. The relevant research results indicate that the structural principle of the designed frog like jumping robot is correct, and the jumping effect is relatively good. For the sake of ideals, this paper provides a certain theoretical basis and basis for further research on bionic jumping robots.

Keywords: Biomimetic; jumping robot; structural optimization.

1. Introduction

In recent years, the development of robots has gradually evolved from simple mechanical structure design to multi learning. Cutting-edge technologies that are interrelated across multiple fields. With the continuous progress of science and technology, the era of Industry 4.0 has arrived. Countries around the world will be committed to integrating resource allocation and building smart factories with the goal of promoting industrial intelligence development. On the road of industrial intelligence, the development and innovation of robot technology will undoubtedly become a top priority. In this context, robotics technology is gradually shifting from traditional fixed-point operations under known environmental conditions. Transition towards autonomous work under unknown environmental conditions [1].

With the continuous development of science and technology, there is a growing interest in biomimicry and the study of organisms in nature, thus promoting the development and application of bionic technology. As an interdisciplinary field, bionics integrates many disciplines such as biology, physics, material science and engineering technology, aiming to study the structure, function and working principles of living organisms and apply these principles to the development and creation of new technologies. Among them, the bionic frog, as a biological model with high intelligence and adaptability, has important research value and practical significance in the field of bionics. Through designing and making bionic frogs, we can cultivate innovative thinking and hands-on ability, master advanced science and technology through practice, and improve the ability to solve practical problems. The design and production of bionic frogs involves the knowledge of many disciplines, such as biology, material science and mechanical engineering, etc. Through the research of this topic, we can promote the communication and co-operation between different disciplines and broaden students' knowledge horizons. Meanwhile, the application of bionic frogs is also of great significance to the field of biomedical engineering. With the technology of bionic frogs, smarter and more precise medical devices and surgical tools can be developed [2]. For example, bionic frogs can provide doctors with more accurate positioning and navigation to help achieve minimally invasive surgeries,

thus reducing patients' pain and recovery time. In addition, the bionic frog's ability to swim can inspire the design of more energy-efficient and environmentally friendly water vehicles, promoting sustainable development and green travel. The structure and form of bionic frogs can also provide inspiration for architectural design, resulting in more stable and efficient building structures. Overall, the design and production of bionic frogs is of great significance in promoting the progress of science and technology and providing new ideas and methods for the development of robotics, artificial intelligence and other fields. By studying bionic frogs, we can better understand and apply the intelligence in nature to create more advanced and adaptable technologies and products. This will not only bring convenience and innovation to human beings, but also provide new ways and possibilities to solve various practical problems.

The main problems to be solved in this design include how to accurately simulate the frog's various biological functions, such as muscle movement, sensing the environment, etc., which is an important issue in the design and production process. How to deeply study the biomechanical characteristics of frog jumping and reveal the mechanical principle of frog bouncing. How to extract the key parameters of the frog jumping process, such as jumping height, distance, frequency, etc., to provide basic data for the design of the bionic frog. How to design mechanical structures that can simulate the elasticity of frog muscles, such as springs, etc., to realise the effect of the frog when jumping. How to design the connection between frog muscle and bone, and design the mechanical structure that can simulate the connection between frog muscle and bone to improve the jumping performance of the bionic frog.

Research on bionic frogs has a long history in domestic and international academic circles, and many scholars have created a series of robots with special functions by imitating the physiological structure and behavioural characteristics of frogs in nature.

A research team from the California Institute of Technology (Caltech) has developed a bionic frog robot called Amphibot [3]. A team of researchers at the Karlsruhe Institute of Technology in Germany has designed a biomimetic frog robot called Biomimetic Salamander Robot [4]. A research team from Beijing University of Aeronautics and Astronautics has developed a biomimetic frog robot called "Bio-bot" [5]. A research team from Sungkyunkwan University in South Korea has designed a biomimetic frog robot called "Frogbot" [6]. The "Jumping Frogbot" bionic frog robot from Tokyo Institute of Technology has a leg structure that mimics the leg muscles and bone structure of a frog [7], allowing the robot to jump effectively on the ground. The Amphibot bionic frog robot from the Georgia Institute of Technology in the United States also has the ability to jump and swim on the ground and in water. Scholars in the field of bionic frog research has achieved fruitful results.

2. Research Methods

2.1. Research Steps

First, the research objectives and research questions for the bionic frog were identified. The main objective is to design and build a bionic frog robot that can survive and move both in water and on land. This includes designing the robot's body structure so that it can move in different environments, as well as giving it perception and decision-making capabilities [8].

Next, literature research was conducted to understand the work of other researchers in this field, including reading relevant scientific papers and technical articles, as well as looking at the design and implementation of other bionic robots.

Next, after defining the research objectives and questions, as well as conducting the literature research, the next step is to design. The design phase may include making sketches and building models. During this process, the robot's body structure, material selection, and locomotion and perception mechanisms need to be considered.

This is followed by the manufacturing and assembly phase. This phase builds the parts of the robot from the design drawings and assembles them together. This process involves the use of various machining tools and equipment, such as saws, drill presses, and 3D printers.

Then, experiments and tests are conducted. The goal of this phase is to verify the performance and functionality of the robot. This includes testing the robot's mobility in different environments and conditions [9].

Finally, the experimental results need to be analysed and summarised. The whole research process is reflected upon to identify the strengths and weaknesses of the research and to make suggestions for improvement.

2.2. Source of Information

1) Literature analysis method: by reviewing relevant scientific literature, the researcher can understand the physiological structure, behavioural patterns and mechanics of frogs. This knowledge is crucial for designing bionic robots. Literature analysis can help the researcher to understand the work of other research teams so as to avoid duplication of efforts and to be able to learn from the experiences and lessons of others.

2) Experimental design method: through experiments, the robot can be tested for jumping performance, swimming performance and other related functions. Experimental design includes choosing suitable materials, constructing suitable mechanical structures, and adjusting control system parameters. The experimental results can be used to evaluate the design and provide a basis for improving the robot.

3) Mathematical statistics: mathematical statistics analysis can be used to quantify robot performance, such as jumping distance, and to assess the relationship between these performances and design parameters. Mathematical statistics can also help the researcher to identify potential problems, such as random errors and systematic deviations, so that appropriate measures can be taken for improvement.

2.3. Research Measures

The biomechanical properties of the frog were observed and analysed in detail, including its muscular structure, skeletal system, joint movement, etc., especially its mechanical properties when bouncing.

Collect the movement data of the frog when jumping, including the height, distance and frequency of the jump. According to the flexibility and stability of the frog's joints, design a mechanical structure that can simulate the frog's joint movement.

According to the biomechanical characteristics of frog jumping, establish a kinetic model, which is used to guide the design of the control system.

Through simulation experiments, the parameters of the control system are continuously optimised so that it can accurately control the jumping of the bionic frog. Under laboratory conditions, the bionic frog's jumping performance is tested, including jumping height, distance and frequency.

In the field environment, the bionic frog's jumping performance is tested, including the performance under different terrain and temperature conditions. Based on the experimental results, the design of the bionic frog is continuously optimised to improve its bouncing performance.

3. Materials

3.1. Motion Control Module

1) Jump control. The main purpose is to use the obtained path information to complete the setting of jumping parameters (angle, energy), complete the adjustment of attitude, energy storage, energy release and other actions, so as to complete a jump with a specific angle and a specific height.

2) Stability control. In the airborne phase of the frog, it is necessary to maintain the balance of the robot and prepare for the landing in advance; in the landing phase, the robot should actively adjust the posture to prevent tipping.

Based on the study of biological frogs, the jumping robot mechanism design explored in this paper is shown in Fig. The robot model is established on the basis of the study of SLIP jumping robot with

improved torso movement angle and leg structure configuration. The robot consists of lower legs, thighs and torso, The details are as follows: 1) The robot calf and foot are solidly connected together by elastic material, the angle is p , the length of elastic foot 1, the length of calf 2l, the mass of calf (including foot) as well as the rotational inertia are m and I respectively, the centre of mass C is at the centre of calf BD and coincides with point C ; 2) The length, mass as well as the moment of inertia of rotation of the thigh are $2l_1$, m_2 , I_2 , centre of mass C , at the centre of the thigh AB ; 3) The length, mass and rotational inertia of the torso are $2l_2$, m_3 , I_3 , centre of mass C ; at the centre of the torso EF , at a distance of l from point A . 4) The angle between the ball of the foot and the horizontal plane is q . The knee joint q_2 and the hip joint q_3 , which are passive joints. A compression spring is fixed between the hip joint and the lower leg with a spring stiffness of k . Where, (x_0, y_0) are the coordinates of the robot's toe position.

3.2. Design of The Transmission Mechanism

The design considers a gear set as the transmission system of the frog-like jumping robot installed inside the torso, so the design needs to ensure that it has a high transmission efficiency, but also to meet the requirements of a compact installation structure. The design considers a small motor as the output power source and applies multi-stage gearing to increase the transmission ratio to achieve torque multiplication. In this way, even a smaller motor can drive a larger load, while meeting the objective requirements of compact structure and high transmission efficiency. At the same time, the cam mechanism is mounted coaxially with the output shaft of the gear set, so that the control of the jumping cycle can be realised by selecting the motor with the appropriate rotational speed. The introduction of the cam mechanism enables the robot to achieve both intermittent jumps and continuous jumps, simplifying the design of the control system.

3.3. Overall Structure Design

The frog-like jumping robot is mainly composed of four parts: torso, hip joint, hip joint support axis and jumping legs, as shown in Figure 1. Among them, the torso is installed with motors, gear systems, cams and other components, the hip joint is a linear bearing, the hip joint support shaft is installed and fixed on both sides of the torso in a mirror image symmetrical way, the jumping leg is elastic, the figure is a simple illustration of the spring for the time being, and the whole is in an M-shape structure.

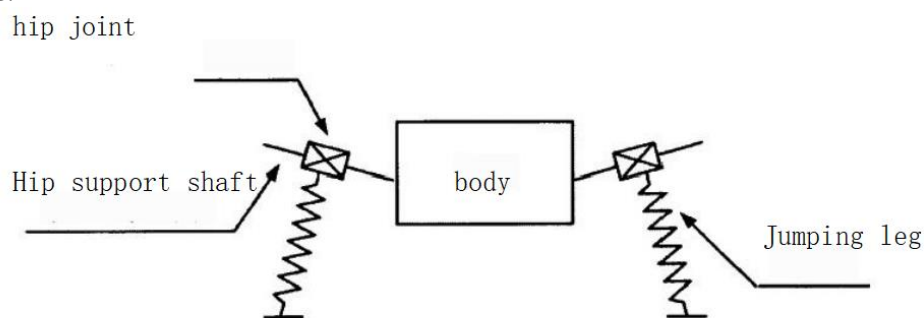


Fig 1. Fron-like jumping robot (Ptoto credited: Original)

It is important to note that the hip support shaft is not simply mounted horizontally on the ground, but is mounted at an angle to the torso in a mirror image symmetrical manner on both sides of the torso. This is because the torso will be unstable due to the rotation of the linear bearing sliding, and the existence of this angle effectively avoids the unstable movement, so that the degree of freedom of the torso is always maintained at 1, i.e., up and down movement. At the same time, this installation also makes the two jumping legs form a certain angle with the ground, which provides a strong guarantee for the stability of the robot in the jumping and landing phases. In conclusion, the optimised structure has a better jumping attitude.

4. Discussion

4.1. Structure of Hind Limb Model

The jumping leg assembly in the structure contains five parts: thigh, knee, calf, ankle and foot, and the optimised jumping leg consists of only three parts: thigh, knee and C-shaped foot. Assembly 3D diagram as shown in Figure 2. The three-dimensional assembly effect diagram of the cam component is shown in Figure 3.

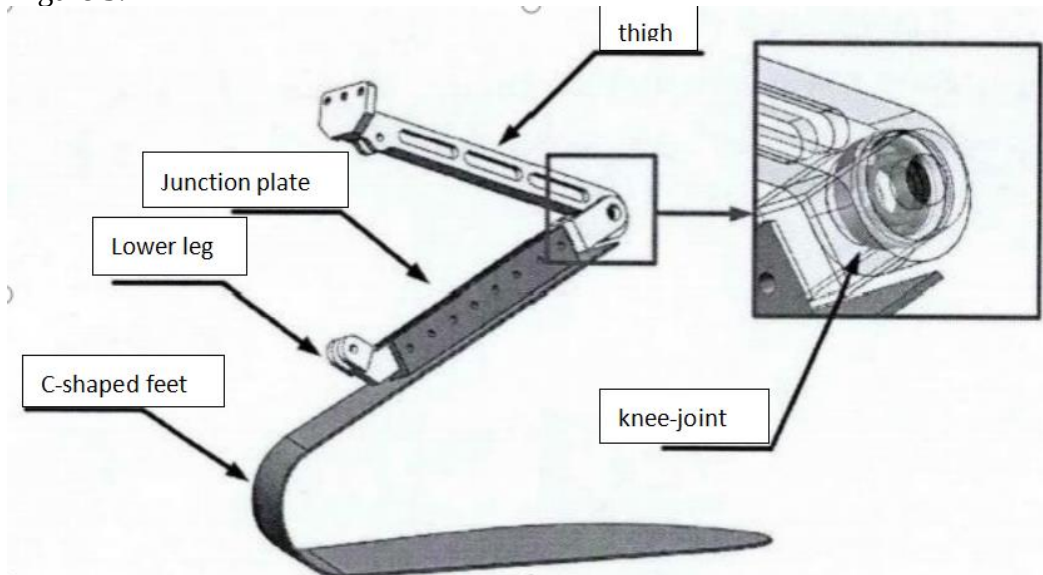


Fig. 2 3D assembly rendering of jumping legs [10]

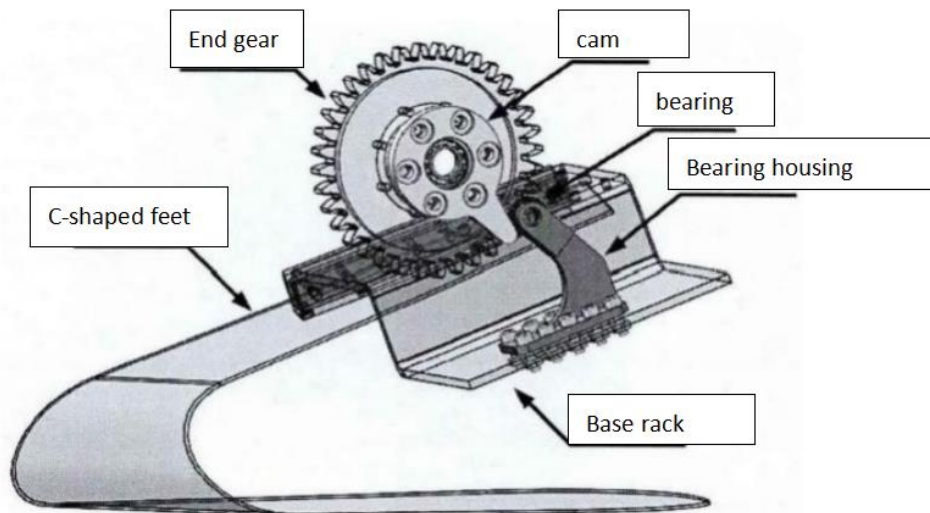


Fig. 3 3D assembly rendering of cam components [10]

4.2. The Movement Process of Hind Limb Structure

In the cam assembly, the bearing is mounted as a follower on the base frame at a constant height relative to the floor, and has one and only one degree of freedom to rotate. The cam is mounted inside the torso on the same axis as the end gears of the gear train. When the cam rotates at equal speed and touches the bearing, which is fixed in height, the bearing rotates and the cam is pushed down by the resistance of the bearing. Since the cam is connected to the end gears of the gear set and the gear set is mounted in the frame of the torso, the cam is pressed downwards and the torso is moved downwards at the same time. After a certain angle of rotation, the cam is released from the bearing and a new compression cycle is initiated. It is important to note that the compression cycle can be adjusted by controlling the cam speed. When the compression cycle is exactly equal to the duration of the airborne

phase, the frog-like jumping robot can finish the compression before the next landing and achieve continuous jumping. Figure 4 shows how the hind limbs work to achieve jumping.

The overall M-shaped structure of the frog-like jumping robot helps to improve the stability of the robot when jumping and landing. As the robot transmission system is smooth, so under the premise of ensuring the reliability of the transmission, the design considers the selection of better overall performance of 45 steel as the gear material. Secondly, the foot has a certain elasticity and large volume, so the design considers a thinner C-type reed (steel) as the foot, which can provide elasticity and ensure the requirement of lighter quality. Finally, the remaining non-standard parts are designed to be made of aluminium alloy in order to reduce the mass.

At the same time, the robot's trunk is a gearbox, which is because the gear assembly is complex, so the design considers the gearbox as the fixed frame of the gear group. In the following sections, the structural design will be introduced accordingly. In hip joint components, the design considers simulating biomimetic hip joints with linear bearings. The design considers installing the hip joint support shaft in a mirror symmetrical manner on both sides of the gearbox, forming a certain angle with the gearbox. The bearings in the cam assembly are installed on the bearing base, which is fixed to the base frame, allowing the bearings to have only one degree of freedom to rotate. When the cam rotates to make contact with the bearing, due to the unchanged position of the bearing, the cam will move the entire torso downwards. At this time, the hip joint slides away from the torso, the thighs fold inward, and the spring compression completes the energy storage step. When the cam rotates at a certain angle and disengages from the bearing, the spring is released, and the thigh collides with the blocking plate fixed on the base frame to achieve jumping. Figure 5 shows a complete compression cycle.

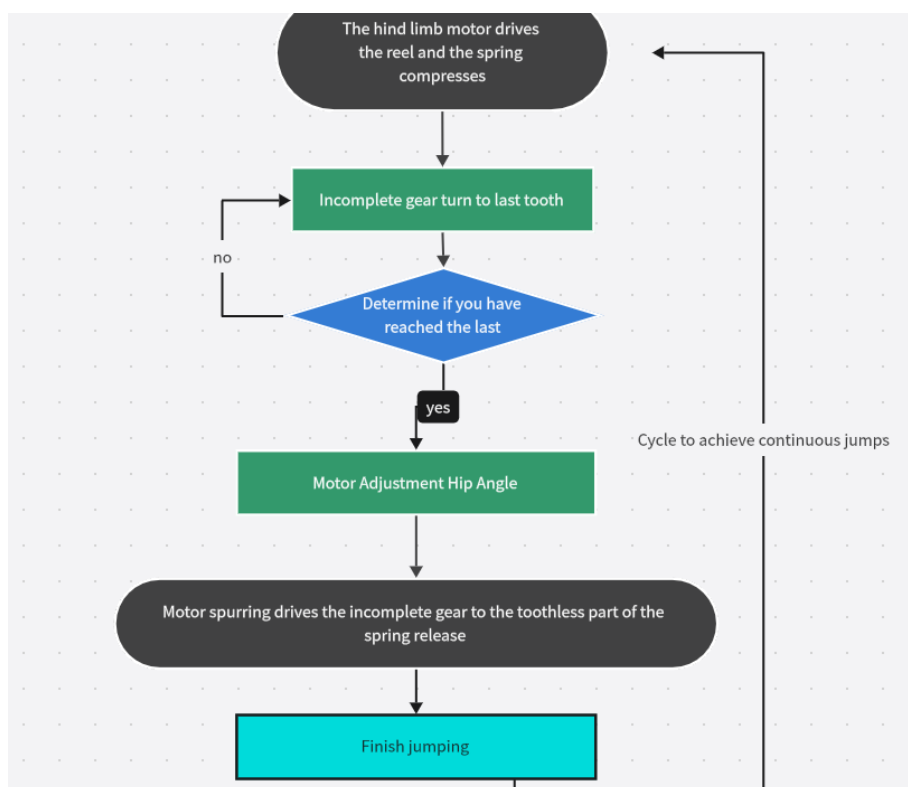


Fig. 4 Biomimetic frog control flowchart (Photo credited: Original)

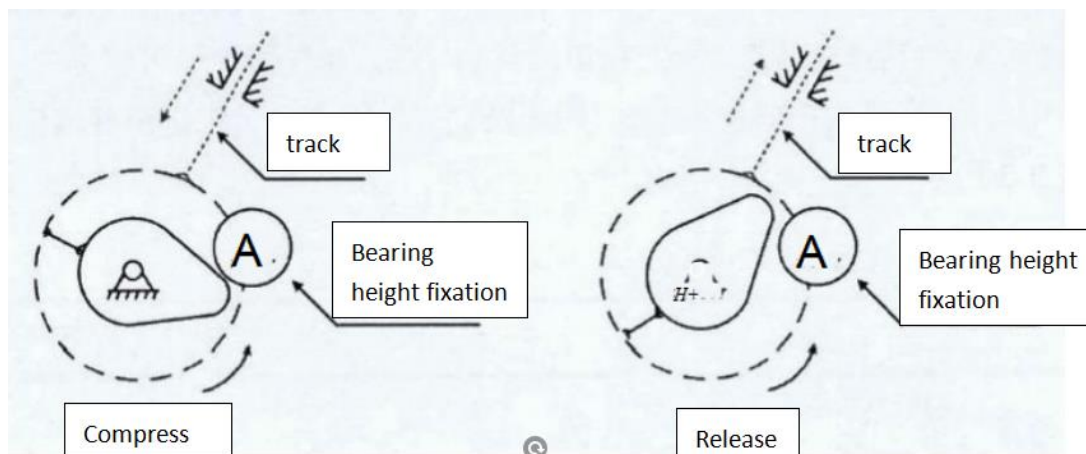


Fig. 5 One complete compression cycle (Photo credited: Original)

5. Conclusion

This paper is based on the skeletal structure, movement mechanism, and previous research design of frogs. A systematic study was conducted on the structural optimization of a frog jumping robot from three aspects: mechanism design and simulation, structural optimization design and simulation, and performance optimization design and simulation, and corresponding motion synthesis was carried out. This study has certain engineering application value and academic theoretical value. The research results are presented as follows: Through the analysis of the prototype, improvement suggestions were proposed for the overall posture and jumping leg structure. The paper aims to ensure the stability of the robot during takeoff and landing, and determine that the overall structure of the robot is M-shaped. Secondly, the jumping leg structure has been simplified and a C-shaped flexible joint design has been added. The use of flexible joints not only increases the storage of elastic potential energy, but also provides good cushioning effect for robot landing, prolonging the service life of components. A compression spring was designed to simulate the thigh muscles of frogs to store and release elastic potential energy. It is worth mentioning that the compression of the spring is achieved by driving the cam mechanism through a three-stage gear set. Among them, the output end of the cam and gear set are installed coaxially. After calculating the robot's jumping cycle, an appropriate motor speed was selected to control the cam, allowing the spring to complete complete complete compression within this cycle. The introduction of cam mechanism makes the landing time of the previous jump of the robot become the takeoff time of the next jump, achieving continuous jumping.

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