Concept of biomimetic mechanical foot based on muscle simulation

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Abstract. An concept of biomimetic mechanical foot based on muscle simulation is proposed to solve the problems of biped robots, such as unstable motion and inability to start at a high acceleration. Firstly, the human plantar muscles are mechanically simulated according to the force area and various factors, and the plantar mechanical matrix composed of several mechanical units is constructed. The biped robot collects its own motion state data through sensors, and then processes the data through the control system and issues posture instructions to the plantar mechanical matrix. Finally, the mechanical matrix module adjusts the mechanical unit according to the posture instructions, thereby greatly improving the movement of the biped robot's stability.

1. Introduction

In recent years, the technology of robots has developed rapidly, and various robot motion modes have emerged one after another. Among them, the biped robot that uses biped walking as the motion mode is one of the hotspots and difficulties in the field of robot research[1]. It not only has important academic significance, but also has practical application value, because an important aspect of dynamic biped walking motion is superior to other motion methods (wheeled movement, crawler movement, etc.) is its flexibility, for example: go up the stairs, go down the stairs, crossing obstacles, running sports, etc[2].

However, there are still bottlenecks in the research and development of robots that use biped walking as their motion mode, such as unstable travel and inability to start at large accelerations, and the development speed of robots with driving mode is slower and the performance is not excellent enough, which also causes a situation that a large amount of scientific research funds are invested but cannot use scientific research results to recover profits. At the same time, the tens of millions of organisms that exist in the world today have evolved through hundreds of millions of years of adaptation, evolution, and development. This has made certain parts of the organism’s ingenious and biological characteristics become perfect, with the most reasonable and most optimized structural features, flexible sports characteristics, and good adaptability and survivability[3]. Therefore, it is necessary and feasible to use the bionic structure to greatly improve the motion performance and stability of the robot by studying the typical creature-human being driven by walking upright with both legs and feet.

The foot is one of the most complex moving organs of the human body. As an organ that only touches the ground when standing and walking, its functions include buffering the reaction force of the ground against the body in the initial stage of support, adapting to different grounds, and providing a
stable support surface for the body, push the body to move in all directions[4]. From these points of view, according to the principle of bionics, mechanical bionics of the human foot structure can greatly improve the motion stability and efficiency of the biped robot. This paper proposes a biomimetic mechanical foot based on muscle simulation. By mechanized imitation of the muscle structure of the human foot, a more reasonable mechanical matrix system is determined to improve the motion performance and stability of the biped robot.

2. Muscle simulation

![Schematic diagram of plantar muscles](image)

Figure 1 Schematic diagram of plantar muscles

Everyone’s gait has its own individual characteristics, and plantar biomechanics is an important branch of gait research[5]. At present, there are measurement systems that can measure plantar mechanical parameters in the world, such as the force plate of Kistler, Switzerland, which measures the total ground reaction force of the human plantar, and American F-Scan and Belgium's RS-scan pressure shoe and insole system, which can measure the contact pressure of the human foot and the ground[6]. These devices provide great convenience for the realization of the concepts described in this article. The parameters for medical evaluation of plantar force include maximum force, maximum pressure, ground reaction force, average pressure and so on. There are relatively complex plantar muscle groups in the sole of the human foot, which are roughly divided into the medial muscles group, the lateral muscles group and the middle muscles group as shown in Figure 1.

The three can be divided in more detail—— medial muscles group: extensor ossis metacarpi pollicis, musculi flexor pollicis brevis, musculi adductor pollicis; lateral muscles group: musculus abductor digit minimi pedis, musculus flexor digiti quinti brevis pedis; middle muscles group: musculi flexor digitorum brevis, musculi quadratus plantae, fidicinales, Musculi interossei dorsales and musculi interossei plantares, etc. All the muscle tissues of the soles of the feet above maintain the balance of the human body through contraction and diastole, and provide basic guarantee for maintaining the complex movement state of the human body. Therefore, if you want to ensure the stability of the robot's motion, it is extremely necessary to use the mechanical structure to simulate the human plantar muscles.
2.1. Simulation of muscle group division

Through the research and observation of human plantar muscles, According to the literature [7-8], it can be known that the main stress parts of the foot are the heel, metatarsal area and phalanx area. In a static standing state, the stressed parts of the foot are the proximal phalanx, metatarsal heads and heels. The main metatarsal hat are stressed are the first metatarsal, the second metatarsal, and the third metatarsal to the fifth metatarsal. The main proximal phalanx is the first proximal phalanx. But the purpose of this concept is to improve the robot's motion performance and motion stability. Therefore, combined with the distribution of the muscles of the sole of the human body and the principles of mechanical design, the mechanical foot can be divided into three mechanical muscle group matrices as shown in Figure 2 according to the specific positions of the plantar medial muscles group, lateral muscles group and all thumb muscles. These mechanical matrices maximize the simulation of the distribution of the human foot muscle groups to maximize the overall stability of the robot. Each mechanical muscle group matrix is composed of several mechanical muscle units. These mechanical units are independent of each other and do not affect each other. The system issues instructions to control their behavior.

2.2. Muscle movement simulation

Figure 2 Mechanical matrix diagram

Figure 3 Schematic diagram of mechanical unit movement
In reality, muscle movement can be divided into contraction movement and diastolic movement. Plantar muscles belong to skeletal muscles. We can know that there are three ways of muscle contraction, namely: 1. Concentric contraction: When the muscle contracts, if the actin filaments slide inward, the Z-line will be pulled toward the muscle. The shortening of the muscle at the center of the joint is called concentric contraction (also called concentric contraction). For example, when performing pull-ups, when the biceps generates tension (contraction) and shortens, when the body is lifted, it is contracting concentrically. 2. Eccentric contraction: On the other hand, during the descent phase of the pull-ups, the actin filaments slide outwards, so that the sarcomere is extended and restored to its original length under controlled conditions, that is, eccentric contraction is in progress. 3. Isometric contraction: There is another situation, that is, the actin filaments did not slide when the muscle was contracted, and remained in the original position (for example: when performing pull-ups, only hang the body on the crossbar), This is called isometric contraction. When the nervous system gives instructions, the plantar muscles contract and harden to gain strength to fight against the ground, thereby providing the force to maintain human movement.

From the above summary, it can be seen that the movement of muscles can be attributed to the sliding of actin filaments, in order to fully simulate the principle of muscle movement and combine the actual limitations of the current technology level, a mechanical muscle unit composed of a tiny hydraulic system is proposed. The mechanical unit simulates normal muscle movement through the vertical movement of the hydraulic device as shown in Figure 3, and through the hydraulic device to provide pressure to simulate the muscle contraction and hardening to gain strength against the ground. The different motion states of several mechanical units can fully simulate the motion behavior of normal muscle groups, and generate the motion angle, torque and other related motion parameters required to maintain the robot's balance.

This description of simulated muscle motion may be unimaginable for readers. Readers can understand that a number of independent cylindrical bodies are installed in the sub-area under a mechanical foot. These cylindrical bodies can move up and down freely and obtain pressure from the hydraulic device. The up and down movement of these cylindrical bodies simulates the posture adjustment of the sole of the normal human body during movement, and the pressure from the hydraulic device is used to obtain the strength to generate the movement angle and torque required to maintain the robot's stability.

The advantage of simulating motion in this way is that only the simplest one-dimensional motion of a single mechanical unit in the vertical direction, and linear combination of it on a two-dimensional plane, fully simulates the result that muscles can form through complex contractions. The production cost is greatly reduced, and the human-like design is maximized, but it also puts forward high requirements on the performance of the hydraulic system.

3. Mechanical unit operation rules
The mechanical unit in the mechanical matrix needs to respond according to the instructions issued by the control system, and then complete the entire movement process of the bionic mechanical foot. In the whole process, the control system needs to obtain the robot's motion parameters and the real-time data of the load on the bionic mechanical foot for calculation and obtain posture information that can stabilize the robot and issue instructions. Therefore, the required information is collected by the sensors and the calculated results can be used to determine the movement posture and structural posture of the mechanical unit.

The collection of data needs to come from two aspects, firstly the real-time motion state and parameters of the robot itself, and secondly the parameters of the force on the sole of the robot and the posture data of its own mechanical unit. When the control system performs calculations, it needs to combine the two to get a brand-new instruction and issue it, so as to ensure the effectiveness of the instruction and achieve better results.

Firstly, sensor elements are installed in various parts of the robot, and the motion state parameters and posture data of the robot itself are obtained in real time through the sensor elements.
The data to be collected are: robot walk cycle, walking unit, stride\[9\], acceleration\[10\], Center of gravity\[11\], torso angle, displacement and freedom of the ankle and hip joints\[12\].

Secondly, regarding the collection of plantar data of biped robots, there are already many equipment and methods that can be operated. For plantar pressure, in the initial stage of mechanical foot debugging, in the laboratory, we can apply Kistler force plate on the robot foot to collect real-time mechanical information. When experimenting on a flat outdoor section, we can place the Pedar force measurement insole system of German Novel company, the F-Scan of the United States and the RS-scan force measurement insole system of Belgium under the mechanical feet to collect and collect the force and pressure on the sole of the foot in real time. For the posture of the plantar mechanical unit of the biped robot, it is necessary to set the reference for the mechanical foot. Because the mechanical unit only performs simple up-and-down movement, it can perform linear superposition of two-dimensional planes based on the position deviation of the mechanical foot from the previously set datum, and then obtain three-dimensional mechanical foot plantar posture information.

Then we can transmit the collected two types of information to the control system for further processing and calculation. Traditional exploitation methods

4. Conclusion and Discussion

4.1. Conclusion of the operation process of the mechanical unit

A biomimetic mechanical foot concept based on muscle simulation is proposed, and three mechanical matrices are divided according to the position of human plantar muscles. The mechanical matrix contains several mechanical units composed of tiny hydraulic devices to simulate muscle movement. Data is collected through sensors, and the control system performs data processing and instruction to complete the posture adjustment of the mechanical unit, thereby stably maintaining the motion state of the biped robot. The specific flowchart is as follows Shown in Figure 4.

4.2. Discussion

First of all, the concept proposed in this article is only at the preliminary stage of envisioning. In the later stage, we need to refer to a large amount of literature to learn more knowledge to support the realization of the concept in this article. Secondly, there are many areas for improvement in the concepts presented in this article. For example, the division of mechanical matrix regions in muscle simulation requires further refinement in conjunction with a large number of experiments. At the same time, with regard to mechanical units, it remains to be explored whether there is a more suitable driving method than hydraulic systems. Finally, with regard to the operating rules of the mechanical unit, this article only gives the basic assumptions of the operating rules and some of the required parameters, but the actual control system has not been studied. Therefore, the focus of future work will be on control. The research and development of the system.

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