Research Article

Adaptive Control System of Intelligent Lower Limb Prosthesis Based on 5G Virtual Reality

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With the rapid development of computer science and technology in our country, especially the advent of the 5G network era, the emergence of smart prostheses makes it possible for disabled, injured, or amputee people with lower limbs to walk and exercise like normal people. However, due to the different selection of prosthetic materials, the final lower limb prostheses produced will also have different performance differences. How to select prosthetic materials to optimize the performance of the intelligent lower limb prosthesis is the focus of extensive discussion in the medical community. For this reason, this article takes the research of the adaptive control system of intelligent lower limb prosthesis based on 5G virtual reality as the research object. By using the current advanced 5G communication technology and virtual reality technology, a high-performance intelligent lower limb prosthesis is produced. Provide assistance with basic walking and motor abilities in daily life of patients with lower limb disabilities. This article first gives a systematic theoretical introduction to 5G virtual reality technology, expounds the current status of patients with lower limb disabilities, and proposes to use intelligent lower limb prosthetics to replace healthy lower limbs to solve the basic walking and sports needs of disabled patients in daily life and then use 5G virtual reality technology. The selection of human knee joints and ankle joints and structural system design were carried out. Finally, it was decided to use the four-bar linkage structure as the knee joint structure of the three-dimensional modeling of the intelligent lower limb prosthesis. At the end of this article, the application and simulation of the intelligent lower limb prosthesis to the human body were also carried out. The results of the experiment found that after 45 weeks of wearing exercises, the gait of the intelligent lower limb prosthesis is consistent with the expected effect whether it is walking on level ground and up and down the stairs or uphill. Due to the strong adaptiveness of the intelligent lower limb prosthesis sexual control, it can well assist the basic life movement ability of patients with lower limb disabilities.

1. Introduction

1.1. Background and Significance. In recent years, with the acceleration of the aging of our country’s population, a considerable part of the elderly population suffers from cerebrovascular diseases and neurological diseases which have caused midwind and hemiplegia, resulting in lower limb damage. In addition, more and more people suffer from physical or neurological injuries caused by accidental traffic accidents and natural disasters. These patients with lower limb disabilities are suffering from physical pain and psychological economic pressure at the same time, and it has become a multilateral appeal to quickly find an effective rehabilitation treatment method and means.

Intelligent lower limb prosthesis is a human prosthetic product developed in recent years. It is a bioelectronic device based on 5G virtual reality technology and biomimetic technology to imitate the gait, posture, and habits of human walking. Most people still retain motor nerves at the end of the thigh after amputation and have certain motor functions. Connecting a smart prosthesis to the stump of the thigh instead of a healthy limb can meet the basic activities of patients in daily life. And through 5G virtual reality technology, the interaction between the smart prosthesis and the
human brain nerves can be realized, so that the smart prosthesis can promptly and effectively listen to the instructions sent by the human brain and make corresponding actions quickly, so that people with lower limb disabilities can live like normal people. New research shows that virtual reality technology has the potential to help amputees “feel” the sensation of touch from prosthetic limbs. Teach their brains to believe that the prosthesis belongs to their body. Many amputees choose to stop using prosthetics after a period of time because they feel uncomfortable. On the one hand, the patient feels that the missing limb seems to remain. That is, there are so-called phantom limbs; on the other hand, prosthetics on the market usually do not provide tactile feedback, and patients need to combine observation to use them correctly. Virtual reality technology cleverly combines vision and touch to enhance a patient’s experience with a prosthetic limb, allowing the brain to “believe” that the prosthetic limb is a natural extension of the body. The device used in the trial is portable and could one day be a therapy to help patients permanently implant prostheses.

1.2. Related Work. Early on, people put forward experimental ideas for human lower limb prostheses and made prosthetic models. Wen et al. proposed a novel application of adaptive dynamic programming (ADP), which can optimize lower limb prosthetics. This is a wearable robot that can help amputees recover their motor functions. However, the current control of these robotic devices usually relies on finite state impedance control (FS-IC), which lacks adaptability to the user’s physical condition. And they also found that manually and heuristically customizing joint impedance settings in the clinic greatly hindered the widespread use of these advanced medical devices. Their simulation study proved the feasibility of ADP to automatically adjust the impedance parameters of twelve knee joints to achieve balanced walking during the complete gait cycle. Since it is difficult to obtain an accurate model of human walking dynamics, they considered a model-free ADP control algorithm. First, direct heuristic dynamic programming (DHDP) is applied to the control problem, and its performance is evaluated on the frequently used dynamic walking simulator Open Sim. For comparison, they chose another established ADP algorithm, Neural Fitting Q with Continuous Action (NFQCA). In both cases, the ADP controller learned to control the right knee joint and achieved a balanced walk, but in the 200-gait-based gait-based test, DHDP performed better than NFQCA in this application [1]. In addition, Su et al. have also pointed out that the electric intelligent lower limb prosthesis can drive the knee and ankle joints, so that transfemoral amputees can seamlessly transition between motion states with the help of the intention recognition system. However, previous intent recognition studies usually install multiple sensors on the prosthesis, and they use machine learning techniques to analyze time series data with empirical characteristics. In this regard, they proposed a novel method of training an intent recognition system that provides a natural transition between horizontal walking, stairs up/down, and ramp up/down. Since the transition between two adjacent states is driven by movement intention, their purpose is to explore the mapping between the movement state of the healthy leg and the movement intention of the amputee before the transition of the prosthesis occurs. They use an inertial measurement unit (IMU) and place it on the healthy leg of a lower extremity amputee to monitor their movement status. They analyze the IMU data in the early swing phase of healthy legs and input the data into a convolutional neural network (CNN) to learn feature maps without the involvement of experts. The method they proposed can predict the movement intentions of unilateral amputees and able-bodied persons and help to adaptively precalibrate the control strategies used to drive the dynamic intelligent prosthesis [2]. In short, research and reports on intelligent lower limb prostheses are not uncommon. This article is based on the research of predecessors and proposes to use the emerging 5G virtual reality technology to optimize the adaptive control system of intelligent lower limb prostheses so that people with lower limb disabilities can be better. It adapts well to the intelligent lower limb prosthesis to meet the needs of daily life activities and even sports.

1.3. Innovations in This Article. The innovations of this paper are mainly reflected in the following aspects: (1) Based on the high coverage of lower limb disabilities in China, this paper proposes the use of intelligent lower limb prosthetics to assist in solving the basic sports needs of patients with lower limb disabilities in daily life. (2) This article introduces and elaborates the 5G virtual reality technology and the gait characteristics of human lower limbs in detail, which provides sufficient theoretical support for the subsequent simulation design and 3D modeling of intelligent lower limb prostheses. The article consists of the technical introduction of the 5G virtual reality intelligent lower limb prosthesis adaptive control system, the prosthetic structure design and the adaptive control experiment, and other parts.

2. Intelligent Artificial Limb Adaptive Control System

2.1. 5G Virtual Reality Technology

2.1.1. 5G Technology. Figure 1 is a schematic diagram of 5G virtual reality technology; 5G technology is a new generation of advanced mobile communication technology after 2G, 3G, and 4G. It is an extension and sublimation of the previous three generations of system technology. The performance of 5G is more optimized, it reduces the delay in the processing and transmission of data, the rate is more efficient and rapid, and the new energy technology is adopted, which greatly reduces the cost and increases the system capacity and large-scale equipment connections. The application and promotion of 5G technology will greatly change people’s production and life. The advent of the 5G era will push people into a more efficient and convenient social environment [3, 4].
5G is different from the previous generations of mobile communication technologies. It has more distinctive network characteristics, as shown in the following:

1. 5G has a higher peak network speed standard, which can meet the transmission of large amounts of data such as high-definition video and virtual reality.
2. 5G technology can be specifically applied to the autonomous driving of unmanned vehicles and the guidance of telemedicine surgery to realize information docking in the air.
3. 5G has a huge network capacity and super device link capability, which can simultaneously meet the transmission of massive information resources and the connection of many devices, and has extremely high mobile IoT communication capabilities.
4. The spectrum efficiency of 5G is also more than 10 times higher than the general long-term evolution technology.
5. 5G can give users a higher sense of experience. Its network area communication coverage is extremely high, it is extremely mobile, and it can quickly receive and reply to messages.
6. Compared with 2G, 3G, and 4G, the traffic density and connection density of 5G have been greatly improved.
7. The level of coordination and intelligence of the 5G network system has been significantly improved, and the internal self-adjustment of the network is also more flexible and convenient.

2.1.2. Virtual Reality Technology. Virtual reality (virtual reality) technology, referred to as VR technology, is also called spiritual technology in our country. It is a way to project images and environments of the real world into the virtual world in a three-dimensional dynamic form by using computer and multimedia technology. And under the premise of wearing some professional sensing equipment such as data gloves and sensor helmets, people can perceive and operate any object in the virtual world in real time with their own sense of sight, hearing, touch, and smell and give users a sense of reality in the real environment [5, 6].

2.1.3. Characteristics of Virtual Reality Technology. Virtual reality technology mainly exhibits three basic characteristics: interactive, immersive, and conceptual, as follows:

1. Interactivity. It means that the user can get feedback on the perception and operation of the object in the virtual environment. In other words, when the user moves the object touched and grasped, the object in the hand will move with the movement of the hand movement; it has a very strong operability.
2. Immersion. Whether the user can reach the state of immersion in the virtual world and the degree of immersion determine the success of the modeling of this virtual environment model. When the user is in the virtual world, with the assistance of professional sensing appliances, he perceives all objects in the virtual world through his eyes, ears, nose, and...
fingers. When the user is fully engaged in the virtual environment, it is difficult to distinguish. When the illusion of true and false, then it highlights the immersion of virtual reality technology [7, 8].

(3) Conceptual. In the virtual world, users continuously learn to improve themselves by acquiring the required information and materials, and on this basis, they produce new ideas, thereby deepening the concept, improving their perceptual and rational understanding, continuously acquiring new knowledge, and forming a learning-creation-re-learning-re-creation process.

2.1.4. Classification of Virtual Reality Technology

(1) Immersive Virtual Reality Technology. It incorporates virtual reality hardware equipment and software technology, has the characteristics of large investment and obvious effects, and is suitable for network settings of large- and medium-sized enterprises [9].

(2) Distributed Virtual Reality Technology. This technology connects users and virtual environments distributed in different locations through digital networks, enabling them to share information and coordinate work to save energy and reduce costs [10].

(3) Desktop Virtual Reality Technology. Use simple and basic virtual reality hardware and software equipment to achieve the minimum requirements for virtual reality technology, which has the characteristics of low investment and large returns.

(4) Pure Software Virtual Reality Technology. It refers to the pure use of computer systems and networks and virtual reality software environments to realize virtual reality technology without having virtual reality hardware and software facilities and equipment. This development method of realizing virtual reality technology has the least investment, the effect is also very obvious, and it is the most economical.

(5) Augmented Virtual Reality Technology. This development method is to superimpose the information of the real world with the information of the virtual world. The user can superimpose the graphics model of the real world and the virtual world drawn by the computer with the help of the head-mounted display to realize the virtual reality technology. The development cost of this method is high, and the calculation process is cumbersome and complicated and is generally suitable for advanced and sophisticated technical fields [11, 12].

2.2. Intelligent Lower Limb Prosthesis and Its Adaptive Control System. The lower limb of the human body is an important part of the human body structure [13, 14]. It is the basic movement joint for people to walk, run, jump, and stand [15]. The movement process is very complicated. Therefore, if you want to control the human lower limb prosthesis, you must first understand the human lower limb.

2.2.1. Human Lower Limb Gait. To understand the gait of the lower limbs of the human body is mainly to understand the gait cycle, step length, and pace of the lower limbs of the human body, including the following aspects [16, 17]:

(1) The Gait Cycle. The gait cycle of the human walking is the process from the heel of one side to the ground to the heel of the other side. It includes two parts: support period and swing period. The support period accounts for about 60% of the entire gait cycle, and the swing period accounts for about 40% [18].

(2) Step Length. The length of the human step length is related to the height, age, and gender of the human body [19]. Usually, after a step is taken on the heel or toe on the same side, the distance walked by the heel or toe is the step length.

(3) Pace. It is also called the frequency of pace and refers to the number of steps the human body walks per unit time during walking. The walking speed of the human body is also affected by age and height.

(4) The Human Body Joint Angle. The human body joint angle includes three aspects, namely, the hip joint angle, the knee joint angle, and the ankle joint angle. The angle of the hip joint refers to the angle between the longitudinal axis of the human trunk and the longitudinal axis of the thigh, where the counterclockwise direction is curling and the clockwise direction is stretching; the knee joint angle refers to the angle formed between the parallel longitudinal direction of the calf and the longitudinal direction of the thigh [20, 21].

2.2.2. Adaptive Control Method of Intelligent Lower Limb Prosthesis. With the development of our country’s economy and the improvement of people’s living standards, the performance and quality requirements of lower limb prostheses for the disabled have become higher and higher. Traditional lower limb prostheses are gradually being replaced by new intelligent lower limb prostheses. The intelligent lower limb prosthesis can realize the interaction with the human body through the use of virtual reality technology and has an adaptive control function. There are three adaptive control methods for intelligent lower limb prostheses:

(1) Behavior-Based Control Method. When a part of the human body is stimulated by the external environment, the intelligent prosthesis can obtain the current gait information of the human body through external sensors and make action judgments based on it, so as to realize the control of the lower limb prosthetic movement and then synthesize and adjust the simple movement into the overall movement of the lower limb prosthesis, so as to complete the response to external information.

(2) Control Method Based on the Human Neural Network System. The neural network system in the human brain is the basic structure for controlling
human activities. For the human body, simple horizontal walking can be applied to the control of intelligent lower limb prostheses by building a neural network model.

(3) Model-Based Control Method. This control method is currently the most widely used control method. Through accurate mathematical modeling of the lower limbs of the human body and then use the existing data for artificial planning to formulate the best motion trajectory of the prosthesis, collect the motion information of the prosthesis through the motion test of the prosthesis, and compare it with the expected result to obtain the deviation information, and then continuously adjust the gait of the intelligent lower limb prosthesis based on this, and finally realize the adaptive control of the intelligent lower limb prosthesis [22, 23].

2.3. Combination of 5G Virtual Reality Technology and Lower Limb Rehabilitation Technology. A large number of studies have found that repeated exercise rehabilitation training will have a good exercise effect on the patient’s cerebral cortex. For the motion simulation learning technology of rehabilitation sports, the best rehabilitation effect must be achieved after repeated training and completion of a series of tasks. In the treatment process of rehabilitation sports training, the patient’s visual and auditory perception and the body’s self-perception are used to judge the effect of the training and complete the feedback on the results of the rehabilitation training. Usually, this rehabilitation process is long and boring, and patients must be fully psychologically prepared [24].

Virtual reality technology is a product of the development of network technology. The virtual reality scenes it creates are realized through computer systems. There is no need to worry about and consider the workload and intensity of work, and there is enough time and ability to meet patients for repeated rehabilitation training. At the same time, in the virtual reality environment, due to its performance characteristics such as immersion and interactivity, it can give patient rehabilitation information feedback based on the patient’s training state through the patient’s sense organs such as sight, hearing, smell, touch, and taste. And during training, patients can perceive any training scene and object in the virtual environment with the help of sensors, which increases the interest of the patient’s training process, which is of great help to improve the patient’s enthusiasm for participated in rehabilitation training [25].

3. Experiment of Adaptive Control for Prosthetic Structure Design

The realization of the movement of the lower limbs of the human body should fully consider the dynamic system of each joint, and the most important structure for the intelligent lower limb prosthesis is the knee joint. Therefore, to design a smart lower limb prosthesis, the choice of the knee joint structure is very important. The excellent knee joint structure not only gives the prosthesis enough stable support when it is in the support period but also gives it flexible movement during the swing period of the prosthesis. This article has carried out the structure design experiment of the intelligent lower limb prosthesis and analyzed its adaptive control according to its sports training effect.

3.1. Design of Dynamic Knee Joint Structure

3.1.1. Selection of Knee Joint Structure. As the most important joint structure of the intelligent lower limb prosthesis, the selection of the knee joint is very important, and it is directly related to the success of the final modeling of the intelligent lower limb prosthesis. To select the knee joint, we must first understand the internal structure of the human knee joint and grasp the functional characteristics of the knee joint. Only on the basis of real understanding of the motion function of the human knee joint can the design of the prosthetic structure be better realized. The knee joint is the largest and most complex joint of the human body. It is mainly composed of the tibia, the inner and outer calf ankle, the humerus, the inner and outer thigh, and the patella. The knee joint between the thigh and the calf mainly has 6 moving parts, namely, the tibial plateau, meniscus, femur, femoral ankle, patella, and the ligaments, that connect each part. The movement process of the knee joint is the process of the femoral ankle, that is, the thigh sliding on the surface of the meniscus under the restraint of the connecting ligaments, thereby forming a special pulley structure between the meniscus and the femoral ankle. In this way, it appears that the structure of the knee joint is extremely complicated, and its movement process is not simple rotation. Therefore, the knee joint structure of the intelligent lower limb prosthesis cannot be simply designed as a pure roller rotation. The contact surface between the tibia, the calf, and the meniscus not only has roller-type rotation but also sliding, and the instantaneous time should be selected as the center of rotation and designed as a uniaxial knee joint, as shown in Figure 2. The rotation trajectory of the instantaneous rotation center ICR of the knee joint is actually a J-shaped curve. This design structure is simpler and more durable; the calculation is convenient, and the production cost is low. But at the same time, this single-axis knee joint structure cannot satisfy the
instantaneous rotation of the prosthesis, and this structure makes it difficult for the prosthesis to raise the height of the foot from the ground. In contrast, multiaxis knee joints can well simulate the motion of human knee joints, but the more the number of multiaxis knee joints, the worse the stability will be, which is not conducive to the balance of the human body structure when the prosthesis is in the support period. And the more the number of axes, the more complicated it is to optimize the design of the prosthesis structure. Therefore, in this experiment, we finally use the four-bar mechanism as the main structure of the knee joint.

The following Figure 3 shows the structure of a four-link knee joint. It can be seen from the figure that, compared with a single-axis knee joint structure, the height of the heel of the four-link knee joint mechanism from the ground is significantly higher, which is more conducive to walking on the prosthesis. It can avoid obstacles autonomously at all times, thereby improving the performance advantages of intelligent lower limb prosthetics.

3.1.2. Selection of Knee Joint Drive System. Passive knee joints are also called cushioned knee joints. Generally, they have no active power and rely only on the residual limb of a single leg to provide power. The passive knee joint can continuously adjust the buffer force according to the external environment and the gait of the prosthetic walking. Because of its simple structure and easy control, it becomes the mainstream design of the prosthetic knee joint. Active knee joints rely on external force driving as their own power source. Active intelligent lower limb prostheses mainly include pneumatic drive, hydraulic drive, and motor drive. The external force drive of active knee joints relies on motor drive. Although the active knee joint can provide power for extension and flexion of the lower limb prosthesis, its small
battery capacity and heavy weight often lead to a short battery life. Based on the advantages and disadvantages of these two types of knee joint driving, this article attempts to combine the two driving methods to implement hybrid driving.

Hybrid drive uses motor drive as the active driving force and damping as the power of the passive knee joint; hybrid drive can not only meet the walking form under active driving but also the driving form of passive walking. The patient wears intelligent lower limbs equipped with a hybrid drive system. After the prosthesis, the active driving force when climbing and stair climbing can greatly reduce the consumption of the knee joint. Since the driving form of the knee joint is hybrid drive, and there is already active driving and damping as the power of the passive knee joint; hybrid drive can not only meet the walking form under active driving and damping as the power of the passive knee joint; hybrid drive can not only meet the walking form under active driving and passive walking. The patient wears a driving form of active and passive at the same time. This not only allows the patient to achieve a walking gait like a healthy limb but also looks beautiful and does not consume too much physical energy when walking.

3.2. Selection and Design of Ankle Joint. When the human body is standing normally, the angle between its calf and the sole of the foot is a right angle, that is 90°, perpendicular to the ground, and the sole of the foot is parallel to the ground. In the process of walking, the angle between the sole of the foot and the calf will swing back and forth between 10°~20° and -30°~50°. The functions of the ankle joint during human walking include assisting the movement of the lower limbs and reducing vibration and antiskid.

By investigating the gait of the ankle joint when walking, we found that the ankle joint mainly presents two states when walking: standing state and swing state. The ankle joint is mainly in the form of pure rolling motion during the whole walking process, so for the design of the ankle joint, we adopt a uniaxial knee joint structure. Since the driving form of the knee joint is hybrid drive, and there is already active driving force here, but the ankle joint needs to be powered to cooperate with it to complete the whole walking process of the knee joint, so it is necessary to add flow damping, by using the flow damping current to change the size of the damping.

3.3. Optimization Design of Four-Bar Linkage Knee Joint Structure. According to the previous article, the increase in the number of axes of the multiaxis knee joint will cause the stability of the prosthesis to decrease. Therefore, in order to make the movement of the four-bar structure more in line with the movement of the knee joint, we will compare the four-bar length, and its initial angle is optimized. The instantaneous coordinates of the knee joint will change with the rotation of its bending angle, so the four-bar linkage can be used as a known condition. Suppose the lengths of the four bars of the four links are L1, L2, L3, and L4, and the angles between them and the coordinate axis are θ1, θ2, θ3, and θ4, and the four bars are represented by CF, DE, CD, and EF, respectively. The CF rod is connected to the thigh, the DE rod is connected to the calf, and the intersection of the extension lines of the other two rods is set as P, which is the instantaneous rotation center of the knee joint.

First of all, we need to determine the design variables and use the four-bar lengths L1, L2, L3, and L4 as the design variable parameters. When the four-bar lengths are known, the angle degrees of θ1, θ3, and θ4 can be obtained directly through the variable formula. The variable formula is

\[ x = [x_1, x_2, x_3, x_4, x_5]^T = [l_1, l_2, l_3, l_4, \theta_2]^T. \]  (1)

After that, the objective function is established. A total of 12 variables are involved in the optimization experiment of the four-bar linkage structure. It is required to minimize the error between the actual trajectory and the ideal trajectory, so the expression is

\[ \min f(X) = \sqrt{\frac{1}{2} \sum_{i=1}^{12} (x_{pi} - x_{pi})^2 + (y_{pi} - y_{pi})^2}]. \]  (2)

Among them, \( x_{pi} \) and \( y_{pi} \) represent the coordinates of the four-link trajectory, and \( x_{pi} \) and \( y_{pi} \) represent the coordinates of the actual trajectory of the knee joint. The projection formula of the four bars of the four-bar linkage on the coordinate axes X and Y is as follows:

\[
\begin{align*}
\{ & l_6 \cos \theta_1 + l_3 \cos \theta_3 = l_4 \cos \theta_2 + l_5 \cos \theta_2, \\
& l_6 \sin \theta_1 + l_3 \sin \theta_3 = l_4 \sin \theta_2 + l_5 \sin \theta_2 \}.
\end{align*}
\]  (3)

According to point P of the center of rotation:

\[
\begin{align*}
x_p &= x_c + \frac{x_f - x_e}{y_f - y_e}, \\
y_p &= y_c - \frac{y_f - y_e}{y_f - y_e}.
\end{align*}
\]  (4)

Combine formula (3) and formula (4) and substitute the coordinates of each point to obtain:

\[
\begin{align*}
x_p &= x_c + \frac{x_f (y_c y_f - x_c y_f) - x_e (y_e y_f - x_e y_f)}{x_c (y_e y_f - x_e y_f) - x_e (y_c y_f - x_c y_f)} = \frac{l_5 \cos \theta_1 [l_6 \sin (\theta_2 - \theta_4) + l_3 \sin (\theta_2 - \theta_4)]}{l_5 \sin (\theta_2 - \theta_1) + l_5 \sin (\theta_2 - \theta_1)}, \\
y_p &= y_c - \frac{y_f (x_c y_f - x_e y_f) - y_e (x_e y_f - x_c y_f)}{x_c (y_e y_f - x_e y_f) - x_e (y_c y_f - x_c y_f)} = \frac{l_5 \sin \theta_1 [l_6 \sin (\theta_2 - \theta_4) + l_3 \sin (\theta_2 - \theta_4)]}{l_5 \sin (\theta_2 - \theta_1) + l_5 \sin (\theta_2 - \theta_1)}.
\end{align*}
\]  (5)
Since the knee joint moves back and forth within a certain angle instead of periodic movement, the CD rod is the main power rod, and the other three rods are passive rods, so the four-link knee joint is a double rocker structure, which needs to meet the conditions:

\[
\begin{align*}
    l_4 &> \max \{l_3, l_5, l_6\} \\
    l_3 &< \min \{l_4, l_5, l_6\}
\end{align*}
\]  

(6)

The length of the four bars and the range of instantaneous center coordinates are as follows:

\[
\begin{align*}
    35 < & l_4 < 55 \\
    30 < & l_5 < 55 \\
    40 < & l_6 < 60 \\
    20 < & l_3 < 40 \\
    0 < & x_p < 40 \\
    0 < & y_p < 150
\end{align*}
\]  

(7)

According to the above calculation process, the final optimization results of the four-link knee joint are \(l_3 = 22\) mm, \(l_4 = 50\) mm, \(l_5 = 35\) mm, \(l_6 = 44\) mm, and \(\theta_2 = 28^\circ\). After optimization, the coordinates of each point obtained after optimization and the expected coordinates of each point are drawn into a graph for comparison, and it can be obtained: After optimization, the trajectory of the four-bar linkage is consistent with the expected trajectory, indicating that the optimized four-bar linkage structure meets the requirements of simulating the instantaneous change of the human lower limb prosthetic knee joint.

3.4. Construction of the Three-Dimensional Model of the Ankle Joint. According to the selection of the prosthetic knee and ankle joints, we finally established the three-dimensional model of the knee and ankle joint with the optimized four-bar linkage structure. The main body is mainly designed as a frame structure that reduces weight. It can also increase the rigidity of the structure and save costs. A magnetic current damper is installed between the upper plate and the lower plate. It is the lower leg part of the prosthesis, and the installation position of the magnetic current damping must meet the following conditions:

1. When the knee joint rotation angle is 0 degrees, the magnetic current damping is in a fully expanded state
2. When the knee joint is bent, it can effectively expand and contract and provide sufficient damping force in the stroke
3. The axis of the shock absorber cannot be collinear with the axis of rotation of the knee joint. The electromagnetic damper is installed between the top plate and the lower part of the lower leg position. A variety of drive motors must be installed on the thigh. One is because the calf does not have enough space to accommodate it, and the other is that the weight of the motor device is too large. If it is installed on the calf, the calf will continue to bend and stretch when walking. The reciprocating motion of the drive motor will affect the flexibility of the prosthesis, and it will also consume more energy from the human body.

The calf is mainly composed of the sole of the foot, the calf connecting frame, and the damping buffer system. For aesthetics and simulation, the size of the sole is mainly based on the actual size of the human body. After putting on shoes, it can also have the flexibility and practicality of ordinary soles. The calf support is mainly connected to the thigh and sole, and the thigh is welded. The shaft is connected to the shaft base so that it can rotate around the shaft. Adjust the calf support and cushioning at the back of the foot to connect the shaft to the shaft seat. Although the axle seat is installed on the back of the foot, the actual expansion distance of the shock absorber is reduced, which will not be convenient for the effective use of the formation, but in order to achieve the coordination, aesthetics, and compactness of the equipment, it is best to install and fix the sole of the foot. The drive system also includes a stepper motor and a reduction gear. Due to the flexibility of the calf, the motor does not take up much space. Therefore, the motor is installed parallel to the lower leg. After the reduction gear changes speed and direction with a certain transmission ratio, the power is connected to the ankle. In this way, the three-dimensional modeling of the ankle joint is completed.

4. Application and Simulation Analysis of Intelligent Lower Limb Prosthesis

In the third part of this article, we selected and designed the structural system of the human knee and ankle joints by using 5G virtual reality technology and established a three-dimensional model of the intelligent lower limb prosthesis and found that the intelligent lower limb prosthesis is adaptive performance advantages in sexual control. In this chapter, we will conduct a simulation experiment of intelligent lower limb prosthesis and apply it to the human body. And we will analyze and discuss the great help of intelligent lower limb prosthesis for disabled people according to the different synchrony of human walking (including walking on flat ground and going up and down stairs).
4.1. Analysis of Gait Simulation Effect When Walking on Level Ground. The two-layer CPG neural network is composed of a neural network and a CPG neuron layer. Since the neuron layer has no input of feedback information, the entire control network does not form a closed loop. Therefore, the researchers introduced a new network layer—neural network layer on the CPG neuron layer. The neurons in this layer can receive the input of sensory feedback information from the external environment, and at the same time, the neurons can be optimized and solved, and further obtain the optimal value of each parameter in the network.

In order to explore the simulation effect of the intelligent lower limb prosthesis on human gait when walking on flat ground, here we introduce the CPG oscillator and use the CPG oscillator to test the simulation effect of the prosthesis on the gait signal. The initial values of the main parameters
of the CPG oscillator are shown in Table 1. Figure 3 shows the gait signal simulation effect of the knee joint when walking on the ground.

It can be seen from Table 1 and Figure 4 that after 45 weeks of practice, the frequency, amplitude, and phase of the output signal of the oscillator network have achieved convergence, and the overall output signal of the oscillator network is close to the signal during actual practice, which is very good.

4.2. Analysis of Gait Simulation Effect When Going Up and Down Stairs. The simulation experiment was carried out to simulate the gait of the human body when going up and down the stairs. The simulation effect is shown in Figures 5 and 6.

According to the gait simulation effect of Figures 4 and 5, it can be seen that when the intelligent lower limb prosthesis goes up and down the stairs, its gait structure is basically the same as our expected human gait structure, and the intelligent lower limb prosthesis adopts a four-link knee joint structure; it shows a greater performance advantage when walking; through the combination of active and passive driving force, it greatly saves the energy consumption of the human body when walking and provides great help to the disabled.
4.3. Knee-Ankle Integrated Finite State Machine Control. The main driving force of the knee and ankle joints is provided by the stepper motor accelerometer, which can use angle changes to control its own motion state. Here, we take the state of walking on flat ground as an example. Because the gait is simple and easy to control, there is no need to divide the state too much. According to the finite state machine control principle, the knee joint control can be divided into four states. Since the body needs stable support, the support period is divided into three states, and the swing period has little effect on the stability of the body, so only one state is needed during the swing period. Similarly, the movement of the ankle joint is divided into four states accordingly, and try to make the points of the four states at the same time point, so that the same starting state can be used to control the four states, so as to realize the knee and ankle joints. The specific situation is shown in Figure 7.

5. Conclusions

The development of society and the improvement of living standards will also increase the demand for prostheses by the disabled, and the performance requirements for the intelligence, aesthetics, and adaptability of the prostheses are also increasing. Therefore, the research on smart prostheses in related fields will be more in-depth. On the basis of analyzing the characteristics of virtual reality technology, system characteristics, and virtual hardware equipment, this paper proposes to participate in virtual reality rehabilitation scenarios in the lower limb exoskeleton rehabilitation system that has been designed in the laboratory and build a more reasonable humanized rehabilitation training. The system can better serve the lower limb rehabilitation training.

At present, rehabilitation training for patients with lower limb disabilities is mainly reciprocating passive training. This training is not only inefficient and slow in effectiveness but also easily affects the patient’s psychology. Long-term repetitive training not only wears down the patient’s rehabilitation patience but also reduced its enthusiasm for receiving rehabilitation treatment. To this end, this research introduces an active collaborative stimulation training method based on 5G virtual reality technology.

By establishing a three-dimensional model of the intelligent lower limb prosthesis, it simulates the three-dimensional virtual scene of the patient’s sports rehabilitation training and stimulates and maintains the enthusiasm of the patient to actively receive the rehabilitation training to promote the patient’s rehabilitation process. Facilitate the patient’s recovery process. The design of this article focuses on the construction of virtual roaming scenes, and it is necessary to formulate scientific and perfect rehabilitation evaluation strategies to carry out rehabilitation planning for patients at different rehabilitation stages. Visualized remote network virtual scene is a new direction of rehabilitation medicine. Relying on network technology to realize remote communication between rehabilitation patients and doctors, this distributed virtual reality technology is also an urgent problem to be solved.

Data Availability

This article does not cover data research. No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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