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Human-Computer Control of Lower Limb Rehabilitation Robot Based on Intelligent Perception

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Abstract:
These days, intelligent robots have started to perform impressively in many scientific fields. Lower-limb rehabilitation robots, a type of intelligent robot, are helping to provide new ways in the rehabilitation community and provide novel treatment options. Studying the control of lower-limb rehabilitation robots based on intelligent perception can promote the development of the medical field and enhance the safety of rehabilitation. This paper reviews the situation of the development of lower limb rehabilitation robot based on studies have been done currently and proposes future challenges and prospects. First, the author introduced lower limb rehabilitation robot. Then, two concepts: Intelligent perception and Human-Computer Control were explained. There are 2 ways of control for the lower limb rehabilitation robot (based on mechanical and biological signals) now and there are several examples in the paper. In an era of rapidly aging populations, the development of rehabilitation can help more elderly people enjoy a more comfortable and fulfilling life, which is in line with the laws of social development.

Keywords: Lower Limb Rehabilitation Robot; Human-Computer Interactional Control; Intelligent Perceptio

1. Introduction

The number of robots, and the things robots are doing, are increasing dramatically with the development of today's society [1]. At the same time, intelligent robots are playing a significant role in various fields, such as science and economics. With the large-scale development of intelligent robots, aging has become an inevitable trend. The demand for social rehabilitation has increased. Lower limb rehabilitation robots based on intelligent perception have gradually entered the public eye with their novel treatment methods. As the "visual plate" of robots, intelligent perception needs to break through to achieve the perception and fusion of two-dimensional to multi-dimensional information and perceive the environment so that robots can perform intelligent operations [2]. The ability to use human-computer interaction for lower limb rehabilitation robots based on intelligent perception can constrain the robot and reduce the possibility of secondary injuries to patients during rehabilitation treatment. When the lower limb rehabilitation robot based on intelligent perception is constrained by human-computer interaction control, it can simultaneously meet the rehabilitation goals of completing rehabilitation and ensuring patient safety. This paper will mainly review the research on human-computer interaction control of lower limb rehabilitation robots based on intelligent perception from the perspectives of mechanical control and biomedical control, understand the research and optimization methods of predecessors, analyze unresolved issues and look forward to the future.

2. Rehabilitation Robot

2.1 An Introduction to Rehabilitation Robots

According to general understanding, a lower limb rehabilitation robot is a mechatronic device that can assist paralyzed patients with impaired lower limb motor function to complete rehabilitation training automatically or semi-automatically. Based on the patient's body posture during rehabilitation training, lower limb rehabilitation robots are roughly divided into the following four categories: sitting and lying robots, upright robots, assisted standing robots, and multi-position robots [3]. Among them, upright robots can be further divided into suspended weight-reducing gait training robots and independent wearable robots [3].

2.2 Intelligent Perception

For lower limb rehabilitation robots, the reliability and structural design of intelligent perception are very important [4]. Lower limb rehabilitation robots rely on precise mechanical design to perform a lot of auxiliary work during human rehabilitation. However, the ability to perception allows the robot to accurately "translate" the needs of the human body and respond with the correct action after the rehabilitation patient makes various movements. This effectively meets the goal of rehabilitation while preventing the patient from suffering secondary injuries.

2.3 Interaction Control

When receiving the paper, we assume that the corresponding authors grant us the copyright to use. Human-computer interaction refers to the technical process of information exchange and interaction between humans and computer systems through input and output devices. The purpose of using interactive control is to create a good recovery environment for patients and protect them from secondary injuries [3]. Currently, the interactive control methods used by researchers are mainly based on mechanical control methods and bioelectric signal control methods. This paper mainly explores the combination of these two methods with perception capabilities. Based on previous research, some ideas are given to optimize and improve the previous solutions.

3. Ways of Control

3.1 Lower Limb Rehabilitation Robot Based on Mechanical Control

At present, the main human-machine interaction control methods of lower limb rehabilitation robots are divided into interactive control based on force signals and control technology based on biomedical signals. Force signals specifically refer to the force acting on the mechanical structure due to the contraction of limb muscles, which is the so-called interactive force [3]. Mechanical control technology refers to adding a torque or force measurement plate to the mechanical structure design and then predicting human body movement by calculating the dynamic model or data. Among them, mechanical control is divided into two methods, force-position hybrid control and impedance control [3]. The force-position hybrid control method was first proposed by Raibert et al. to solve the control problem of robots in constrained environments [5], that is, to control the displacement of robots in a specific environment. Impedance control is different from force-position hybrid control. The impedance control method focuses on achieving active compliance of rehabilitation robots, avoiding excessive confrontation between the mechanism and the limb, thereby creating a safe, comfortable and natural tactile interface for patients and avoiding the risk of re-injury of the affected limb [6]. In terms of force-position hybrid control, a good example is to add sensors to the force control system, which transmit accurate information to the control center after decoding through the interactive system. The center then guides the robot to execute the correct instructions for the user. Based on force control technology, Shi et al. from Beijing University of Aeronautics and Astronautics proposed a three-dimensional spring space equivalent model to represent the interactive torque between humans and robots (Figure 1), reflecting the torque applied to humans by robots. They then overcame the uncertainty of the human limb and robot parameters and the stiffness coefficient in the interaction force model and designed an autonomous force controller [7]. This optimization enables the robot to adapt to the user through adjustment, innovates in force

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control technology, and transmits more accurate information to the control center. When the patient is being treated, the robot can apply appropriate force to ensure that the patient will not suffer secondary injuries.

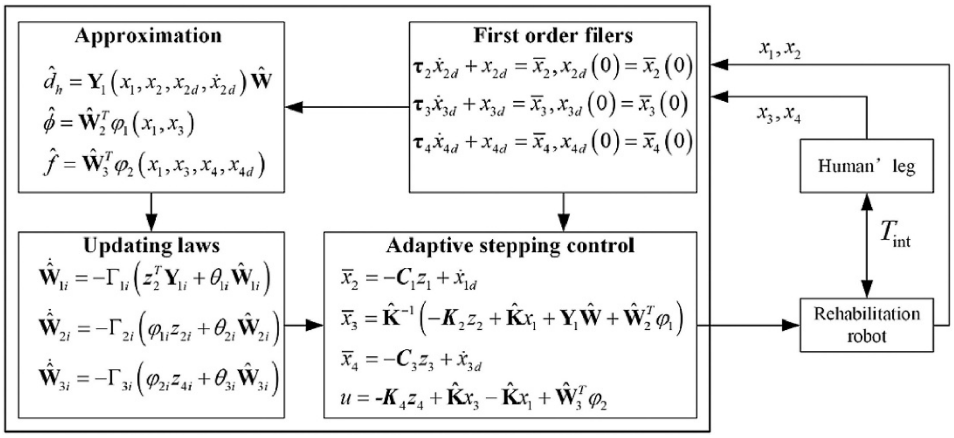

Fig. 1 Adaptive Controller Designed by Shi et al. [7]

In terms of impedance control, Taiwanese scholars Lee et al. proposed a prototype and controller for a mobile rehabilitation robot (MRR) under the premise of safety control (Figure 2): during normal operation, this controller provides accurate and safe control and ensures safe recovery and overdamping characteristics after abnormal events. It also does not require the identification of system models and the measurement of unknown system states and external interference [8]. This safety control improves the robot's perception ability and ensures safety to prevent patients from suffering secondary injuries.

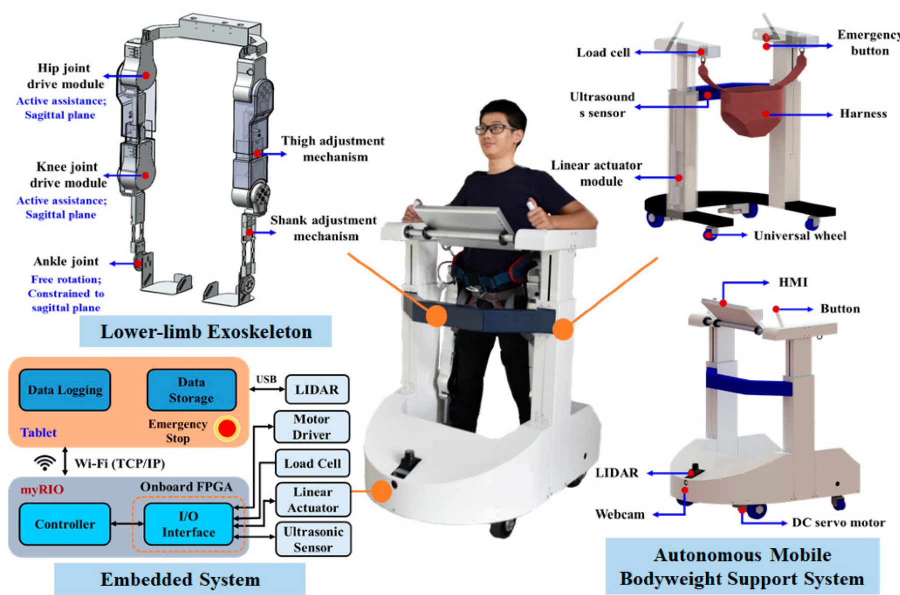

Fig.2 Control Model by Lee et al. Used on Lower Limb Rehabilitation Robot [8]

3.2 Lower Limb Rehabilitation Robot Based on Biomedical Signal Control

There are two types of biomedical signals that are most used in the field of rehabilitation robots: electroencephalogram (EEG) and surface electromyography (sEMG). Within this framework, they are further divided into lower limb rehabilitation robots based on intelligent perception and sEMG-based control and EEG-based control [3]. At present, the biggest obstacle to the development of biomedical signals is the difficulty in obtaining and measuring values. The solution is to obtain values accurately and design algorithms that fit the human body. These algorithms need to be closer to human brain waves and surface waves while ensuring safe use.

Currently, sEMG is a method that has less impact on the human body and is more widely used than EEG. First, data collection is required, and electromyography sensors are often used in the process. Single-channel electromyography sensors focus on specific areas of muscles to try to eliminate signals from muscles that are not of interest. The sensors are usually used in groups to form a multi-channel acquisition system, collecting electromyography signals from different parts of the body at the same time. In contrast, high-density sEMG sensors can use electrode arrays containing dozens of electrodes to obtain spatial and temporal electromyography information of specific areas [9]. Preprocessing is then required to obtain a stable signal source. The most useful information from sEMG signals is distributed in the frequency band of 0 Hz–500 Hz, and the primary energy is concentrated in the frequency band of 20 Hz–150 Hz [9]. Feature extraction and signal segmentation are then performed, and the signal is divided into different window periods for feature extraction, and its signal type is determined for easy research. Finally, recognition is performed, and the data obtained through the above processing should be input into a classifier for pattern recognition. The classifier can extract human behavior from sEMG signals through machine learning (ML) methods. The classifier can then be applied to specific scenarios, such as HMI or prosthetic control. Among them, long short-term memory (LSTM) is used in sEMG control as a low-cost method for recognizing gait. Since its design, LSTM has been used to solve the long-term dependency problem of general recurrent neural networks (RNNs). It can effectively transmit and express information over a long time series without causing useful information to be ignored (forgotten). At the same time, LSTM can solve the problem of gradient disappearance/explosion in RNNs [9]. Zhang et al. from Beijing Institute of Technology proposed a human motion intention recognition algorithm based on machine learning (Figure 3). This algorithm uses information from multiple sensors (such as force, displacement, and speed sensors) to enable the system to recognize various human movements using the Bidirectional Long Short-Term Memory (BILSTM) algorithm, with a recognition rate of 99.61%. This algorithm is tailored to the human brainwaves, and under this algorithm, the system can recognize and perceive human movements such as walking, turning, and even falling [10].

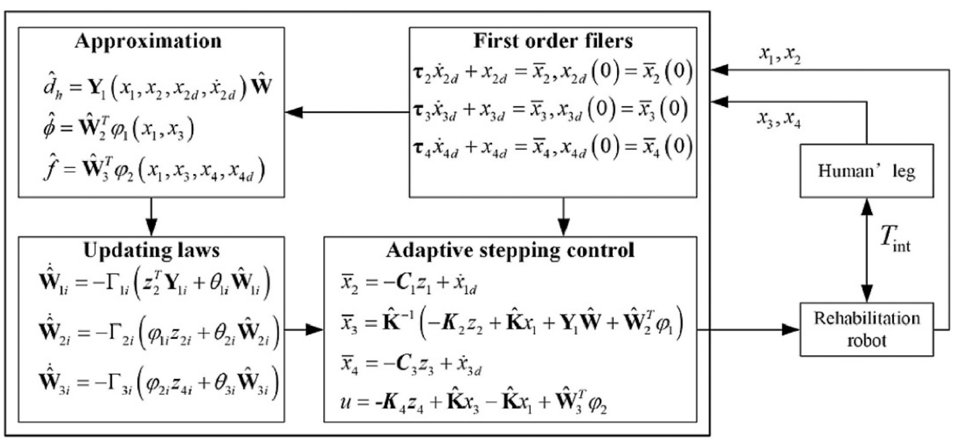

Fig.3 BILSTM Frame designed by Zhang et al. [10]

4. Discussion

4.1 Advantages & Disadvantages

As can be seen from the above examples, control based on mechanical signals relies on human muscle contraction, which is then estimated through mechanical design measurements or the establishment of dynamic models. Control based on mechanical signals is more intuitive because mechanical signals are simple to measure and easy to obtain. Control based on biomedical signals involves intercepting biocurrents, such as surface muscle currents or EEG. These values are precise, but obtaining and measuring them is more difficult. Currently, the industry almost exclusively uses non-invasive methods to intercept currents. The damage caused by invasive interfaces to the human body is currently difficult to estimate and can easily lead to uncontrollable consequences.

4.2 Opinions From the Author

Although previous studies have solved many problems of lower limb rehabilitation robots based on intelligent perception, there are still many challenges to be overcome in the rehabilitation field. At present, mechanical signal control has been widely used in lower limb rehabilitation robots based on intelligent perception. However, biomedical signal control is rarely used because of its cumbersome measurement and strong randomness. How to provide rehabilitation treatment for patients who cannot move and send force signals and infer their movement intentions

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will become the biggest challenge in the development of biomedical signal control. In the future, with the development of virtual imaging technology (VR technology), lower limb rehabilitation robots based on intelligent perception may interact with VR technology [3]. VR technology is known for its intuitive experience. So, in the future, can VR technology be involved in rehabilitation treatment: for example, using VR glasses to simulate roads to assist lower limb rehabilitation robots in walking rehabilitation treatment; or can VR technology open up a new path for biomedical signal control in rehabilitation robots based on intelligent perception: for example, predicting movement based on the bioelectricity of various parts of the human body in specific scenarios.

4.3 Future Visions

Research on human-machine interactive control of intelligent perception-based lower-limb rehabilitation robots aligns with societal development goals. It alleviates clinical workloads and injects new vitality into the rehabilitation field. It provides patients with novel and safe treatment options that meet their expectations. The use of diverse control technologies enables intelligent perception-based lower-limb rehabilitation robots to adapt to a wider range of environments and perform a wider range of rehabilitation treatments. The adoption of new technologies continuously revitalizes intelligent perception-based lower-limb rehabilitation robots, preventing them from becoming obsolete due to disconnection from new technologies.

5. Conclusion

This research, based primarily on previous research on lower-limb rehabilitation robots, reviews current research on human-robot interaction for intelligent-perception-based lower-limb rehabilitation robots. It first briefly explains the necessity of developing lower-limb rehabilitation robots, then briefly introduces what intelligent-perception-based lower-limb rehabilitation robots are. It then examines the two main control methods used for them: mechanical control and biomedical control. It then examines practical examples and finds that mechanical signal control technology has been widely applied to intelligent-perception-based lower-limb rehabilitation robots. However, due to difficulties in measurement and high randomness, biomedical signal control, while more straightforward, has not achieved the desired results in intelligent-perception-based lower-limb rehabilitation robots. Currently, intelligent-perception-based lower-limb rehabilitation robots still face numerous challenges in terms of human-robot interaction control. For example, how can biomedical signal control be used to infer the movement intentions of patients with complete paralysis? Or how can emerging technologies be integrated with intelligent-perception-based lower-limb rehabilitation robots to achieve better rehabilitation treatment? In the future, with the gradual development of emerging technologies, people's understanding of rehabilitation robots will move beyond consoles and metal frames. Emerging technologies such as VR will inject vitality into intelligent-perception-based lower-limb rehabilitation robots, allowing their development to be closely integrated with the new era.

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