Research on the Control System Design of Exoskeleton Rehabilitation Robot Based on Pole Assignment Algorithm

Kai Guo¹*, Ming Li¹, Jun Han¹, Zhi Bai¹

¹The School of Mechanical and Electrical Engineering, Suzhou University, Anhui, Suzhou, 234000, China

*Corresponding author e-mail: jdxyguokai@ahszu.edu.cn

Abstract. Exoskeleton rehabilitation robot control system can effectively ameliorate the rehabilitation quality of patients, reduce the rehabilitation pressure of patients, and can formulate scientific training steps according to the program to help patients recover more quickly, so it has important research and utilization value. Based on this, this paper first analyses the feedback control and pole assignment of the exoskeleton rehabilitation robot, then studies the key technologies of the exoskeleton rehabilitation robot, and finally gives the control system design strategy of the exoskeleton rehabilitation robot.

Keywords: Exoskeleton Rehabilitation Robot, Pole Assignment Algorithm, Control

1. Introduction

With the iterative progress and maturity of computer tech, it has been widely and deeply studied and popularized in many fields, especially in the field of robot control, which greatly promotes the progress and performance amelioration of intelligent machine system represented by exoskeleton rehabilitation robot. Exoskeleton rehabilitation robot control system can effectively ameliorate the rehabilitation quality of patients, reduce the rehabilitation pressure of patients, and can formulate scientific training steps according to the program to help patients recover more quickly [1]. On the other hand, with the increasing number of stroke patients in recent years, rehabilitation treatment and training becomes the key to effective quality. The rehabilitation of stroke patients mainly depends on regular and scientific training to reduce motor dysfunction and ameliorate the quality of life, mainly with the help of unloading device.

The traditional treatment of patients with spinal cord injury, stroke and lower limb joint disorders mainly relies on the assistance of therapists. However, this kind of training and rehabilitation method has some shortcomings, such as long cycle, high training intensity, slow effect and so on, which is difficult to effectively guarantee the continuity and stability of rehabilitation training [2]. With the help of lower limb rehabilitation medical equipment to carry out rehabilitation training for patients with neurological function, it can avoid the shortcomings of traditional training and ameliorate the rehabilitation effect of patients, so it has become the focus of current research. In this context, the control system of the exoskeleton rehabilitation robot is studied to realize the speed coordination and
control between the patient and the mobile body motor during gait training, and realize the synchronous movement of the patient and the rehabilitation robot.

In addition, the lower limb exoskeleton rehabilitation robot has several typical advantages and features as shown in Figure 1 below, which can carry out customized rehabilitation treatment with intensity, frequency and duration according to the patients' limb dysfunction. This treatment process can better fit the individual needs of patients, so as to bring stronger embodiment and ameliorate the exercise ability of patients. As a key link in the design of lower limb exoskeleton rehabilitation robot, the mechanism design of its mechanical system and rehabilitation training control algorithm play an important role and influence on the intelligent degree and control accuracy of the robot [3]. The utilization of pole placement algorithm can ameliorate the accuracy and flexibility of the control system, thus making the human-machine motion compatibility higher.

In a word, exoskeleton rehabilitation robot has a broad utilization market and utilization scenarios. Its utilization in the rehabilitation of patients with nervous system diseases can significantly ameliorate the training state and training effect of patients [4]. The emergence and in-depth utilization of exoskeleton rehabilitation robot has greatly ameliorated the efficiency and effect of traditional rehabilitation training, and can significantly ameliorate the efficiency of training and treatment effect. The control of exoskeleton rehabilitation robot based on pole assignment algorithm can effectively assist patients to carry out rehabilitation training, reduce the dependence of patients on medical staff, and enhance their rehabilitation potential. Therefore, the research on the control system design of exoskeleton rehabilitation robot based on pole assignment algorithm has important engineering practice value.

![Figure 1. Utilization advantages of lower extremity exoskeleton rehabilitation robot](image)

2. Feedback control and pole assignment of exoskeleton rehabilitation robot

2.1. State feedback pole assignment

For SISO and MIMO systems, the transfer function matrices of open-cycle and closed-cycle systems are obtained respectively. The characteristic polynomials of the two transfer function matrices are compared, and the conditions for pole assignment are established [5]. If the controlled system can carry out any pole assignment, the state of the system is completely steerable. When the state of the controlled system is fully steerable, its poles can be arbitrarily assigned. When the poles of the closed-cycle system coincide with the zeros of the open-cycle system, there will be pole zero cancellation in the transfer function of the closed-cycle system. According to the zero pole cancellation theorem, the closed-cycle system or state cannot be controlled.

2.2. Pole assignment design in state enclosure

Pole placement design method in state enclosure is part of the elementary design means. If the system is completely state steerable, then the required closed-cycle poles in the plane can be chooses, and the system with these poles as closed-cycle poles can be designed. In the pole placement design mean, all state parameters are fed back so that all closed-cycle poles are set at the anticipated positions. In addition, the state feedback pole assignment problem is usually divided into two parts. Firstly, it is
assumed that all States of the system can be used for feedback, and a control system with full state feedback is designed [6]. Then, a state observer is designed to estimate the state parameters for state feedback. The parameters used in the design are the anticipated closed-cycle pole position and sampling period. It is assumed that all state parameters of the system can be gauged and used for feedback. If the system is completely state steerable, the poles of the closed-cycle system can be located at any anticipated position in the plane by using the state feedback mean and choosing the state feedback gain matrix appropriately.

3. Research status of key technologies of exoskeleton rehabilitation robot

3.1. Key technologies of exoskeleton rehabilitation robot

Exoskeleton rehabilitation robot is a wearable device which combines AI, mechanical power device and mechanical energy. According to the structure, exoskeleton robots can be divided into upper limb, lower limb, whole body and joint robots. The control model of exoskeleton rehabilitation robot can be divided into perception layer, control layer and decision layer. The control system needs to ensure that the exoskeleton can quickly and accurately respond to various human movements, and also consider the tacit understanding between the exoskeleton and different patients, that is, the exoskeleton needs to have certain learning ability to adapt to the movement characteristics of different operators. Secondly, the mechanical structure of exoskeleton rehabilitation robot should comprehensively analyze the range of motion and motion characteristics of human joints [7]. In the process of design, the anthropomorphic principle should be fully considered, and the degrees of freedom of each joint should be consistent with the form of human motion, so as to ensure the safety of action. Exoskeleton robot should also have a wide range of environmental adaptability, so that patients can adapt to the scene more flexibly.

In addition, the weight and volume of exoskeleton rehabilitation robot should be controlled in a certain range, and it should be able to provide enough torque and torque, and it should have good heat dissipation performance. At present, the commonly used driving forces of exoskeleton rehabilitation robot include hydraulic driving, pneumatic driving and motor driving. The advantages and disadvantages of these driving forms are shown in Table 1.

**Table 1. The advantages and disadvantages of different driving forms**

| Driving forms | Advantages | Disadvantages                  |
|---------------|------------|--------------------------------|
| Hydraulic     | Small inertia and simple structure | High noise and low energy efficiency |
| Motor         | Simple structure and mature tech  | Poor dynamic balance characteristics |
| Pneumatic     | Simple structure and low cost     | Poor control and slow signal transmission |

3.2. Control signals of exoskeleton rehabilitation robot

The control signals of exoskeleton rehabilitation robot mainly include needle electrode EMG signal and surface EMG signal. The needle electrode is used as the guide electrode to gauge the action potential directly [8]. The surface electrode is used as the guide electrode to pick up the potential of muscle activity. Surface electromyography (sEMG) is the bioelectrical change of neuromuscular system during random or non-random activities, which is guided, amplified, realized and recorded by skin surface electrode.

In addition, surface electromyography (sEMG) signals are different due to individual differences, but they also have many common characteristics, such as AC signal, micro electric signal, low frequency signal and random signal [9]. Due to the regularity of EMG signals of the same muscle group and the difference of different muscle groups, it is possible to control the exoskeleton rehabilitation robot by using sEMG signals as human-machine interface.
3.3. Control elements of exoskeleton rehabilitation robot

As an element for measuring and transforming the elastic deformation, the input parameter of the control force sensor of exoskeleton rehabilitation robot is force or torque, which outputs the corresponding strain and displacement, and then converts the corresponding signal into electrical signal. Force sensors mainly include elastic sensitive element, piezoresistive force sensor, strain force sensor, piezomagnetic force sensor and piezoelectric force sensor. In addition, the photoelectric encoder of the exoskeleton rehabilitation robot can be divided into incremental, absolute and hybrid forms according to the calibration mean and signal output form of the photoelectric encoder.

4. Control system design strategy of exoskeleton rehabilitation robot

4.1. Overall scheme of control system for exoskeleton rehabilitation robot

The motion part of exoskeleton rehabilitation robot is composed of many kinds of joints, which need to be given reasonable degrees of freedom [10]. In this paper, the lower limb joint of exoskeleton rehabilitation robot is taken as the research object, and its motion model structure is designed as shown in Figure 2. The length of the connecting rod structure in the control system of exoskeleton rehabilitation robot should be able to be adjusted to meet the rehabilitation training needs of patients with different body types. The hardware structure of the control system of exoskeleton rehabilitation robot is equipped with joint angle sensor, pressure sensor and other components to realize the dynamic monitoring of joint angle and the monitoring of patient interaction. In addition, the controller signal of the robot is realized through serial communication, and the rehabilitation training mode is sent to the controller through the upper computer, and then the position signal is sent to the upper computer through serial communication to realize lower limb gait movement.

4.2. Control algorithm of exoskeleton rehabilitation robot system

In order to design the control software of exoskeleton rehabilitation robot system, the training mode of rehabilitation robot should be set first, so as to determine the amplitude, speed and other parameters of rehabilitation gait, and adjust the display of control instructions with the help of serial interface. The control system flow of lower limb rehabilitation robot uses timer to control the sampling period of the whole system. In addition, at the level of pole placement controller design, the closed-cycle control with pole placement control algorithm as the core is adopted. The output of the system is calculated by the controller designed based on the pole placement algorithm. Through the discretization of the controller, the motion parameters are set on the display screen, and the driver is enabled. According to the set bottom speed, the control system enables the rehabilitation robot to respond to the action request in time according to the set program, so as to meet the training needs of patients.
5. Conclusion

In summary, the control of exoskeleton rehabilitation robot based on pole assignment algorithm can effectively assist patients to carry out rehabilitation training, reduce the dependence of patients on medical staff, and enhance their rehabilitation potential. In this paper, through the research of feedback control and pole assignment of exoskeleton rehabilitation robot, the key technologies and components of exoskeleton rehabilitation robot are analyzed. Through the analysis of feedback control and pole assignment of exoskeleton rehabilitation robot, the overall scheme and algorithm design of exoskeleton rehabilitation robot control system are studied.

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