Research on Key Technologies of Elders' Exoskeleton Robot Assisted by Physical Exercise Based on Fuzzy PID Control

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Abstract. In the past, walking aids (such as crutches and walking aids) widely used by the elderly in physical exercise had relatively single functions, low intelligence, insufficient safety and comfort, and could not meet the needs of users for independent living. Therefore, it is necessary to apply robot technology to the field of traditional walking aid equipment and design a more intelligent, comfortable and safe walking aid robot system. The gait control of the exoskeleton robot assisted by physical exercise for the elderly is studied, and an algorithm based on fuzzy PID is proposed. Firstly, a fuzzy PID control algorithm for the exoskeleton robot assisted by physical exercise for the elderly is given. Secondly, membership functions are selected according to the parameters of the robot joint angle error and error variation. Finally, combined with practical operation experience, a fuzzy rule table is established, and online self-tuning of PID parameters is completed. The experimental results show that the fuzzy PID control method can make the exoskeleton robot move smoothly and realize the gait control of the robot initially.

1. Introduction
According to the research report of the National Aging Office, China has entered a stage of rapid aging [1-13]. At this stage, China will add an average of 5.96 million elderly people every year, reaching 250 million by 2020. The most obvious feature of the aging process is the decline of walking ability caused by the decline of body function, which seriously affects the quality of daily life of the elderly. In contrast, currently widely used walking aids (e.g. crutches, walking aids, etc.) have relatively simple functions, low intelligence, insufficient safety and comfort, and cannot meet the needs of users for independent living [14-19]. Therefore, it is necessary to apply robot technology to the field of traditional walking aid equipment and design a more intelligent, comfortable and safe walking aid robot system [17-21].

In recent years, scholars at home and abroad have invested a lot of research time in the field of exoskeleton robots and have achieved certain results. For example, the HAV series exoskeleton robots [29-31] developed by Professor Shanhaijiazhi of the University of Tsukuba in Japan and the lower limb rehabilitation exoskeleton robots [3] developed by Professor Qian Jinwu of Shanghai University have
all reached a higher research level. Lanzhou Industry and Equipment Co. Ltd, Lanzhou University of technology Zhang Wanjun studied some model identification control systems [22-33] of flexible training equipment and control methods. For the research of exoskeleton robot control methods, many methods have been put forward, such as control method based on electromyography signal and control method based on muscle hardness detection, etc. [34]. Although these methods have achieved certain results, their control effect is still not ideal. Therefore, the gait control method of exoskeleton robot based on fuzzy PID proposed in this study is not only of realistic social significance, but also of certain scientific research significance.

Firstly, this paper presents a fuzzy PID control algorithm for exoskeleton robots assisted by physical exercise for the elderly. Secondly, through the simulation experiment, the simulation results show that the fuzzy PID control method can make the exoskeleton robot move stably and realize the gait control of the robot initially.

2. Design of Fuzzy PID Control Algorithm

The goal of exoskeleton robot control is to enable the robot to walk smoothly according to the theoretical planned gait trajectory. Since the control platform is a digital DSP system, gait data should be discretized in algorithm design, i.e. a gait cycle is divided into several discrete times \( \Delta t \). Considering the inevitable error in the transmission process of the motor and the actuator of the mechanical leg, the robot system adds an encoder to collect the angle information of the joint in real time and then feeds it back to the controller. Through the calculation of the controller, the difference between the actual gait and the theoretical gait caused by the error can be reduced in real time.

The block diagram of fuzzy PID control structure is shown in Fig. 1.

![Figure 1. Structural block diagram of fuzzy PID control system.](image)

In \( \Delta t \) time, the deviation and variation between the theoretical gait angle of the robot and the gait angle measured by photoelectric encoder are taken as the input of the controller, and the increment of the robot gait angle is taken as the output of the controller.

If the current measured angle at the robot joint is \( \theta(k) \) and the theoretical angle is \( \theta_0(k) \), the joint gait angle error is:

\[
E(k) = \theta(k) - \theta_0(k)
\]  \( (1) \)

Assuming that the last discrete-time joint angle error is \( E(k-1) \), the current robot joint angle error changes as follows:

\[
\Delta E(k) = E(k) - E(k-1)
\]  \( (2) \)

The quantitative processing method of input in this study is as follows: the robot is tested for many times, all data of each experiment are recorded, and the maximum values of \( E(k)_{\text{max}} \) and \( \Delta E(k)_{\text{max}} \) at each discrete time at the robot joint can be obtained through comparison. According to the maximum value measured by experiment, each joint angle value measured by photoelectric encoder can be normalized:
3. Introduction of Test Platform
The purpose of this test is to test and verify the above control method, and compare it with the theoretical gait trajectory and analyze the error. The test platform is shown in Fig. 2.

![Test platform](image)

Figure 2. Test platform.

In order to facilitate the collection of experimental data of the elderly exercise-assisted exoskeleton robot, this study uses the elderly exercise-assisted exoskeleton robot to walk in situ, and the actual gait trajectory of the robot can be measured by the motion capture instrument. The motion capture instrument is a position sensor, which can capture the metal mark points attached to the robot joints. When the robot moves, it can acquire the spatial coordinates of the joints in real time through the mark points, and the gait track of the joints can be obtained after the data processing.

4. Results and analysis
In this study, two sets of data were obtained by real-time measurement of the motion angle at the knee joint of the robot with motion capture instruments. As shown in Fig. 2, the dotted line represents the planned gait trajectory and the solid line represents the measured gait trajectory. Test experiment simulation diagram 1

![Test experiment simulation diagram 1](image)

Figure 3. Test experiment simulation diagram 1.

Compared with gait cycle, gait amplitude, maximum gait angle and minimum gait angle, the error is greatly reduced in fuzzy control algorithm. For example, the maximum gait amplitude of the planned gait angle is 18.338, while the measured gait angle is 8.592, with an error of 53%.
When the robot moves under the closed-loop control system, the error between the measured gait angle and the planned gait angle is small, which is basically consistent with the planned gait angle. For example, the maximum gait amplitude of the planned gait angle is 18.338, while the measured gait angle is 17.432, and its error is only 4.9%, which is within the design error range. According to the experimental analysis, the fuzzy PID control algorithm realizes the gait control of the robot and meets the requirements of step assistance.

The simulation results show that the fuzzy PID control method can make the exoskeleton robot move stably and realize the gait control of the robot initially.

5. Summary

(1) In this study, the motion of the exoskeleton robot assisted by physical exercise for the elderly under different exercise control states is analyzed through experiments. Through the analysis and comparison of simulation experiments, it is concluded that the fuzzy PID control algorithm plays a very good role in gait control. It not only makes up for the out-of-step problem of open-loop control, but also makes the robot move more stably and safely through the real-time feedback of closed-loop fuzzy PID control.

(2) The MATLAB experiments and research results show that the fuzzy PID control algorithm can effectively improve the gait control ability of the elderly exercise-assisted exoskeleton robot, enhance the anti-interference ability, stability and safety of the robot, and has certain practical significance for the medical application of the elderly exercise-assisted exoskeleton robot.

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