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Research on the Control Strategy of Active Upper Limb Rehabilitation Robot Based on Force Feedback

Jiaxin Li[1], Yuting Jin[2]

[1]CSUST International Institute of Technology, Changsha University of Science & Technology, Changsha, Hunan, China
[2]School of Mechano-Electronic Engineering, Xidian University, Xi'an, Shannxi, China

Abstract: *Aiming at the current wide application of robots in the rehabilitation field, in order to enhance the assisted rehabilitation effect of upper limb hemiplegic patients during the rehabilitation period and improve the assisted effect for patients' rehabilitation, for patients in different recovery periods, this paper proposes an active upper limb rehabilitation robot control method based on force feedback and modifies the impedance parameters by designing a regulation controller to achieve a better assisted effect. Based on the impedance control theory, an emerging regulation controller is designed and tested by changing the damping and stiffness parameters of the robot, and through extensive experimental comparisons, set robot parameters that better match the patient during each step of rehabilitation. Improve the active participation of the patient by setting different parameters. In this paper, simulation experiments were conducted for different impedance parameters, and the impedance parameters of the robot were changed through the design of the modulation controller, The robot motion with different parameter settings was also simulated and analyzed. Finally, by analyzing the robot motion curves under different conditions, it was concluded that larger stiffness parameters are suitable for patients with more severe conditions and larger damping parameters are suitable for patients with good recovery*

Keywords: *Control strategy, upper limb, rehabilitation, robots*

1. Introduction

Currently, technologies related to rehabilitation robotics are rapidly developing and gaining more and more attention and applications [1]. At the same time, the development and utilization of robots has gradually started to transition from the industrial field to the field of human-robot collaboration and has gradually expanded from the traditional manufacturing industry to among highly sophisticated fields such as medical care. Not only that, medicine, engineering, and robotics continue to make many breakthroughs at the technological level. The integration of new materials, big data and artificial intelligence with the medical field is gradually deepening., the industrial application of medical robots has become a major trend [2]. In the field of human-robot collaboration scene practice gradually found that if you want to achieve better human-robot interaction and significantly improve the flexibility and participation of human-robot collaboration. It is necessary to start with practical applications and to make continuous improvements according to the higher requirements of patients for the control strategy and performance of the robot.[3].

In the upper limb rehabilitation training of patients with movement disorders, the traditional rehabilitation therapy usually relies on the rehabilitation physiotherapist to take the patient's affected limb manually for passive rehabilitation training, this training strategy is too homogeneous and requires a lot of repetitive physical work on the part of the physical therapist. [4]. The Upper Extremity Rehabilitation Robot assists patients with upper extremity motor training. The process and results of rehabilitation training are evaluated by installing sensors on the robot. [5]. Surface EMG signals can reflect the activation level of specific muscle groups, and thus interactive control strategies based on surface EMG signals can enable the robot to change from a passive instruction-receiving approach to an active understanding of human behavioral intentions [6]. In the literature [7], it was proposed that the interaction control between rehabilitation robot and human body is indispensable in rehabilitation training, and this was used to propose a control strategy based on surface EMG signals for hemiplegic patients. Peng et al. proposed a robot-assisted training method based on a surface EMG signal-driven model, which can effectively identify the patient's motor intention and translate it into the patient's knee joint drive torque, which in turn controls and influences the patient's autonomous force generation to assist the patient's rehabilitation [8].Cheng et al. proposed a neural network-based adaptive control method that enables the robot to change the robot's control parameters more quickly and accurately in the face of uncertain influences such as kinematics, dynamics, and drive models, so that the robot can still have good tracking performance [9].

Currently, for patients in different rehabilitation periods, to in order to realize the right remedy and rational design of rehabilitation scheme, this paper designs an emerging regulation controller based on position-velocity impedance control theory. Compared with the traditional control method, this paper achieves the tracking of desired force and desired position at the end of the robot by setting the position control loop and velocity control loop independently, respectively.

The robot is tested by changing the damping and stiffness parameters, and through many experimental comparisons, the parameter settings of the robot that are more consistent with the patients at each stage of rehabilitation are derived, this greatly increases the active participation of patients. It has great application value in practical scenarios.

2. Force feedback active control method

2.1. Proposal of active soft control

Active and supple control of the robot is achieved by introducing a force closed-loop control concept based on the closed-loop robot position control, i.e., The motion of the robot is controlled by force control commands. For a rehabilitation robot, the patient's rehabilitation needs to be analyzed first. The patient's condition has an integral influence on the control of the robot. A practical application example of human-robot collaboration is shown in Figure 1 below.

Figure 1: Example of human-machine collaborative robot application

In the early stage of rehabilitation, the patient's muscle strength is weak, and he can only rely on the assistance of the robot for rehabilitation training of the upper limbs. However, in the later stages of rehabilitation, the patient's muscle strength has been restored to a certain degree. And the patient's recovery is faster at this time, and the patient's hand will generate a greater force with the end of the robot, and the effect of relying mainly on robot-driven rehabilitation training at this time is poor. If the training program at this time is limited to the traditional auxiliary exercise, it will not be conducive to the improvement of the subsequent treatment effect. Therefore, in this paper, the interaction between human and robot is considered for the above practical analysis. And the design enables the robot to comply with the patient's external force, and the patient's force leads the rehabilitation exercise to improve the patient's active participation.

3. Impedance control algorithm modeling

The relationship between the human-machine contact force and position at the end of the robot can be described by the second-order differential equation.

$$f = m\ddot{q} + b\dot{q} + kq \tag{1}$$

Where q , $\dot{q}$ and $\ddot{q}$ denote the position, velocity, and acceleration of the end of the robot, respectively, and m, b, and k denote the inertia coefficients of the robot, respectively. damping coefficient and stiffness coefficient.

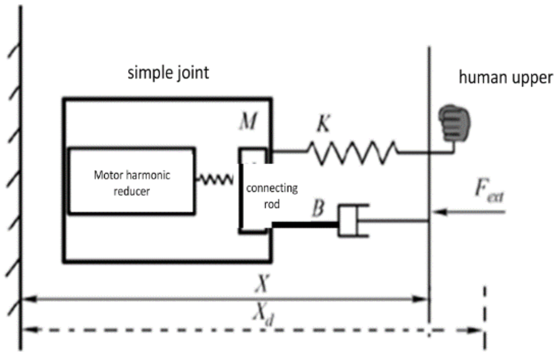

Figure 2: Impedance control model

Through equation 1 and combined with Fig.2, impedance control consists of inertia, stiffness and damping control, but compared with the traditional control target, impedance control is given a target model whose parameters can be changed, and the internal loop control is performed by continuously calculating the amount of deviation. Therefore, the impedance control relationship at the end of the robot is listed below:

$$F(s) = M_d(\ddot{Q}_r - \ddot{Q}) + B_d(\dot{Q}_r - \dot{Q}) + M_d(Q_r - Q) \tag{2}$$

The transfer function is shown in equation 3.

$$Z(s) = \frac{F(s)}{\Delta Q(s)} = M_d s^2 + B_d s + K_d \tag{3}$$

Where F is the contact force vector at the end of the robot; the actual motion parameters of the end of the robot are represented by $\ddot{Q}$, $\dot{Q}$, Q; $\ddot{Q}_r$, $\dot{Q}_r$, $Q_r$represent the theoretical motion parameters of the end; $\mathrm{M_d}$, B_d, K_d represent the stiffness, damping and inertia of the robot respectively.

The core of impedance control lies in linking the forces and motions of the robot. By designing the transformation matrix, the coordinate offset l during motion is reflected in the form of force. Usually, the impedance control performance of the robot is determined by both the working environment and impedance parameters. To achieve impedance control of the robot in different rehabilitation environments, corresponding changes need to be made to the motion correction matrix of the robot to adjust the degree of assistance of the upper limb in operating the robot for training. The appropriate motion correction matrix should be selected for patients in different rehabilitation stages.

4. Force-based impedance control algorithm

In conventional robot control, the setting of impedance parameters is often fixed and cannot be adjusted according to the actual situation of the patient's recovery. In order to solve the above problems, a new regulatory controller design is used in the study, which adds a variable impedance parameter module to the traditional control method and can effectively make adjustments according to the patient's ground recovery. The simulation model is shown in Fig.3.

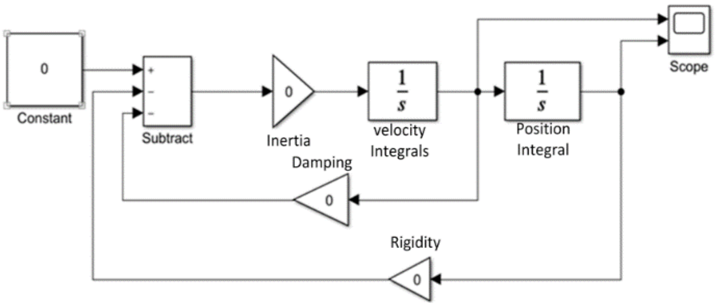

Figure 3: Impedance control Simulink model

The damping parameters and stiffness parameters are modified in two modules to achieve the effect of regulatory control. When the controller is working normally, it can be modified at any time according to the recovery situation of different patients at different times. It is also possible to compare the motion of the robot under each parameter setting. The control system includes a velocity control loop and a position control loop that track the desired force and the desired position, respectively. The impedance parameters are modified according to the desired motion of the robot end to obtain better assistance. In essence, the control of the robot end is achieved by controlling the torque of the robot. The force and position of the robot can be directly controlled by controlling the torque of the robot, and this method has high accuracy and responsiveness.

5. Experimental results and analysis.

In this paper, Simulink module is used to simulate the motion process of the manipulator, and the influence of stiffness parameters and damping parameters on the actual motion is analyzed by collecting and comparing its motion signals under different conditions. The coordinate signal x is used to indicate the position where the end of the robot is located, and the force signal v is used to indicate the magnitude of the motion speed of the end of the robot and indirectly respond to the smoothness of the motion. Firstly, according to the motion characteristics of the robot, a constant value module is generated to set the motion end point for the manipulator. By comparing the results of many experiments, the article finally selects 2 as the motion endpoint coordinates of the rehabilitation robot and sets its motion inertia to 0.1. By understanding the actual situation of the patients, Setting Large End Point Coordinate and Inertia for Rehabilitation Robot is easy to cause secondary injury to the patients. But if set the two smaller cannot help patients to get good rehabilitation effects. 1 In the traditional robot impedance control, the stiffness parameters and damping parameters are set to fixed values, and its motion effect is shown in Fig.4.

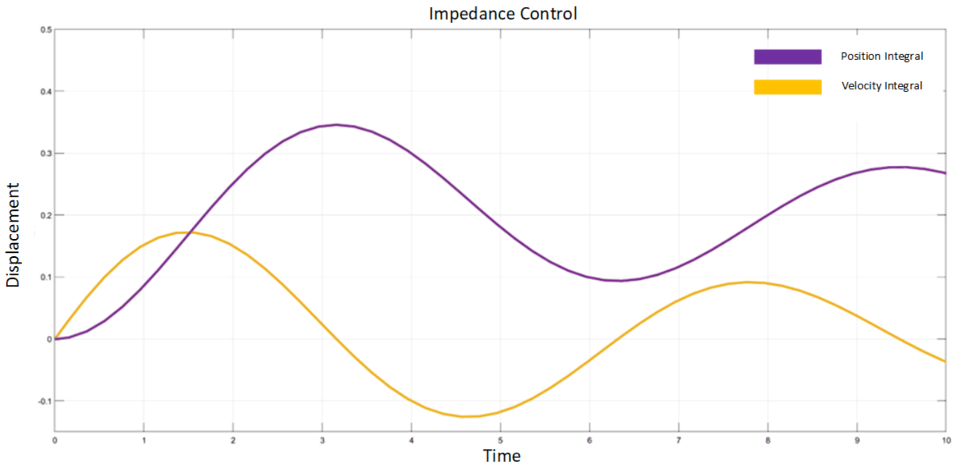

Figure 4: Conventional robot motion curve

The analysis shows that the robot has a smooth curve during motion at this time, which can assist in the rehabilitation of most patients. However, by analyzing the robot motion curve in the traditional state, it is found that it is obviously not suitable for patients at different rehabilitation stages. By analyzing the motion state of the robot, we can see that the velocity profile and position profile of the robot are currently changing rapidly. By setting the velocity curve and position curve of the robot as indicators of the auxiliary effect, it can be clearly seen that for patients with good recovery, the auxiliary function of the robot is too strong at this time, which is not conducive to the recovery of patients. For severe patients, overtraining may lead to secondary injury. In summary, patients with more severe conditions need to be rehabilitated with the strength of the robot, while patients with better recovery need to be rehabilitated with their own strength, with the assistance of the robot.

In this paper, we enhance the continuity and applicability of rehabilitation training by designing the adjustment controller so that it is applicable to patients in different recovery stages. For patients with poor recovery, a larger stiffness parameter can be set to smooth the movement curve. By reducing the patient's training time, it is possible to guide the patient's rehabilitation training; for patients with better recovery, the training effect is achieved by setting a larger damping parameter to reduce the motion speed of the end of the robot itself, to comply with the patient's own force.

Overall, when the stiffness parameters increase significantly, through the analysis of figures 5 and 6, the robot impedance parameters are adjusted, the motion curve is obviously smooth. By analyzing figure

5, the speed curve of the robot fluctuates less in this case. What's more, by analyzing the position curve in Figure 6, it can be found that the robot will reach the predetermined end point more slowly, and it is more suitable for patients with poor recovery effect to carry out rehabilitation training, which can protect patients from secondary injury and has good applicability.

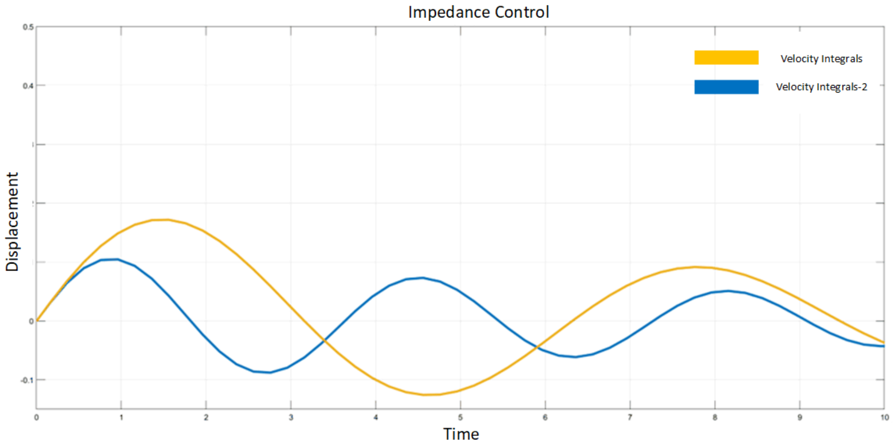

Figure 5: Robot velocity curve with large stiffness parameters

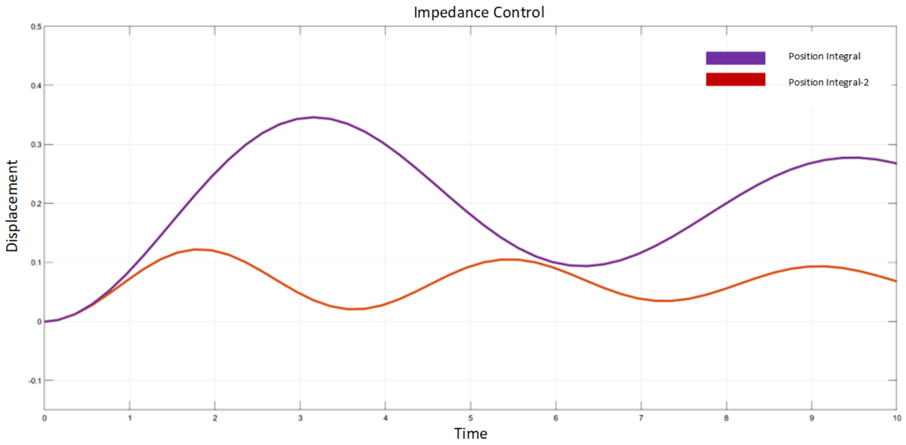

Figure 6: Robot displacement curve with large stiffness parameters

When the rehabilitation effect of patients is good, large damping parameters can be selected to achieve good rehabilitation effect. The effect of setting larger damping parameters is shown in Figures 7 and 8. By comparing the two curves in the graph, the robot with larger damping parameters has slower motion speed and more stable trajectory. Currently, patients need to actively force to guide the movement of the end of the robot, which also has a certain rehabilitation effect on patients with good recovery.

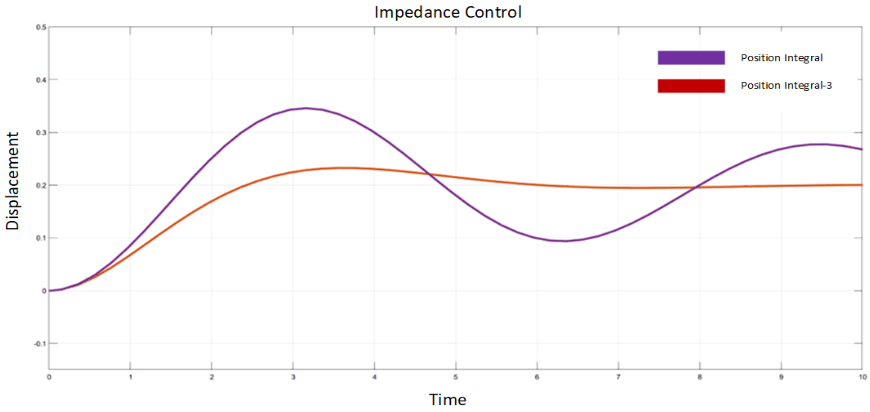

Figure 7: Robot displacement curve with large damping parameters

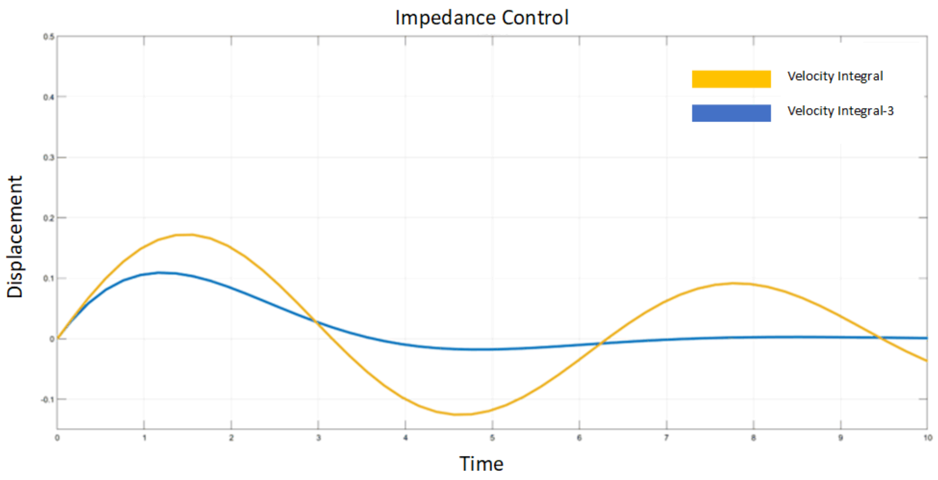

Figure 8: Robot velocity curve with large damping parameters

The analysis shows that with the addition of the new impedance control regulator, the robot can perform well in more situations, this is more in line with the needs of rehabilitation training. And it can be applied to different patients at different stages of rehabilitation.

6. Conclusion

In this paper, a control strategy is designed for patients in different recovery periods during the rehabilitation process. The controller adopts a new design scheme from impedance control theory. It can adjust the impedance parameters according to the recovery degree of the patient while satisfying the assisted rehabilitation training: when the patient's recovery is poor, the patient can be better assisted in the rehabilitation training by setting a larger stiffness parameter; when the patient's recovery is good, the patient can be guided to exert force by setting a larger damping parameter to achieve a better rehabilitation effect. At the same time, the impedance parameters of the controller can be adjusted according to the patients in different rehabilitation periods. The continuity and applicability of rehabilitation training is enhanced by according to the patient.

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