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2.5.3: FES III - Locomotion

Application of Neural Network-based Controller for the Knee-joint Position Control with Quadriceps Stimulation

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Abstract

A neuro-control system has been designed to control the knee joint to move in accordance with the desired trajectory of movement with stimulation of quadriceps muscle. This control system consists of a neural controller in feedforward loop and a fixed parameter PID feedback controller. The neural network is trained as an inverse model of quadriceps-lower leg system for directly feedforward control. With the aid of neural controller, the knee joint angle is controlled within small region around the desired trajectory, then is fine controlled by the PID controller. Experimental results showed that the neuro-PID controller is promising for the position control of knee joint with quadriceps stimulation.

Introduction

Functional electrical stimulation (FES) is a promising technique of a controlled electrical stimulus to the intact peripheral in an attempt to restore functional tasks in paralyzed musculoskeletal system. However, many obstacles are encountered in stimulating paralyzed musculoskeletal system to produce the desired movements.

Various control strategies have been developed to provide enhanced repeatability and predictability of muscle responses, including fixed-parameter feedback control [1], model reference adaptive control [2], and neural network-based control [3]-[5]. The design methods of fixed parameter feedback control involve the construction of a precise mathematical model describing the musculoskeletal system to be controlled. However, muscle is very complicated, if it is to be modeled, making the physiologically-based models tends to be complex and have limited accuracy. Thus, the fixed-parameter feedback control techniques have met with only limited success due to inadequate system models. Although the model reference adaptive control avoids the need for precise models of the musculoskeletal system, but control performance was only satisfactory when the closed-loop bandwidth were limited by appropriate choice of the reference model parameters.

On the other hand, artificial neural networks may be a better alternative for the modeling and control of complex nonlinear systems because of the ability to map any arbitrarily complicated nonlinear input/output relationships. In recent years, neural network techniques have been led into the domain of FES by several researchers [3]-[5]. They indicated that the neural network techniques may provide improvements to existing FES control system technology. However, neural network techniques in the filed of FES is still at a early stage. Thus further research and evaluation on animal or human trials is required before a neural control scheme can be designed for practical FES control with a satisfactory performance.

The aim of this study is to develop a practical design method for the simple problem of controlling the knee joint position with quadriceps stimulation through the use of neural network techniques.

Experimental equipment

Laboratory apparatus was built to study the knee joint control by FES, as shown in Fig. 1. Subjects are seated in a tested chair. The thigh of the test leg is fixed, but the lower leg is free to swing at the knee. The desired movement required activation of only the quadriceps muscle group (knee extensors) through a pair of surface silicone electrodes. One electrode (cathode) is placed on the motor point of rectus femoris, and the second near the patella. Knee angle θ is defined in Fig. 1, with $\theta = 0$ degree, when the lower leg is at rest.

Design of the Control Strategies

The block diagram of the control system is illustrated in Fig. 2. This control system contains a neural controller in feedforward loop and a fixed parameter PID feedback controller. First, the neural controller is trained to obtain an inverse dynamics of the plant in a off-line mode. Once the neural controller has been successfully trained to mimic the plant inverse dynamics, it can be used directly for inverse feedforward control. Therefore, given a desired reference trajectory of movement, the neural controller can calculate the required stimulus activation of the quadriceps muscle using an inverse process model.

However, some degree of modeling error is unavoidable, since neural network modeling can never perfectly represent physical musculoskeletal systems. Therefore, the PID feedback controller in-parallel is incorporated into the design of the neural control system to compensate for the residual tracking errors caused by the disturbances and network modeling errors.

Since the quadriceps-lower leg system is inherently dynamical, the control must involve the plant's present and past state information. Therefore, in this study, a three-layered feedforward neural network with recurrent feedback and time delays in the input layer was employed because this neural network topology can capture more system dynamics. The error backpropagation algorithm was used to train neural connection weights.

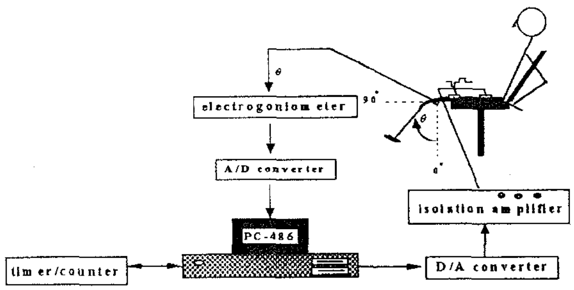

Fig. 1 A computer-controlled FES system

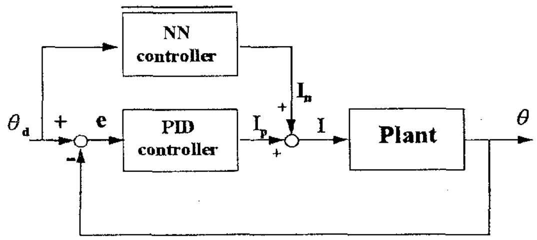

Fig. 2 The block diagram of the control system.

Experimental Results

Fig. 3 illustrates the typical responses of tracking a ramp-step-ramp sequences by the neural network controller alone and neuro-PID controller. The solid line indicates the actual knee joint angle trajectory and the dash line indicates the reference tracking trajectory. The results from the control of knee joint indicates that the trained neural network controller is able to approximately control the knee joint to reach and maintain the target knee joint position, although producing small steady-state and isokinetic ramp tracking errors.

To compensate for the insufficiency of neural controller, the neural controller and the PID feedback controller are combined to track the desired trajectory of knee joint movement. As expected, the steady-state error is improved after combining the PID controller. However, the isokinetic ramp tracking is still poor, particularly in ramp-down phase. It could result from the different characteristics between muscle recruitment and decruitment processes. In the decruitment process, the hysteresis phenomenon always affects the control system.

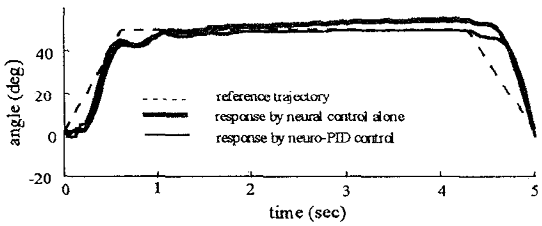

Fig. 3 Typical responses of tracking by the neural controller alone and neuro-PID controller.

Discussion

This study has presented a practical design for controlling the knee-joint position with quadriceps stimulation through the use of neural network techniques. The main attraction of neural networks is that they can learn any arbitrarily complicated mapping and hence is adequate for the problem requirements of this study. However, the neural network-based control system are not panacea. The performance of neural controller is limited by the degree to which the plant can be approximated by a neural network. Therefore, in this study, the union of the neural controller and fixed parameter PID is used to improve the tracking performance.

Reference

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