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An adaptive fuzzy sliding mode control for angle tracking of human musculoskeletal arm model☆

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ABSTRACT

The paper studies the angle tracking control of the elbow joint and the end-point of the human musculoskeletal arm model. It uses a Hill-type planar model with six muscles and two links. During the motion, the gravity compensation is emphasized since it has significant influence on actual anthropomorphic arm system. An adaptive fuzzy sliding mode control method is proposed and applied to make the elbow joint and the end point of the human musculoskeletal arm model track certain angles. Through the adaptive fuzzy system, it may realize the adaptive approximation of switching scales of sliding mode controller so as to avoid chattering. Numerical simulations are performed in order to verify the proposed control method. Results show that accurate angle tracking control may well be accomplished by proposed sliding mode controller.

1. Introduction

Once the electrical signals between the brain and muscles have interrupted, it may result spinal cord injuries (SCI) and cause paralysis on patients [1]. The patients may be trained and exercised by Functional Electrical Simulation (FES) for rehabilitation. The FES stimulates the peripheral nerves of disable limbs by impaired motor control. From recent researches, the motor control may efficiently improve the recovery of upper extremity movements as the stimulation associated with the voluntary attempt [2–6].

In the early research, the most common control method for FES is the feed-forward control [7]. The obvious advantage of the feed-forward control is that it is very simple to implement without requiring sensors. The drawback of the feed-forward control is that it depends much on accurate parameters of the model due to the absence of sensors. Many other researchers have also focused on feedback control utilizing sensors to detect arm properties and to modify actual actions to desired behaviors. The feedback control of the human upper extremity involves the shoulder function [8], the elbow extension [9] and so on [10].

Other advanced and intelligent control strategies for the human musculoskeletal arm are investigated as follows. Blana proposed a control combining the feed-forward and feedback control [11]. Tahara firstly studied the nonlinear Hill-type human musculoskeletal arm model with 2 degrees of freedom (DOF) [12,13]. Then, taking into account the gravity compensation, they proposed an iterative learning control of the arm's sensory-motor in order to implement the reaching movement. Finally, they verified their control method by the numerical simulation. Vatankhah designed an adaptive optimal

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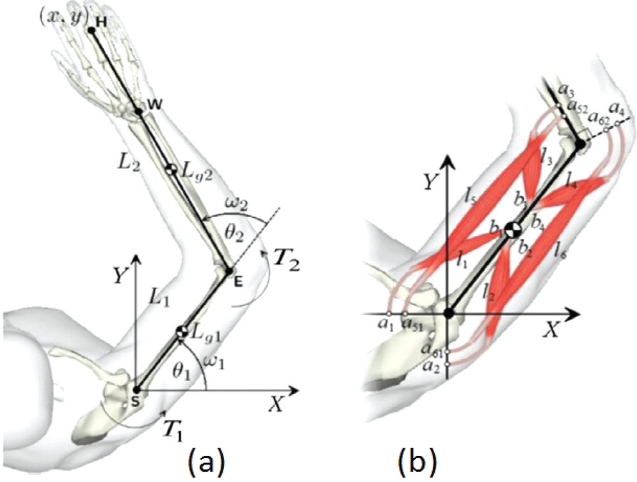

Fig. 1. The planar human musculoskeletal arm model [14].

neuro-fuzzy controller and applied it to the reaching movement control [14]. Their redundant human musculoskeletal arm model also adopted a Hill-type planar model which includs 2 joints and 6 muscles. Atawnih also focused on the reaching movement control of redundant musculoskeletal human arm and proposed a controller based on the redundant arm torque controller. Their controller needed neither the trajectory planning nor the prior knowledge. Through results of the simulations, their controller may ensure the desired completion time as well as accuracy requirements [15]. Freeman proposed the iterative learning control to apply FES to the upper extremity for rehabilitation [2]. Jagodnik and other researchers studied the PD controller based on the reinforcement learning structure and used it to accomplish the FES control of high-level upper extremity [16–18]. Jagodnik proposed a proportional-derivative (PD) controller, in which the optimize gain is set by a 3-dimensional human shoulder and the arm system so as to improve performance. They verified their PD controller to a 3-dimensional bio-mechanical human arm which has 5 DOF [10].

Many researchers studied the sliding mode control (SMC) and applied it to mimic reaching movements of the human upper extremity. The SMC approach is used widespread since it has advantages to control the nonlinear system without accurate parameters and the specific model. In addition, the SMC is simple to use and is suitable transient performance with quick response [1]. Corradini proposed a discrete-time SMC for robotic manipulators. Their controller had less coverage than normal continuous time SMC controller [18]. Sharifi acquired the optimal performance of the SMC controller by an optimal policy and they used it to the reaching movement of the planar human musculoskeletal arm [19]. An inherent problem of the SMC is the chattering, which may cause damages to the system. In order to decrease the chattering, many researchers suggested various methods, such as the saturated sign function [20] or the hyperbolic tangent function [21], Quasi-SMC [22] and so on. Ngo added the fuzzy logic to SMC control accomplishing the trajectory of robots' manipulators [23]. Moussaoui designed a fuzzy approximation-based SMC controller with adaptive scheme to solve under actuated systems with uncertain nonlinear perturbations [24]. Shahbazzadeh proposed a fuzzy exponential SMC controller to achieve trajectories of the elbow and the shoulder joints with numerical simulations [1].

Due to the redundancy of muscles, the human musculoskeletal arm model has strong non-linearity. Using general convergence laws can not well deal with the chattering problem of SMC so that it may lead to the deterioration of the stability of the system, or even destroy the system. In order to avoid chattering, it must enhance the adaptivity of the sliding mode control. Therefore, an adaptive fuzzy sliding model controller is proposed to implement the angle tracking of the end point and the elbow of the human musculoskeletal arm model. Through adjusting scales of the sliding surface by the adaptive fuzzy system, the sliding surface can be adaptive inclined to state variables at the same time as state variables reach to the sliding surface. Therefore, the method can efficiently avoid switching of state variables back and forth in the sliding surface and sharply decreased the time of state variables arriving to the sliding surface.

The paper is organized as follows. The human musculoskeletal arm model is introduced in Section 2. The adaptive fuzzy SMC controller is explained in Section 3. Numerical simulations and results of angle tracking control have been analyzed in Section 4. Future work and some conclusions have been given in the conclusion part.

2. Planar human arm model

The planar human arm model is shown in Fig. 1, involving 2 links. The upper link is the upper limb and the lower link refers to the forearm and the hand. Here, the hand is simplified as an end-point. The two rotational joints of the model are the elbow and the shoulder. The gravitational effects are taken into account in the model.