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Optimal Position Control of Nonlinear Muscle Based on Sliding Mode and Particle Swarm Optimization Algorithm

M. Karami Gavgani[1], M. Hasanlu[*,2] , M. Nikkho[3]

[1] Department of Biomedical Engineering ,Electronic Branch, Islamic Azad University, Tehran, Iran
[2] Department of Mechanical Engineering ,University of Guilan, Rasht, Iran
[3] Department of Biomedical Engineering, Sciences and Research Branch, Islamic Azad University, Tehran, Iran

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ABSTRACT

Rehabilitation is a way to care muscle and skeleton disorders and disease, using mechanical equipment. The aim of rehabilitation is that help disable persons who they reach to minimum physical activities. Since pneumatic actuators have high respect of power to weight, are cleanliness, reachable fluid, are to repair and low cost that can use to implement in robot which interact with human body parts. The other features that use on pneumatic actuators that this is comprisable fluid and variable stiffness traits. Due to importance and performance of these actuators in medical science and also they have high security and exact control which can preserve bodies. Therefore in this project, we search pneumatic actuators with high precision controller that can manufacture various mechanisms for rehabilitation process. Pneumatic actuators mathematical modeling is presented in this thesis. According to modeling of pneumatic actuator, differential equations of actuators are presented. In this research, we used solenoid valves, because proportional valves are expensive. We used sliding mode theory for position control of actuator. There are many importance on these systems and the main aim of this project, optimal path of 2 links mechanism for rehabilitation problems. So optimal tracking robot, we use particle swarm optimization for finding optimal gain controller in sliding mode control because we want to achieve minimum tracking errors in path planning of mechanism.

1. INTRODUCTION

For many years ago, human beings have involved to disease and they have noted to treat and preserve themselves from disease. After the First World War and increasing polio, scientists and experts face many disable people and also they thought for many disable persons. Dr. Edward Rusk who is first doctor that established Bellevue hospital based in NEW YORK. Therefore, rehabilitation which is started on new doctoral courses. In rehabilitation is defined

* Corresponding author: Hasanlumojtaba@gmail.com
Faculty of Mechanical Engineering, University of Guilan, Rasht, Iran

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traits that such as objective process and short period time, due to those specification can be powered disabled persons who can reach to intelligence, body and social levels. Mechanical instrument equip them who can change own life. Robots have potential ability, whether or not, robot can acceptably improve life quality of disable peoples, and especially rehabilitation is need on physiotherapy which is contained fast, heavy and repeatedly actions. Usage rehabilitation robots are tremendous profits. One of the rehabilitation robots traits which can continuously collect patient data and a physiotherapist assets disease progression in period treatment and also robotic physiotherapy systems can do long period treatment time by physiographist and also physiotherapist should decrease time period for everyone because it should increase performance and decrease costs.

Essentially physically disabled patients should reinvigorate sooner by optimal force which robots of rehabilitation are best options. Roughly 10% of world population have disabled problems based on the world health organization statistics. The most important of disabled cases and bodies are independent of stroke and spinal cord injuries. Every year, in the USA, 750000 members involve different strokes that 400000 members can be survived that finally they involved to disable and paralyze one or some body parts. In past time, we had a few results on robot rehabilitation and some projects can change to apply commercial products for patients. Nowadays, due to advanced searching and important company can make beneficial performance robots and hospital gradually equipped by these robots. Using of standard facilities are more costly on rehabilitation centers and in many times, it is not feasible for patients, so many people cannot pay these costs and also they have many different problems because of their respective and long activities.

Therefore it is necessarily seemed we are using modern technology for decreasing problems and involvement. These days, robots are used unique performance with physiotherapists. Rehabilitation robots should have suitable motion and it has interaction with patients and physiotherapists are preserved to damage and injury. Pneumatic actuators are the same hydraulic actuators which can effect on something without intermediaries. There are some unique specifications such as high power proportion to weight, high performance, force apply for fixed position for long time and cylinder velocity with compressible air are between 2 m/s and 3 m/s which is acceptable in many industries[1]. The first activities on modeling servo pneumatic systems are presented in [2] and in their research, math model is presented for two directional cylinder which had short motion and they could validate proportional valve mass fluid with experiments. Due to needing modern computers in futures, in [2], simple model has not be interesting but other researchers have continued to promote their models. In [3] has developed model's [2] and they could present linear model based on an arbitrary point. In [4] that has developed linear time invariant (LTI) which open-circuit pneumatic cylinder. That is control via swivel spool valve and they could compare that model with LTI and then they had increased accuracy model with friction effect [4]. In [5] had controlled velocity of proportional 5 ways valve of pneumatic cylinder and it was illustrated acceleration feedback that this is the same pressure feedback on these systems, using acceleration feedback, which is stabled system [5]. In [6] had presented new control position approach for pneumatic system which was including an actuator and proportional 5 ways valve [6]. This new controller was including internal pressure closed-loop control and external position control that this was PID controller based on linear feedback in pressure closed-loop. Because, they wanted to decrease nonlinear parameters of air compressibility. In external closed- loop had PID controller with frictional compensator and also there were had 0.2 Hz frequency, 70 mm amplitude and 9 mm maximum error on sinusoidal input. If using servo pneumatic on-off solenoid valve, there will incredibly reduce final costs.

So some researchers had analyzed by some methods such a Pulse Width Modulus (PWM) that could be controlled servo pneumatic actuator by using those valves, pressure and force control closed- loop are promoted 2D position control of pneumatic system and it could achieve flexibility controller design by testing pressure or force and also controller was robusted to face uncertainty and nonlinear parameters. Therefore it could be controlled between efficiency and stability, in [7] had researched impedance and control methods in 3 papers. Servo pneumatic actuators are presented in new discovering methods for interaction robots with environment such adding passive flexibility[8], active compliance control [9], parallel position and force control [10] hybrid position force control [11] position control with external force and closed-loop [12] those researches did not have been accurate and even which are not feasible in many cases. In [13], installed impedance control strategy in physiotherapy robot with an electrical actuator. In [14], had implemented impedance control in artificial muscle. In this paper, firstly we modeled and simulated tracking and control 2-links robot for rehabilitation by using sliding mode method and secondly particle swarm optimization algorithm is used for reaching optimal gain sliding mode controller, due to decreasing costs and increasing performance robot and finally, optimum results are showed such as angular displacement, errors control, control efforts, gain controller and mechanical properties of artificial muscles.

2. MODELING

Robot is 2D planner arm with 2 revolute joints and in figure 1 is showed kinematic equations model based Lagrange method is presented:

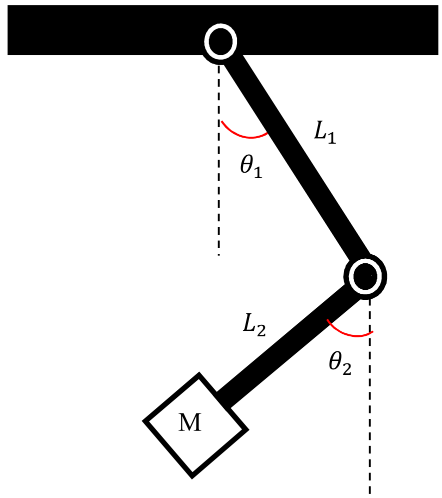

Fig. 1. 2 – Links Mechanism

$$B(q)\ddot{q} + V(q,\dot{q}) + G(q) = v \tag{1}$$

Now, equation 1 is defined for first and second links, so first and second equations:

First Equation:

$$\begin{aligned}[2m_2 l_1 c_2 \cos(\theta_2) + I_{z1} + I_{z2} + m_1 c_1^2 + m_2(c_2^2 + l_1^2)]\ddot{\theta}_1 + [m_2 c_2(l_1 \cos(\theta_2) + c_2) + I_{z2}]\ddot{\theta}_2 \\ - m_2 l_1 c_2 \dot{\theta}_2 \sin(\theta_2)\,\dot{\theta}_1 - m_2 l_1 c_2(\dot{\theta}_1 + \dot{\theta}_2)\sin(\theta_2)\,\dot{\theta}_2 \\ + [(m_2 l_1 + m_1 c_1^1)\cos(\theta_1) + m_2 c_2 \cos(\theta_1 + \theta_2)]g = v_1\end{aligned} \tag{2}$$

Second Equation:

We have some parameters on previous equations that are defined in table 1.

$$\begin{aligned}[m_2 c_2(l_1 \cos(\theta_2) + c_2) + I_{z2}]\ddot{\theta}_1 + [m_2 c_2^2 + I_{z2}]\ddot{\theta}_2 + m_2 l_1 c_2 \sin(\theta_2)\,\dot{\theta}_1^2 \\ + m_2 c_2^2 \cos(\theta_1 + \theta_2)\,g = v_2\end{aligned} \tag{3}$$

Table 1. Parameters of Equations of Model

Description	Parameters
l_{z1}	Moment of Inertia of 1st Link
l_{z2}	Moment of Inertia of 2nd Link
$m_i \quad (i = 1,2,3,\ldots.)$	Mass of Links
τ	Torque

Now, we have considered control force that is based on local friction.

$$F(\dot{q}) = F_v\dot{q} + F_d\dot{q} \tag{4}$$

$$F_v\dot{q} = \begin{bmatrix} v_1\dot{q}_1 \\ \vdots \\ v_n\dot{q}_n \end{bmatrix} \qquad F_d\dot{q} = \begin{bmatrix} k_1 sgn(\dot{q}_1) \\ \vdots \\ k_n sgn(\dot{q}_n) \end{bmatrix} \tag{5}$$

And also:

Rather than friction, pneumatic muscle damping are torques saving that those parameters are tending to initial conditions. Therefore, general definition for equations 4 is presented as:

$$F(\dot{q}) = \begin{bmatrix} f_1(\dot{\theta}_1, P_{m1}, P_{m2}) \\ f_2(\dot{\theta}_2, P_{m1}, P_{m2}) \end{bmatrix} \tag{6}$$

Now, the constitutive equation of robot is defined as:

$$\begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}\begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix} + \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} + \begin{bmatrix} G_1 \\ G_2 \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} - \begin{bmatrix} f_1(\dot{\theta}_1, P_{m1}, P_{m2}) \\ f_2(\dot{\theta}_2, P_{m1}, P_{m2}) \end{bmatrix} \tag{7}$$

3. SIMULATION

According to previous equations on modeling section, the aim f this paper is position control of links respect reference's path why we want to decrease errors of displacement. Sliding mode is used to tracking position links of robot, because this controller has some specification such as simple math model and easy implementation. Sliding mode controller has 2 gains that these gains have main rule for trajectory of links. These gains are K and η, that particle swarm optimization have to search optimum value based on random search in maximum and minimum interval. In this interval which is the best interval. In this interval which is the best interval, because robot has to be stable and feasible condition. Certainty nonlinear model can be stability in equilibrium zone, therefore robot should work on that interval. This robot can alternate human hand and so this robot can easily act for human. We present figure 2 and 3 that show analogy model between mechanism and human hand.

Fig. 2. Analogy Human Hand to 2- Links Mechanism

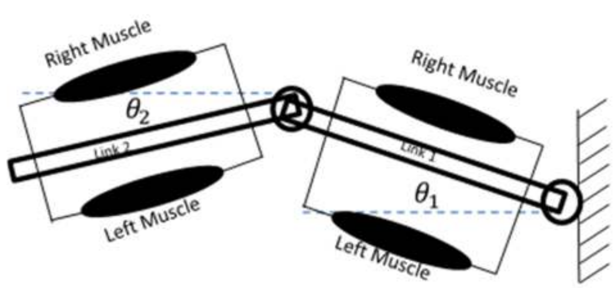

Fig. 3. 2-Links Robot with Muscle Actuators

The main aim to use single objective optimization algorithm is finding optimal gain controller based on minimization error angular displacement in links. So it is presented a new optimum model with 10 optimization iteration. Now we are presenting inputs that these are as sinusoidal torques for each links.

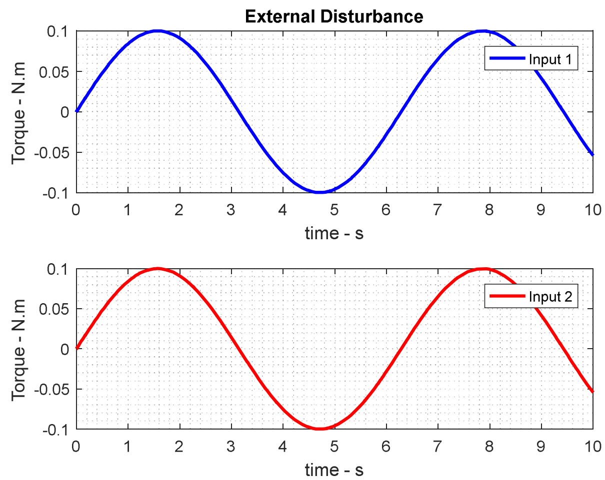

Fig. 4. Torque Input for 2-Links Robot

Figures of 4 and 5 are presenting angular displacement for first and second links with and without controllers

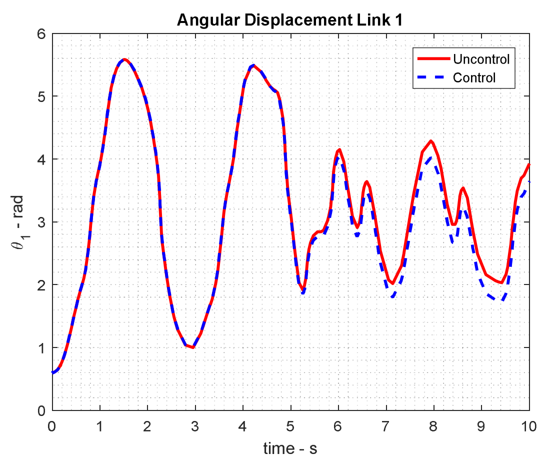

Fig. 5. Angular Displacement First Link

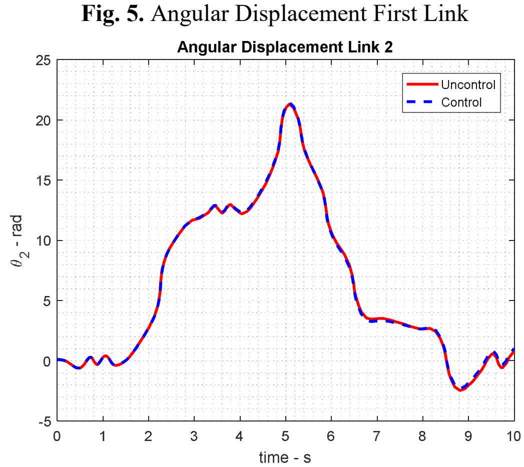

Fig. 6. Angular Displacement Second Link

Errors control are presented in figure 7:

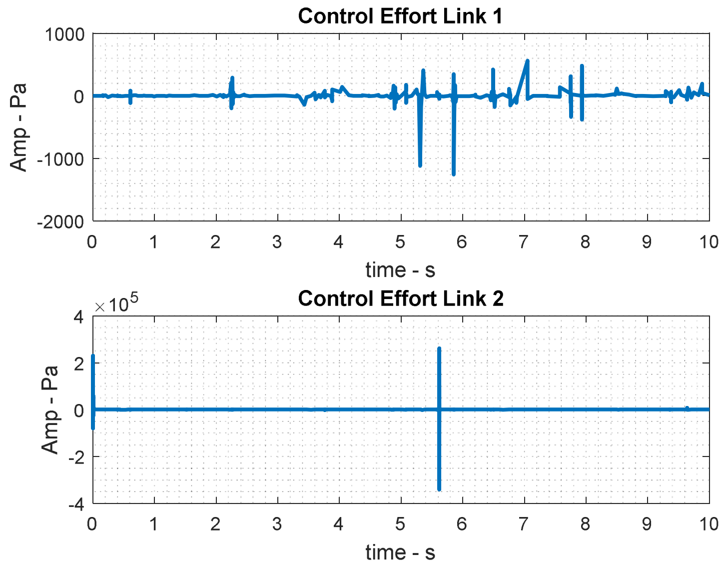

Fig. 7. Control Efforts of 1st and 2nd Links

Figures of 8 and 9 are presented that we are figuring mechanical properties of artificial muscle actuators out. These figures are showing mechanical properties such as damping and spring parameters, linear displacement and actuator forces.

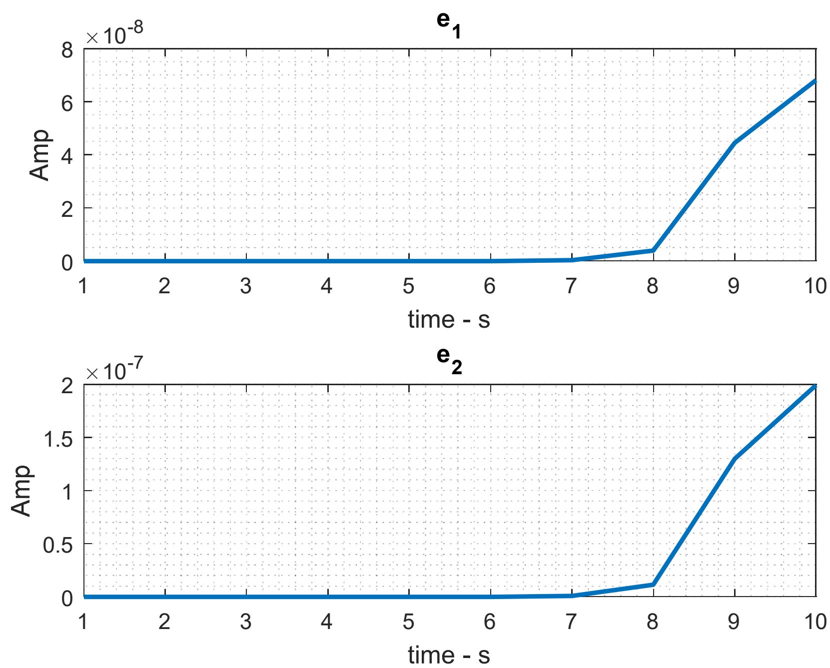

Fig. 8. Errors of Control 1st and 2nd Links

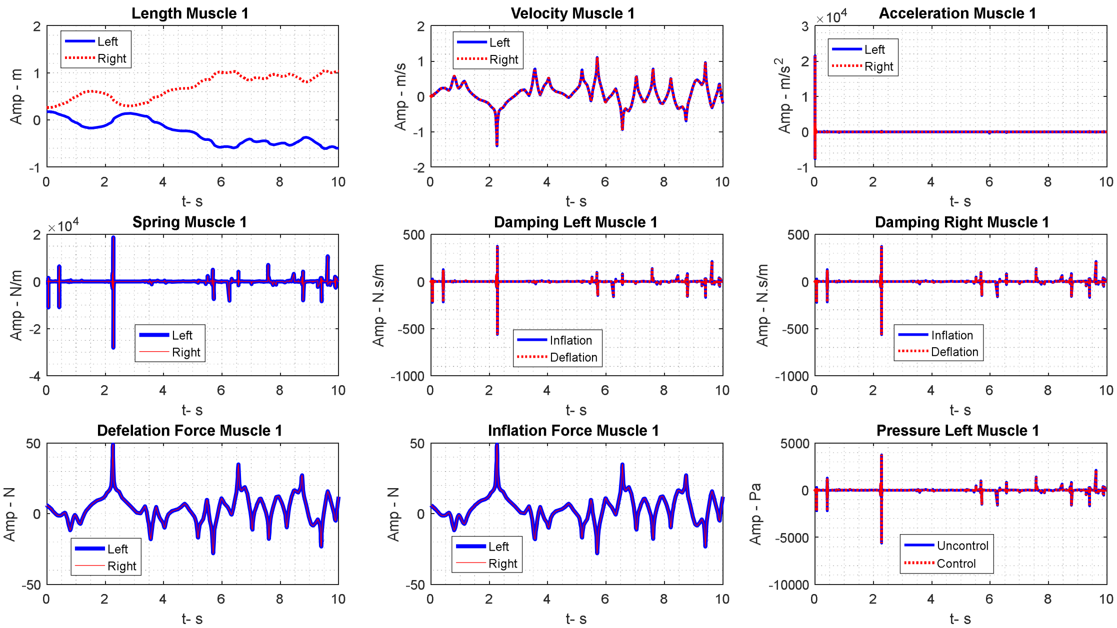

Fig. 9. Mechanical Properties 1st Link Pneumatic Artificial Muscle

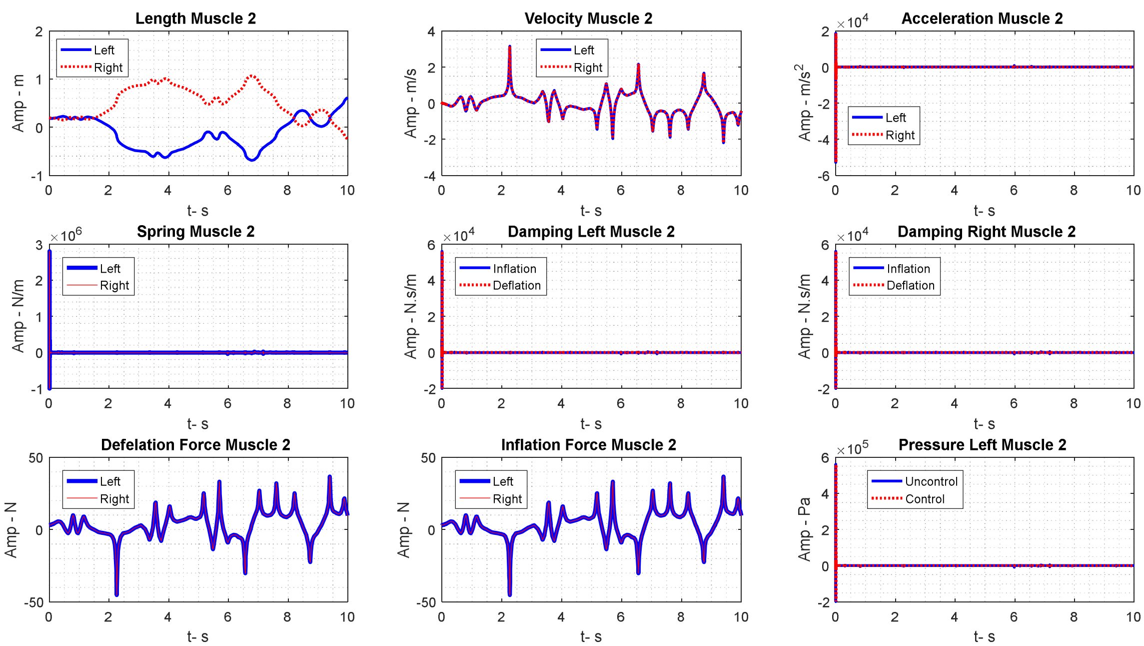

Fig. 10. Mechanical Properties 2nd Link Pneumatic Artificial Muscle

The optimal gains are showed in figure 11:

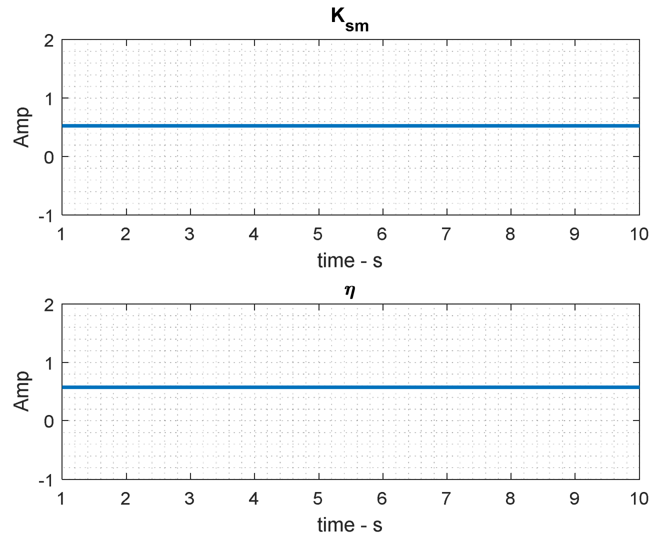

Fig. 11. Optimal Gain Sliding Mode Controller

4. CONCLUSION

This paper has modeled and simulated optimal position control of nonlinear muscle based on sliding mode and using particle swarm optimization algorithm (PSO). Sliding mode controller has 2 gains which are found optimum magnitudes by PSO. According to use PSO, we have minimum errors control and considerable trajectories in angular displacement.

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