VOL. 16, NO. 1, JANUARY 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SLIDING MODE CONTROL DESIGN FOR PROSTHETIC HAND SYSTEM

Mohd Hafiz Jali[1], Rozaimi Ghazali[1], Chong Chee Soon[1] and Ahmad Razif Muhammad[2]
[1]Centre for Robotics and Industrial Automation (CeRIA), Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[2]Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Vietnam
E-Mail: mohd.hafiz@utem.edu.my

ABSTRACT

This paper describes the Sliding Mode Controller (SMC) for the Prosthetic Hand System. There are different nonlinear controls theories, as for example the SMC approach; it has proved sound and well-established literature. Recently prosthetic hands turn out to be more significance since its capability to be potential substitute hand for an amputee. By utilizing a different kind of actuators, prosthetic hands become more practical as it could work with neuro motors energy which started by the Automatic Nervous System (ANS) of the brain. However, the mathematical modelling of the system should be fittingly resolved to guarantee the precision of the controller design. Then, the system needs to be designed based on the theory of the Lyapunov stability and the control rules of the SMC through the MATLAB/Simulink software. The results accomplished affirm reasonable specialized means and synthesis by using sliding modes for nonlinear control tasks. Then the performance of the system is validated and verified via simulation environment. By referring to the results obtained, it can be concluded that the SMC capable of reducing the controller effort while enhancing the Prosthetic Hand performance.

Keywords: sliding mode controller, prosthetic hand, robustness, PID controller.

1. INTRODUCTION

The human hand is used to holding few tasks like investigation, adjustment, perception, control, and pretension. In a recent trend, people who have post-stroke may lose control of their upper limb. In case if they are treated with beneficial recovery training, the patients can restore their movement capacities and working abilities. The failure of sending the electrical signal from the mind to the leading nerves requires electrical stimulation from the external source to muscles. Electrodes are utilized for signal discovery of electrical movement in muscles. The study of this electrical movement is important for a mix of electromyogram into the rehabilitation device. These rehabilitation devices are utilized to recover the development of arm after a stroke, which is the well-known prosthetic hand.

Prosthetic hand is separated into three sections of finger considering one dimension that has similarity with the compound pendulum. Human finger development can be model utilizing Lagrangian motion equation almost the same to the compound pendulum by considering the linearity [1], [2]. At present time, there is no broad technique for nonlinear control system synthesis. Furthermore, every technique is applicable for certain sort of nonlinear control subsystems. The nature of close control system without knowledge of mathematical model or measurable unsettling influences can be ensured by using sliding mode control. Sliding mode control implies discontinuous control, where according to value switching function the control has negligible value [3].

The sliding mode control (SMC) approach to be an effective device to manage such class of dynamic systems by virtue of its simplicity and robustness. Moreover, any non-ideal behaviour, prompting limited frequency switches of the control [4]. Next, a dynamic model of the prosthetic finger model is produced, and a non-chattering robust sliding mode control is connected to make the model follow a specific direction. The SMC, as a special class of variable structure systems, can be connected to the non-linear systems even within the presence of parameter variations and external disturbances. In these systems, conditions of the system are driven towards a sliding surface and compelled to stay on or close it [5].

2. SLIDING MODE CONTROL

The Sliding Mode Control approach is perceived as one of the proficient tools to design robust controllers for complex high-order nonlinear dynamic plant operating under instability conditions. The most advantages of the sliding mode are its low sensitivity to plant parameter variations and unsettling influences which eliminate the needed of exact modelling. Sliding mode control empowers the decoupling of the general system movement into free partial parts of lower dimension and, accordingly, reduces the complexity of feedback plant. The essential properties are the order diminished, invariance guideline and its viability towards chattering in real time applications make it more prominent. The SMC consists of two steps. The initial step is the choice of a manifold in the state space where once the state trajectory is obliged to it, the controlled plant shows the desired performance. The second step is shown by the plant of a discontinuous state-feedback capable for compelling the system state to reach, in limited time such a manifold like a manner called sliding manifold. In this work, the design and implementation of SMC utilizing coefficient diagram method are displayed to enhance standard plans in versatile control schemes [6].

For steadiness, the following Lyapunov function, which is proposed for a non-chattering action, must be sure positive definite and its derivative must be negative semi-definite. Equivalent control is valid just on the sliding surface. In this manner, an extra term should be characterized to pull the system to the surface [5]. While in [4] considering the chattering phenomenon, that is the high frequency limited amplitude control signal created by the sliding mode technique, a few creators seem to relate this behaviour to the discontinuity of the sign capacity on the sliding manifold. In another term, they essentially propose to replace this function with a smooth approximation to neutralize the chattering impact at the cost of a little deterioration in performances. However, the utilization of smoothing devices, which are characterized by a high gain to have a little estimation error, does not ensure that motions will disappear. The rough sliding motion is ensured to lay on a little region of the sliding manifold, yet nothing can be told about the conduct inside this region.

3. MATHEMATICAL MODELLING

The general structure of prosthetic hand system can be demonstrated in Figure-1.

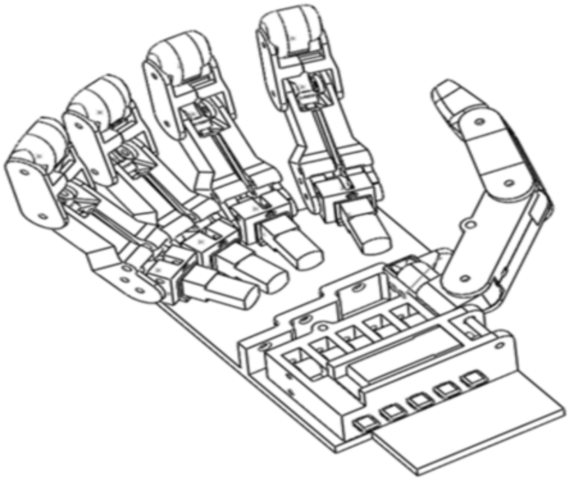

Figure-1. General structure of prosthetic hand [7].

According to the study in [8], the mathematical modelling of the prosthetic hand system can be referred as below:

$$\ddot{\theta} = \frac{V + \dfrac{Rmgl\cos\theta}{2Ktz} - \dfrac{RB\dot{\theta}}{Ktz} - Kez\dot{\theta}}{\dfrac{Rl^2mKtz + 4RLKtz}{4Kt^2z^2}} \tag{1}$$

where:

R = Resistance
V = Voltage
m = Mass
g = Gravity
L = Length
B = Friction
K_t = Constant torque
K_e = Constant electric
z = Gear ratio

3.1 Sliding surface design

$$S = C_1\dot{h}_2 + C_2h_2 \tag{2}$$

$$\dot{S} = C_1\ddot{h}_2 + C_2\dot{h}_2 \tag{3}$$

$$U_{smc} = U_{sw} + U_{eq} \tag{4}$$

$$U_{eq} = U_v = V \tag{5}$$

$$U_{sw} = -K\ sign\ (s) \tag{6}$$

Let $\dot{h}_2 = \dot{\theta}$, $\ddot{h}_2 = \ddot{\theta}$,

When $\dot{S} = 0$,

$$\dot{S} = C_1\ddot{\theta}_2 + C_2\dot{\theta} \tag{7}$$

$$\begin{aligned}\dot{S} &= C_1\left[\frac{V + \dfrac{RmgL\cos\theta}{2Ktz} - \dfrac{RB\dot{\theta}}{Ktz} - Kez\dot{\theta}}{\dfrac{RL^2mKtz + 4RLKtz}{4Kt^2z^2}}\right] + C_2\dot{\theta} \\ &= C_1\left(V + \frac{RmgL\cos\theta}{2Ktz} - \frac{RB\dot{\theta}}{Ktz} - Kez\dot{\theta}\right) \\ &\quad \cdots + C_2\dot{\theta}\left(\frac{RL^2mKtz + 4RLKtz}{4Kt^2z^2}\right) \\ &= C_1\left(\frac{4Kt^2z^2V + RmgL\cos\theta 2Ktz - RB\dot{\theta}4Ktz - 4Kt^2z^2Kez\dot{\theta}}{4Kt^2z^2}\right) \\ &\quad \cdots + C_2\dot{\theta}\left(\frac{RL^2mKtz + 4RLKtz}{4Kt^2z^2}\right)\end{aligned} \tag{8}$$

$$\begin{aligned}\frac{C_1 4Kt^2z^2V}{4Kt^2z^2} &= \frac{-2RmgLKtz\cos\theta + 4RB\dot{\theta}Ktz + \cdots}{4Kt^2z^2} \\ &\quad \frac{4Kt^2z^2Kez\dot{\theta} - C_2\dot{\theta}RL^2mKt^2z - \cdots}{4Kt^2z^2} \\ &\quad \frac{4C_2\dot{\theta}RLKtz}{4Kt^2z^2}\end{aligned} \tag{9}$$

$$\begin{aligned}U_v &= \frac{-2RmgLKtz\cos\theta + 4RB\dot{\theta}Ktz + \cdots}{4Kt^2z^2C_1} \\ &\quad \frac{4Kt^2z^3Kez\dot{\theta} - C_2\dot{\theta}RL^2mKtz - \cdots}{4Kt^2z^2C_1} \\ &\quad \frac{4C_2\dot{\theta}RLKtz}{4Kt^2z^2C_1}\end{aligned} \tag{10}$$

The list of parameters as shown in Table-1 is substituted to the equation in (10) based on study in previous paper [9].

Table-1. List of Parameters.

Parameters	Unit	Values
Resistance	R	2.96Ω
Mass	M	0.5kg
Gravity	G	9.81ms^{-2}
Length	L	90m
Friction	B	0.04N
Constant torque	K_t	5.17NmA^{-1}
Constant electric	K_e	5.17Vsrad^{-1}
Gear ratio	Z	12.03

4. SIMULATION RESULTS

The performance of the prosthetic hand system is optimized by changing the value of C1 and C2 that act as a control variable in the SMC controller to get the best performance result. The results are verified and validated by simulation using MATLAB/Simulink programming as depicted in Figure-2.

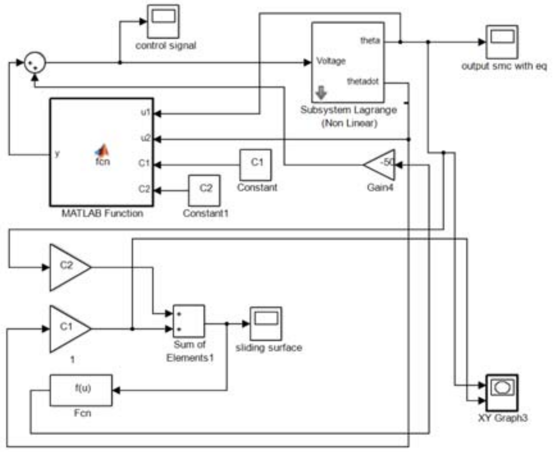

Figure-2. The SMC block diagram in MATLAB/Simulink.

When the value of C1=1 while C2=4, the performance of the SMC is shown in Table-2.

Table-2. The best result of sliding surface performance.

Rise time (sec)	0.25
Overshoot (%)	0
Settling time (sec)	1.22

After the performance of the sliding surface has been collected, several changes to the control variables of C1 and C2 have been made. The best performance is determined where value of C1 and C2 are 1 and 4 as shown in Figure 3.

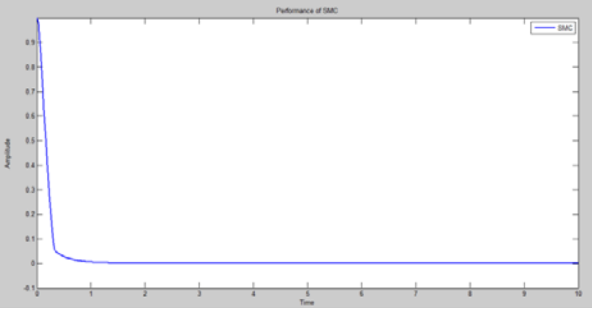

Figure-3. The output performance.

The output results indicate its takes 1.22s to reach to the desired value, which is zero, with 0% of overshoot and 0.25s of rising time as shown in Table-2. The results implied that the SMC have gave less effort to achieve the desired performance. Figure-4 shows the sliding surface demonstrated in XY graph.

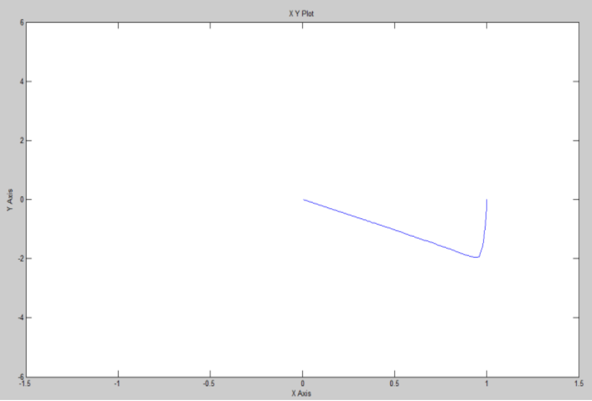

Figure-4. Shows sliding performance demonstrated in XY graph.

While the designed SMC controller is compared with PID controller and shows superior performances compare to PID controller with faster settling time and no undershoot occur compared to PID controller as depicted in Figure-5.

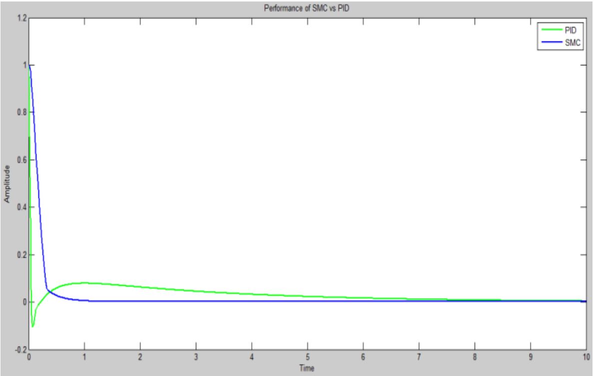

Figure-5. Graph performance between PID and SMC.

5. CONCLUSIONS

For a conclusion, SMC controller method gives a big impact in the controller where it can deal with the time varying and non-linear system. The performance of both systems which is SMC and PID for prosthetic hand system will give a different performance on the settling time. For the SMC controller, the value of C1 and C2 will give a big impact where it needs a few trials. When the value of C1 is constant and C2 value increases, the graph reaches at the zero with the fastest duration with low disturbances in the system. It means that SMC controller is a good system to predominate the non-linear, robustness and distance. Therefore, it can be inferred that the SMC capable of reducing the controller effort while increasing the performance of the prosthetic hand.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for the funding thru research grant with code number JURNAL/2019/FKE/Q00045.

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