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Development of Prosthethic Hand Hardware and Its Control System

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Abstract- This paper described the development of prosthetic hand and its control system. Initially the research start by reviewing the existing prosthetic design. After investigating of those designs, a better design approach has been presented in this work. The objective of this research is to design and develop the prosthetic hand control system in order to provide solutions for the amputee who lose their hand. This project describes an under actuated artificial hand for functional replacement of the natural hand. The hand comprised of an actuator embedded in an under actuated mechanical system. After the prosthetic hand hardware completed the fabrication process, it is modelled using system identification method. An input data (voltage) and output data (position) is collected using MyRIO. Then, the PID controller is designed based on Zigler Nichols method. Finally, the prosthetic control system is verified via simulation. It is expected that the PID controller could perform well for the prosthetic system.

Keywords—Prosthetic hand, Ziegler Nichols method, system identification, PID controller

I. INTRODUCTION

A prosthetic hand is an artificial device for a replacement of missing body part for those who amputated their arm. It is designed for person who has lost their hand due to accident and diseases. In addition for everyday use, amputees need this device to help in participation of sports and recreational activities. The main requirement for this device is that it should be function as near to natural hand as possible. There are various designs of artificial hand available in the market that can be categorized as electrical, mechanical, myoelectric and hybrid hand. Mechanical prosthetic use some motion of the body to provide the force necessary to control prosthetic component. Electrical hand operate the hand by a motor which driven by microcontroller. Myoelectric hand is stimulated by muscle signal available from amputee. The intention of this paper is to provide a technical overview of the design of the prototype that has been developed as well as to evaluate the control performance of the prototype. The prototype hand is expected to be simple and easy to control the movement of fingers.

II. RELATED WORK

The aim of the developing the prosthetic hand is to help the group of people who have physical disabilities to gain normal life again. Nowadays, various research has been done to make sure the prosthetic hand properly functional and comfortable for the user.

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In fact, the officer in the military sector is facing a very high risk in losing their limbs during battle. This research of the prosthetic hand was founded since World War 1 until World War 2 [1]. During that period, the instrument, material and study of the prosthetic hand was not as advanced as today. In view of that, the United States government made an arrangement with some military organizations to enhance prosthetic body parts as opposed to weapons. In addition, the administration institutionalized prosthetic preparing, rather than the past apprenticeship, and additionally expanding the financing for building research in colleges. These days, the risk of losing limbs is not only coming from the war, but health problems in which this phenomenon becomes more severe. There are a lot of diseases that can cause loss of limb for amputee, due to this reason there is the need to develop prosthetic hand as one of the priority for the community. Generally this research is focusing on improving the function of the prosthetic limbs to be more efficient. Generally, this device makes the prosthetic hand identical to the natural hand, restoring functionalities and efficacies of natural hand movement [2].

III. METHODS

The project methodology takes into consideration the main stream of activities that will takes place from beginning of project stage until completion. It can be divided into several phases.

A. *Design the prosthetic hand using SolidWorks CAD*

The mechanical design for this prosthetic hand is done by using SolidWorks 2013 software. By using this software, this prosthetic hand can be designed by following the real human hand dimension. This prosthetic hand design is separated into 8 parts excluding the actuator and mechanical linkages. The designs start with designing the Proximal Phalange (PP) each of fingers.

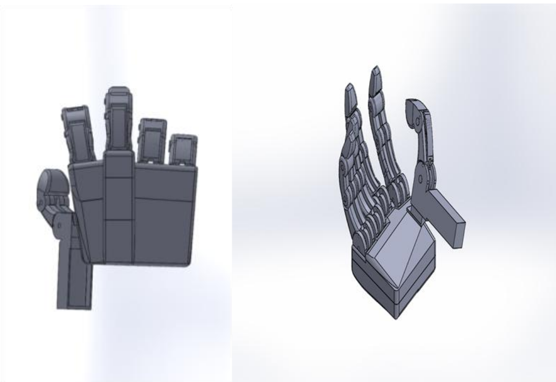

Figure 1: Prosthetic Hand Model in SolidWorks

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Figure 1 shows the prosthetic hand model that has been designed in SolidWorks. After completion of the design, the design is checked in details and verification of the working status of the design is again checked to ensure the final design meets the target criteria.

After the completion of the design stage, the construction of prosthetic hand prototype is performed. Designing the prototype takes into consideration the following factors:-

- Design layout concept of the components
- Space availability to accommodate the components
- The practicality/ suitability of the design layout

The construction the prosthetic hand needs to emulate the human hand shape. It is constructed by using 3D printer; the structure of the hand is built with ABS plastic. After the structure has been fabricated, the prototype is integrated with the DC motor as shown in Figure 2.

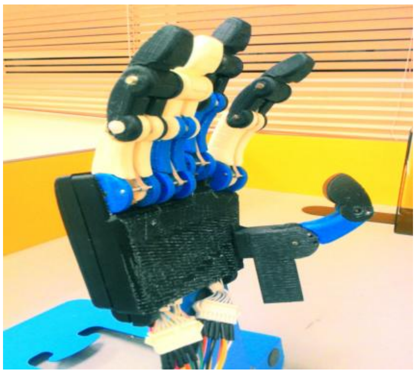

Figure 2: Prosthetic Hand Prototype

B. *System Identification Modeling*

After the hardware of the prosthetic hand has been fabricated, the mathematical model of the system is generated using system identification toolbox in Matlab. For this work, it is based on black box model as shown in Figure 3 where the model is discovered solely based on the input and output data without any preliminary knowledge about the system. Step function, ARMA sequences, sum of sinusoids and pseudo random binary sequence (PRBS) are the standard input signals in system identification. It is mathematically randomized bit stream so that it will become neutralized and balanced data [3].

Firstly, a portable reconfigurable I/O (RIO) device which is The National Instruments myRIO-1900 is used to design control system. Before that, the NI myRIO-1900 is connected to the host computer by using USB and also to the adapter that supplies voltage, the NI myRIO-1900 led will blinking. After that, the connecting wire is used to connect to the 4 Channel Motor Driver and NI myRIO-1900's user manual is referred for info regarding the connector pin outs [4]. Then, the DC Motor that applied to the arm prosthesis model is connected towards the 4 Channel Motor Driver . The block diagram is designed where there are three input of sine wave signal to the system and the data is collected as the finger is grasping for several times [5]. During the data collection, the sampling time is set to 0.01. Figure 4 shows the input data (voltage)and output data(position) of the prosthetic's finger.

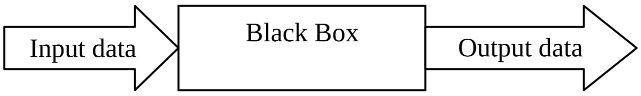

Figure 3: Black box modeling

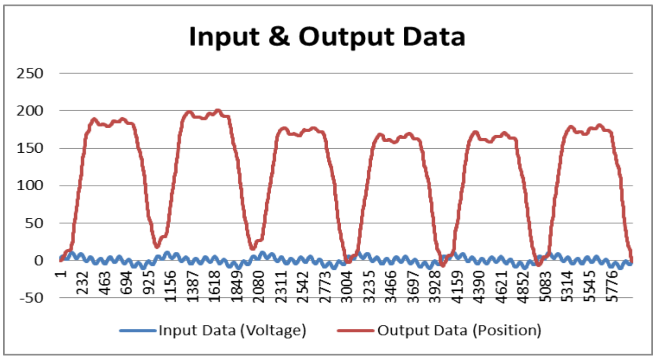

Figure 4: Input and output data for system identification

C. *Controller Design*

Control design is a process to learn about their dynamic characteristics of the model and creating a controller to achieve certain dynamic characteristic [6]. In this analysis, the PID controller is designed based on Zigler Nichols method. Figure 5 shows the model transfer function that is generated from system identification process. First of all the transient response of the open loop system is simulated in Matlab Simulink as shown in Figure 5.

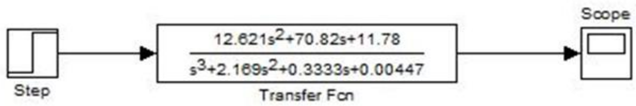

Figure 5: Block Diagram in Open Loop System

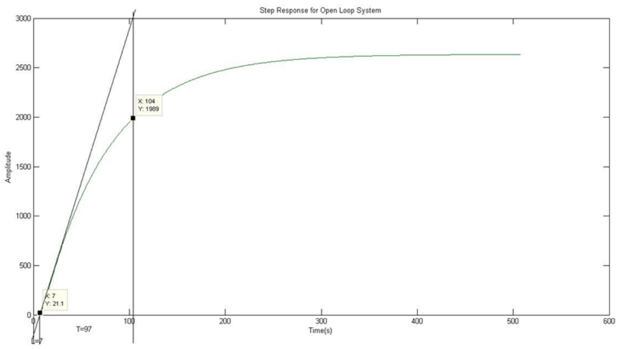

Figure 6: Measurement of L and T in Open Loop Response

In order to perform the Zigler Nichols PID tuning method, the tangent line is drawn as shown in Figure 6. The figure shows how to measure the value of L and T. From the information, we get the value of L is 7 while the value of T is 97. The values of L and T is important to find the value of Kp,Ti and Td. Table 1 shows the Ziegler Nichols formula to get the value of Kp, Ti and Td for P, PI and PID controller.

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Table 1: Ziegler Nichols technique

Type of Controller	Kp	Ti	Td
P	T/L=13.857	∞	0
PI	0.9T/L=12.471	L/0.3=23.333	0
PID	1.2T/L=16.629	2L=14	0.5L=3.5

IV. RESULT AND DISCUSSION

This section describes the result and analysis of the control system. Figure 7 shows the block diagram of the closed loop system. The value of PID already calculated in Table 1 based on Zigler Nichols method. The simulation is conducted to observe the transient response of the prosthetic hand system.

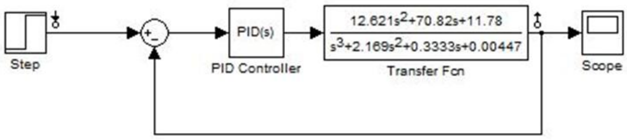

Figure 7: Block diagram of the close loop system

Figure 8 shows the system performance using P controller. The system required a long settling time which around 154ms to reach a steady state. The overshoot is around 22.4% and the steady state error is around 7%. While for PI controller as shown in Figure 9, it produces slower settling time than P controller result which is 245ms, larger overshoot than P controller which is 26.9% and higher steady state error which is 12%. Finally for PID controller, It proved to be vast improvement compared to the previous controller. It produce fastest settling time which is around 142ms, smallest overshoot which is around 21.7% and reduction of steady state error to up to 3% as shown in Figure 10.

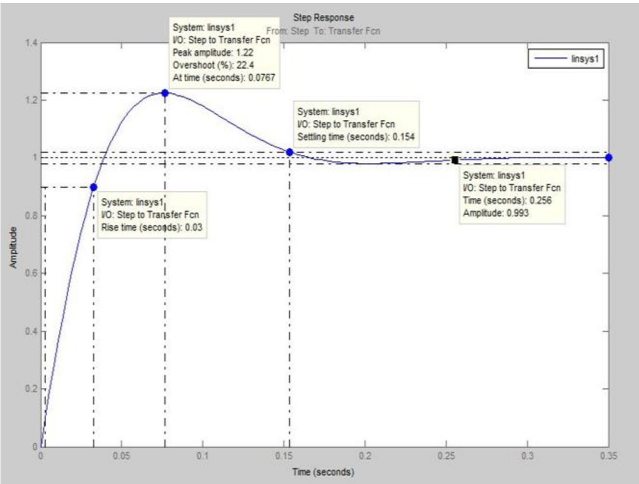

Figure 8: Transient response of P controller

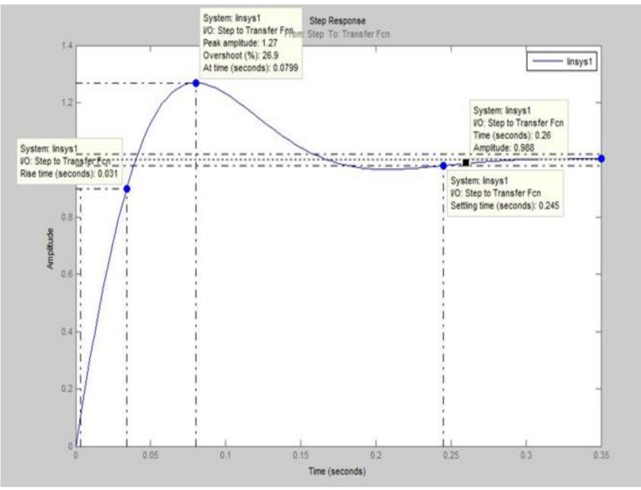

Figure 9: Transient response of PI controller

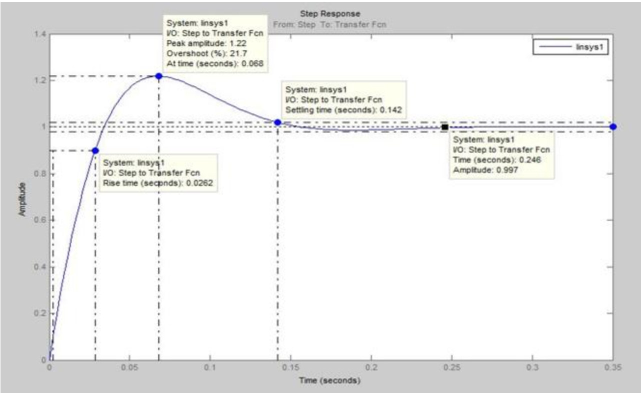

Figure 10: Transient response of PID controller

Table 2 shows the summary of the performance comparison between the three controllers. It is not arguably that PID controller is the best controller to be implemented in the DC motor speed analysis. It offers fastest settling time, least percentage of overshoot as well as lowest percentage of steady state error.

Table 2: Comparison between P, PI and PID controller

Items	P Controller	PI Controller	PID Controller	Judgement
Setting Time(ms)	154	245	142	Overall performance, the PID Controller is the best among others.
Overshoot (%)	22.4	26.9	21.7	
Steady State Error (%)	7	12	3	

V. CONCLUSION AND RECOMMENDATION

Based on the performance comparison between P, PI and PID controller, PID controller has better performance and higher accuracy compared to another controller. Therefore, it can be concluded that PID controller is the most suitable control system for the prosthetic hand system.

For future works, some recommendations is proposed to improve the performance of the controller. For fabrication of prosthetic hand, redesign of mechanical packaging is needed to reduce the size and weight of system. Despite that, the worm gear and helical gear need to be improved to make the movement of every phalange smoother to perform functional testing of hand actuation.

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