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Intelligent Controller Design for Multifunctional Prosthetics Hand

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Abstract—**Prosthetics hand is replacement of original hands that lose or damage because of war, trauma, accident or congenital anomalies. However, problems often occur on a prosthetics hand when dealing with the control capabilities and devising functional. Thus, an advanced mechanical design with control approach is required to improve the performance in terms of quality control in prosthetics hand and also enhance existing capabilities to the optimum level. This paper aims to develop a functional prosthetics hand at upper limb, which will focus on position of human hand particularly using the movement of finger instructions. In this paper, an intelligent controller, Fuzzy with Proportional-Integral-Derivative (Fuzzy-PID) controller is proposed to realize accurate force control with high performance. The performance of prosthetics hand model controlled by Fuzzy-PID controller is outperform the conventional PID controller and Fuzzy controller, where the improvement of the transient response and steady state error is achieved. Performance comparison of three different controllers has been presented through these evaluation process.**

Index Terms—**prosthetics hand, proportional-integral-derivative controller, fuzzy logic controller, fuzzy-PID controller**

I. Introduction

Recent years, the number of cases requiring assistance in daily life has been increased for physical disability. The physical disability is the people who suffer from permanent disability or loss of a limb or limbs as a result of disease, trauma, accident, disability congenital and so on. For the activities and movements of daily life, the group of disable people have facing many difficulties and hardships [1]. Therefore, most of them need help from their family's members both in terms of physical or mental support. However, some patients who have lost limbs had the desire to do anything without problems and they expect to rely on prosthetics hand to help them in their daily lives. Prosthetics devices are the tools that commonly used in medicine in the era of technology and it is quite easy for patients who are fitted with artificial limbs. Advances in prosthetic devices should be expanded aggressively where many studies that need to be improved so that the development of robotic artificial limbs can achieve great advances and their availability at a high level [1], [2].

The development of prosthetic hand is a very demanding endeavour which is essential to support the daily activities of amputated people. Design criteria for prosthetic hands are cosmetics, comfort, controllability and also low power consumption. The purpose of a prosthetic hand control system is to interpret the limited set of control signals available to the user in a way that maximizes the amount of available actions without requiring too much of the user's attention. The function of controller also affected in the design of prosthetic hand where efficiency of prosthetic hand which must attain a real ability of human hand [2].

Fuzzy control is an example of the most popular controller explored in industrial process where this control do not depend on the traditional techniques. Fuzzy logic used in the fuzzy logic control system which had a closer link with human thinking and natural language. Fuzzification, defuzzification strategies and fuzzy control rules are used in fuzzy reasoning mechanism. Various fields of application ranging from automatic train operation system shows the cost effectiveness of using Fuzzy Logic Control (FLC). Control engineers can use fuzzy logic to develop control strategies in the application area characterized by dynamic low- order non- linearity is poor.

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However, the control approach contains weakness due to lack of quantitative data on the input and output relationship. Besides that, it is difficulty to develop fuzzy rules and also membership functions and fuzzy output can be interpreted in several ways to make the analysis difficult. In addition, it must expertise to develop a fuzzy system and requires lot of data. It does not deliver the results not convincing and programs have been conducted for each individual patient. Therefore, clinical applicability and use of the software is difficult without pre-programmed for different pathologies and clinical basic training to use the program.

In order to optimize a particular control system, many industrial implement a Proportional-Integral-Derivative (PID) controller arrangement can be adjusted. For controller design, PID is the easiest design controller compared to other existing controllers. Thus, PID is the most commonly used controller in industry. Addition, many industries use controller either PID or improved version PID controller. The serial controller, parallel controller and mixed controller are basic type of PID controller. The design velocity algorithm, which also known as incremental algorithm used PID controller algorithm. In the industry, PID controllers are the most common control method to use in real applications [3].

There are many unique elements and advantages of fuzzy logic controller and PID controller over another controller such as Proportional-Derivative (PD) controller and Proportional-Integral (PI) controller. The main advantages of fuzzy logic controller it is intuitive knowledge base design and flexibility. Consistency, redundancy and completeness also part of validation can be checked in rule bases. PID controller has all the necessary dynamics: proportional gain controls the effect of reducing error and derivative gain control the effect of reducing the overshoot. While for integral gain act to improving the transient response and increasing the stability of the system [4]. However, PID controller, it has some drawbacks, when unique processes are required to perform the task when PID controllers are significantly limited in their capabilities. PID controller is capable of measuring a variety of input and calculates the difference between them.

Based on earlier studies, six myoelectrodes collected surface electromyography (sEMG) raw signal and the three differ input features to the Fuzzy Logic have 63Hz, 125Hz and 250Hz band. All three patterns of output were lateral grasp, palmar 3-finger grasp and hook grasp. In a previous research work in [5], the similarities and differences of sEMG signal have been measured for six major grasping patterns of the human hand, such as lateral, cylindrical, palmar, hook, spherical, and tip. In biomedical signal processing and classification, Fuzzy logic system is the suitable controller to be used [5], [6]. For biomedical signal, it is not always strictly repetitive and may sometimes be contradictory. Additionally, when using the system to escape easily trained, to find patterns in data that are not easily detected with other methods are not possible, it is also possible with neural networks. Most advantage of fuzzy logic over Artificial Neural Network (ANN) is that in fuzzy logic system it is possible to integrate this incomplete but valuable knowledge into the fuzzy logic system due to the system reasoning style, which is similar to the human decision-making and more closely than ANN [6].

In order to reduce vulnerability in existing controls on the PID controller and fuzzy controller where the combination between the two controllers was created to accommodate all the weaknesses that exist. In addition, it also allows them to control the prosthetic hand directly and easily. Therefore, patient can to do things with their own wishes and also act alone independently. Now, it is interesting to know the detailed parts of the controller either fuzzy logic or PID controller and study the method to be used for tuning in the same time and then apply this method during the process of designing controller for prosthetic devices. This paper presents intelligent control strategy for prosthetics hand which controlled by Fuzzy with Proportional-Integral-Derivative (Fuzzy-PID) controller. The performance for the proposed controller in prosthetics hand is compared to the PID and fuzzy controller.

II. Methodology

A. *Development of Prosthetics Hand*

An electromyography method (EMG) is a medical method that rendered by the medical field to measure muscle reaction to anxious stimulation. EMG instrument is used to perform EMG techniques to produce the record of the so-called EMG. An EMG sense the electrical signal generated by muscle cells when these cells tense.

A myoelectric prosthetics hand using EMG signals or possible of voluntary muscle contraction in the rest of one's body to the skin to control the movement of the prosthesis, such as elbow flexion, open hand, finger cap or wrist supination/pronation (rotation). This prosthesis using a neuro-muscular system of the human body to manage the rest of the functions of an electric-powered prosthetic [7]. This contrasts with the switch electric prostheses, which requires ropes and cables driven by the movement of the body to move or operate a switch that controls the movement of the prosthesis or a completely mechanical. It has a jack hang person by taking electrodes placed on the flexors and extensors of extension and extension movements respectively. Advances in technology myoelectric in current years has made it the top end of forged components are far superior to the governing body equivalent [2].

In Fig. 1 shows pectoral muscles have the four main brachial nerves (musculocutaneous, median, radial and ulnar) after be transferred where it are little functional use to a person with shoulder disarticulation. After the nerves are communicate to distinct regions of pectoral tissue by anastomosis, conventional surface electrodes can monitor these restored sources of neural signals that now correspond to musculature that would have been distal to the amputation (elbow, wrist, and hand).

The movement of a prosthetic arm requires amenities control system for controlling the movement consists of three main parts: the input signal, motor driver part and motor control algorithms. Part processing the input signal include real-time data and also its buffer part. Additionally, it measure EMG signals from the hands of the forearm muscle subject and generate a stable flow of root mean square (RMS) value [1]. The next movement of the arm can be determined by using the range of RMS value. After that, motor control will be determine the motor movement based on the range of RMS value and device driver acts to control the performance of motor. By using correct selection of threshold and fitness level, any type of exercise can be successfully trained in the application.

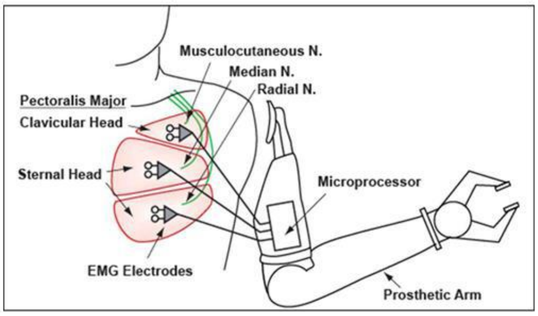

Figure 1. EMG method in prosthetic hand.

Detailed on mechanical design will be accomplished through the use of rough hand drawn sketches and Computer Aided Design (CAD) software. Individual parts in prosthetic hand were carefully modelled with as much detailed information and accurate dimensions as possible. All aspects of the design such limited space, size components and accuracy will be set as a priority. Fig. 2 shows the assembly part by part in prosthetics hand was completed where the glove will be connected with flex sensor to move the finger of prosthetics hand.

Figure 2. InMoov 3D printed robot with assisted glove.

B. System Identification

Model identification and control algorithm have designed using MATLAB and Simulink in order to perform a closed-loop intelligent control on the prosthetics hand. This project has been focus primarily on the identification for multifunctional prosthetics hand. The prosthetics hand only has one degree of freedom (DOF) that only can move to another position [8]. In addition, Flex sensor is implemented as input to manipulate the position of finger will control the position at prosthetics hand. The data from Flex system will be collected at forearm which it near with muscle that controls the fingers. System identification toolbox will be utilized in order to obtain the connection between muscle signals and generated force from the prosthetics hand. The system identification will analyze the data that get from the output and produced the transfer function. Fig. 3 shows the process of identification and controller design process.

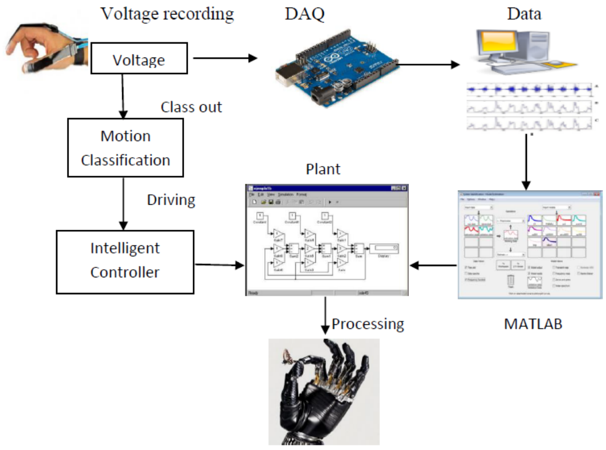

Figure 3. Identification and controller design process.

From the estimation and validation of input and output signal, the value of poles and zero be determined from System Identification Toolbox. The value of poles is two and value of zeros is one. Result from the estimation shows the best fit from this transfer function is 81.17% as in Fig. 4.

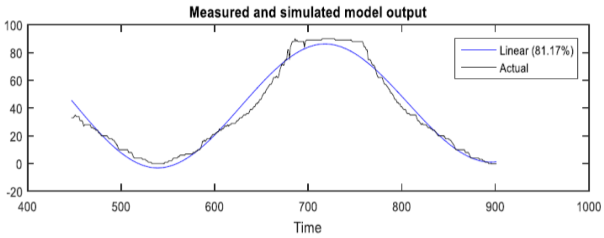

Figure 4. Measured and simulated model output.

The transfer function as in (1) for this simulation have been obtained through System Identification Toolbox based on the actual data collected for performance evaluation of prosthetics hand.

$$tf = \frac{0.6858s + 1.712}{s^2 + \left(1.225 \times 10^{-10}\right)s + 0.06855}. \quad (1)$$

III. Control Scheme

A. Proportional-Integral-Derivative (PID) Controller

In industrial control systems, the PID controller is the frequently feedback controller used such as automation industry. Function of PID controller is to calculate the error of the system between the measured and a desired set point of the system [8]. For reducing error by changing th e controller gains which are is called as K_P, K_I and K_D. In the controller field, the PID controller are effective controller where it can affect the steady state error (SSE) and transient response. But, for the best performance of PID controller, appropriate PID parameters should be tuned rigorously for particular system [9]. The block diagram of PID controller is illustrated in Fig. 5.

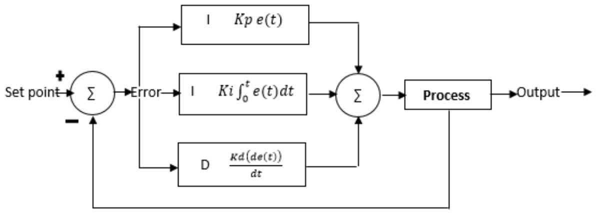

Figure 5. Block diagram of PID controller.

The PID controller algorithm contains three different variables which are called as three-term controller. A proportional gain acts to identify the response to the error of the system and for the integral gain is to identify the response based on the summation of current errors changed. To determine the response based on the rate by adjusting the derivative gain. The entire weight of these three-term controller is used to adjusting the process via a feedback of control variables or an actuator such as movement of a control valve, position and speed of the robotic hand and other [10], [11].

In order to calculate the output of the PID controller as in Fig. 6, the proportional, integral, and derivative terms shall be added. Defining u(t) as the controller output, the final form of the PID algorithm is in (2).

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{d}{dt} e(t). \qquad (2)$$

where the parameters are tuning:

- u(t) = output
- e(t) = error
- K_P = proportional gain
- K_I = integral gain
- K_D = derivative gain

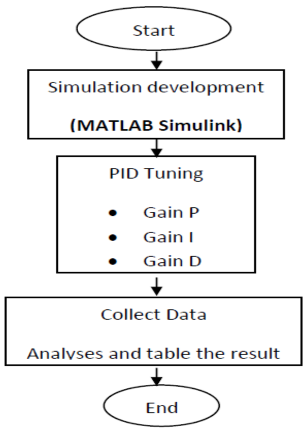

Figure 6. Flowchart of tuning PID controller.

B. Fuzzy Logic Control (FLC)

In 1965, Lofti Zadeh is a professor at the University of California has inspired the concept of a method called fuzzy logic. However, this study was not presented as a method of control, but as a way to process the data by allowing some of the skill set fresh set of membership or non-members. Until the '70s, this approach to theory implies that the control system due to lack of capacity towards computer at the time. Professor Zadeh said that people do not need the right data and input numerical information, but they were able to control the highly adaptive. In such situations there is a feedback controller, which can be programmed to act to receive noisy and imprecise input, the control will be more efficient and may be more easily implemented. However, this method has not been received with so extreme for US manufacturers than Europe and Japan are implementing aggressive to build real products in the vicinity [12].

FLC using concept of if-then to provide a mathematical framework to allow for model uncertainties associated with estimates of reasoning, over to the control system in which a mathematical model is difficult to obtain, including information processing and human perceptual. For fuzzy system, fuzzifies input starting to Using a set of membership functions (MF), the fuzzy system, a prelude to fuzzifies input to the value of the interval [0,1] which is 'HIGH' and 'LOW'. In three pattern recognition of myoelectric signals, some researchers have used concept of fuzzy logic for hand prosthesis [13]. FLC as shown in Fig. 7, consist of three main components: fuzzification, defuzzification, fuzzy inference engine and role of fuzzy rule base is to allow the process of uncertainty.

Such information can be disclosed to other forms of linguistic imprecise as 'low', 'medium' and 'high'. In a fuzzy system, the subjective judgment formulated by the fuzzification acting to transform them into fuzzy linguistic variables according to functional characteristics of expertise in a certain universe of discourse.

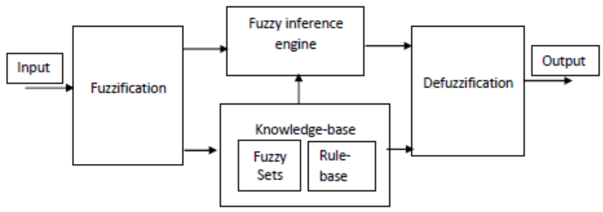

Figure 7. Fuzzy system structure.

This part to be explain about step to tune a FLC into a transfer function of prosthetic hand that be generated as illustrates in Fig. 8. By adjusting the FIS and selecting three membership, it is used to control the performance of output in prosthetic hand. Two input that be used into the FLC where the error (*e*) and rate of error (*de*) is reused. An output from FLC that be used. This FIS setting summarized below are based on design choices described in:

- Mamdani method fuzzy inference system that be used.

- Algebraic product for AND connective that be used.
- The ranges of input 1 and input 2 are normalized to [-90 90].
- The range of output is [-180 180].
- The defuzzification by using center of gravity method (COG).

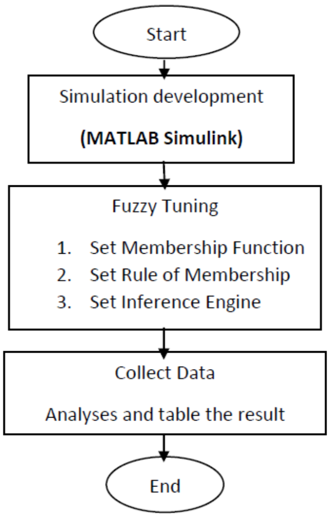

Figure 8. Flowchart of tuning FLC.

C. *Fuzzy-PID Controller*

This method using two different controllers consists of PID controller and FLC. Combination of PID both controllers known as Fuzzy-PID controller that implemented in this study gives different approach as compared to the conventional approach where this method using the transformation of the PID gains to the linear Fuzzy controller. Fig. 9 and Fig. 10 illustrate a block diagram of Fuzzy-PID controller in the prosthetic hand.

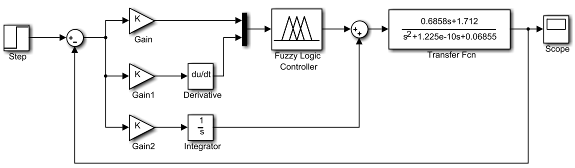

Figure 9. Identification and controller design process.

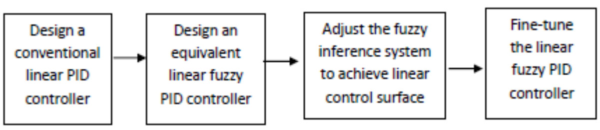

Figure 10. Process to design Fuzzy-PID controller.

Two input that be used into the Fuzzy controller where the *e* be connected with gain K_P and while *de* connected with K_D is reused. An output from Fuzzy controller that be used. This FIS setting summarized below are based on design choices described in:

- Mamdani method fuzzy inference system that be used.
- Algebraic product for AND connective that be used.
- The ranges of input 1 and input 2 are normalized to [-90 90].
- The range of output is [-180 180]

IV. Results and Discussion

Simulation works have been conducted by using PID, Fuzzy and Fuzzy-PID controllers which is designed in MATLAB and Simulink. In order to obtain optimized membership functions, the input and output membership functions of the Fuzzy Logic controller is being tuned continuously based on rule base. Whereas, to get optimum transient response and steady state error where the simulation is ongoing by using the Fuzzy-PID controller as tabulated in Table I and Table II.

TABLE I. Parameter of KP, KI and KD in PID and Fuzzy-PID

Controller	K_P	K_I	K_D	Filter Coefficient
PID	2.6413	0.6836	0.7260	3.4311
Fuzzy-PID	1.0000	0.0005	1.0000	-

TABLE II. Rule Base of Fuzzy and Fuzzy-PID

Input 1 /Input 2	Negative	Zero	Positive
Negative	Negative	Positive	Zero
Zero	Positive	Zero	Negative
Positive	Zero	Negative	Positive

Fig. 11 shows the comparison of step response between three different controller that be used to control the performance of prosthetic hand model. Performance of Fuzzy-PID controller shows the better transient response and steady state error than the PID and Fuzzy controller. The comparison of transient response between PID, Fuzzy and Fuzzy-PID controller are tabulated in Table III.

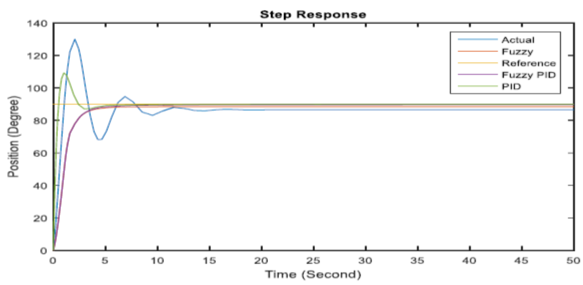

Figure 11. Identification and controller design process.

TABLE III. Transient Response using Fuzzy-PID

	PID	Fuzzy	Fuzzy-PID
Rise time	0.3810 second	1.4410 second	1.3021 second
Settling time	4.0900 second	6.1036 second	4.0075 second
Overshoot	21.50%	3.40%	0.00 %
Steady state error	0.0000	0.1200	0.0000

Furthermore, three different controllers were tested with minimal root mean square error (RMSE) method. This method is used to indicate the minimum error when the plant of system tuned by the controller so that it reaches the desired value. Besides that, this method that ensured finding the minimum RMS value of the error between the reference and controller output. Based on Table IV shows the root mean square (RMS) value of Fuzzy-PID controller lower than the other whereby showing 0.4073. Whereas, the PID controller shows 0.7206 and Fuzzy controller shows 1.466.

TABLE IV. RMS VALUE FOR THREE DIFFERENT CONTROLLER

Controller	RMS value
PID	0.7206
Fuzzy	1.4660
Fuzzy-PID	0.4073

V. CONCLUSION

This paper presents an intelligent design and control strategy for a prosthetics hand. The mechanical design of prosthetics hand is important element of which able to control movement and grasping of hand in daily life routine. In this paper, three different controllers for the prosthetics hand have been developed. By select different controller mode with proper tuning, the prosthetics hand can reach the desired position and different performances of the system for three different controllers are obtained. The response graphs for different controller approach are presented. This paper shows performance of PID, Fuzzy Logic and Fuzzy-PID controllers for prosthetics hand have been compared. PID controller has reduces less overshoot and able to deal with more changing conditions while Fuzzy controller has reduce mostly the overshoot and better transient response. It can be concluded that the Fuzzy-PID controller perform better as compared to the conventional PID and Fuzzy controller where it has improve significantly the transient response especially the overshoot and gives higher accuracy.

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