FACULTY OF ELECTRICAL ENGINEERING

CONTROLLER DESIGN FOR NON LINEAR MOTORIZED PROSTHETIC HAND SYSTEM

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ABSTRACT

This paper described the controller design for nonlinear motorized prosthetic finger system. It can be used as a human assistive device to the amputee. Since the prosthetic device is wear by human, the accuracy of the system is crucially important to avoid unnecessary hazard to the user. In addition, the mathematical modelling of the system need to be find appropriately to ensure the accuracy of the system later on. The main objective of this project is to design the controller for the system. There are many type of controller that can be used in order to design the stable system of nonlinear actuated finger such as Proportional Integral (PI), Proportional Integral and Derivative (PID) and Fuzzy Logic controller. In this project, the Proportional Integral and Derivative (PID) controller will be use. The tuning of PID control parameter is for the position reference design and the position feedback control of the motor. Gradient Descent or Auto tune method can be used to improve the transient response performance of the motor by tuning the parameter of PID control. From this project, it is expected that prosthetic finger will move according to the desired position and smoothly with the presence of PID controller. The value of rise time, settling time, overshoot and steady state error can also be improved.

ABSTRAK

Penggerak selari jari merupakan jari palsu yang digerakkan secara selari oleh motor. Ianya boleh digunakan sebagai alat bantuan bagi individu yang tidak mempunya jari ataupun kudung. Memandangkan jari tiruan ini dipakai oleh individu, ketepatan sistem sangat penting bagi mengelakkan sebarang masalah yang tidak diingini kepada pengguna. Sebagai tambahan, persamaan matematik juga haruslah dicari secara teratur bagi memastikan sistem tersebut dapat beroperasi dengan tepat. Tujuan utama projek ini dijalankan adalah untuk mencipta satu unit kawalan bagi jari palsu tersebut. Terdapat pelbagai jenis unit kawalan yang boleh digunakan bagi memastikan kestabilan sesuatu sistem seperti unit kawalan perkadaran bersepadu (PI), unit kawalan perkadaran bersepadu dan terbitan mutlak (PID) dan unit kawalan logik kabur. Dalam projek ini, unit kawalan perkadaran bersepadu dan terbitan mutlak (PID) akan digunakan. Penyelarasan unit kawalan PID adalah untuk kedudukan rujukan dan tindak balas kedudukan kawalan bagi motor. "Gradient Descent" atau penyelarasan automatic boleh digunakan bagi menambahbaikkan kepada tindak balas transisi bagi motor apabila unit kawalan PID diselaras. Keputusan yang dijangkakan dari projek ini ialah jari palsu tersebut akan bergerak pada kedudukan yang dikehendaki dan kajian juga membuktikan bahawa jari palsu tersebut boleh bergerak dengan lancar dengan bantuan penyelaras parameter PID yang dapat mengurangkan masa kemuncak, masa menaik, ralat keadaan kukuh dan masa pengenapan.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The designing of fully functioning prosthetic finger or hand with smooth movement and strength like a real finger is the ultimate goal in motorized prosthetic finger. Unfortunately, current technologies that exist in designing and material are still long way to go in making this goal a successful. There are major factor that limiting the process to make the prosthetic finger model which is the power, weight and size of that model. In addition, other difficulty that faces in order to develop the model of prosthetic finger is to find the sufficient number of appropriate control source to control the required number of degree of freedom. Based on the research made, the prosthetic finger is dominated by the consideration of control. However, the importance of better multifunctional mechanism and better actuator cannot be ignored. The control will become useless if the effective finger mechanism is not available.

Human hand is perplexing that comprises of 27 bones with the huge number of muscle and ligaments to give countless of flexibility (DOF) in development. Moreover, each hand has a cluster more than 17000 material sensors. In any case, it is practically difficult to supplant something that is comparable with the genuine finger particularly when it is identified with strength and unwavering quality by utilizing the current innovation. The principle inspiration in directing this venture is to defeat the aggravation, grinding and commotion that happen in plant or process. As an expansion, the issue in outlining the controller is the instability about the subject and the nonlinear dynamic. Consequently, keeping in mind the end goal to get the soundness and unwavering quality for the framework, the most appropriate controller must pick.

1.2 Research Background

For a few recent decades, in manufacturing industry robot was widely used to assist human work. These robots have different type of speciality that suit the different purpose of manipulation. The normally used of robot machine in industries are suction cups and gripper but it have less flexibility compared to the fingered end effectors. Other than that, by using a multi-fingered robotic hand it can deliver an accurate and precise motion of the position. However, the most vital aspect in development of multi-fingered robotic hand is stability, cost and reliability. In order to produce a prosthetic hand that can perform like human hand, the system required control and stability. Thus, it is very important to build a prosthetic hand with accurate motion control [1].

Figure 1.1 shows the real-time control of a 7-DOF robotic hand for object grasping. The structure of the prosthetic hand consists of three 2-DOF fingers that have two joints and two links for each finger. The motor that is located inside of the robot link will actuated each of the robot joints. The motor is then joint together with encoder and interfaces with Motion Manager application for control via a motion controller [1].

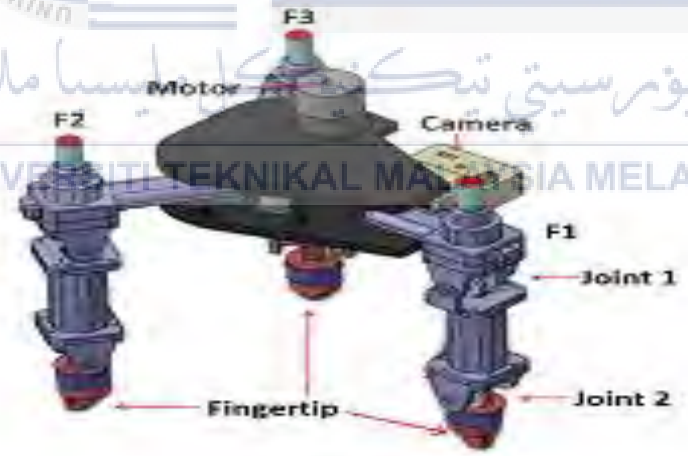


Figure 1.1 Real-time Control of a 7-DOF Robotic Hand for Object Grasping

During the last three decades, the development of robotic gripper for grasping many type of object has develop from using a simple mechanism to multiple degree of freedom of design. Most robotic grippers were designed specifically just to grasp on certain object form only. It is a difficult task to design a gripper finger because it required many considerations such as geometry of gripper, task requirement and the complexity of mechanism.

According to traditional way, it is necessary to have a physical prototype in order to test the ability of the hand to perform a variety of task. However, it is quite costly because many designs are required to develop the prototype. Thus, the simulation technique will provide another tool that enables the modern designer to simulate kinematic and dynamic of physical system and to investigate the performance of the design quickly. This technique will reduce the cost of prototype. Simulation is one of the powerful tools that exit in supporting the design, planning and analysis of dynamics performance of robotic grippers [2].

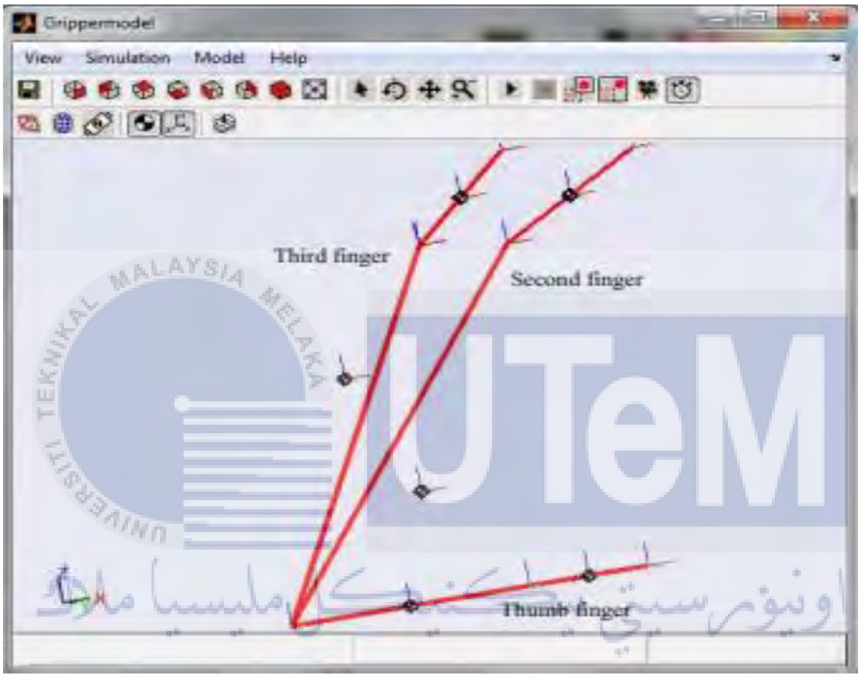


Figure 1.2 Gripper Position of Robotic Finger

Human hands are one of the body parts that are capable in manipulation task and grasping many type of object. As an example we can learn to play the musical instrument with our hand, use chopsticks and perform daily routine such as writing and cooking with a proper training. Unfortunately, the robotic hand that existing are not capable to demonstrate human level of dexterity. Dexterity of movements in human hand is achieved due to the neuromuscular control and biomechanics of the hand. The human level of dexterity must be analyse and understand in order to mimic the neuromuscular control and the biomechanics to develop the robotic hand [3].

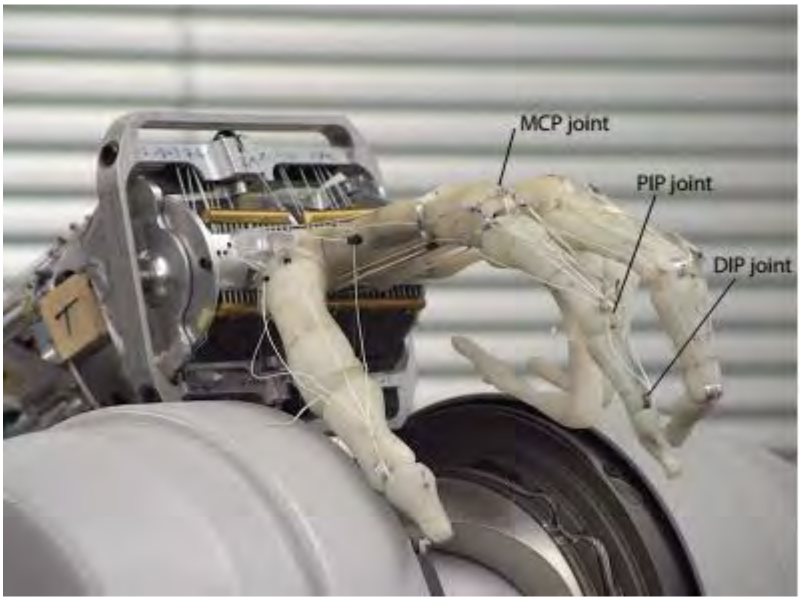


Figure 1.3 Skeleton Structure of Robotic Finger

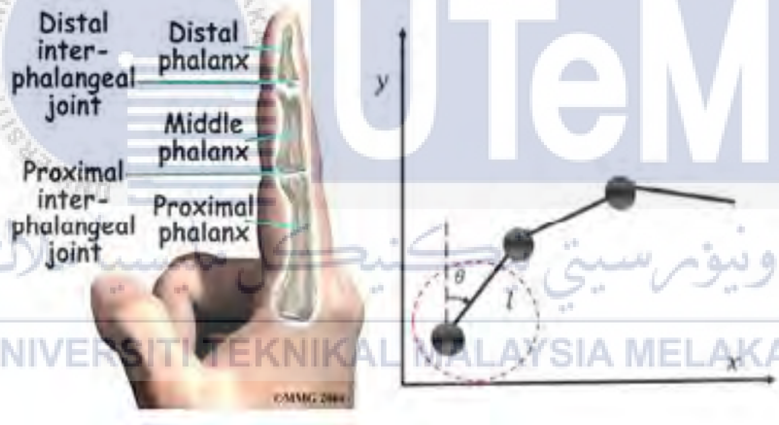


Figure 1.4 Structure of Human Finger and Flexion of Angel of One Finger

Figure 1.4 illustrates the structure of human finger that consist of three parts which is distal phalanx, middle phalanx and proximal phalanx. In between of the phalanx there is distal inter-phalangeal joint and proximal inter-phalangeal joint. The finger's movement with flexion of angel of one finger can be described with one degree of freedom model (1 DOF).

1.3 Problem Statement

The problem statement for this project is a pure motion controller usually gives poor performance and can even cause instability. It also has a non-linearity problem along with the inaccuracy of the system. Thus, to overcome this problem the best controller that have high accuracy for the nonlinear actuated finger must be selected. Accuracy and control are important to produce an actuated finger that can perform as the real human finger. In addition, the simulation with PID controller was needed to be tuned in order to get more stable result for the system.

1.4 Objective

This project embarks into following objectives:

1. To model the prosthetic hand system by using Lagrange's equation.
2. To design the controller using PID based controller.
3. To verified and validate the performance of the controller via simulation.

1.5 Scope

The scope of this study is firstly, mathematical modelling have to be developed before the controller was designed to the system. In this paper the Lagrange's equation was used as an approach to the nonlinear motorized prosthetic finger system. Then, the controller of Proportional Integral and Derivative (PID) will be applied in order to gain the stable system. As for the tuning of PID, Gradient Descent method can be used to improve the transient response performance of the motor. This method was then compared to auto tuning method in order to prove it will give the most accurate result for the tuning of PID.

1.6 Expected Project Outcome

The expected project outcome is to obtain the most accurate result after the PID controller was design to the system. Then, the tuning method for PID controller will be proposed. The result from the tuning method which is Gradient Descent will be compared with the result obtain from the auto tune method. The best closed loop characteristics then can be determined from this comparison.

1.7 Proposal Outline

Chapter 1 discussed about the overall proposal of the project such as motivation, research background that related to the project, problem statement, objectives, scope and expected result that will be obtain later on. This project was conducted based on the problem statement and objective that has been listed.

Chapter 2 discussed about the literature review that related to this project. There are few papers that have been going through in order to gather some information about prosthetic finger system, controller applied to the system and it tuning method. Other than that, system modelling was also been discuss in this chapter.

Chapter 3 discussed about the methodology involves while doing this project. First of all, the prosthetic finger system was model by using the Lagrange's equation. Then, the controller has been design for the system along with it tuning method. In this chapter the steps for tuning method of PID controller will be discuss and describe. The Gradient Descent was used as the tuning method for the controller. Flow of the project can be seen in this chapter with some explanation for each step.

Chapter 4 discussed about the most important part for this project which is the result of the simulation. The result before and after designing of PID controller was observed in this chapter. It is obviously shown that the best result only can be obtained when the controller was installed in the system. Next, to determine the most accurate result, the tuning method was used for the system. This tuning method was then compared with other method in order to obtain the best trade off result.

Chapter 5 discuss about the conclusion for the whole project and also some recommendation about the future work plan.

CHAPTER 2

LITERATURE REVIEW

2.1 PID Controller

Past reviews have announced that Proportional Integral and Derivative (PID) is a procedure of referee the controller parameter to decide the coveted yield of control framework. The mistake between the procedure variable and its set point can be limited by utilizing the controller. In this manner, experimentation strategy has been utilized as a part of request to recognize the PID control parameter [1].

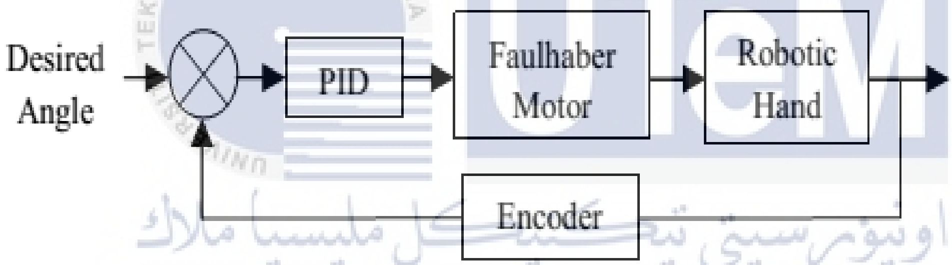
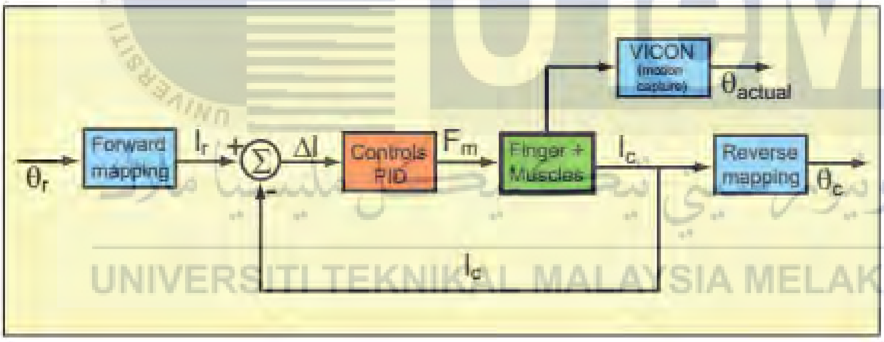


Figure 2.1 The control system of robot control

This paper has presents a coordinated plan handle for planning the five fingered gripper that is appropriate for smooth movement by utilizing analysis and reproduction of the model. Next, multi-shut circle with the powerful control of PID was connected to the framework for controlling both dynamic and kinematics movement of the five fingered gripper framework. The joint controller is a criticism controller comprises of two terms which is relative to speed and position blunders, it additionally presenting the subordinate and corresponding activities known as PID control. The kinematics movement of the position plots for each finger was controlled by utilizing the propel PID control with auto tuning [2]. A discrete Proportional Integral Derivative (PID) control procedure would significantly decrease the cost and size of the controller since it can supplant the complex electronic hardware [3].

Late confirmation demonstrates that with a specific end goal to acquire the precise situating of automated hand for getting a handle on, the tuning of PID control parameter was imperative to enhance the transient reaction. Prior to the tuning of PID is executed, position has somewhat vibrated because of the unfaltering state blunder and overshoot delivered by the engine [1]. The appropriate increases of differential (Kd), indispensable (Ki) and relative (Kp) esteem are controlled by utilizing auto tuning technique to accomplish quick reaction of consistent state (setting tune) without extreme overshoot. By tuning these three appropriate estimations of steady picks up in the PID controller calculation, the controller was found to give the essential control activity to particular process prerequisites [2]. At the given time interim which is test period (T), a discrete PID controller will peruses the blunder flag, figure it yield and control the information supply to the engine. In this way, to get the coveted outcome, the specimen time should dependably be not as much as the most brief time consistent in the framework [3]. The PID controller is set up for each muscle to track the coveted in light of the mistake of the framework [4].



Figures 2.2 The difference from the current muscle length, Lc is fed into the PID controller to determine the force that directly control the muscle

2.2 Fuzzy logic controller

From the current proof, it can be seen that to restrict the development of the coveted heading and to keep up a steady compel along the moving course, a position or drive controller with fuzzy logic must be created [5]. To exhibit on how simple the fuzzy sets enrolment can influence the execution of the framework, the examination is partitioned into two unique parts. The initial segment will just consider the question shape as the information and the edge introduction as it yield while for the second part the execution was investigate just when two data sources are nourished into the framework. In fuzzy logic step, the framework can comprehend the execution of various fuzzy set enrolment with a specific end goal to choose the best technique for the getting a handle on framework.

In spite of the fact that the fuzzy tenets appear like extremely basic, despite everything it can give a superior outcome particularly in considering the best getting a handle on framework since it can give a general picture just by picking the fitting enrollment work [6]. Various specialists likewise have announced that simulated control, for example, Fuzzy logic, hereditary calculation, neural system and neurofuzzy control have been connected in numerous applications. Its application zone is wide in light of the fact that the fundamental shape for all summon sorts of controller comprises of info fuzzy govern base, surmising, fuzzification and yield defuzzification [7].

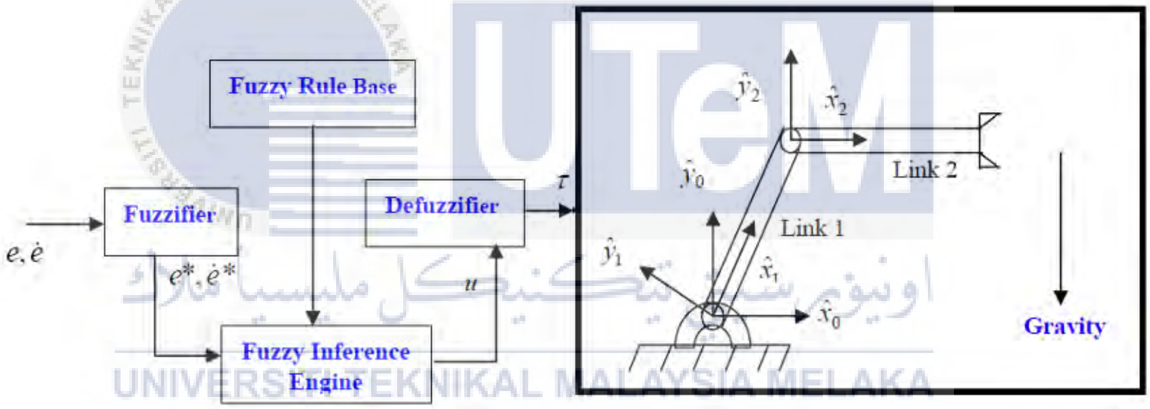


Figure in 2.3 Block diagram of fuzzy controller

The past review expressed that to decide the ideal control parameter precisely, a regular straight corresponding basic (PI) controller and fuzzy PI tuner ought to be joined as the constrain controller. On the off chance that this two things are not joined it is difficult to get the exact ideal control parameter in light of the fact that fuzzy PI tuner is working as an adjusted for the non-straight elements of the robot and the obscure aggravating power from the subject [5]. The fuzzy logic control can have preferred control over straight PI or PID control however it just can be accomplish if all the fundamental data about nonlinear dynamic plan framework and the parameter of robot controller can be decide. At that point, the technique for figured torque control can work great [7].

2.3 Conclusion

Overview that led by Shauri, Salleh, Hadi [1] demonstrated that the PID tuning of finger joints was effectively created to decrease the transient reaction, for example, rise time, overshoot, settling time, crest time and enduring state mistake. Engine will moved easily and it position was exactly to the objective position when the mistake and the overshoot have been disposed of from the framework. At that point, the reviews expressed that each finger of the gripper can be controlled by utilizing the vigorous control of PID plan since it is viably used to control the situating of the fingers [2]. The PID controller is working fine yet at some point it is important to make the controller more powerful (utmost runaway/flood) in a few applications. The exactness for either subsidiary (D) or vital (I) variable will end up noticeably poor if the example time is significantly littler or bigger than 1 second [3].

As a conclusion for the fuzzy logic controller, the controller was steady in the application scope of development and strengths. The underlying outcome demonstrated that the robot was succesfull to control the subject through straight and round developments by utilizing the typical and stroke subjects. At that point, amid the development the robot could keep up the steady drive regarding the matter [5]. A fuzzy logic based robot getting a handle on framework that was outline with three fingers which comprises of two typical fingers and a thumb is utilized for assessments. The triangular and Gaussian participation are two sorts of enrollment that were mostly examined [6]. The past reviews have demonstrated that the fuzzy tuning can tackle the issue with respect to the induction of blunder and change of mistake in light of the web based tuning coefficients. In light of reenactment and diagram strategy, the overshoot and swaying in nearness of the instability and outer aggravation can lessen [7].

Past work is directed to investigate the steadiness of the plan in the event of defective remuneration of the gravity term and potentially fall back on an adaption component on the framework satiate. In this way, the controller comprises of PD is plan on the position circle while a PI is created on the drive circle alongside the gravity pay and wanted contact constrain feedforward [8].

2.4 Tuning Method for PID Controller

There are many tuning method exists in order to tune the PID controller. The Zieglar Nichols is generally used for tuning the PID. This method will shows a successful result but it required an effort and takes a long time in order to obtain more satisfactory response. Ziegler–Nichols method depends on the parameter gain from the step response plant [10]. In the previous paper, the optimization of PID controller by using Gradient Descent method has been discussed. By applying the optimization technique from Gradient Descent method the performance of positioning tracking shows a significant improvement [11].

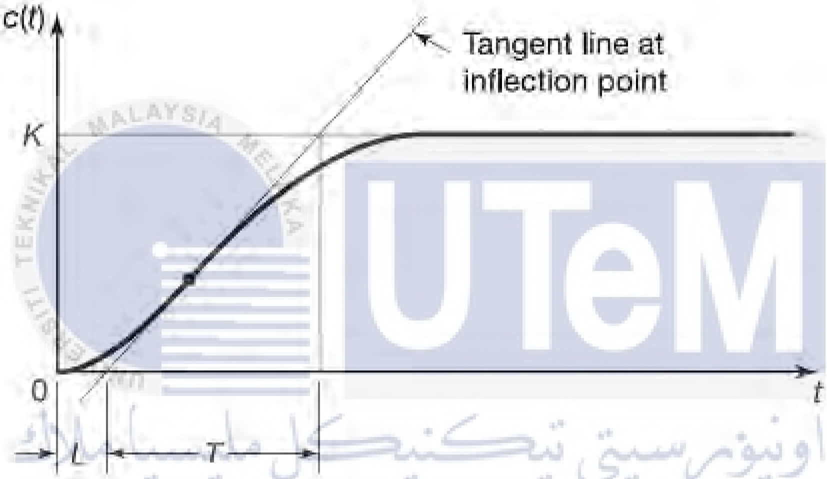


Figure 2.4 Ziegler Nichols Tuning Method

Type of controller	Kp	Ti	Td
P	$\frac{T}{L}$	∞	0
PI	$0.9\left(\frac{T}{L}\right)$	$\frac{L}{0.3}$	0
PID	$1.2\left(\frac{T}{L}\right)$	2L	0.5L

Table 2.1 Parameter Obtained for Ziegler Nichols tuning method

The result shows that the tuned of PID controller give a feedback system of good disturbance rejection. However, in general the compensated system response to a step signal has a high control signal and high percent of overshoot which may lead the saturation of actuator [10]. The evaluation of PID controller performance by using Gradient Descent technique that was applied to the controller has been done. The result from the numerical simulation prove that an optimization techniques will produced more precise position trajectory tracking and significant improvement to the controller [11].

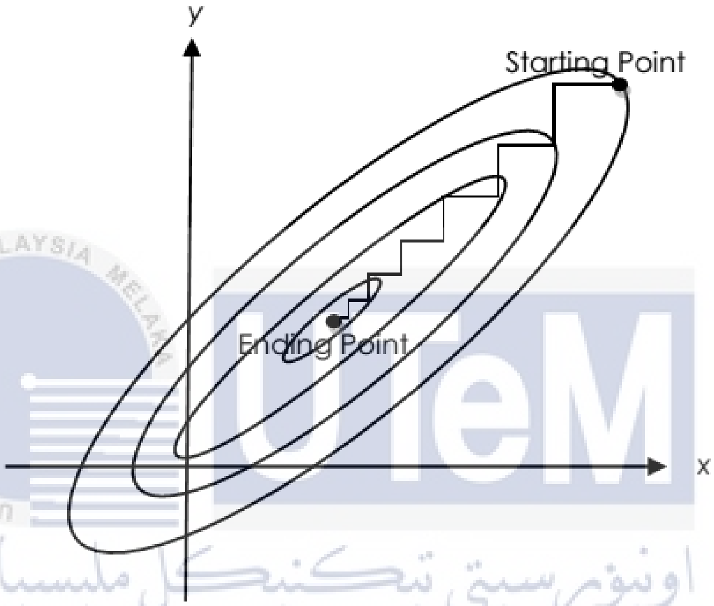


Figure 2.5 Directions to Reaching Local Minimum

CHAPTER 3

PROPOSED RESEARCH METHODOLOGY

This section covers the methodology part with the detail clarification to guarantee that this venture is finished and functioning admirably. There are numerous diaries that have been made in light of this venture can be utilized to energize some essential point and can be enhance as the up and coming reviews. The technique is use to decide the goal of the venture with a specific end goal to acquire the ideal and smooth outcome. Keeping in mind the end goal to assess this venture, the strategy comprises of five stages which are:

1. Data collection from literature review
2. System modelling of Prosthetic Finger system
3. Controller design (PID)
4. Tuning method of the controller
5. Result evaluation

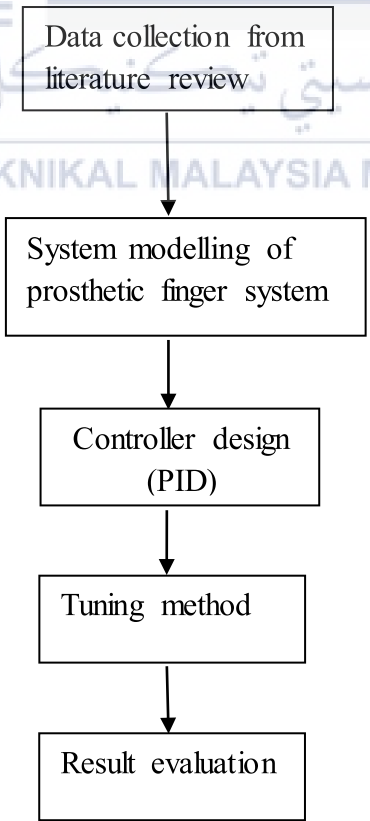


Figure 3.1: The flowchart of proposed research methodology

3.1 Literature review

In this part, the project was firstly started by finding the related journal and collects the important data from it. All of the journals are finding from the library and internet. There are many previous related journal was generated based on the title of prosthetic finger system. Thus, I have classified the data into four parts which is PID controller, Fuzzy logic controller, the comparison between these two controllers and method for tuning the controller which is Ziegler Nichols and Gradient Descent method. From the journal, I also can find further information about the controller and the advantages of each controller which is very useful for me to complete this project successfully. Other than that, by doing further research from the journal, I can listed the tuning method that exits and which method is commonly used for tuning controller. Then, I can make the comparison which tuning method is better for tuning the controller. In addition, I can understand more about the modelling, controller, tuning method and the moving position of the prosthetic fingers.

Figure 3.2: The design of five robotic fingers

3.2 Modelling of Prosthetic Finger

3.2.1 Mathematical modelling of Prosthetic finger

From the previous study, it shows that Lagrange Equation was used frequently in order to derive the model of prosthetic finger. Thus, as for the mathematical modelling Lagrangian Equation has been chosen.

Symbol	Parameter
l	Length
m	Mass
v	Linear velocity
ω	Angular velocity
g	Gravity (9.81 ms-1)

Table 3.1 Dynamic Parameter of Prosthetic Finger

The Lagrangian, L = T – V

(1)

T = Kinetic energy

V = Potential energy

Referring equation forward kinematic above, the angular velocity is computed using Euler Lagrange formula.

$\omega = \frac{d\theta}{dt}$

The angular velocity, $\omega = \dot{\theta}$

(2)

The Kinetic energy, T

$T = \frac{1}{2}\sum(mV + l\omega^2)$

(3)

$T = \frac{1}{2}\, l\dot{\theta}^2\, (\frac{1}{4}\, ml + 1)$

(4)

The Potential energy, V

$$V = \frac{1}{2}\sum mgy \qquad (5)$$

$$V = \frac{1}{2}\,(mgl\sin\theta) \qquad (6)$$

The Kinetic energy, T and Potential energy, V of the whole system are:

$$L = \frac{1}{2}\,l\dot{\theta}^{2}\,(\frac{1}{4}\,ml + 1) - \frac{1}{2}\,(mgl\sin\theta) \qquad (7)$$

3.2.2 Eular Lagrange equation of DC motor expression

An electrical and mechanical part of the DC motor that connected to the prosthetic finger can be expressed by:

$$F = (\frac{l^{2}\,\theta\ddot{m}}{4} + l\ddot{\theta}) - \left(\frac{mgl\,\cos\theta}{2}\right) + B\dot{x} \qquad (8)$$

For a field controlled motor, a field circuit has an input voltage, V, which is applied to the DC motor. So, rather than control the current directly to a motor, the electric field is varied to control the motor speed.

$$V = \frac{RF}{Ktz} + Kez\dot{x} \qquad (9)$$

$$F = \frac{V\,Kt\,z}{R} - \frac{Ke\,Kt\,z^{2}}{R}\dot{x} \qquad (10)$$

Then, substitute (8) into (10) which included the mechanical part of the prosthetic finger to the equation.

$$\left(\frac{l^2\,\ddot{\theta} m}{4} + l\ddot{\theta}\right) - \left(\frac{mgl\,\cos\theta}{2}\right) + B\dot{x} = \frac{V\,Kt\,z}{R} - \frac{Ke\,Kt\,z^2}{R}\dot{x}$$

(11)

$$V = \left[\frac{R}{Kt\,z}\right]\left(\frac{l^2\,\ddot{\theta} m}{4}\right) + \left[\frac{R}{Kt\,z}\right](l\ddot{\theta}) - \left[\frac{R}{Kt\,z}\right]\left(\frac{mgl\,\cos\theta}{2}\right) + \left[\frac{R\,B}{Kt\,z} + Kez\right]\dot{x}$$

(12)

The nonlinear equation of position/theta is expressed as:

$$\ddot{\theta} = \frac{V + \frac{Rmgl\,\cos\theta}{2Kt\,z} - \frac{RB\dot{x}}{Ktz} - Ke\,z\dot{x}}{\frac{Rl^2\,m}{4Kt\,z} + \frac{Rl}{Kt\,z}}$$

(13)

3.2.3 Simulation model of nonlinear prosthetic finger movement

The result from the Eular Lagrange was describe in this part and it need to be simulate to get the data response. The equation from Eular Lagrange is identify whether it is usable or not by using Simulink in MATLAB software. Figure 3.3 shows the subsystem in block diagram of the Prosthetic Finger System.

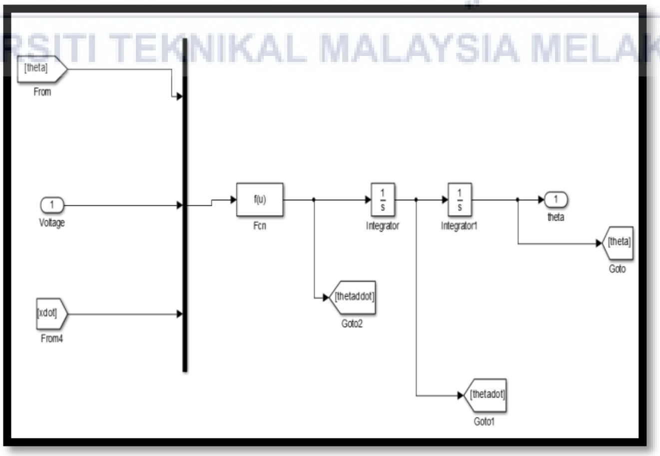


Figure 3.3 Subsystem in block diagram of Prosthetic Finger System

Figure 3.4 shows the Simulink Block Diagram of the system. The parameter of nonlinear motorized prosthetic finger system that implemented in the MATLAB was shown in Figure 3.5. In this system the control parameter is a position or theta. The list of parameter that has been used in the prosthetic finger system was shown clearly in Table 3.2 below. Based on the subsystem figure, it shows that the input for the system is voltage while the output is the position or theta. All of the parameter was set up as followed. The input voltage for the system is step input which has been set up to 1 Volts. The step input signal will represented as the supply to operate the movement of the finger. Then, the characteristic of the finger movement system is analysed.

PARAMETER	UNIT	VALUES
Resistance	R	2.6Ω
Constant torque	Kt	0.007NmA-1
Constant electric	Ke	0.007Vsrad-1
Gear ratio	Z	15
Radius pulley	Rp	0.02m
Length	L	0.75
Mass	M	1
Gravity	G	9.81
Friction	B	12.32

Table 3.2 List of Parameter

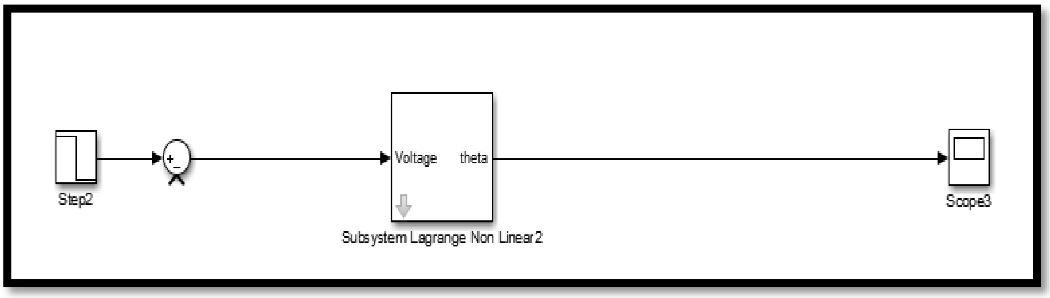


Figure 3.4 Block Diagram of Prosthetic Finger System Simulated in MATLAB Simulink

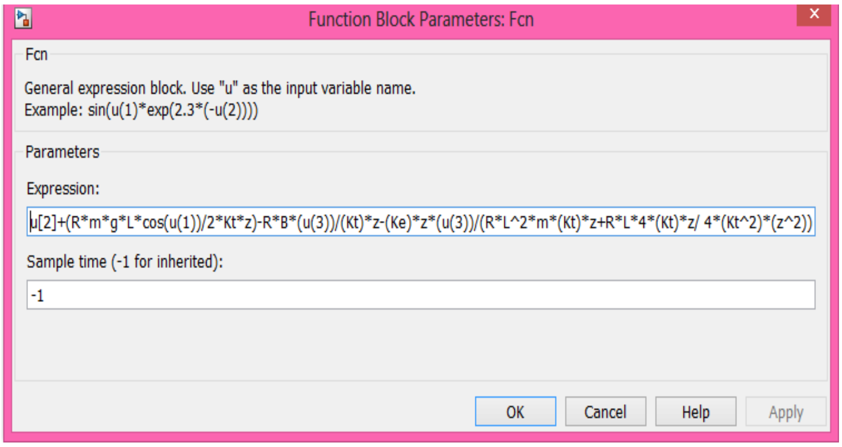


Figure 3.5 Expression Block of nonlinear system in MATLAB

3.3 Simulation model of Prosthetic Finger with PID controller

The Proportional Integral and Derivative (PID) controller has been installed into the system to ensure that the system can process smoothly with little disturbance. PID is a controller that is commonly used in the industry because it can reduce the overshoot, settling time, rise time and steady state error. In addition the PID controller will give a better result of step response.

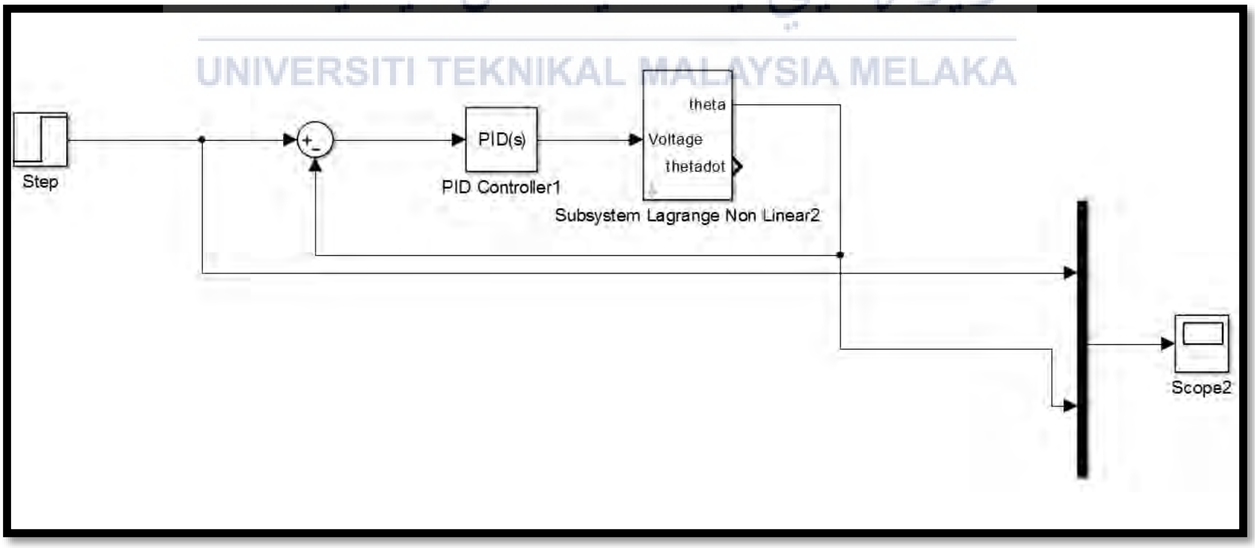


Figure 3.6 Simulink Block Diagram with PID Controller

As for the value of Kp, Ki and Kd,the value is obtained from the auto tune method. The value was then added to the PID block diagram and after the system was run, the step response graph will appear as a result. Then, the graph was analyzed.

3.4 Gradient Descent Tuning Method

Gradient Descent method is an algorithm applied to the system in order to obtain a minimum point for the particular function. It is to find a maximum point that is nearer to the current result. The value will decrease for each of the iteration that is take place. The iteration is the number for optimization solver attempt to evaluating the objective function and constraint. The F-count is a header in the iterative display for many solvers. All the attempt steps increase the F-count by one at the nearby point, regarding to the algorithm (14) to (17). Then, the Check Step Response Characteristic indicate the result according to the constraint of piecewise linear bounds illustrated in (15). The iteration process had repeated according to the equation (14):

$X_{i+1}=X_i - \lambda_i \nabla f(X_i) = X_i - \lambda_i g(X_i)$

(14)

At which the $\lambda_i > 0$ satisfies:

$f(X_i - \lambda_i g(X_i)) = \min f(X_i - \lambda_i g(X_i))$

(15)

where λ represent the step size and gradient operator ∇ of the function f(X). While g(Xi) is stated for the gradient at the current point.By moving to the point where function f taking on a minimum value, the directional derivative is given by:

$\frac{d}{d\lambda_i} f(X_{i+1})^T . \frac{d}{d\lambda_i} X_{i+1} = -\nabla f(X_{i+1})^T g(X_i)$

(16)

The λ>0 is a minor value that leads a small step to the function. An appropriate value for the λ is very significant, smaller value could increase the convergence time while higher value may lead to diverging. The appropriate value of λ yield to stable condition as:

$f(X_{i+1}) \leq f(X_i)$

(17)

The Gradient Descent method has been proposed as the tuning method for PID. The simulink block diagram of PID controller was shown in Figure 3.7. As for Gradient descent method, the check step response characteristic block has been added into the PID block diagram to obtain the result of closed loop characteristic graph. The gradient descent method is expected to arrive at the minimum point faster than other non-gradient based optimization method.

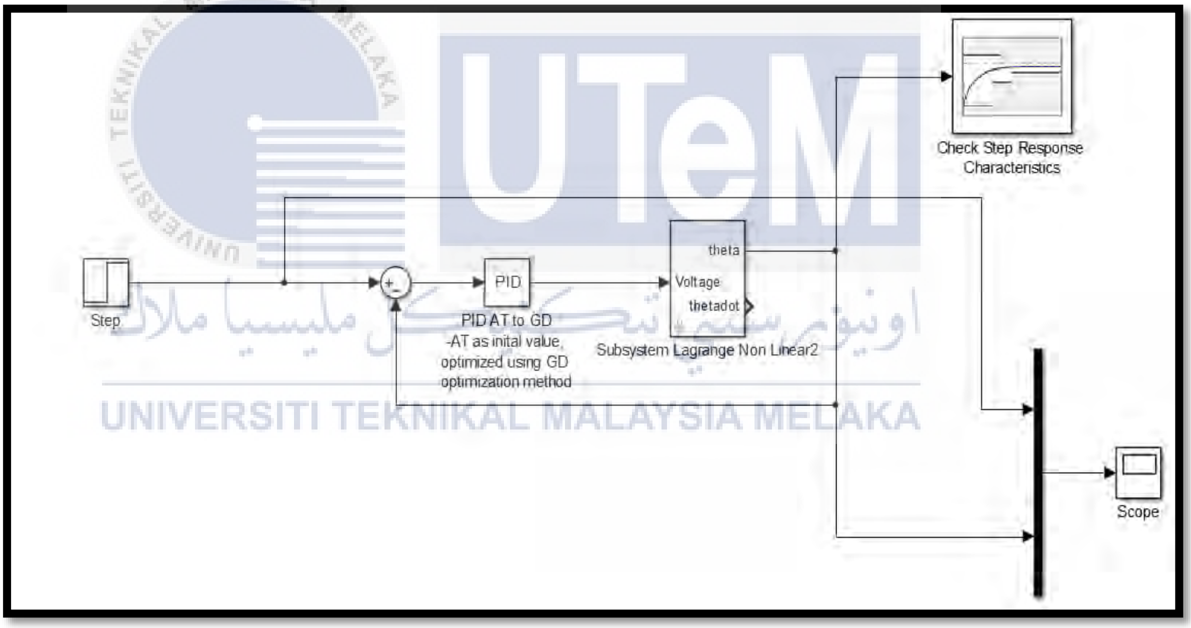


Figure 3.7 Block Diagram of Prosthetic Finger

3.4.1 Design Approach

For the design approach several trial has been done in order to get the most desired result. The gradient vector was adjusted and the value of parameter such as rise time, % rise, settling time, % settling, overshoot and undershoot was shown as in table 3.3. Then, from the parameter gain, the result from the trial can be compared to obtain the best result for the system.

Characteristic	First trial	Second trial	Third trial
Rise time	0.6650	0.7650	0.8650
% Rise	90.4870	90.5870	90.6870
Settling time	2.6650	2.6650	2.8650
% Settling	1.0000	1.0000	1.0000
Overshoot	10.0000	10.0000	10.0000
% Undershoot	1	1	1

Table 3.3 Parameter of Adjustment

Figure 3.8 shows the block diagram for the comparison of step response by using gradient descent method. The block diagram have been combined to obtained the graph of comparison for each trial. Other than that, the value of Kp, Ki and Kd are different for each block and it value was gain from the iteration process.

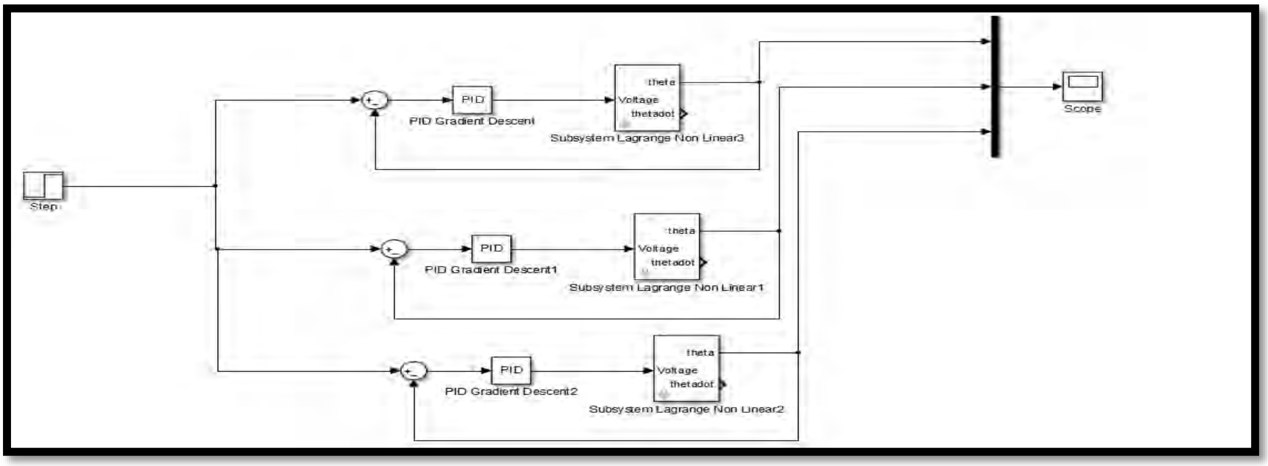


Figure 3.8 Block Diagram for Comparison of Step Response

3.4.2 Step For Gradient Descent Tuning Method

Step 1: The value of Kp, Ki and Kd was declared in command window

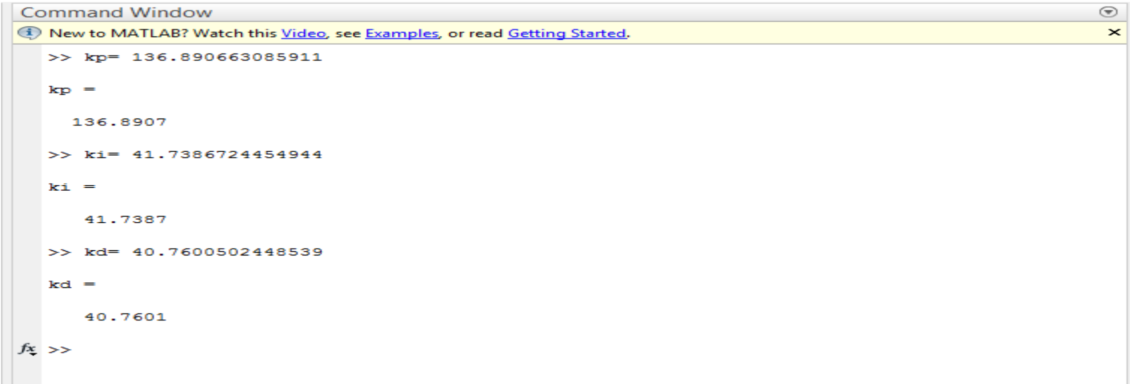


Figure 3.9 Step 1 for tuning

Step 2: Run the block simulation

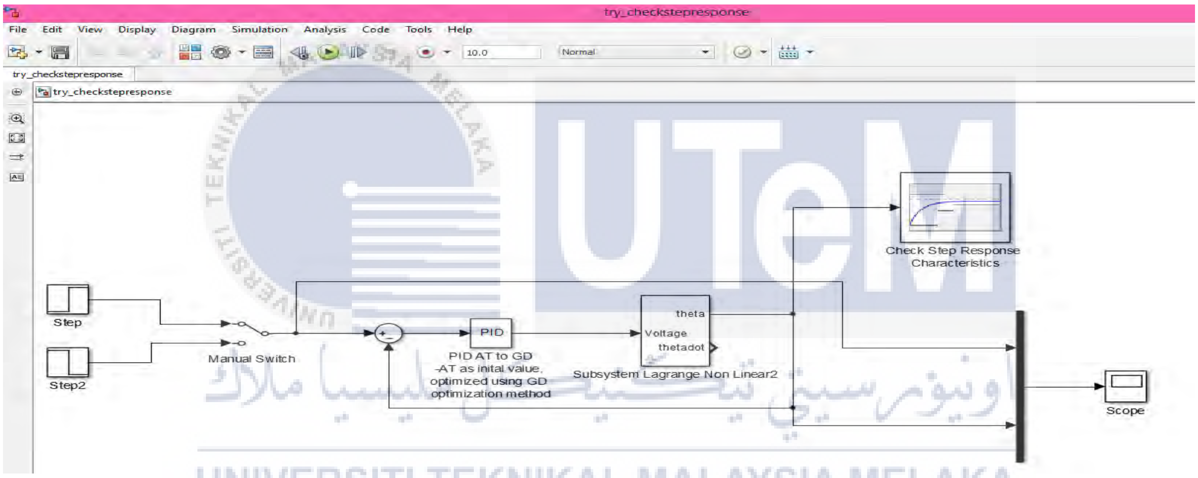


Figure 3.10 Step 2 for tuning

Step 3: Click on the check step response characteristic block

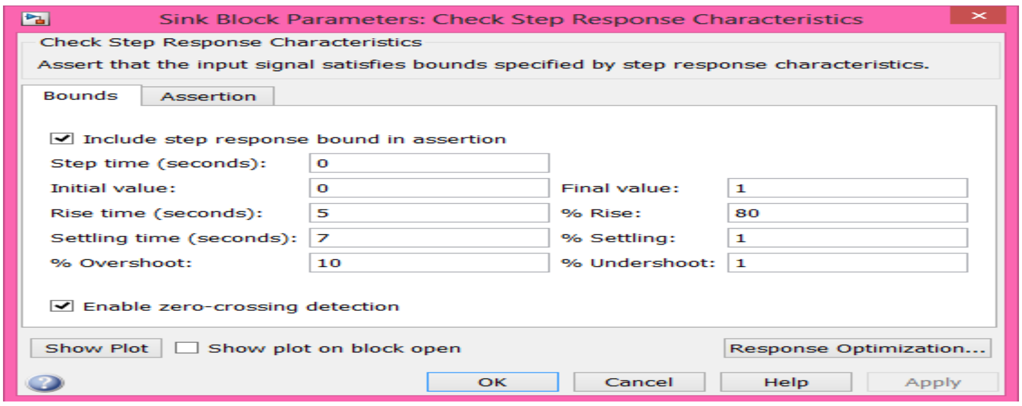


Figure 3.11 Step 3 for tuning

Step 4: Evaluate the requirement graph

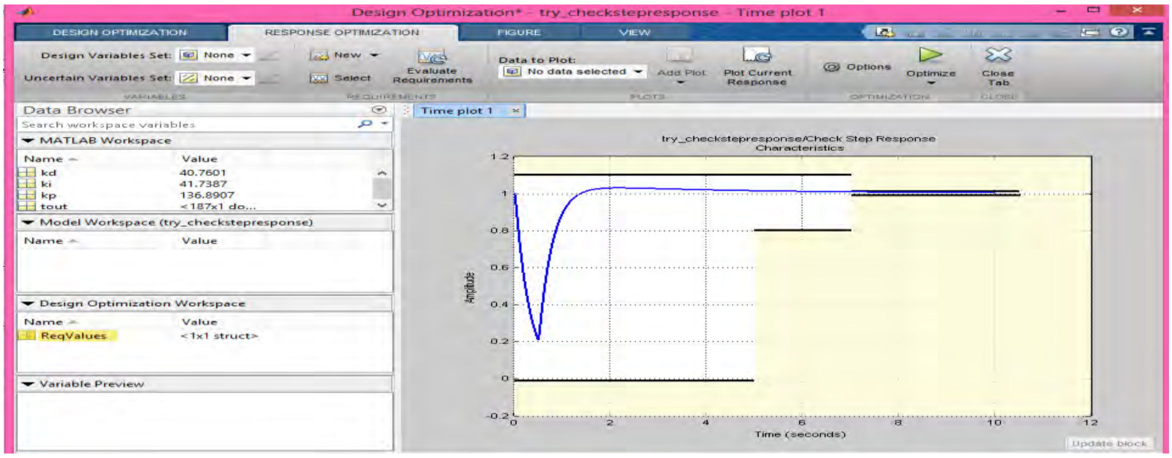


Figure 3.12 Step 4 for tuning

Step 5: The value of Kp, Ki and Kd is import

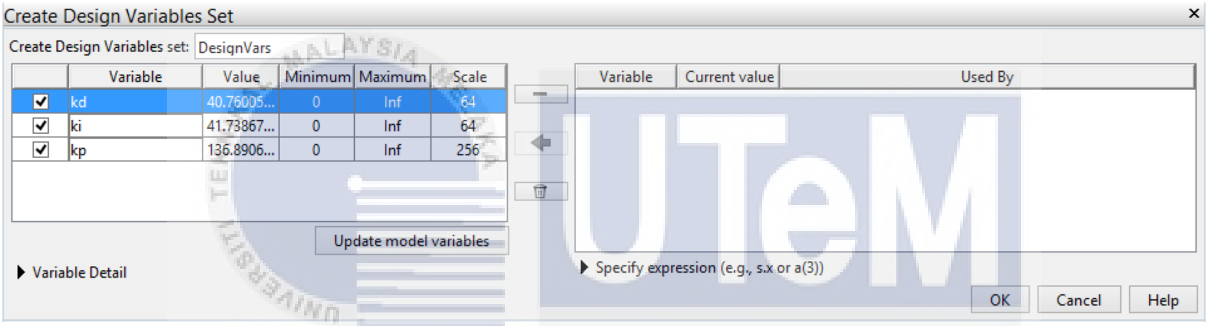


Figure 3.13 Step 5 for tuning

Step 6: The design requirement was edited

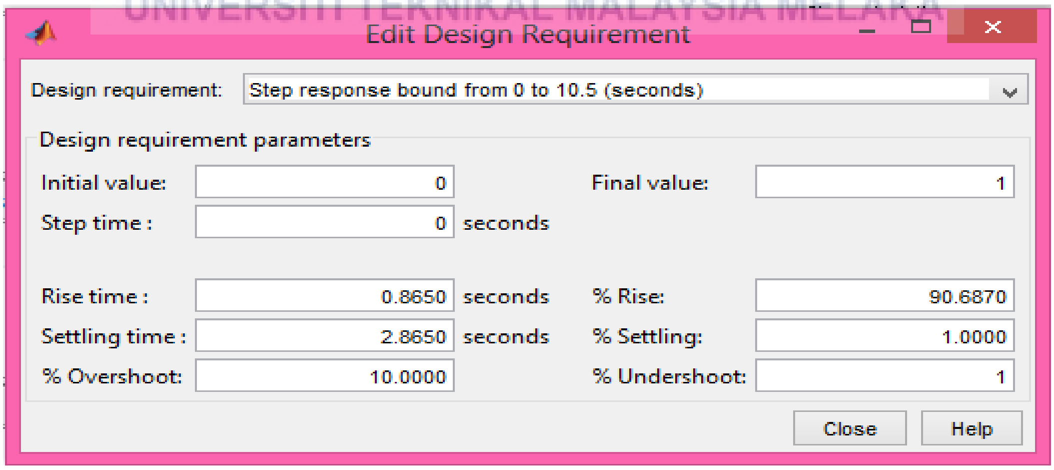


Figure 3.14 Step 6 for tuning

Step 7: Run the optimization iteration process

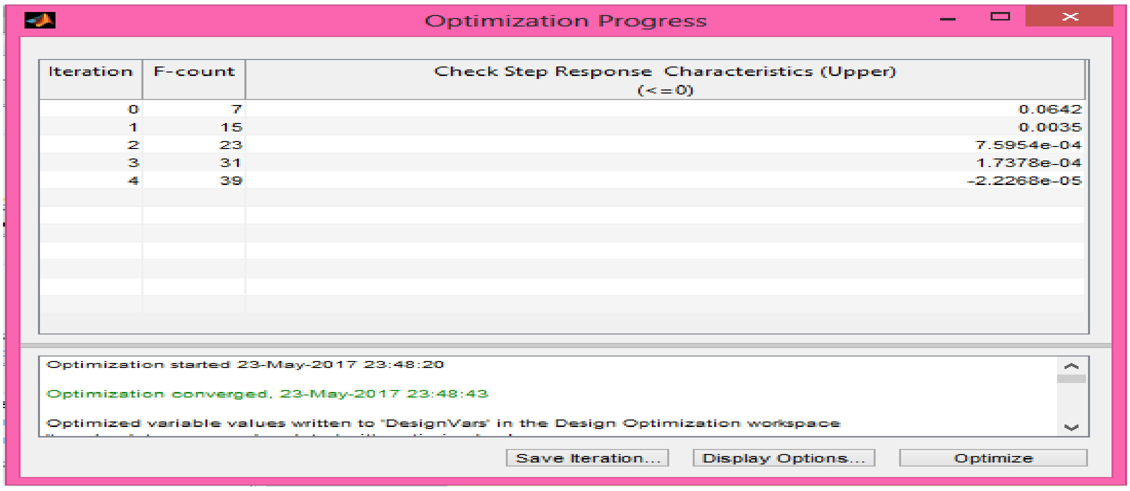


Figure 3.15 Step 7 for tuning

Step 8: Graph obtain after the optimization process

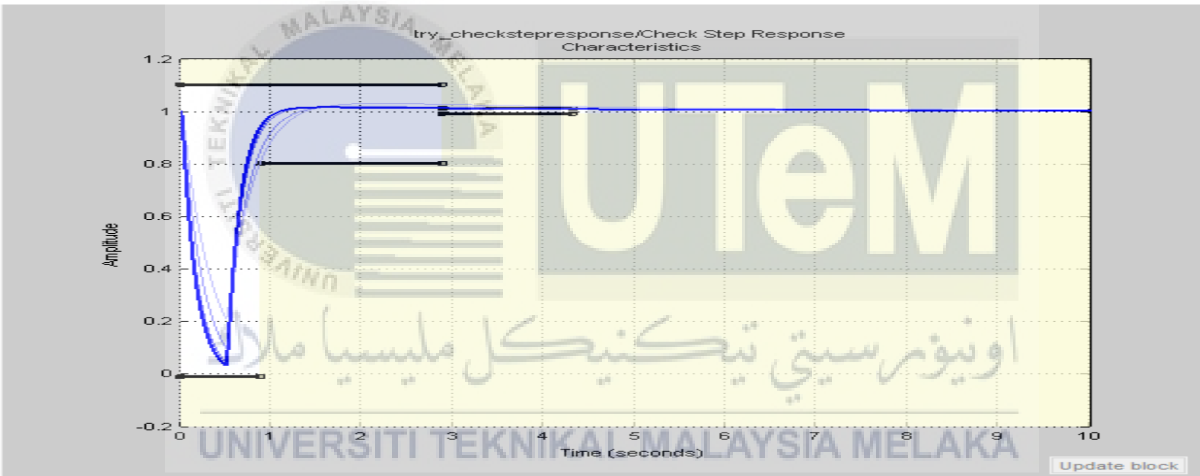


Figure 3.16 Step 8 for tuning

Step 9: The Kp, Ki and Kd obtain from the Gradient Descent tuning method

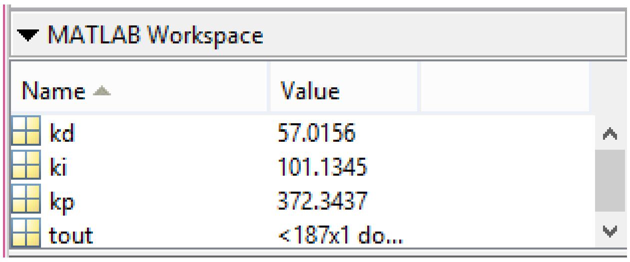
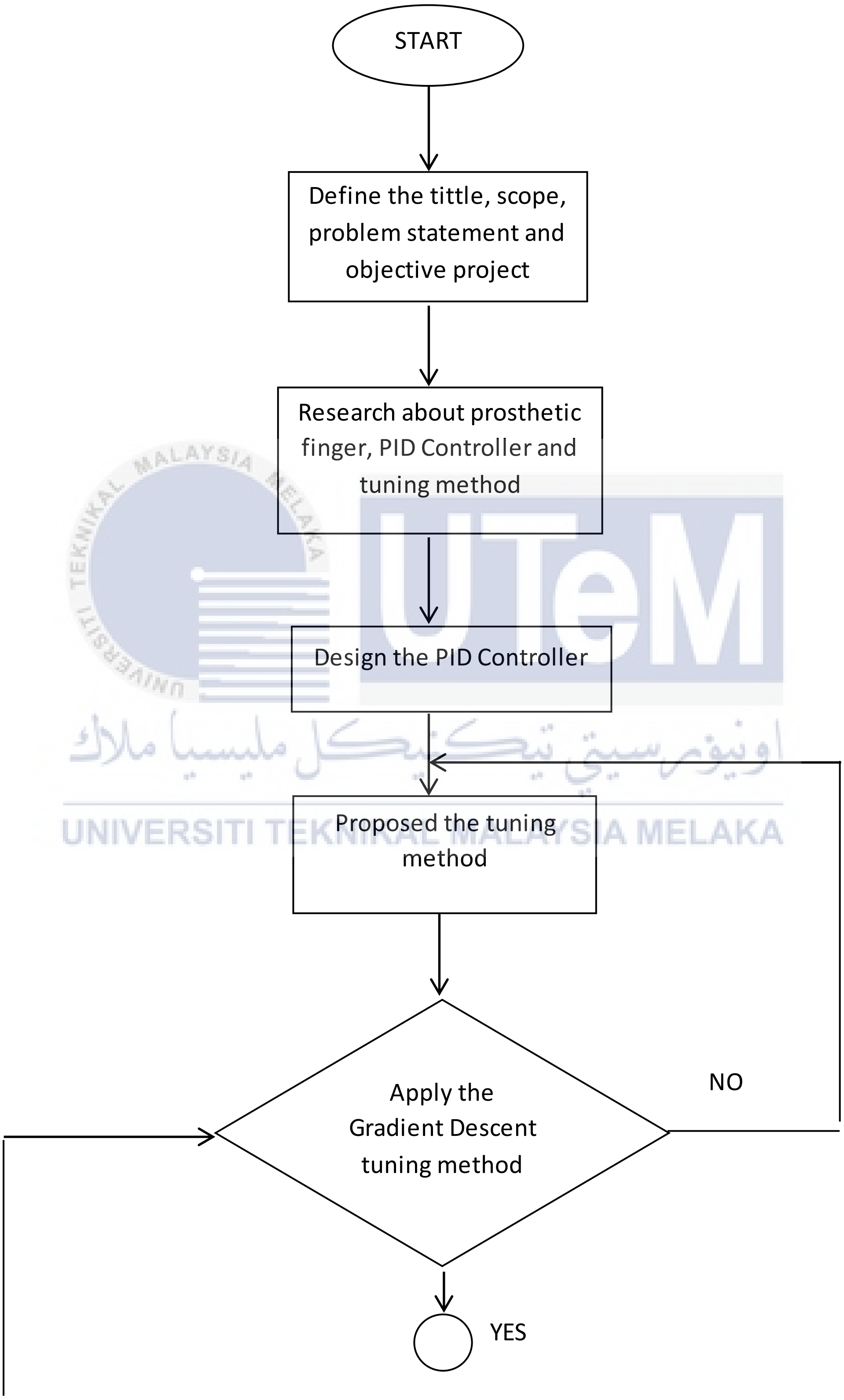


Figure 3.17 Step for tuning

3.5 Flowchart



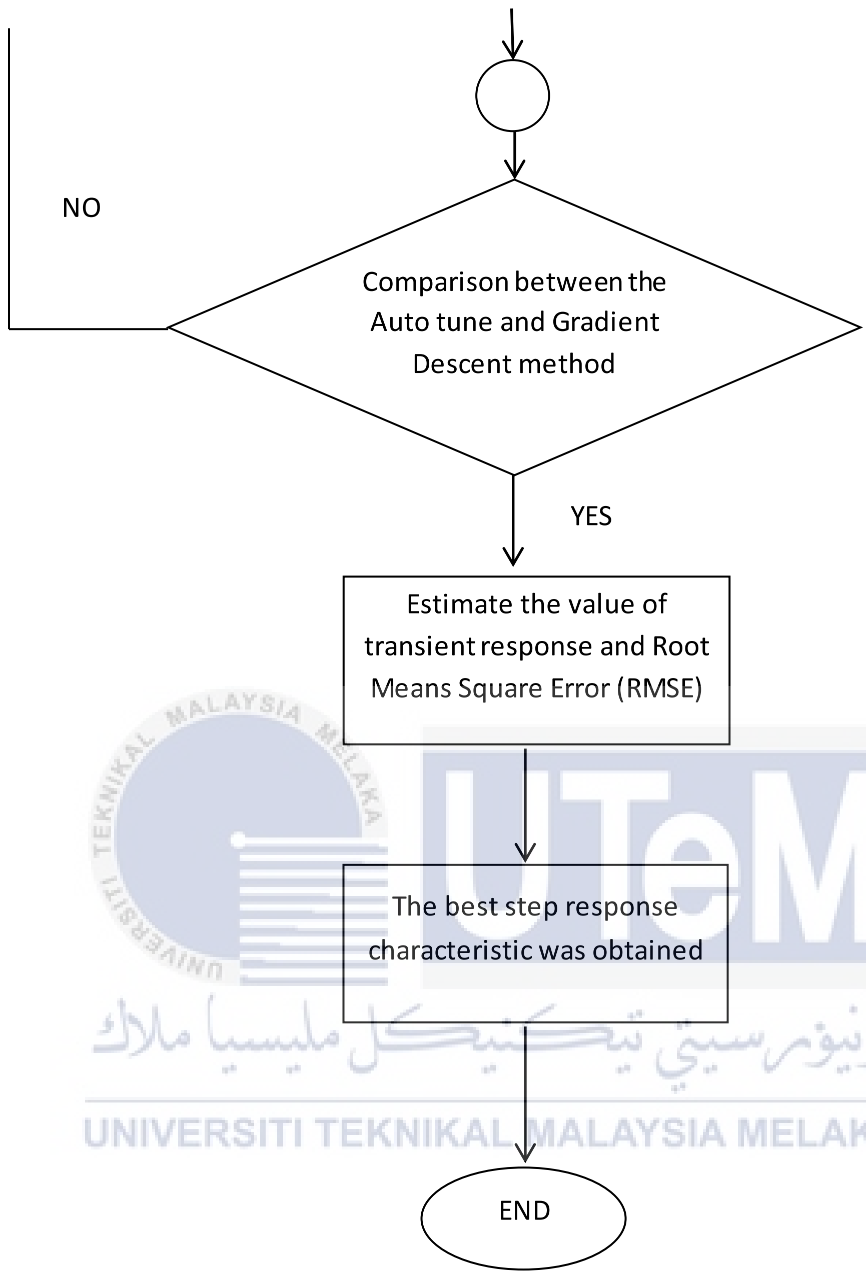


Figure 3.18 Flowchart for modelling and verification of prosthetic finger

3.5.1 Flowchart explanation

Figure 3.18 shows the complete flow chart of the project methodology. After done with the part of literature review, the project was started with the development of simulation for the system. In this project, MATLAB-Simulink has been used to verified and validate the performance of controller design.

After deciding the software, the controller for prosthetic finger system was design. In order to get a stable system, Proportional Integral and Derivative (PID) controller was proposed. PID is suitable to use for this system because it can improve the transient response performance. Furthermore, PID Controller was widely used in the industries.

The next step that involve in this project is deciding the tuning method for PID controller. Some research about the tuning method was made to ensure that it will give the best result for the system. Then, Gradient Descent method is decided as the tuning method for PID controller because it gives more accurate result.

From the Gradient Descent tuning method the best step response was finding by making the comparison between three step responses obtained from the optimization iteration process. The process will repeated until the graph with the best transient response performance was determined.

When the best step response from Gradient Descent method was obtained, the graph was then be compared with the graph from auto tune method. This process is to make the comparison on which graph show the most stable performance. There are two factors to be considered in order to decide which result is better. The first one is the transient response performance such as rise time, settling time, overshoot and steady state error. The other factor is the value of Root Means Square Error (RMSE).

Finally, the best tuning method for PID controller was decided. As a result, Gradient Descent method gives the smoothest graph compare to the Auto tune method.

CHAPTER 4

RESULT AND DISCUSSION

4.1Open Loop System for Prosthetic Finger

Before the PID controller was purposed to the system, the graph obtained is an open loop graph with no feedback which is in blue colour while the green one is the references. It shows the sine wave graph because the system keep on repeating. The graph was not stable compared to the graph after the designing of PID controller. It does not reach stability of the system. So, we cannot find it steady state error.

In addition, the rise time of the output response without the presence of PID controller was dramatically increase compare to the one that have PID controller. So, the presence of PID controller is important to produce a stability and good performance result of prosthetic finger system. Graph in figure 4.1 shows the open loop of the Prosthetic Finger system.

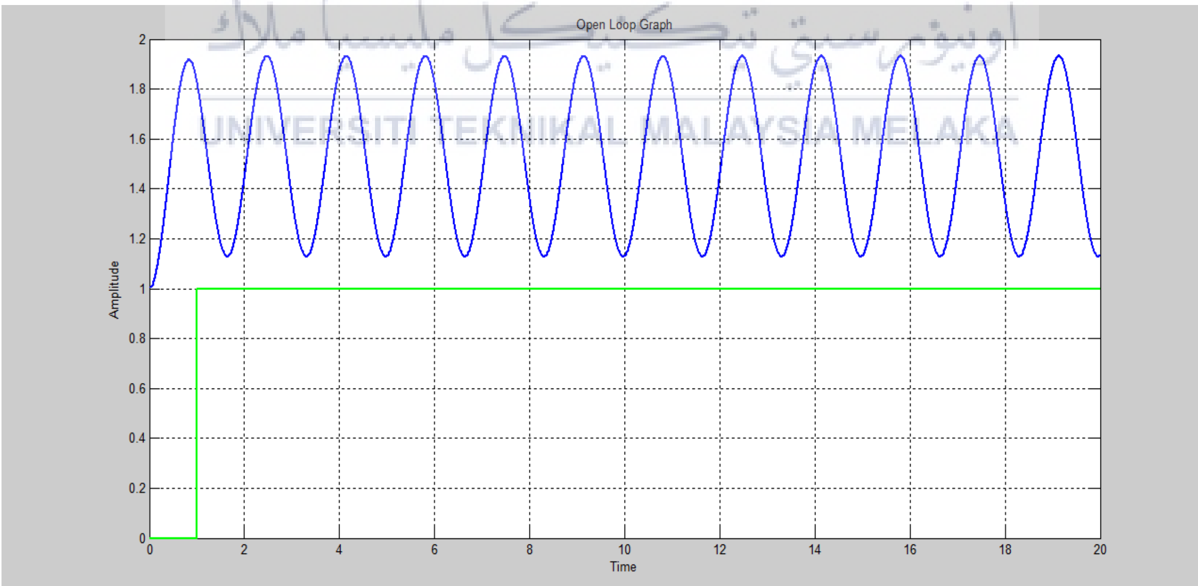


Figure 4.1 Open Loop Graph

4.2 Gradient Descent Method

The graph in Figure 4.2 shows the step response characteristic before tuning by using the gradient descent method. In this tuning method the iteration process will take place to obtain a minimum point closed to desired result. From the result obtain, the graph show a poor performance of transient response such as rise time, settling time, overshoot and steady state error. Thus, the tuning method of gradient descent will be applied to PID controller to obtain the better performance.

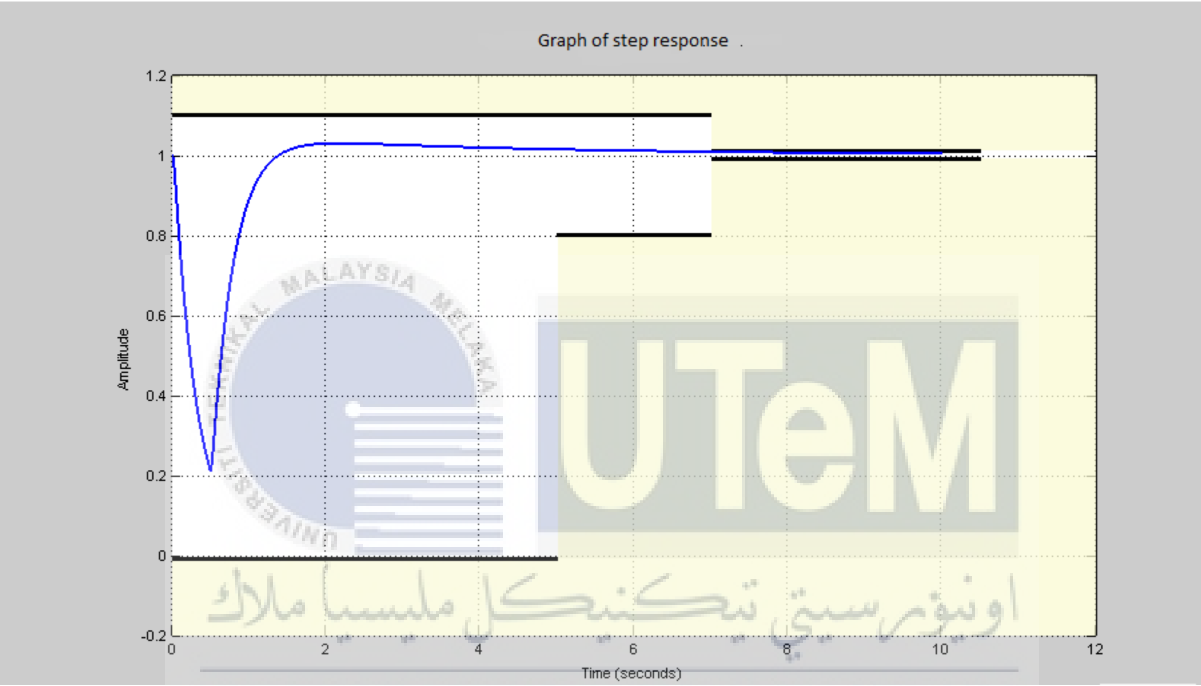


Figure 4.2 Step Response Graph

Before obtain the most stable step response, the gradient vector was adjusted and the value of it rise time, settling time and overshoot will appear as shown in table 4.1. The adjustment have been done about three time in order to get the smooth graph with better transient response. However, after the optimization iteration process the graph may not able to reach the value as adjusted. This is because there is a limit in iteration process. The Gradient Descent method is one type of algorithm that applied to the system to obtain the minimum point for some particular function. Thus, the iteration process will take place until it reach the minimum point.

Characteristic	First trial	Second trial	Third trial
Rise time	0.6650	0.7650	0.8650
% Rise	90.4870	90.5870	90.6870
Settling time	2.6650	2.6650	2.8650
% Settling	1.0000	1.0000	1.0000
Overshoot	10.0000	10.0000	10.0000
% Undershoot	1	1	1

Table 4.1 Value of Transient Response

Graph in figure 4.3, 4.5 and 4.7 show the step response obtain from the optimization iteration for first, second and third trial. Then, the figure 4.4, 4.6 and 4.8 are the value obtain after the optimization process was done which is iteration, F-count and check step response characteristic.

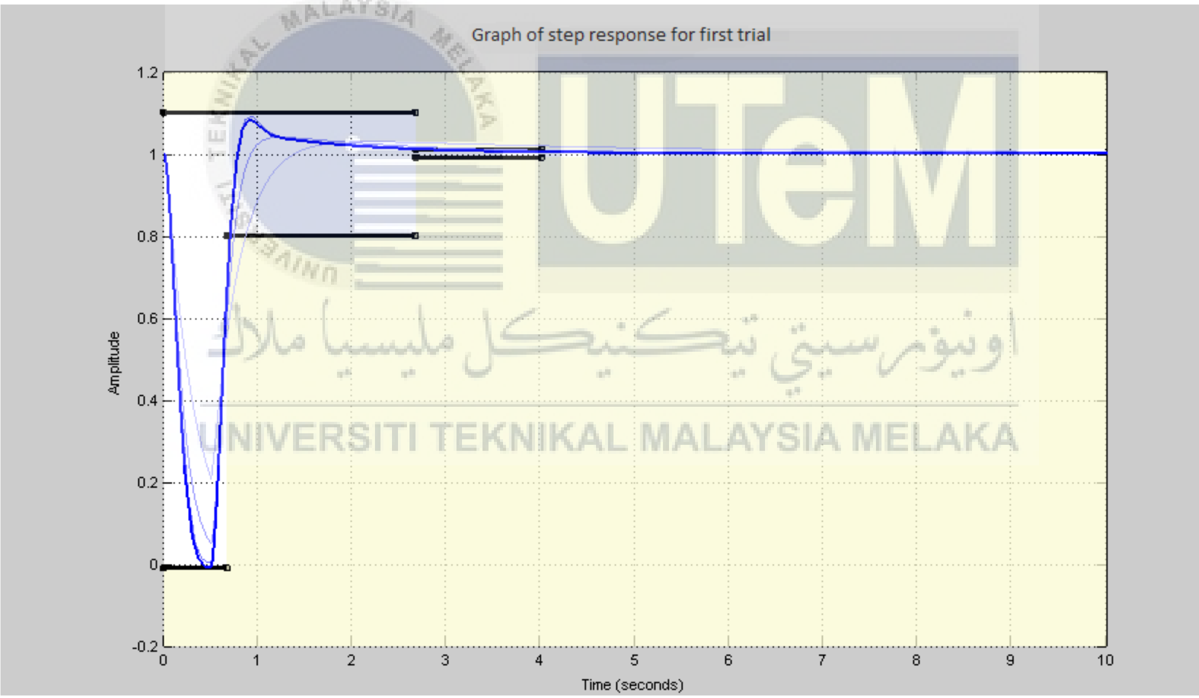


Figure 4.3 Graph of Step Response for First trial

Figure 4.3 shows the step response for firsttrial of iteration process. The graph obtained has higher overshoot which is 11%. The graph was not so stable to be used by the motorized prosthetic finger system.

Iteration	F-count	Check Step Response Characteristics (Upper) (<=0)
0	7	0.2809
1	17	0.1835
2	26	0.0020
3	34	3.1460e-05
4	42	-1.5633e-04

Figure 4.4 Table of First Trial for Optimization Process

From the first trial the iteration process is four time refered to the figure 4.4 show at above. The F-count was started at 7 followed by 17, 26, 34 and 42 and for each of the iteration process the value will reduce.

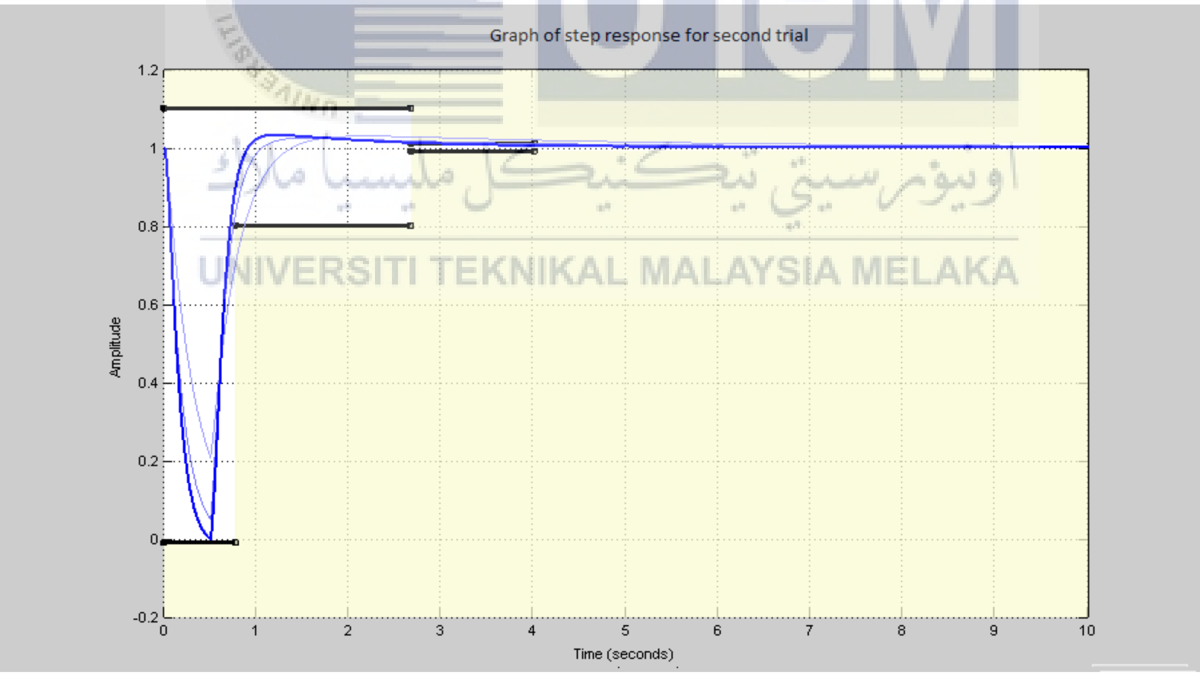


Figure 4.5 Graph of Step Response for Second Trial

Figure 4.5 shows the second trial graph obtained from the iteration process. However, the graph obtained still not satisfied the required. It still have an overshoot which is 3% and it was not stable.

Iteration	F-count	Check Step Response Characteristics (Upper) (<=0)
0	7	0.0967
1	15	0.0048
2	24	4.8520e-04
3	32	3.3340e-04

Figure 4.6 Table of Second Trial for Optimization Process

The iteration process that take place in second trial is three time. The F-count for this trial is 7, 15, 24 and 32 as shown is the figure 4.6 above.

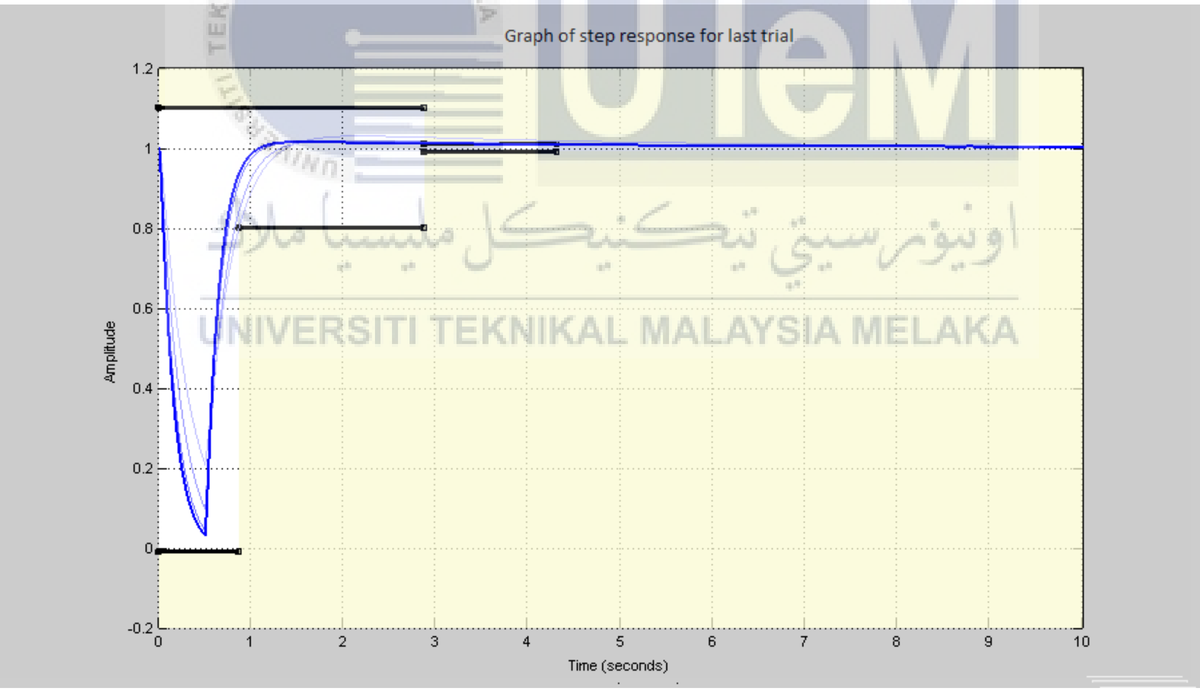


Figure 4.7 Graph of Step Response for Third Trial

The step response for the third trial is the most stable result. It has a lowest overshoot which is only 0.6% compare to the other trial that have the higher overshoot. The graph of step response for third trial was shown in figure 4.7.

Iteration	F-count	Check Step Response Characteristics (Upper) (<=0)
0	7	0.0642
1	15	0.0035
2	23	7.5954e-04
3	31	1.7378e-04
4	39	-2.2268e-05

Figure 4.8 Table of Third Trial for Optimization Process

Figure 4.8 shows the optimization process for third trial. It has four time of the iteration process with the F-count of 7, 15, 23, 31 and 39.

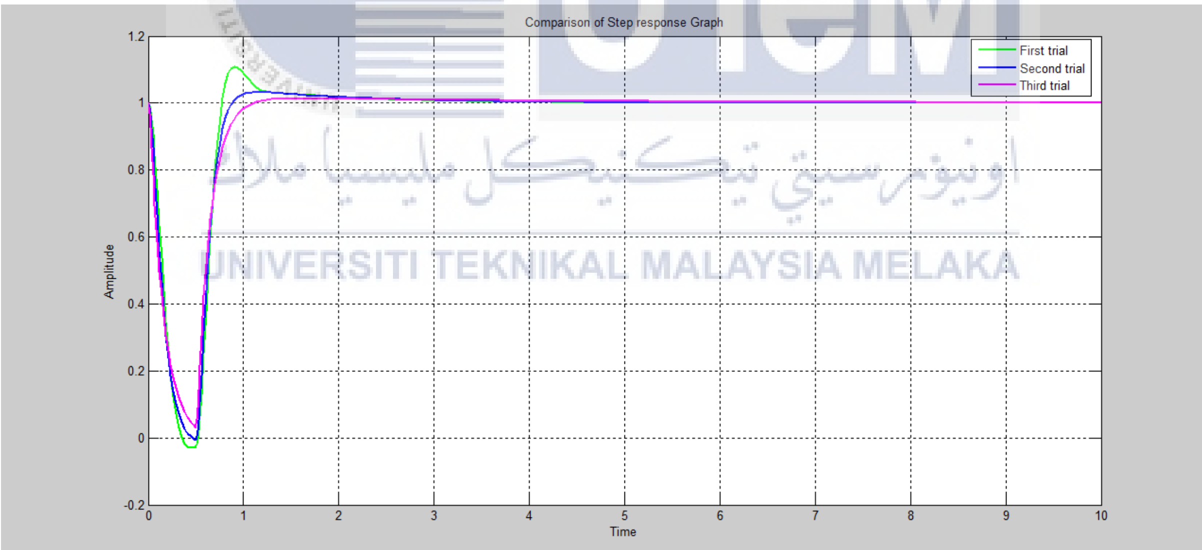


Figure 4.9 Comparison of Step Response Graph

After comparing the result from each trial, the third trial show the most stable result with lower overshoot, higher rise and settling time. The graph in figure 15 shown the comparison between first, second and third trial. From the comparison the third trial give the best result because it take shorter time to reach 1and it show more smooth graph compare to the others.

Based on this result, there is significance finding on the criteria of Gradient Descent which are variation of gradient, variation of parameter, function reach lower bounded and fixed maximum for the number of iteration. This criteria can be used as a reference to determine the best result of comparison. So, the graph for third trial is quite satisfied with the criteria listed.

Result	Rise time, Tr (s)	Settling time, Ts (s)	Overshoot, Os (%)	Steady state error, e_{ss}
First trial	0.18	0.76	11	0
Second trial	0.21	0.84	3	0
Third trial	0.27	0.99	0.6	0

Table 4.2 Transient Response Performance

Result	Root Mean Square Error (RMSE)
First trial	0.09951
Second trial	0.09193
Third trial	0.08486

Table 4.3 Root Mean Square Error

One of the method that can be used to prove the better result from the comparison is Root Mean Square Error (RMSE). Table 4.3 show the comparison of RMSE between three trials. First trial give the most highest error compare to the other two trial. Although the transient response performance in table 4.2 indicate that the rise time and settling time for first and second trial is better than the third trial, but the third trial still have a lower overshoot compare to those two result. In addition, the best criteria in choosing the most stable step response is the step response with the lowest value of RMSE. Thus, from the table the third trial has been chosen.

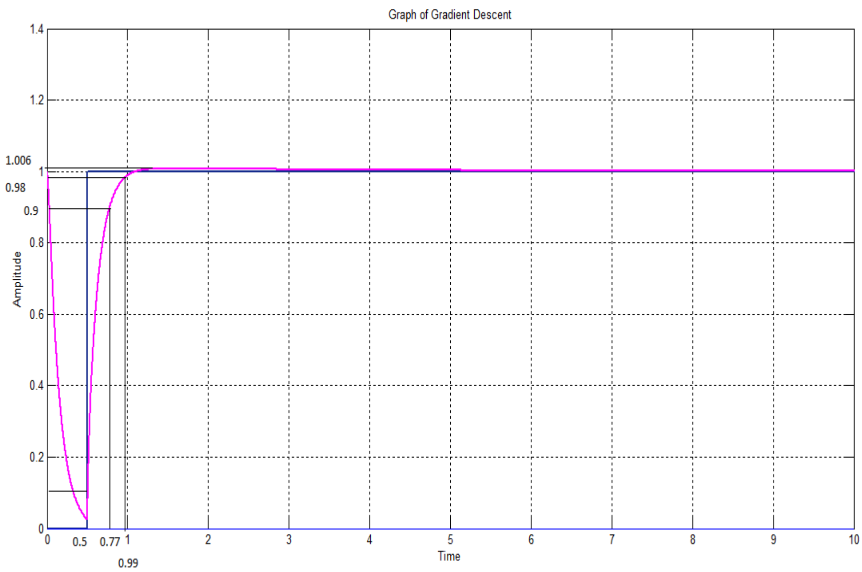


Figure 4.10 Graph of Gradient Descent

Desired value = 1

10% =0.1 (18)

90% = 0.9 (19)

$X_1 = 0.5$, $Y_1 = 0.1$ (20)

$X_2 = 0.77$, $Y_2 = 0.9$ (21)

Rise time

$X_2 - X_1 = 0.77 – 0.5$ (22)

$T_r = 0.27s$

(23)

$+2\% = 1.02$

(24)

$-2\% = 0.98$

(25)

Settling time

$T_S = 0.99s$

(26)

Overshoot

$$Os\% = \frac{maximum\ peak - reference\ signal}{reference\ signal} \times 100\%$$

(27)

$$= \frac{1.006 - 1}{1} \times 100\%$$

(28)

$$= 0.6\%$$

(29)

Steady state

e_{ss} = Final point – target point

(30)

= 1.0001-1

(31)

=0.0001

(32)

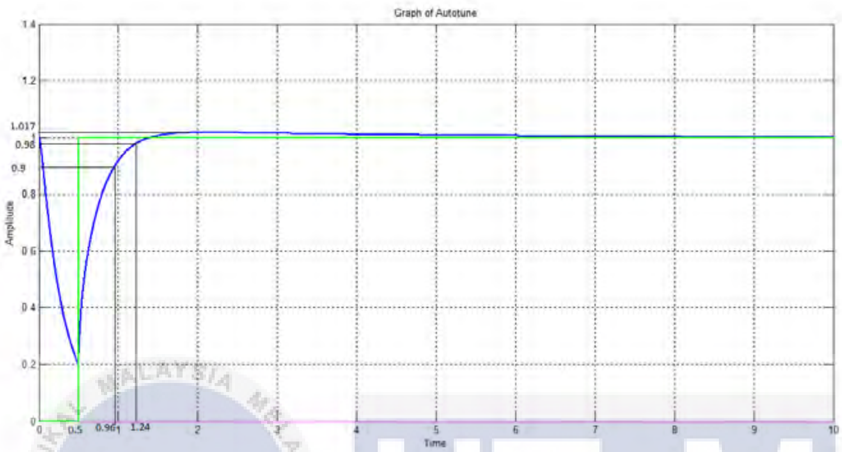


Figure 4.11 Graph of Autotune

Desired value = 1

10% =0.1

(33)

90% = 0.9

(34)

$X_1 = 0.5$, $Y_1 = 0.1$

(35)

$X_2 = 0.96$, $Y_2 = 0.9$

(36)

Rise time

$X_2 - X_1 = 0.96 - 0.5$

(37)

$T_S = 0.46s$

(38)

$+2\% = 1.02$

(39)

$-2\% = 0.98$

(40)

Settling time

$T_S = 1.24s$

(41)

Overshoot

$Os\% = \frac{maximum\ peak - reference\ signal}{reference\ signal} \times 100\%$

(42)

$= \frac{1.017 - 1}{1} \times 100\%$

(43)

$= 1.7\%$

(44)

Steady state

e_{ss} = Final point – target point

(45)

= 1.0001-1

(46)

=0.0001

(47)

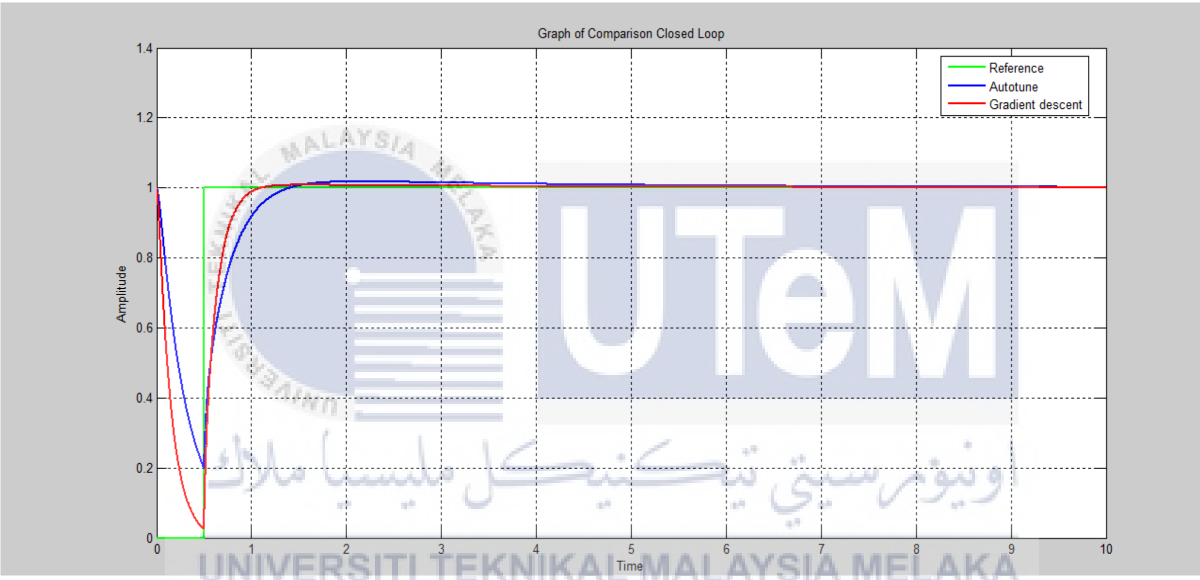


Figure 4.12 Comparison Step Response between Autotune and Gradient Descent

The graph in figure 4.12 is the comparison of step response by using Autotune and Gradient Descent method. From the graph obtain, the transient response performance can be find to decide which tuning method give the best result for the syatem. As for step response with PID controller tuned with Gradient Descent method, the value of overshoot, rise time, settling time and steady state error are lower compare to Autotune method. The value of transient response for both comparison was shown in table 4.5.

The other method that can be used to prove which graph is better is Root Mean Square Error (RMSE). Root Mean Square Error is the standard deviation of the residual. Residual is actually a measure of how far from the regression line the data point are. In addition, RMSE is about the concentrated of data around the line of best fit. Thus, the lower the RMSE, the better the result outcome.

Method	Root Mean Square Error (RMSE)
Auto tuning	0.105733
Gradient descent	0.0848619

Table 4.4 Root Mean Square Error for Tuning Method

PID Tuning method	Rise time,Tr (s)	Settling time, Ts (s)	Overshoot, Os (%)	Steady state error, ess
Autotune	0.46	1.24	1.7	0.0001
Gradient descent	0.27	0.95	0.5	0.0001

Table 4.5 Comparison of Transient Response

4.3 Output Response with Disturbance

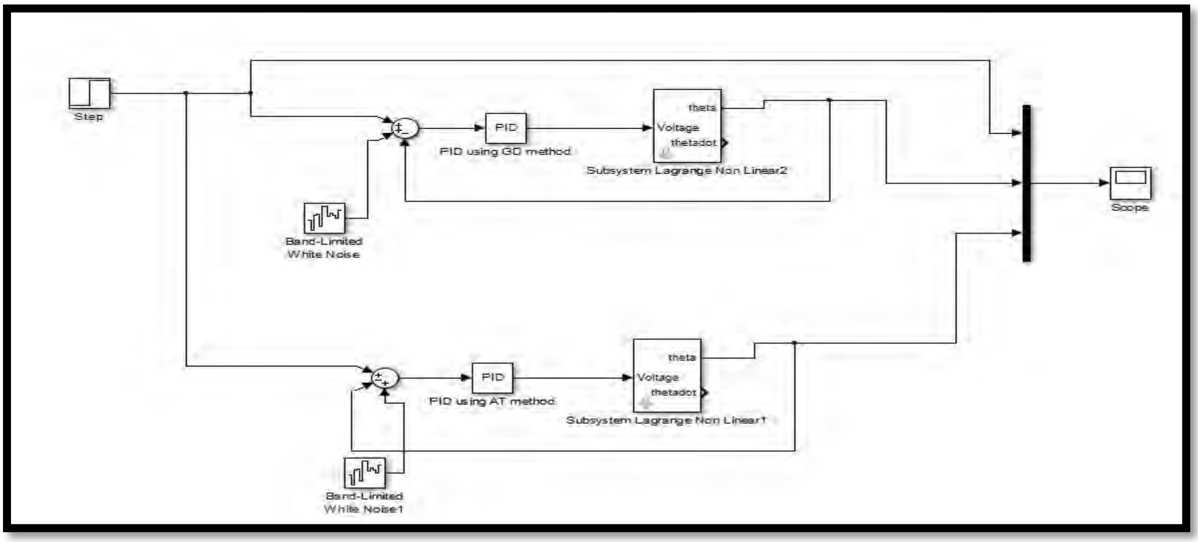


Figure 4.13 Block Diagram with Disturbance

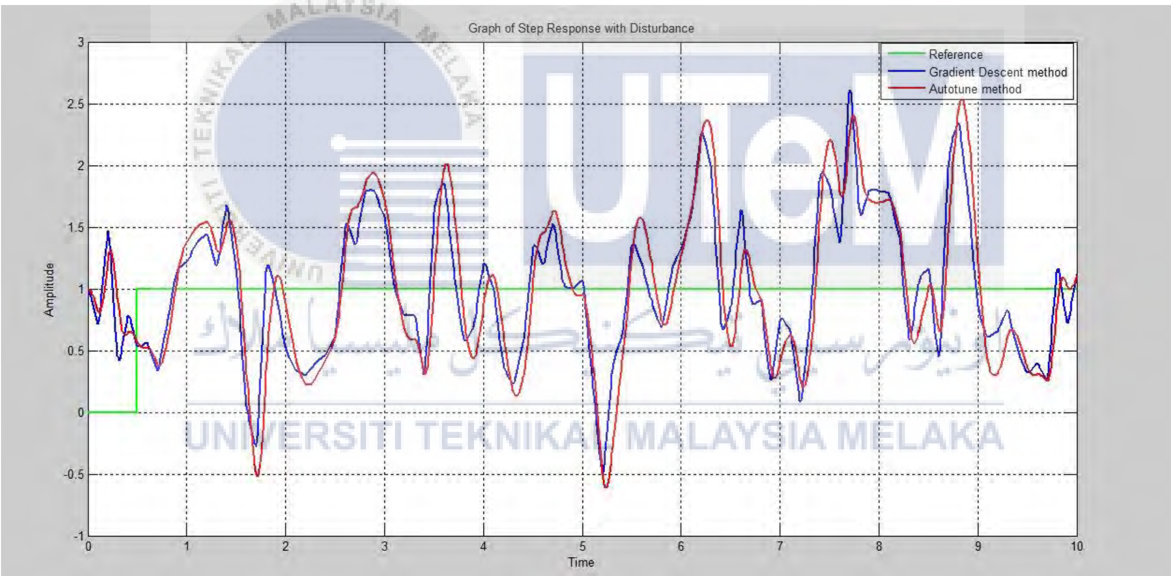


Figure 4.14 Graph of Step Response with Disturbance

When the disturbance has been enjected into the system, the graph with Gradient descent method is more roobust toward disturbance due to it tracking performance to the set point. Therefore, Gradient Descent method is more sensitive to any changes such as disturbance compare to the autotune method. In addition, Gradient Descent also has better filtering capabalities toward disturbance. It can be shown in Figure 4.14 which is the graph of disturbance with the presence of Gradient Descent is much more closer to the step reference.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

There are many tuning method that can be proposed to tuned the PID controller such as Zieglar Nichols, Autotune, Particle Swarm Optimization (PSO) and Gradient Descent method. Each of these method have different requirement for tuning the PID controller. For this project the tuning method that was used is Autotune compare with the Gradient Descent. Autotune method is the most simpliest method for tuning and the result gain was not so accurate compare to the other tuning method.

As a conclusion, the PID controller had been design to the system and gradient descent was proposed as it tuning method. It is because by using this method the result shows better transient response performance for the system. In addition, the Root Means Square Error (RMSE) also give a smaller value compare to the RMSE from Autotune method. Thus, the Gradient Descent is the most suitable method for tuning the PID controller compare to Autotune method.

5.2 Recommendation

There are some recommendation that can be done in this project for the future work. In this project, Proportional Integral and Derivative (PID) controller has been used but in the future Particle Swarm Optimization (PSO) can be proposed as a tuning method of PID controller for this system. Unfortunately, there is not much time to do a researh regarding this method. Other that that, Root Locus technique can also be used in order to determine the stability of the system. Thus, in the future there are a few additional controller and technique that can be applied to obtain more accurate and stable output result.

REFERENCES

[1] S. Alam, "PID Position Control of 7-DOF Three-Fingered Robotic Hand for Grasping Task," no. November, pp. 28–30, 2014.

[2] W. Widhiada, T. G. T. Nindhia, and N. Budiarsa, "Robust Control for the Motion Five Fingered Robot Gripper," vol. 4, no. 3, pp. 226–232, 2015.

[3] R. Agrawal, K. Kabiraj, R. Singh, and E. T. Al, "Modeling a Controller for an Articulated Robotic Arm," vol. 2012, no. August, pp. 207–210, 2012.

[4] A. D. Deshpande, J. Ko, D. Fox, and Y. Matsuoka, "Anatomically Correct Testbed Hand Control: Muscle and Joint Control Strategies."

[5] A. I. Technology, "LINEAR AND NONLINEAR DYNAMIC MODELING OF MOTORIZED PROSTHETIC HAND SYSTEM," vol. 93, no. 1, 2016.

[6] M. Ju, C. K. Lin, D. Lin, I. Hwang, and S. Chen, "A Rehabilitation Robot With Force-Position Hybrid Fuzzy Controller: Hybrid Fuzzy Control of Rehabilitation Robot," vol. 13, no. 3, pp. 349–358, 2005.

[7] H. Ahmad, S. Razali, and M. R. Mohamed, "Fuzzy Logic Controller Design for A Robot Grasping System with Different Membership Functions."

[8] M. Mirzadeh, M. Haghighi, S. Khezri, J. Mahmoodi, and H. Karbasi, "Design Adaptive Fuzzy Inference Controller for Robot Arm," no. August, pp. 66–73, 2014.

[9] F. Park, F. Park, P. Paul, C. Yoon, B. Siciliano, and L. Villani, "Forcflosition Regulation of Compliant Robot Manipulators," no. 2, 1994.

[10] E. E. Faculty, "DC MOTOR SPEED CLOSED LOOP," no. Kxgt 6301.

[11] "PID controller tuning optimization using gradient descent technique for an electro-hydraulic servo system Jurnal Teknologi," no. November 2016, 2015.

APPENDIX

Gantt chart

Project task	Final Year Project 1 2016				Final Year Project 2 2017					
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Discussion with supervisor related to FYP tittle										
Search journal regarding with prosthetic finger system										
Understand the theory and operation of previous work										
Introduction and Literature Review										
Methodology, Preliminary Result and Conclusion										
Completed proposal										
Simulation of project										
Analysis and Discussion										
Project presentation										
Submit final report										

The coding to plot the graph from scope to workspace

```
t=ScopeData (:,1);
r=ScopeData (:,2);
a=ScopeData (:,3);

plot (t,r,'g');
hold on
plot (t,a);
hold on

grid on
```

The coding for Root Mean Square Error (RMSE)

```
disp ('=================================================================');
disp ('              Root Mean Square Error(RMSE) Analysis              ');
disp ('=================================================================');

time = ScopeData3(:,1);
o1=ScopeData3(:,2);     % Reference signal
o2=ScopeData3(:,3);     % PID AUTO TUNE signal
o3=ScopeData3(:,4);     % PID GD signal

error_pid_AT = o1 - o2;    %Error occured between PID_GD with Reference signal
error_pid_GD = o1 - o3;    %Error occured between PID_AT with Reference signal

% plot(time,error_smc_pso,'r',time,error_smc,'b',time,error_ZN,'g',time,error_ZN_pso,'c')


rmse_pid_AT = rms(error_pid_AT);
fprintf ('rmse_pid_AT = %g\n',rmse_pid_AT);

rmse_pid_GD = rms(error_pid_GD);
fprintf ('rmse_pid_GD = %g\n',rmse_pid_GD);

time = igraph(:,1);
o1=igraph(:,2);     % First trial signal
o2=igraph(:,3);     % Second trial signal
o3=igraph(:,4);     % Third trial signal
```