**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**Faculty of Electrical Engineering**

# AN IMPLEMENTATION OF FUZZY CONTROLLER FOR MICRO-GRIPPER

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**Bachelor of Electrical Engineering with Honor**

**2018**

# APPROVAL

I hereby declare that I have read through this report entitled “AN IMPLEMENTATION OF FUZZY CONTROLLER FOR MICRO-GRIPPER (MEMS) ” and found that it has compiled the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering.

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**A report submitted in partial fulfilment of the requirement for the degree of Electrical Engineering**

**Faculty of Electrical Engineering**

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**2018**

# DECLARATION

I declare that this report entitles "AN IMPLEMENTATION OF FUZZY CONTROLLER FOR MICRO-GRIPPER (MEMS) ." is the result of my research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………...……………..

Name : Saeed Abdulhalim Abdulwahid Mohammed Aldhubhani

Date :…………………..……..

# DEDICATION

I dedicate this work to my beloved country, Yemen, the country that I was born and raised within its borders. I also dedicate this project to my beloved family; my dear father, En. Abdulhalim Abdulwahid, who has been supporting me; my beloved mother Tchr. Eman Saeed for encouraging and motivating me throughout the years of my life to reach this level; to my dear sisters. Also, I would like to dedicate my project to all my friends who helped and supported me.

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Lastly, I am very thankful to my family whom always gives me the courage and confidence throughout the whole research of my Final Year Project. I keep receiving all the support from them to do my best in achieving the success in my whole life.

# ABSTRACT

Micro-gripper is one of MEMS application that used to grip a micro object in medical field in case that it cannot be done by human hand. In this project, the design of micro-gripper actuator is explored which has several designs such as electro-thermal, shape memory alloy, piezo-electric, pneumatic, electrostatic, and electromagnetic actuations. Based on the comparation, electrostatic micro-gripper was chosen in this project to be studied since it is widely applied for microactuation and provides a largely displacement without hysteresis with a simple structure. However, electrostatic micro-gripper suffers from vibration and shaking during the pick and placed movement. Therefore, it is very crucial to implement a controller for the system to achieve the best response that provides a smooth closing and opening movement of the gripper fingers. Fuzzy Logic Controllers is an intelligent technique that proves to be the one of the most reliable controller that suits well for system due to the simple control based on user input without any prior knowledge to the mathematical model. To be more specific, three types of fuzzy logic rules are being selected which is 9,25,49 rules and applied in two different designs for the linguistic variables that has different universe of discourse range. The implementation of this project is conducted by using simulation of micro-gripper through MATLAB Simulink. The performance was analyzed and studied in terms of transient response based in overshoot (OS%), settling time (Ts), rise time (Tr), and steady state error (ess). The result shows the improvement in the transient response. The rules have been designed and compared with the original mems micro gripper system. From the comparative study second design of 3x3 rules shows the better performance result can be gained from fuzzy logic controller. It has modified the transient problem and directly eliminate the vibration and shaking in the mems micro gripper system. So, it will benefit the medical field and its application.

# ABSTRAK

Gripper mikro adalah salah satu aplikasi MEMS yang digunakan untuk menggenggam objek mikro dalam bidang perubatan sekiranya ia tidak dapat dilakukan oleh tangan manusia. Dalam projek ini, reka bentuk penggerak mikro gripper dieksplorasi yang mempunyai beberapa reka bentuk seperti elektro-haba, aloi memori bentuk, piezo-elektrik, pneumatik, elektrostatik, dan elektromagnetik. Berdasarkan perbandingan, elektrostatik mikro-gripper dipilih dalam projek ini untuk dikaji kerana ia digunakan secara meluas untuk microactuation dan menyediakan sebahagian besar ansalan tanpa histeresis dengan struktur mudah. Walau bagaimanapun, elektrostatik mikro gripper mengalami getaran dan gegaran ketika memilih dan bergerak. Oleh itu, sangat penting untuk melaksanakan pengawal bagi sistem untuk mencapai tindak balas terbaik yang menyediakan pergerakan penutupan dan pembukaan jari-jari gripper yang lancar. Pengawal Logik Fuzzy adalah teknik cerdas yang terbukti menjadi salah satu pengawal yang paling boleh dipercayai yang sesuai dengan sistem kerana kawalan mudah berdasarkan input pengguna tanpa pengetahuan sebelumnya terhadap model matematik. Untuk menjadi lebih spesifik, tiga jenis peraturan logik fuzzy dipilih iaitu 9,25,49 peraturan dan diterapkan dalam dua reka bentuk yang berbeza untuk pembolehubah linguistik yang mempunyai julat cakerawala yang berbeza. Pelaksanaan projek ini dijalankan dengan menggunakan simulasi mikro gripper melalui MATLAB Simulink. Prestasi dianalisis dan dikaji dari segi tindak balas sementara berdasarkan overshoot (OS%), masa penyelesaian (Ts), kenaikan waktu (Tr), dan ralat keadaan mantap (ess). Hasilnya menunjukkan peningkatan dalam tindak balas sementara. Peraturan-peraturan telah direka dan dibandingkan dengan sistem gripper mikro mems asal. Dari reka bentuk perbandingan perbandingan 3x3, menunjukkan prestasi prestasi yang lebih baik dapat diperolehi daripada pengawal logika fuzzy. Ia telah mengubah suai masalah sementara dan secara langsung menghapuskan getaran dan gegaran di dalam sistem gripper mikro mems. Jadi, ia akan memberi manfaat kepada bidang perubatan dan aplikasinya.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Motivation

MEMS has been implemented in medical fields for ages. It is call Biomems, stand for biological microelectromechanical systems. The capabilities for Biomems is promising and it has been widely applied in diverse science and engineering domains. Which the number of its applications keeps increasing noticeably. MEMS micro-gripper is one of the application in medical field that plays an important role in the human body since it is used to develop and organize an artificial organ and organ tissue to help to alleviate some of the problems surrounding organ failure. This is called tissue engineering. Nowadays it is a very important process for any region to guarantee the safety of people. Several types of MEMS micro-gripper are currently being tested by researchers. Researchers are working on perfecting its components and its controls to achieve high proficiency, more accuracy and stability. On the other hand the micro-gripper also offers low-coast and compact size.

## 1.2 Problem statement

Microelectromechanical system is a system that can be used for several medical purposes. One of its application is micro-gripper where it is a type of device that developed based on microelectromechanical system in order to ease the surgery that involved in micro medical operation that deals with organ tissues [1]. Different types of controllers involve to control the displacement of pick and place applications. However, some micro-grippers suffer from lack of robust control for vibration and shaking during the pick and placed movement required an accurate controller that provide a smooth closing and opening movement of the gripper fingers [2]. Hence, the fuzzy controller is one of the controller that can be implemented to control the gripper's fingers movement with avoiding vibration and shaking of gripper itself.

## 1.3 Objective

Upon completion of this project, the following proposed goals should be achieved:

1. To investigate the modelling equation of the micro-gripper system and the types of controllers that involved in controlling the micro-gripper.
2. To implement the fuzzy logic controller into the micro-gripper.
3. To evaluate the performance base on of fuzzy logic controller in term of time response, maximum overshoot and steady state error.

## 1.4 Scope and limitation of the project

The project will be applied for Bio-MEMS (micro-gripper). It will be implemented based on the simulation rather than hardware. In this project the fuzzy logic controller is the controller that will be used in this project to control the gripper movement. The target is to analyze and validate the stability and accuracy of the parameters. The MATLAB-Simulink is the simulation that will be conducted in this project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this chapter, the deep knowledge of this project will be briefly explained. This section provides a review of the pervious pertinent works. The published information related to this research will be discussed to gain some of the useful knowledge as well as theoretical and methodological contributions to make this research successful.

## 2.2 Microelectromechanical System (MEMS)

Micro-Electro-Mechanical System is an invisible device to human eye that integrates of micro fabricated mechanical and electrical structures components. So, it is considered as a complete system due to the electrical elements process data while the mechanical elements implement that data. In another word, the electrical elements act as the brain of the system while the mechanical system act as the arms and eyes. MEMS also known as Micro System Technology (MST) in Europe .In Asia it is known as Micromachines while the MEMS is the technology in the United States [3]. MEMS is a tiny device that has a range in size of less than 1mm to 1 micron that has been fabricated along with integrated circuit (IC) in one chip by using batch fabrication [4] . During the past decades, MEMS had developed in a different number of manufacturing techniques such as wafer bonding, high aspect ratio micromachining technology and bulk micromachining. Currently, surface silicon micromachining beings the most popular manufacturing techniques for MEMS. This is due to the silicon has a unique characteristics (high elastic , repeatable motion , reliability and low cost) [1]. MEMS can be classified into two categories microsensors and microactuators that can be used in different application to convert from one energy to another which lead to be used in some different applications.

The advantages of MEMS are the suitable size due to the small size, mass, and volume, better performance. Economically advantages of MEMS are large reduction in power consumption, low cost, small thermal constant with high thermal expansion tolerance, and possibilities for batch fabrication in massive quantities [5].

Microelectromechanical System has been widely applied in various fields .Which lead its applications to be increasing noticeably in different domains such as automotive , military and industrial domains as well as it has been applied in irrelevant fields such as microelectronics and biology [1].

## 2.3 BioMEMS

Biomedical microelectromechanical systems (BioMEMS) is a MEMS implementation on the biology and medical field. Micro-Electro-Mechanical System (MEMS) is currently noticed as an area of high potential impact. MEMS application is very broad. In medical industry, Biomems is expanding rapidly with explicated income of $850 million in 2003 to over $1 billion in 2006 in rate of 11.4% [6]. Currently Biomems market is approximately $2.1 Billion.

In future BioMEMS potential are endless such as in tissue engineering field which has a widely used to develop and organize an artificial organ and tissue. Charles stark Draper laboratory said that Biomems help to alleviate some of the problems surrounding organ failure.

### 2.3.1 Fabrication

In order to study the BioMEMS in literature review. It is important to have knowledge about the Micro-fabrication processes as the main materials of the Biomems. Basically, over the last decades, the MEMS devices were imported from (IC) integrated circuit fabricating to MEMS devices that have undergone another transition for Biomems. This is due to the raising awareness of microfluidic physics and the surface science of silicon, glass, polymers, and ceramics.

Nowadays, the fabrication becomes more complicated. Polymers materials are expected to have a prestigious future for manufacturing of microfluidic systems. In industrial companies they are interesting in using plastics in MEMS fabrication because this materials are cheap and easier to work with it [6]. In some Biomems processing , they search about different polymers such as spin castable polymer , EPON SU-8, Polypyrrole (PPy) and Polydimethylsiloxane (PDMS) [6].

### 2.3.2 Areas of Applications

BioMEMS have been applied in various areas, following is some areas that already being utilized in market as well as in researches studies:

i. Detection
ii. Analysis
iii. Diagnosis
iv. Therapeutics
v. Drug delivery
vi. Cell culture Detection

Figure 2.1 shows the illustration of Biomems areas of applications.

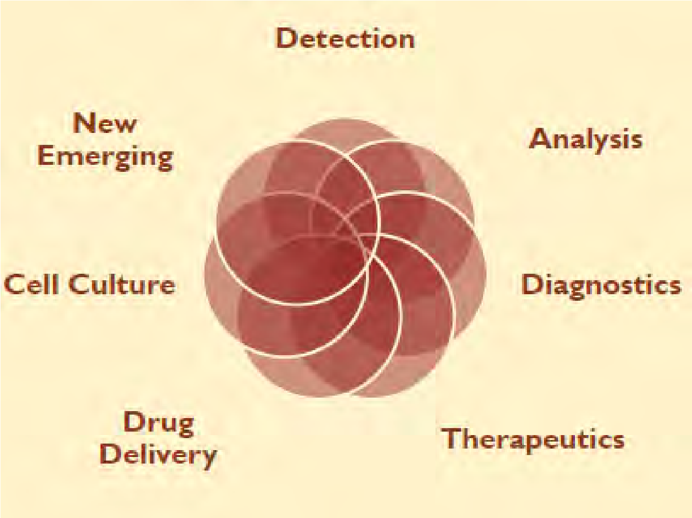


Figure 2.1: Areas of Biomems Applications

### 2.3.3 BioMEMS Applications in Term of Surgery

The treatment of illness in human body by instrumental or manual called surgery. Over the past years exactly in 1867 (first-generation technique) the surgery involved the sewing and cutting of tissue by using the basic tools and medical equipment. Huge number of incision was made in the patient by the surgeon to make save the patient which is known by "open surgery". In this technique, the surgeon was able to see the real view of the surgical site. Plus, he was enabled freely to manipulate the tissue or organ directly by his hand or using fundamental tools. This technique has been applied to a wide range of surgery during the near past years. Consequently, this method has many side effects since this technique costs a long time hospitalize and the patient is suffering [7].

September 1985, was the beginning of the second generation technique lead by Muhe as first laparoscopic gall bladder removal [8].This technique of surgical it is called "minimally invasive surgery" (MIS) and it was known as telescopic, micro, and minimal access surgery. MIS is considered as an advanced technique since the operations needs a small incision as holes or port and trocars (tube with valve using in medical operation to save the body from oxidation). This method required an endoscope to give the surgeon a view of its internal parts[9]. It takes short hospitalize stay and speedy recovery. It is 35% safer and more effective compared to the first-generation technique which is open surgery.

Figure 2.2: Intuitive Surgical da Vinci Robotic System

Figure 2.3: Minimally Invasive Surgery Stereo Display

## 2.4 Micro –Gripper

Micro-griper is a micro device that uses to handle small objects such as tissue or cells under a microscope in order to act in cases that surgeon cannot achieve it by human hand.

In 1980s, micro-gripper had been introduced by the researcher community [10]. Since that time, the micro-griper comes with several designs. The main microactuators and microsensors type that used in microgripper such as electro-thermal, Shape Memory Alloy , piezo-electric [1], pneumatic, and electromagnetic actuations [11].

Through the aforementioned different types of actuators the electrostatic actuators is widely applied for microactuation [12]. Since it provide a largely displacement without hysteresis with a simple structure [11]. Movement configuration specifically has two types:

i. Transverse comb drive: which can achieve a large movement [11].
ii. .Lateral Comb drive: which generates a stability and high accuracy [1].

### 2.4.1 Electrostatic Actuator

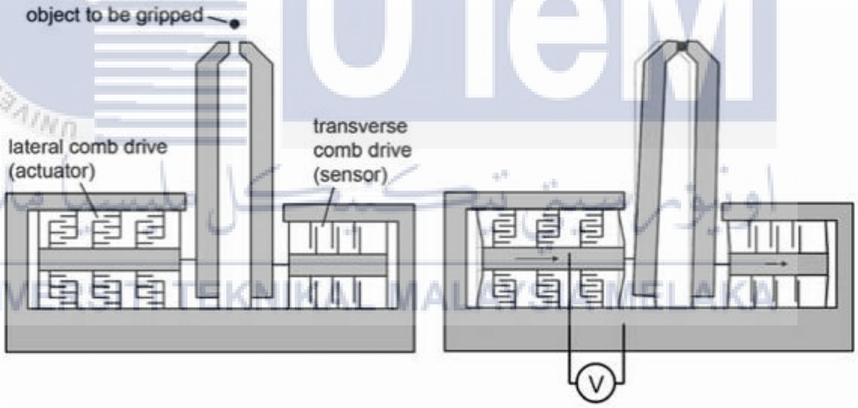


Figure 2.4: Electrostatic Micro-Gripper with Integrated Force Sensor

Electrostatic actuator can be considered as electrically isolated. Since it provides a large displacement, no hysteresis with negligible current in the gripper’s arm. Figure 2.4 shown the solid model of the electrostatic micro-gripper. The main components of electrostatics actuator are the combo drives. The electrostatic actuator micro-gripper has two electrodes fingers which one is movable and the other one is fixed to be connected with parallel-plate capacitor. In order to move the comb, the actuator should be forced by apply voltage to the fixed and movable plates as shown in Figure 2.5 [11].

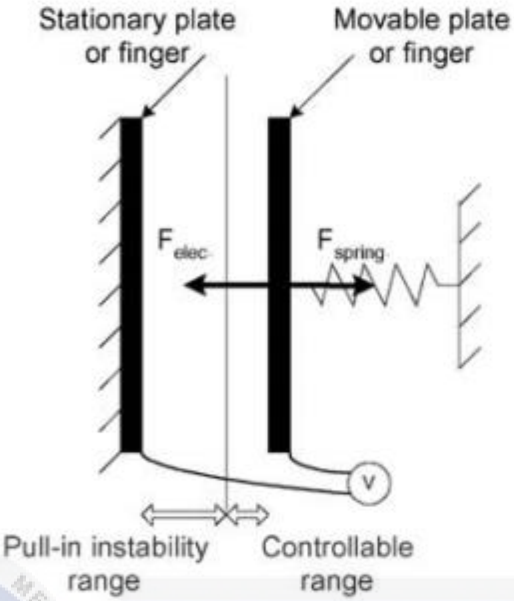


Figure 2.5: The Parallel-Plate Arms

### 2.4.2 Modeling of Electrostatic Micro-gripper

As shown in Figure 2.6 one lower electrode is fixed and the upper electrode is movable. The movement of the electrode is tied by spring. The forced of electrostatic electrode is zero when the applied voltage is zero. It is known as the initial status. G is the air gap between the two electrodes. As the voltage applied and increasing the applied voltage from zero, the electrode moves toward the electrode until the gape be zero and the spring force equals the electrostatic force.

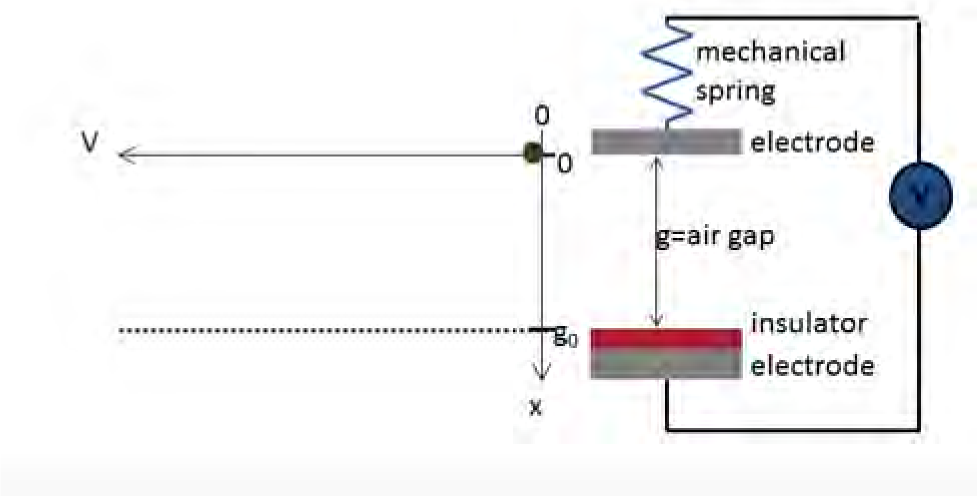


Figure 2.6: Model of Parallel Plate Actuator

The transfer function of the system is stated below based on previous studies [20]:

$$G(s) = \frac{0.17213}{0.1s^3+0.99s^2+0.48s+0.85}$$

## 2.5 Artificial Intelligence

Artificial intelligent is a science that has been introduced to simulate human intelligence, recognize the decisions and act as human reasoning process [13]. It is an important field that has widely used in various areas and systems in order to develop and improve the behavior of systems. There are many artificial intelligence techniques to be applied in the real-word to solve problems and get more desired result [14] such as:

i. Neural Networks.
ii. Fuzzy Logic.
iii. Chaos Theory.
iv. DNA Computing.
v. Quantum Computing.
vi. Expert System.

## 2.6 Fuzzy Logic Controller

In 1960s, Dr. Lotdi Zedah was introduced the Fuzzy Logic. In English Fuzzy means blurred [15]. Fuzzy logic controller (FLC) considers as one of the intelligent techniques that have been applied and studied in various engineering, researchers and studies. It becomes the most successful controller to be applied in applications systems as a controller [16]. The Fuzzy logic is acting as human being's felling and thinking. Fuzzy logic controller can be received one or more number of parameters or conditions that can be measure in the system to be analyzed or controlled Figure 2.7 shows the block diagram of the fuzzy controller.

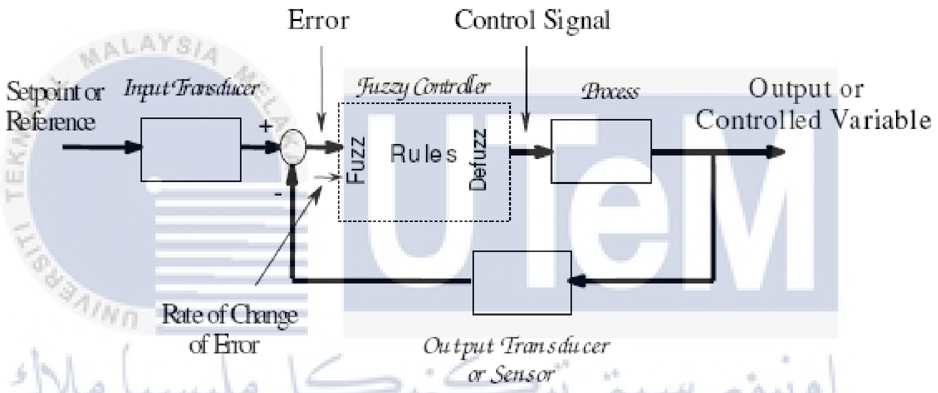


Figure 2.7: Fuzzy Logic Control System

### 2.6.1 Classical vs Fuzzy Sets

The possible range of values for the inputs of (FLC) is called universe of discourse. Figure 8 Illustrates the X universe of discourse with classical set as A

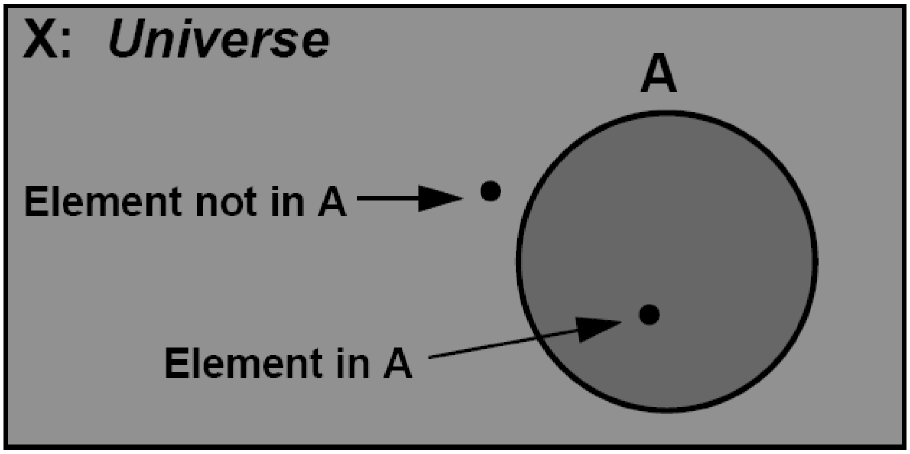


Figure 2.8: Universe of Discourse for Classical Set

Classical set is known as crisp boundaries which have not uncertainty set and sharp boundaries. It can be defined as a collection of object that have the same characteristics belong the universe of discourse. The classical set can be described as the language that implemented in machines and computer which they understand either '0' or '1', and 'HIGH' or 'LOW' which 1 indicates membership and 0 nonmembership [17].

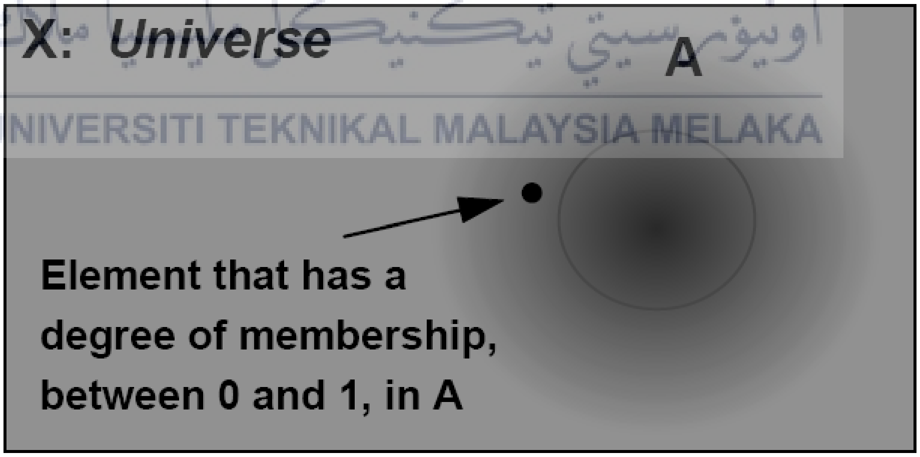


Figure 2.9: Universe of Discourse for Fuzzy Set

Fuzzy set is the characteristics function that have different degrees of membership for the element of the set-in range between 0 to 1. It is a powerful way which is provides a method of human being’s thinking and making decision. Figure 2.9 shows that fuzzy logic has no sharp boundaries as shown [18].

To implement the fuzzy logic three consecutive steps should be applied as shown in Figure 2.10 which is:

- Fuzzification
- Fuzzy Inference (rule matrix)
- Defuzzification

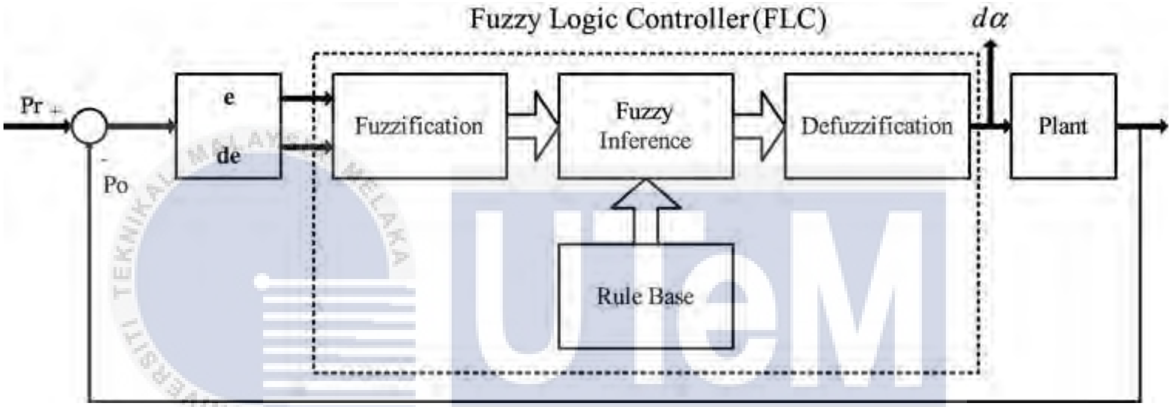


Figure 2.10: Fuzzy Logic Controller

### 2.6.2 Fuzzification and Membership

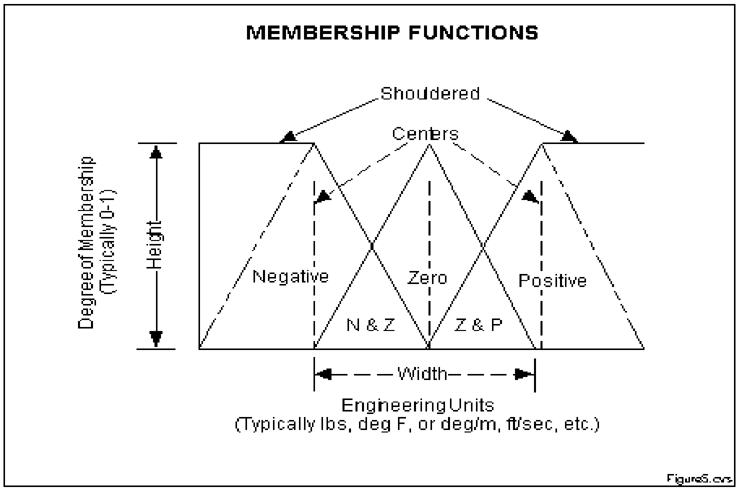


Figure 2.11: Membership function graph

Fuzzification is the first phase to be applied in fuzzy logic system. It is the phase that change the input from real value (classical variables) into fuzzy sets. This method can be done with various types of fuzzier (membership functions). Membership function is a technique to represent the degree of the truth in fuzzy logic. The representation of the membership is done by graphical forms as illustrate in Figure 2.11. It has been noticed that the membership function has different shapes, such as trapezoidal waveform, bell-shaped waveform, S-curve waveform, triangular waveform and sigmoidal waveform. In the membership graph the horizontal axis is representing the degree of the membership it has the value between 0 and 1. Zero means the variable has 0 membership of the selected fuzzy set while one means the variable has fully membership in the selected fuzzy set.

Below is some of the common types of membership functions figure as shown in Figure 2.12 , 2.13, 2.14 and 2.15:

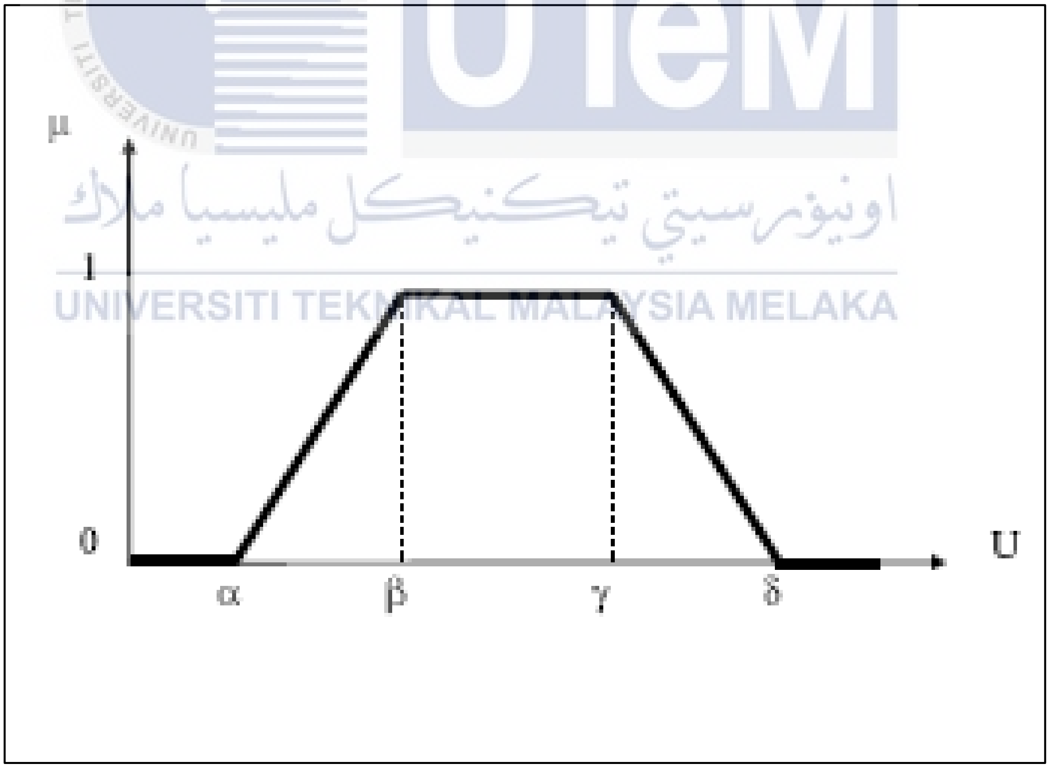


Figure 2.12: The Trapezoidal Membership Function

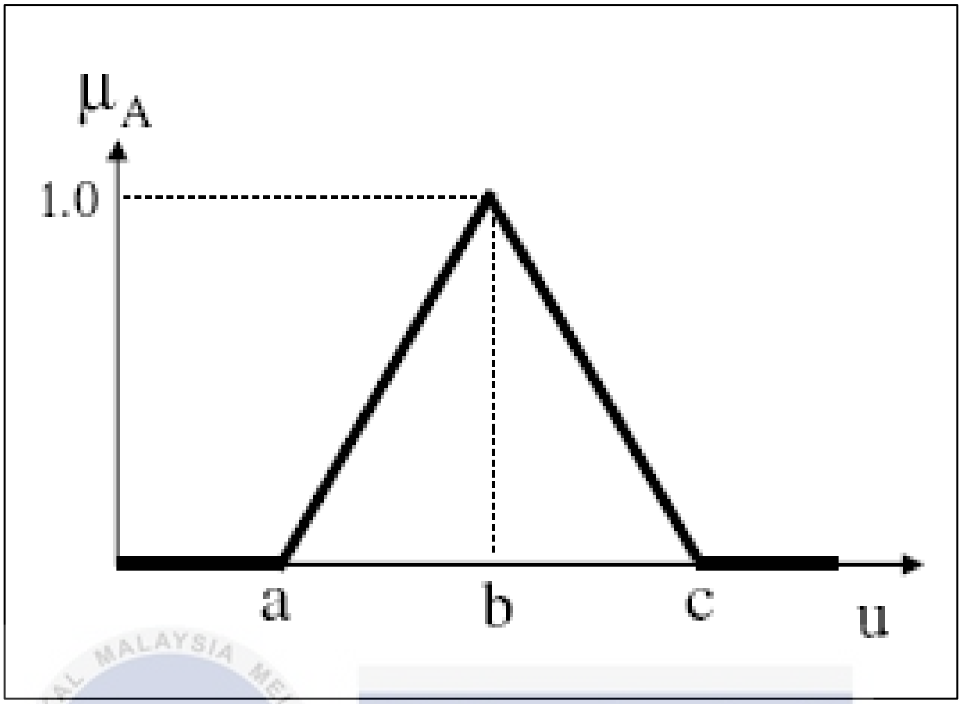


Figure 2.13: The Triangular Membership Function

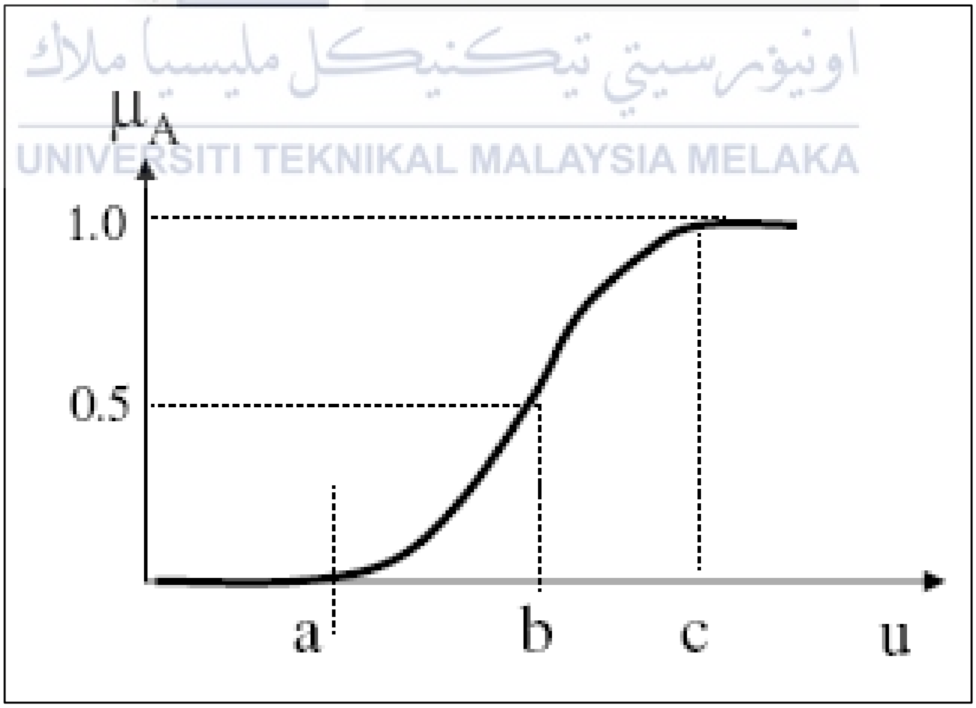


Figure 2.14: The S-Membership Function

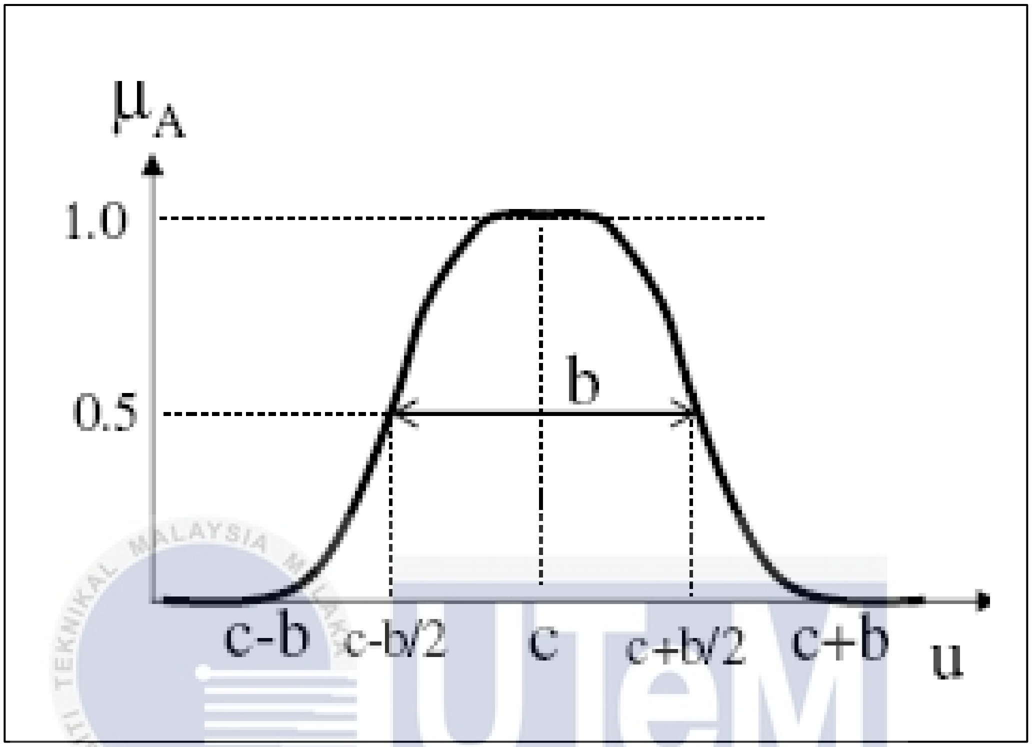


Figure 2.15: The π-Membership Function

### 2.6.3 Fuzzy Inference & Rule Matrix

Fuzzy controller is a system that use rule of matrix terms of linguistic variables instead of algorithms that define the control action of the controller input variables. Fuzzy set is created to describe the rule of matrix in term of if-then rule. Example:

If X is A Then Y is Z

A is a set of conditions that should be contented.
Z is a set of logical result that can be inferred.

After we define all the rules, the fuzzy controller starts to compute all rules. Then it should be assembled into one fuzzy set which is represent all the possible control actions. The different rule of fuzzy can be in term of graphical tool as shown:

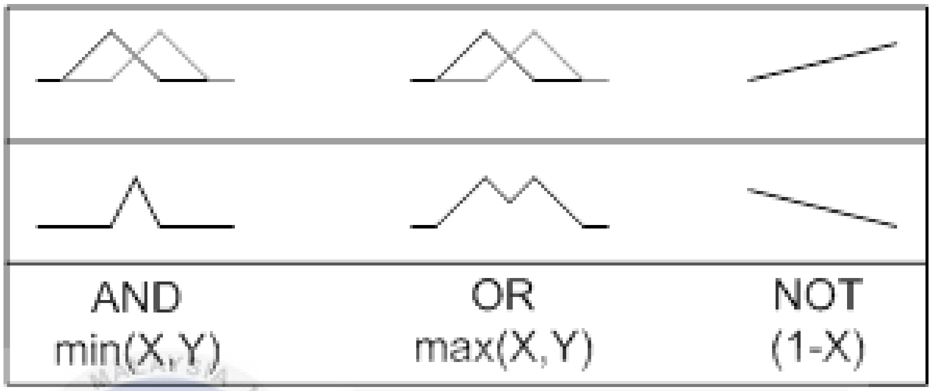


Figure 2.16: Graphical Interpretation of Fuzzy Operators

Fuzzy inference is a process of creating the mapping from input to output by using the FLC. Fuzzy inference or which is known as rule matrix involves two or more input and provides one logical product as output [18].

### 2.6.4 Defuzzification interface

As technical process should be implemented in crisp control action. Defuzzification interface is the tool phase that change the fuzzy set into crisp set to the output and it is considered as the final phase of FLC [19]. Defuzzification has various types of such as:

- Weighted average.
- Maximum.
- Centroid.
- Bisector.
- Mean

Figure 2.17 illustrate the value of each Defuzzification methods.

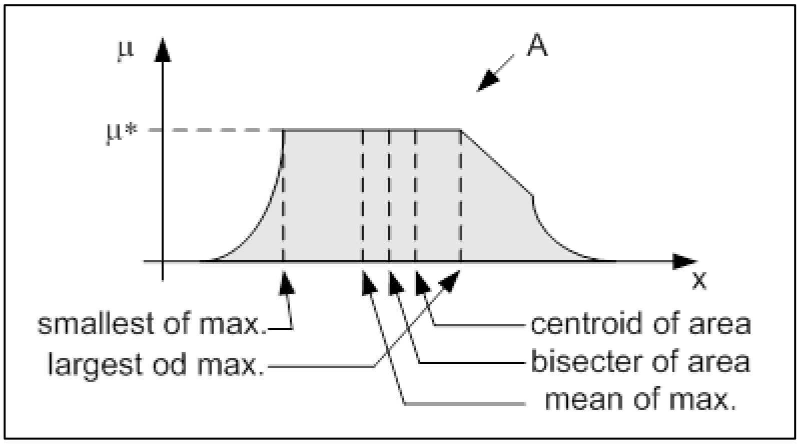


Figure 2.17: Graphical Demonstration of Defuzzification Methods [17]

The most commonly used method is centroid defuzzification since it has a high accuracy it can be expressed by the formula

$$z_0 = \frac{\int \mu_i(x)x\,dx}{\int \mu_i(x)\,dx}$$

$z_0$ is the defuzzified output.
$\mu_i$ is the membership function.
x is output variable.

Mean of maximum defuzzification this method by using the average value of the aggregated membership function outputs. It can be expressed by the formula

$$z_0 = \frac{\int_{x'} x\,dx}{\int_{x'} dx}$$

Where x' = {x; $\mu_A(x) = \mu^*$}.

Weighted average defuzzification method. Calculates weighted sum of these peak values based on peak value of each fuzzy sets. It can be expressed by the formula

$$z_0 = \frac{\sum \mu(x)_i \times W_i}{\sum \mu(x)_i}$$

μi is the degree of membership in output.
i, Wi and is the fuzzy output weight value.

Largest of maximum defuzzification method by using the maximum value of the aggregated membership function outputs. It can be expressed by the formula

$$z_0 \in \left\{ x \,\middle|\, \mu(x) = \max_{\omega} \mu(\omega) \right\}$$

Smallest of maximum defuzzification method by using the minimum value of the aggregated membership function outputs.

$$z_0 \in \left\{ x \,\middle|\, \mu(x) = \min_{\omega} \mu(\omega) \right\}$$

Finally, even the fuzzy controller considers as the most successful but still has weakness since it is required high computation time and system complexity.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

It is known that Micro-gripper is very important to be applied in biomems since it has used in a wide filed to develop and organize an artificial organ and organ tissue to help alleviate some of the problems. Based on the problem statement in chapter 1, it is found that the Micro-gripper needs controller to be more accurate and stable. Fuzzy logic controller will be implemented in this project by using MATLAB software version R2016a. Finally, the performance of the fuzzy logic controllers will be evaluated based on transient response performance (Overshoot OS%, Settling time Ts, Rise time Tr) and steady state error (ess).

## 3.2 Project Methodology

In this chapter the design and analysis performance of the micro-gripper was the first stage that will be discussed. Then the original system without controller should be evaluated. After that the fuzzy logic with different rules (3×3, 5×5, 7×7) will be applied. Finally, the comparison between the different rules will be analyzed and compared together and the performance will be verified. Figure 3.1 shows the process clearly in flowchart.

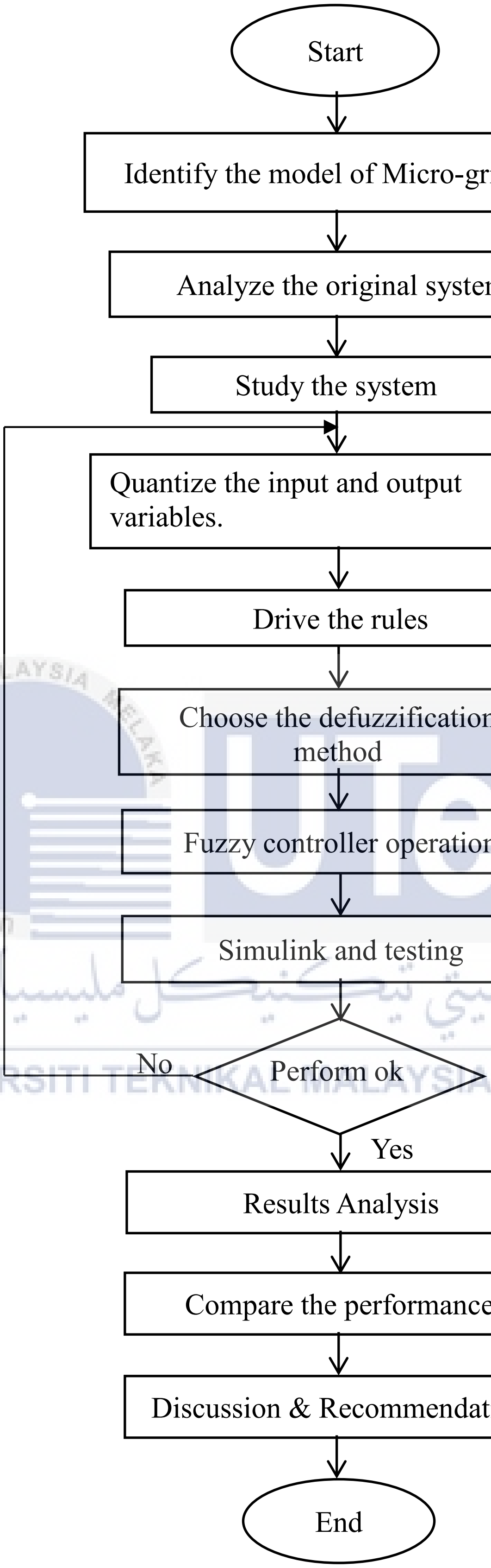


Figure 3.1: Project Flowchart

## 3.3 Modelling of Micro-gripper

In Figure 3.2 the G is the increasing gap in the positive direction as

$$G = G_0 - X$$

$G_0$ is the initial gap when the voltage applied is zero.

X is the displacement of the

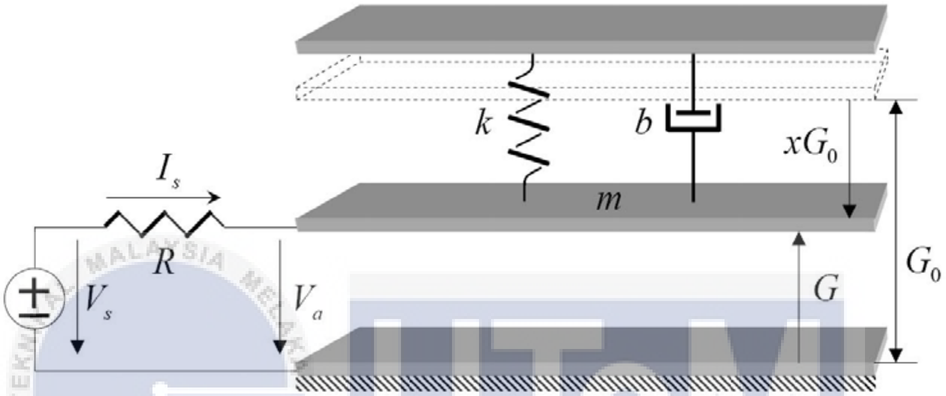


Figure 3.2 Electro-Mechanical Model of An Electrostatic Actuator [2] [19].

In Figure 3.3, Volt is the input for the micro-gripper which the voltage forces the electrostatic parallel plate to move. The output is the displacement of the movable finger of the parallel plate which is in 1 micrometer to 1 millimeter. In this figure there are two capacitors which one of them is the fixed finger electrode and another capacitor is adjustable electrode. The adjustable electrode is defined the distance that should be between the arms to grip the object.

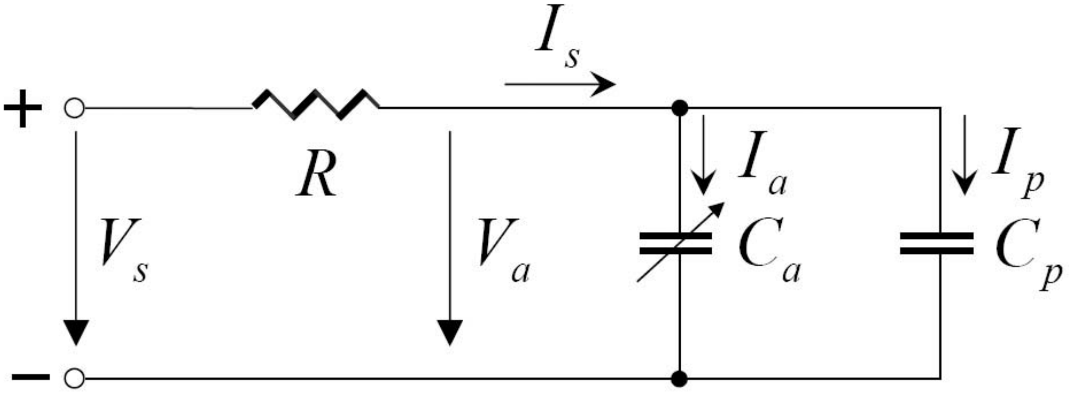


Figure 3.3: Equivalent Circuit with Parallel Parasitic Capacitance [19] [2].

Equation (3.1) is expressed the transfer function of the actuated system of microgripper as shown;

$$\frac{X(s)}{V(s)} = \frac{4}{9}\frac{Qeq}{rs^3+(1-Xeq+2\xi r)s^2+[2\xi(1-Xeq)+r]s+(1-3Xeq)}$$ [19] [20]

(3.1)

Where the symbols in Figure 3.2, 3.3 and Equation 3.1 are:

$C_0 = \frac{\varepsilon A}{G_0} = Capacitance\ of\ the\ device\ at\ rest$

$q = \frac{Q}{qpi}, \quad r = \omega_0 R C_0 \ , \omega_0 = \sqrt{\frac{K}{m}}$

$X = displacement$

$V = Voltage\ input$

$Qeq = equilibrium\ charges$

$Xeq = equilibrium\ displacement$

$S = maximum\ displacement\ or\ stroke$

$\omega_0 = undamped\ natural\ frequency$

$K = electric\ constant$

$m = mass\ of\ the\ movable\ upper\ electrode$

$b = damping\ coefficient$

$A = plate\ area$

$\varepsilon = dielctric\ constant$

$G_0 = zero\ voltage\ gap$

Micro gripper system is modelled and simulated according to [19] [20], where the parameters for the linearized model of the micro-gripper is shown in Table 3.1.

Table 3.1: Parameters of micro-gripper model

| $Xeq$ | $Qeq$ | $Veq$ | $\xi$ | $r$ | $\rho$ |
|---|---|---|---|---|---|
| 0.05 | 0.3873 | 0.5519 | 0.2 | 0.1 | 0.2 |

Based on equation (3.1) with using the parameter in Table 3.1, the linearized model will be as shown:

$$\frac{X(s)}{V(s)} = \frac{0.17213}{0.1s^3+0.99s^2+0.48s+0.85} \quad (3.2)$$

Figure 3.4 show the closed loop feedback control system of micro-gripper. This system has been applied to MATLAB Simulink.

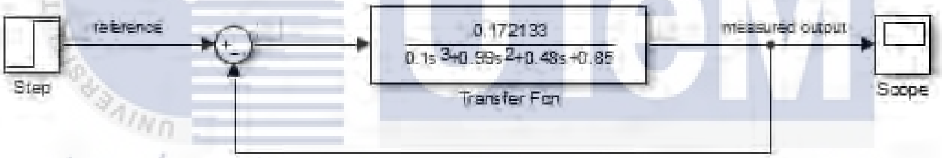
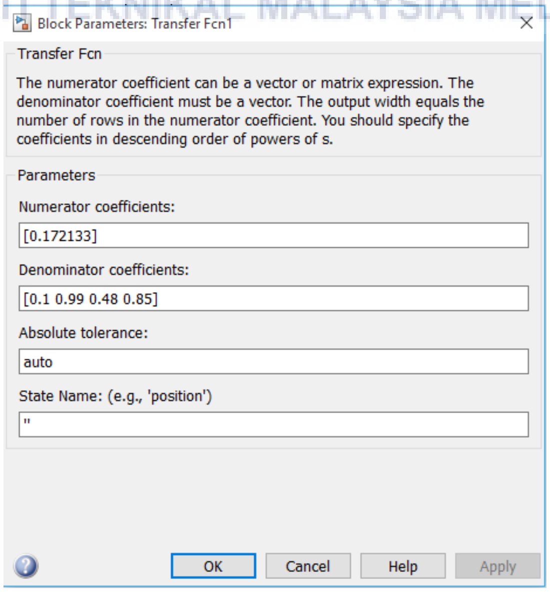


Figure 3.4 Simulink Setup of Microgripper.



Transfer Fcn

The numerator coefficient can be a vector or matrix expression. The denominator coefficient must be a vector. The output width equals the number of rows in the numerator coefficient. You should specify the coefficients in descending order of powers of s.

Parameters

Numerator coefficients: [0.172133]

Denominator coefficients: [0.1 0.99 0.48 0.85]

Absolute tolerance: auto

State Name: (e.g., 'position') ''

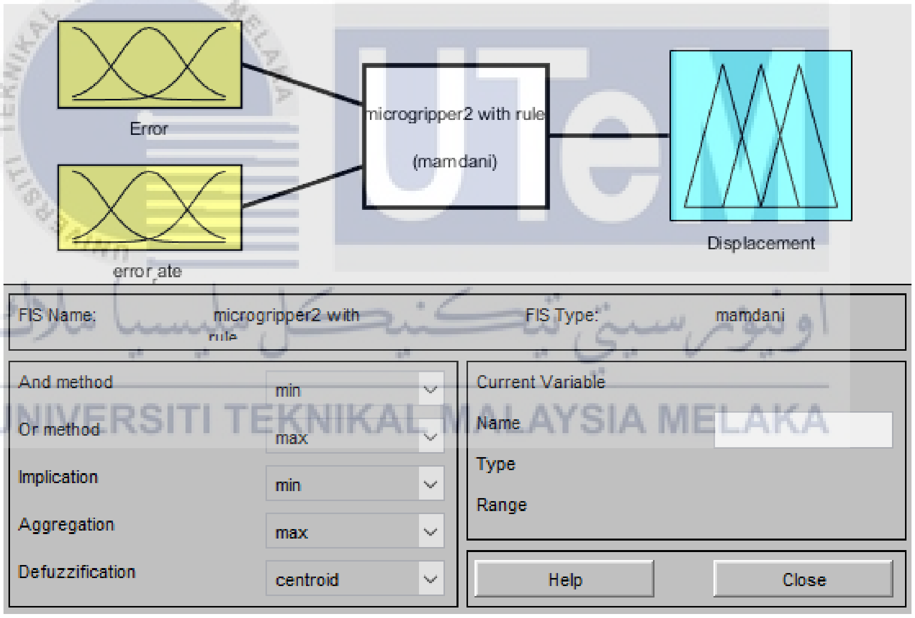
Figure 3.5 Parameter Variable Setting.

## 3.4 Fuzzy Logic Controller Design

As mentioned in the literature review the fuzzy logic involves three stages which are fuzzification, fuzzy inference mechanism as an input and defuzzification which is the output. This stage is proceeding to design the fuzzy control system by using MATLAB Simulink as follow in the steps shown below.

Step 1: Identify the input and output variables of the system, each one of the inputs and outputs has a scaling factor.

- Error and change of error (error rate) are the inputs
- Voltage is the output.



FIS Name: microgripper2 with rule
FIS Type: mamdani

And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid

Current Variable
Name
Type
Range

Figure 3.6: Setting of The Input and Output Variable

Step 2: Identify the linguistic variables of the inputs and output variables of the system and membership function design.

The universe of the discourse has been set in two different designs for the linguistic variables that has different universe of discourse range. The range of these membership function has been adjusted in order to improve the system performance and to cover all the possibilities values as shown in table 3.2.

Table 3.2: Universe of discourse range

| | First Design | Second Design |
|---|---|---|
| Error (Input 1) | (-10,10) | (-3.5,3.5) |
| Error Rate (Input 2) | (-20,20) | (-6,6) |
| Voltage (Output) | (-30,30) | (-200,200) |

Step 3: Modeling of the fuzzy logic controller

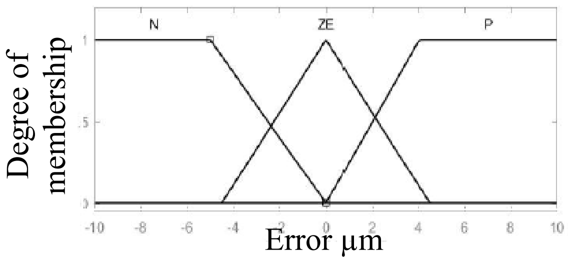
Three different FLC membership function were assumed based on the knowledge and experience of the operator and on specific condition of inputs [21] in three different fuzzy logic rules. The rules of fuzzy logic opted to be evaluated as shown in table 3.3, 3.4 ,3.5 for (3x3) ,(5x5) and (7x7) rules respectively .

Table 3.3: Fuzzy rules of (9 rules)

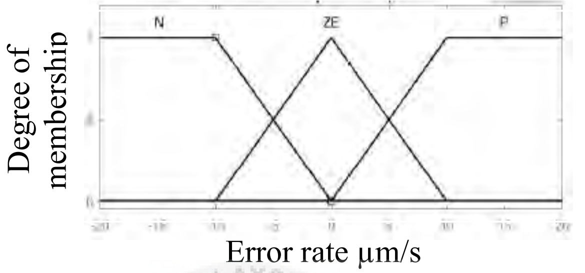
| **error**<br>**Rate of error** | **N** | ZE | **P** |
|---|---|---|---|
| **N** | N | N | P |
| ZE | N | ZE | P |
| P | N | P | P |

Where

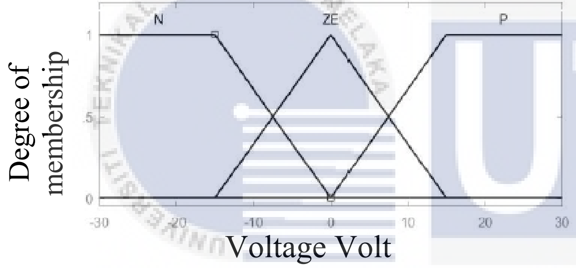
N (Negative) ZE (Zero) P (Positive)



(a) Input membership function of error e

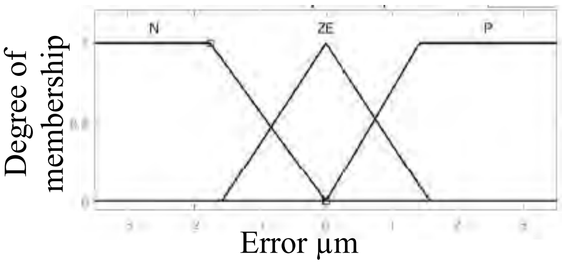


(b) Input membership function of error rate

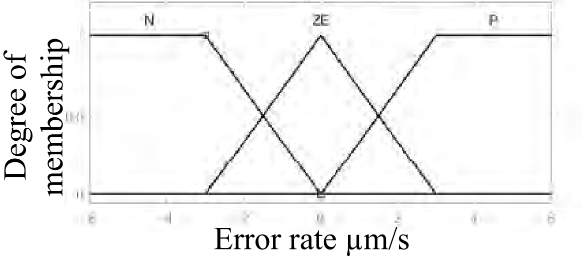


(b) Output membership function

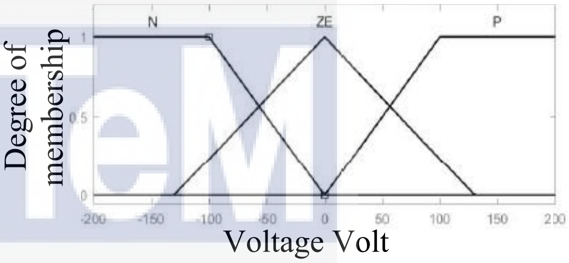
Figure 3.7: Membership Function of 9 Rules in First Design



(a) Input membership function of error e



(b) Input membership function of error rate



(b) Output membership function

Figure 3.8: Membership Function of 9 Rules in Second Design

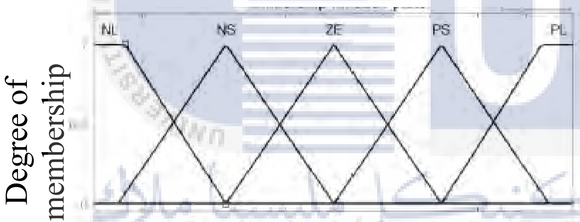
Table 3.4: Fuzzy rules of (25 rules)

| **error** / **Rate of error** | **NL** | **NS** | **ZE** | **PS** | **PL** |
|---|---|---|---|---|---|
| **NL** | NL | NL | NS | NS | ZE |
| **NS** | NL | NL | NS | ZE | ZE |
| **ZE** | NL | NS | ZE | PS | PS |
| **PS** | ZE | PS | PS | PL | PL |
| **PL** | ZE | ZE | PS | PL | PL |

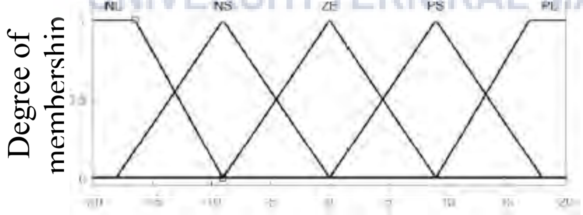
Where

NL (Negative Large) PL (Positive Large) ZE (Zero)

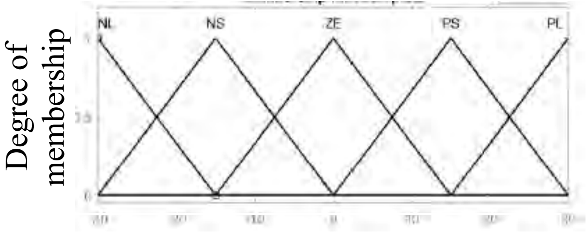
NS (Negative Small) PS (Positive Small)



(a) Input membership function of error e

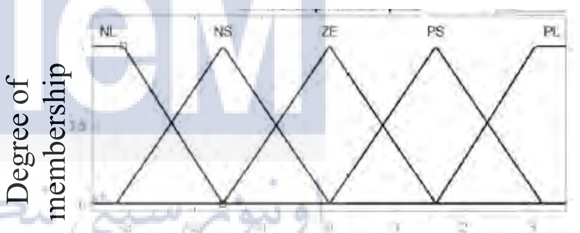


(b) Input membership function of error rate

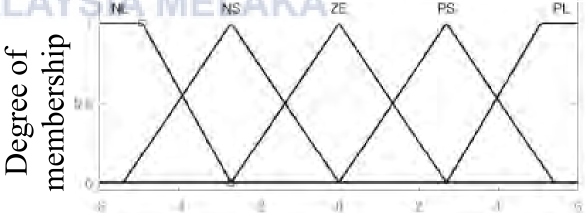


(b) Output membership function

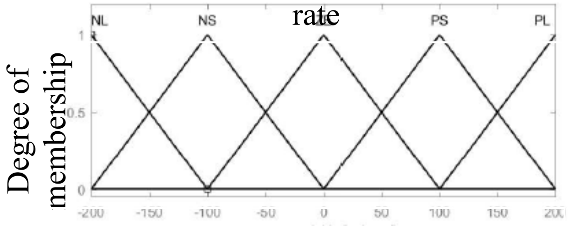
Figure 3.9: Membership Function Of 25 Rules in First Design



(a) Input membership function of error e



(b) Input membership function of error rate



(b) Output membership function

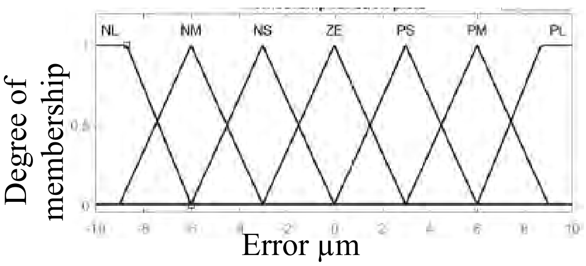
Figure 3.10: Membership Function of 25 Rules in Second Design

Table 3.5: Fuzzy rules of (49 rules)

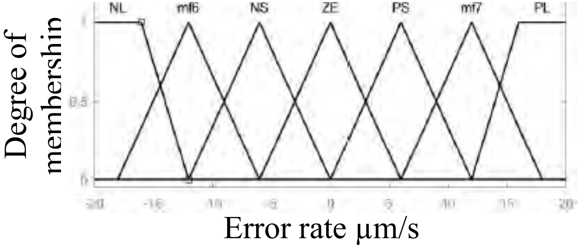
| **error**<br>**Rate of error** | **NL** | **NM** | **ZS** | **ZE** | **PS** | **PM** | **PL** |
|---|---|---|---|---|---|---|---|
| **NL** | NL | NL | NL | NL | NM | NS | ZE |
| **NM** | NL | NL | NL | NM | NS | ZE | PS |
| **NS** | NL | NL | NM | NS | ZE | PS | PM |
| **ZE** | NL | NM | NS | ZE | PS | PM | PS |
| **PS** | NM | NS | ZE | PS | PM | PL | PL |
| **PM** | MS | ZE | PS | PM | PL | PL | PL |
| **PL** | ZE | PS | PM | PL | PL | PL | PL |

Where

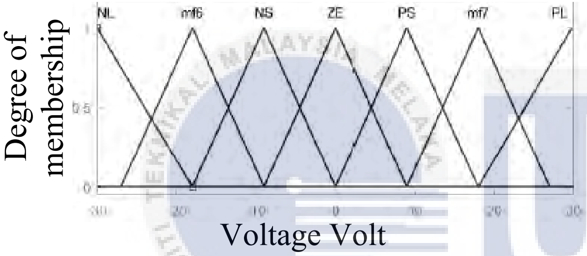
NL (Negative Large) PL (Positive Large) ZE (Zero)
NM (Negative Medium) PM (Positive Medium)
NS (Negative Small) PS (Positive Small)



(a) Input membership function of error e

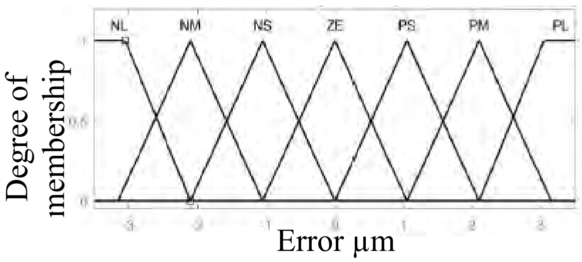


(b) Input membership function of error rate

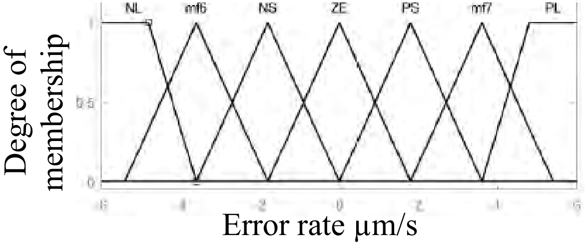


(d) Output membership function

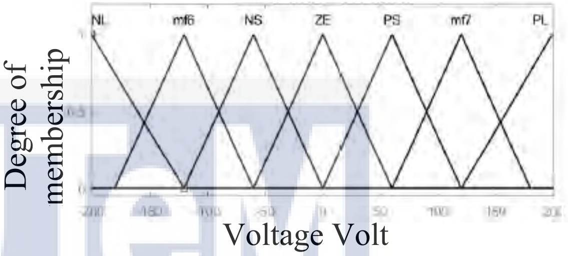
Figure 3.11: Membership Function of 49 rules in First Design



(a) Input membership function of error e



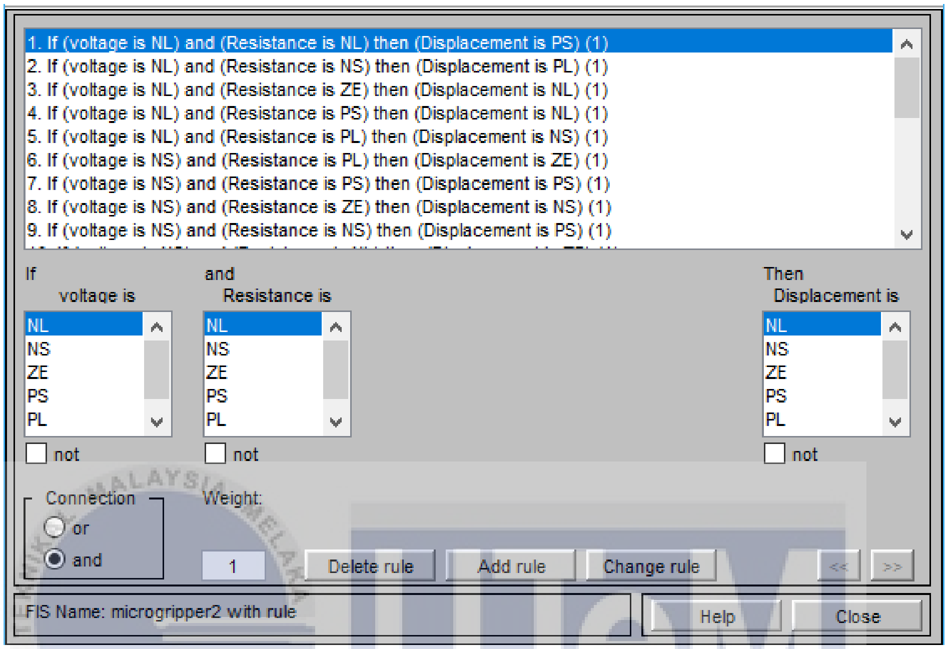
(b) Input membership function of error rate



(d) Output membership function

Figure 3.12: Membership Function of 49 Rules in Second Design

Based on the rules in Table 3.3, 3.4 ,3.5 the rules the rules can be inserted to the MATLAB Simulink as shown in Figure 3.13.


1. If (voltage is NL) and (Resistance is NL) then (Displacement is PS) (1)
2. If (voltage is NL) and (Resistance is NS) then (Displacement is PL) (1)
3. If (voltage is NL) and (Resistance is ZE) then (Displacement is NL) (1)
4. If (voltage is NL) and (Resistance is PS) then (Displacement is NL) (1)
5. If (voltage is NL) and (Resistance is PL) then (Displacement is NS) (1)
6. If (voltage is NS) and (Resistance is PL) then (Displacement is ZE) (1)
7. If (voltage is NS) and (Resistance is PS) then (Displacement is PS) (1)
8. If (voltage is NS) and (Resistance is ZE) then (Displacement is NS) (1)
9. If (voltage is NS) and (Resistance is NS) then (Displacement is PS) (1)

Connection: ○ or ● and

Weight: 1

FIS Name: microgripper2 with rule

Figure 3.13: Fuzzy Logic Rules

Step 4: The type of membership of this controller is setting as triangular shape for each of the linguistic values.

Step 5: The defuzzification method is center of gravity (COG)

Step 6: The fuzzy logic controller was added to the micro-gripper control system simulation as shown in block diagram in Figure 3.14.

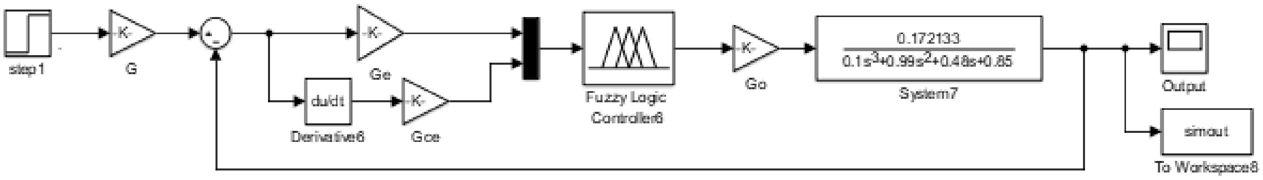


Figure 3.14: Block Diagram of Fuzzy Controller.

Step 7: Fuzzy Logic Controller Tuning (Scaling factor)

The FLC using in microgripper has one output (voltage) and two inputs (error) and (change of error). Each one has adjusted by constant gain which called scaling factor, Where G is the system input scaling factor, Ge is error input scaling factor, Gce change of error scaling factor and Go output scaling factor. The scaling factors has been tuned in heuristic techniques in order to enhance the performance. Table 3.6 present the values of scaling factors.

Table 3.6 Scaling factors

| | G | Ge | Gce | Go |
|---|---|---|---|---|
| First design | | | | |
| 3x3 rules | 1.99 | 1 | 4.2 | 1 |
| 5x5 rules | 2.322 | 1 | 4.2 | 1 |
| 7x7 rules | 2.676 | 1 | 4.2 | 1 |
| Second design | | | | |
| 3x3 rules | 1.0763 | 1 | 0.9972 | 1 |
| 5x5 rules | 1.0548 | 1 | 0.8 | 1 |
| 7x7 rules | 1.06859 | 1 | 0.9 | 1 |

## 3.5 Evaluation of Performance

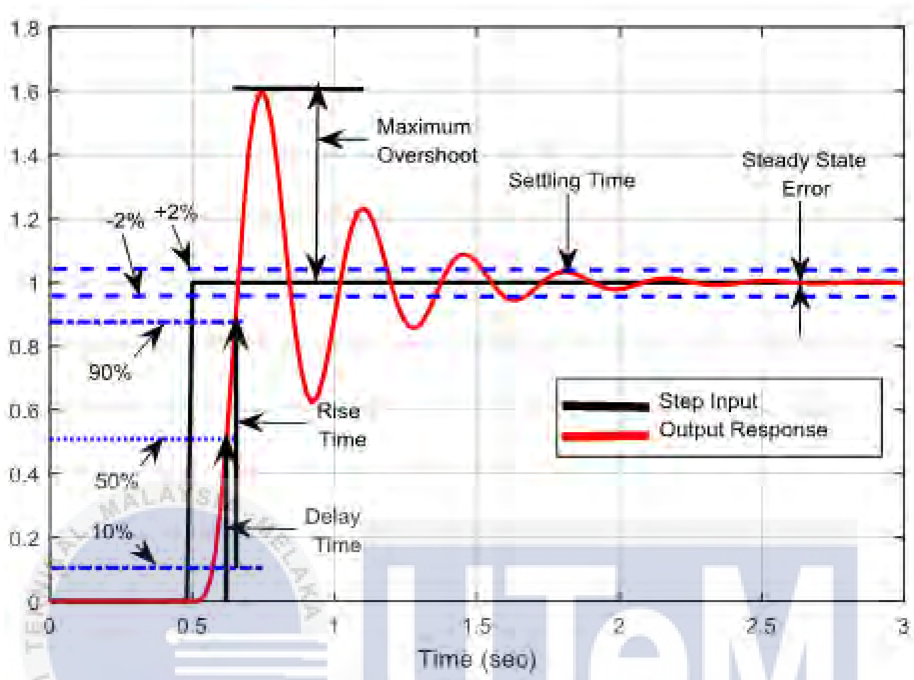


Figure 3.15: Transient Response Analysis.

After the design of fuzzy logic control with different fuzzy logic rules, the system will be analyzed in term of percentage overshoot (OS%), Settling time Ts, Rise time Tr and steady state error ($e_{ss}$). Based on the study conducted by Nise (2011) and refer to Figure 3.15 The system performance can be determined as shown below:

I. Rise time, ($T_r$)

“The time required for the system response to go from the percentage of 10% to the percentage of 90% of its final value.”

II. Settling time, ($T_s$)

“The time required for the system response to reach and stay within ± 2% of its final value.”

III. Overshoot, (OS%)

“The percentage of overshoot OS% is determined by Equation (3.3).”

$$OS\% = \frac{Maximum\ overshoot - Final\ Value}{Desired\ value} \times 100\% \qquad (3.3)$$

IV. Steady state error, ($e_{ss}$).

“The difference between the steady state response and the desired output”

## 3.6 Gantt Chart

Table 3.7: Gantt chart FYP 1

| Progress | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | W11 | W12 | W13 | W14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FYP TITLE** | | | | | | | | | | | | | | |
| **Find Supervisor** | | | 🟦 | | | | | | | | | | | |
| **Title Confirmation** | | | 🟦 | | | | | | | | | | | |
| **Overview of the project** | | | 🟦 | 🟦 | | | | | | | | | | |
| **Project Introduction** | | | | | | | | | | | | | | |
| **-Motivation**<br>**-Problem Statement**<br>**-Objective**<br>**-Scope** | | | | 🟦 | 🟦 | 🟦 | | | | | | | | |
| **Literature review** | | | | | | | | | | | | | | |
| **-MEMS**<br>**-BioMEMS**<br>**- Micro-gripper**<br>**- Fuzzy logic** | | | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| **Methodology** | | | | | | | | | 🟦 | 🟦 | | | | |
| **Preliminary Result** | | | | | | | | | 🟦 | 🟦 | 🟦 | | | |
| **MATLAB/Simulink Design of the system** | | | | | | | | | 🟦 | 🟦 | 🟦 | | | |
| **Conclusion** | | | | | | | | | | | | 🟦 | 🟦 | |
| **FYP Presentation** | | | | | | | | | | | 🟦 | | | |
| **FYP1 Report** | | | | | | | | | | | | | | 🟦 |

Table 3.8: Gantt chart FYP 2

| **Progress** | **W 1** | **W 2** | **W 3** | **W 4** | **W 5** | **W 6** | **W 7** | **W 8** | **W 9** | **W 10** | **W 11** | **W 12** | **W 13** | **W 14** | **W 15** | **W 16** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Literature review** | 🟦 | 🟦 | 🟦 | | | | | | | | | | | | | |
| **Methodology** | | | 🟦 | 🟦 | 🟦 | | | | | | | | | | | |
| **Result** | | | | | | | | | | | | | | | | |
| **-First design of FLC**<br>**- 3x3 rules**<br>**-5x5 rules**<br>**-7x7 rules**<br>**-Second design of FLC**<br>**- 3x3 rules**<br>**-5x5 rules**<br>**-7x7 rules**<br>**-Tuning (Scaling factor)** | | | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | | |
| **Analyses and discussion** | | | | | | | | | | 🟦 | 🟦 | 🟦 | 🟦 | | | |
| **Conclusion** | | | | | | | | | | | | | | 🟦 | 🟦 | |
| **FYP Presentation** | | | | | | | | | | | | | | | | 🟦 |
| **FYP1 Report** | | | | | | | | | | | | | | | 🟦 | |

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

In this chapter the performance of fuzzy controller with using 9, 25 and 49 rules will be discussed. All of the rules are developed in two different designs for the linguistic variables that has different universe of discourse range. By using MATLAB Simulink R2016a the results are analyzed and compared between the original system of microgripper which is without controller and the system with fuzzy logic controller rules. The comparison will be done in term of Settling time Ts, Overshoot OS%, Rise time Tr and steady state error $e_{SS}$.

## 4.2 Result of The Original System

Figure 4.1 shows the performance and the result of the electrostatic actuation of micro-gripper system.

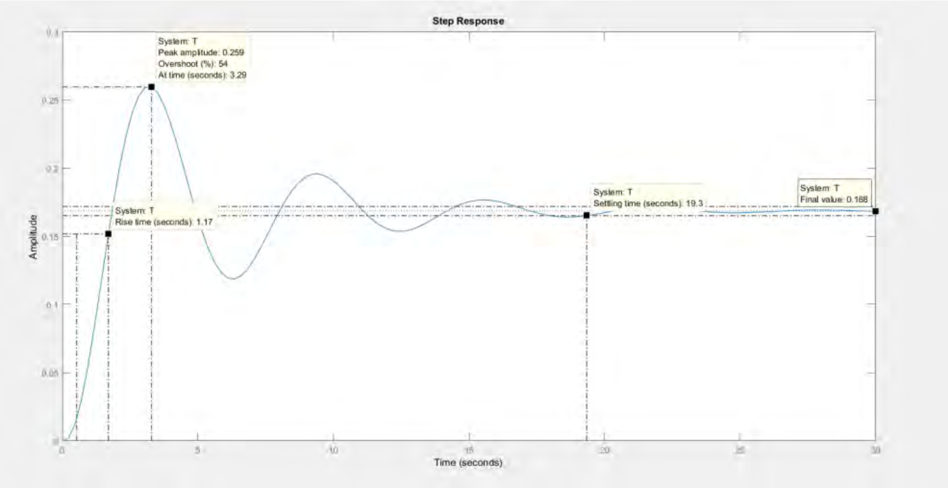


Figure 4.1: Response of The Original System

The response of the original system in Figure 4.1 illustrate that the system is not suitable since it has a high overshoot and low steady state which yield to has a high steady state error and the settling time is also considered high settling time. The value of the transient response specification is shown in Table 4.1.

Table 4.1: Parameter Analysis for Original System

| **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|
| 54% | 1.17s | 19.3s | 83.2% |

## 4.3 First design results

As mentioned in chapter 3 the universe of the discourse has been set in two different designs for the linguistic variables that has different universe of discourse range. The universe of discourse range of membership function has been adjusted between ( -10µm, 10µm) for error, between ( -20µm/s,20µm/s) for error rate and between ( -30, 30) for voltage. In this design three standard FLC (9,25.49) rules were chosen to be evaluated.

### 4.3.1 Result of the System with Fuzzy Controller 3x3 Rules

Figure 4.2 shows the output result of the gripper with fuzzy. The first 3×3 rules of fuzzy logic controller that have been applied to the micro-gripper to develop the behavior.

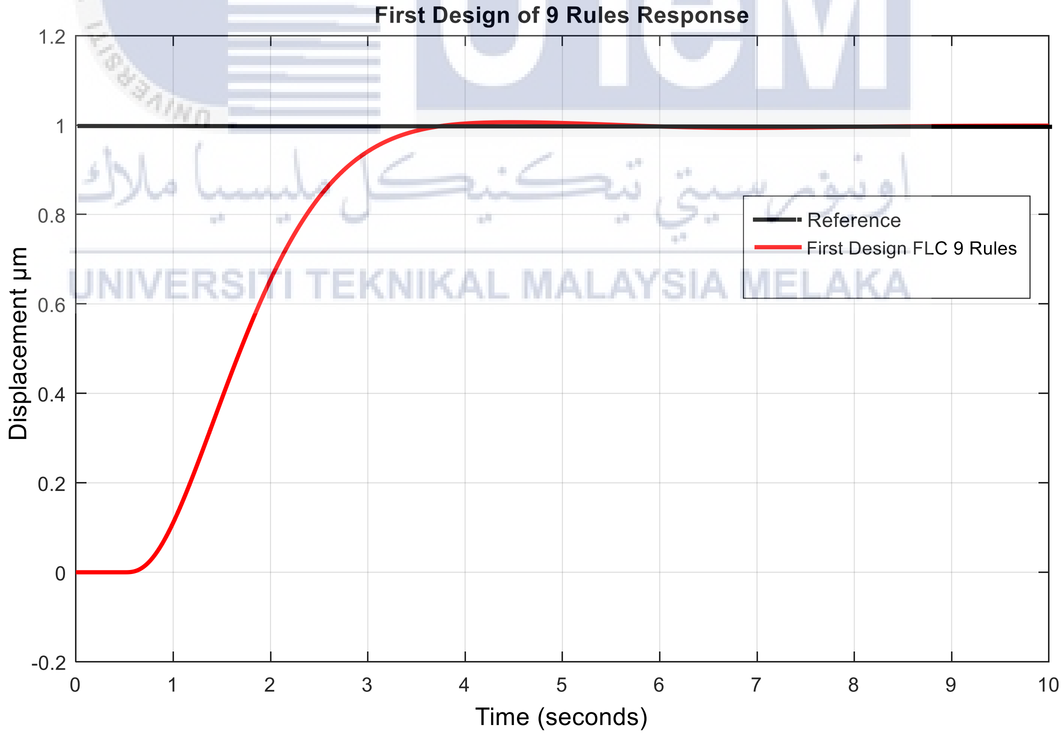


Figure 4.2: Response of First Design with Fuzzy Logic Controller 3x3 Rules

The simulation is carried out and the controller requires 2.0762 second to rise from 10% to 90% of its final value and its overshoot is 0.85% and settling time 3.052 seconds. The steady state error it can be neglected since it is almost zero and same goes with overshoot which has 0.85%. The value of transient response specification is shown in Table 4.2. The tuning of scaling factor of (G) the system input and (Gce) change of error play an important role in term of reducing the steady state error and reducing the overshoot respectively.

Table 4.2: Transient response specification of first design 9 rules

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Fuzzy (3x3rules) | 0.85% | 2.0762s | 3.052s | 0% |

### 4.3.2 Result of The System with Fuzzy Controller 5x5 Rules

Figure 4.3 shows the output result of the gripper with fuzzy. The first 5×5 rules of fuzzy logic controller that have been applied to the microgripper to develop the behavior.

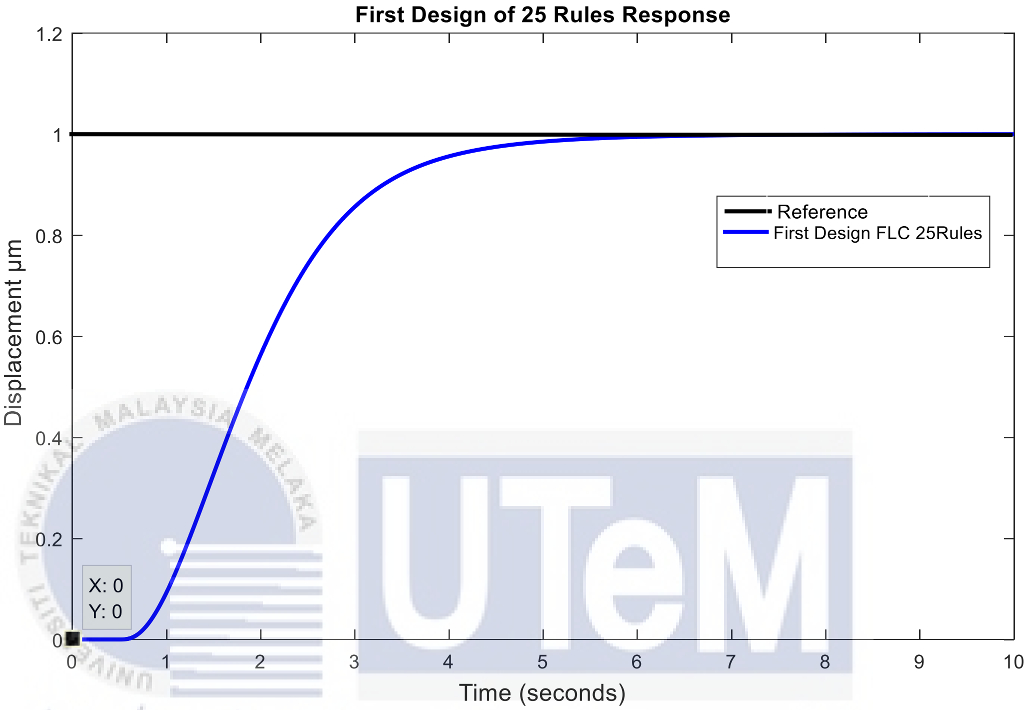


Figure 4.3: Response of First Design with Fuzzy Logic Controller 5x5 Rules

The simulation is accomplished, and the controller requires 2.283 second to rise from 10% to 90% of the final value and its overshoot is 0% and 4.21 seconds settling time. The steady state error it can be neglected since it is very small and can consider almost zero and same goes with overshoot which has 0%. The tuning of scaling factor of (G) the system input and (Gce) change of error play an important role in term of reducing the steady state error and reducing the overshoot respectively. Table 4.3 is shows the value of transient response specification.

Table 4.3: Transient response specification of first design 25 rules

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Fuzzy (5x5rules) | 0% | 2.283s | 4.21s | 0.03% |

### 4.3.3 Result of The System with Fuzzy Controller 7x7Rules

Figure 4.4 shows the output result of the gripper with fuzzy. The first 7×7 rules of fuzzy logic controller that have been applied to the microgripper to develop the behavior.

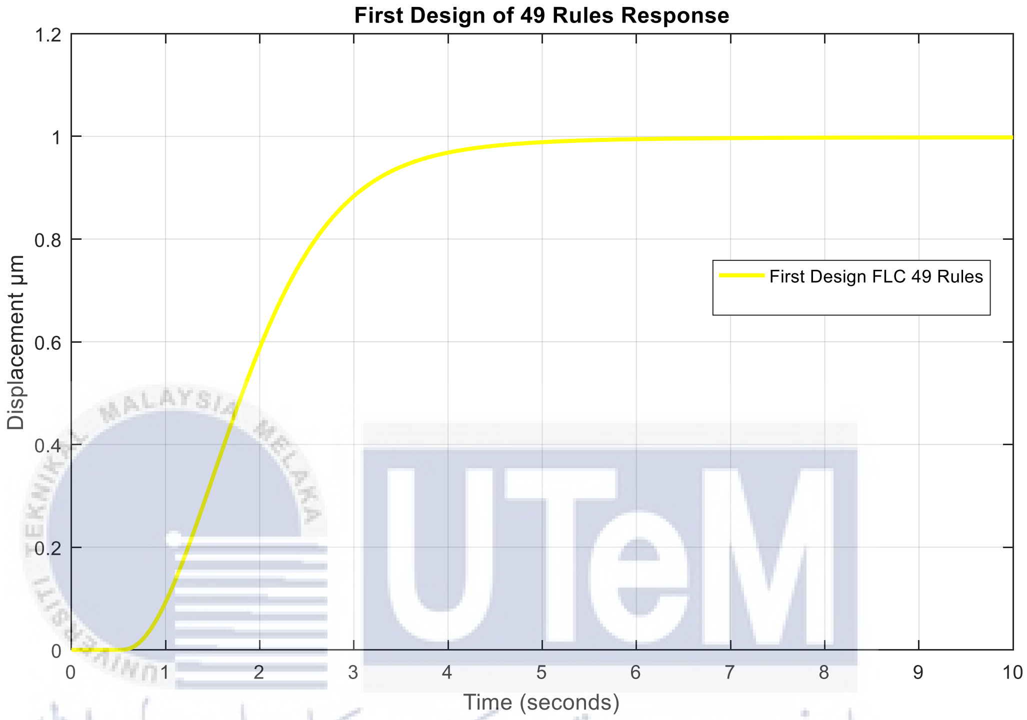


Figure 4.4: Response of First Design with Fuzzy Logic Controller 7x7 Rules

The simulation is carried out and the analysis has been done and the controller requires 2.093 seconds to rise from 10% to 90% of the final value and its overshoot is 0% and 3.914 seconds settling time. The steady state error is 0.22% and it can be neglected since it is very small and can consider almost zero. The tuning of scaling factor of (G) the system input and (Gce) change of error play an important role in term of reducing the steady state error and reducing the overshoot respectively. . Table 4.3 shows the value of transient response specification.

Table 4.4: Transient response specification first design 49 rules

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Fuzzy (7x7) rules | 0% | 2.093s | 3.914s | 0.22% |

## 4.4 Second design results

As mentioned in chapter 3 the universe of the discourse has been set in two different designs for the linguistic variables that has different universe of discourse range. Since the first system has a long time to raise from 10% to 90% which affect the settling time. The universe of discourse range of membership function in second design has been adjusted based on system experience and investigation of the performance and limitation of each signal in the variables to cover all the possibilities values. The range was between ( -3.5µm, 3.5µm) for error, between ( -6µm/s,6µm/s) for error rate and between ( -200, 200) for voltage. In this design three standard FLC (9,25.49) rules were chosen to be evaluated.

### 4.4.1 Result of The System with Fuzzy Controller 3x3 Rules

Figure 4.5 shows the output result of the gripper with fuzzy. The second design 3×3 rules of fuzzy logic controller that have been applied to the micro-gripper to develop the behavior.

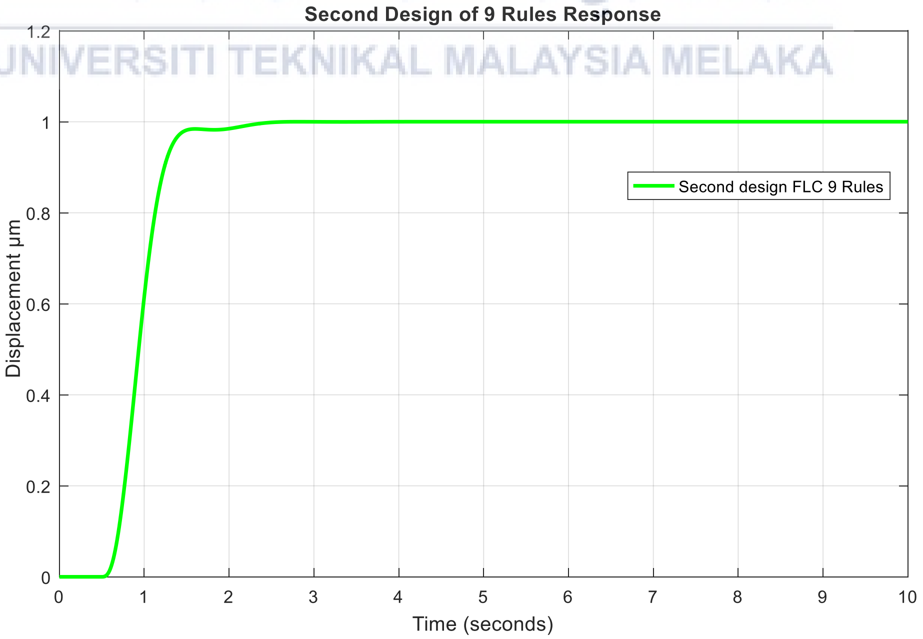


Figure 4.5: Response of Second Design with Fuzzy Logic Controller 3x3 Rules

The simulation is carried out and the controller requires 0.5397 second to rise from 10% to 90% of the final value and its overshoot and settling time is 0% and 0.978 seconds. The steady state error is 0. The value of transient response specification is shown in table 4.5. The tuning of scaling factor of (G) the system input and (Gce) change of error play an important role in term of reducing the steady state error and reducing the overshoot respectively.

Table 4.5: Transient response specification of Second design 9 rules

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Fuzzy (3x3) rules | 0% | 0.5397s | 0.978s | 0% |

### 4.4.2 Result of The System with Fuzzy Controller 5x5 Rules

Figure 4.6 shows the output result of the gripper with fuzzy. The second 5×5 rules of fuzzy logic controller that have been applied to the microgripper to develop the behavior.

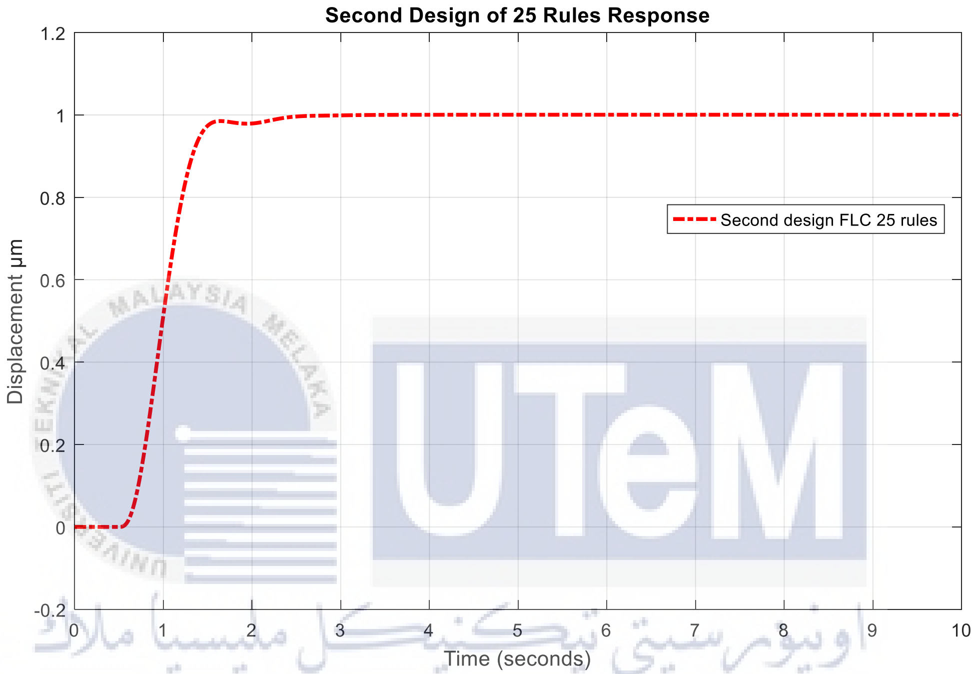


Figure 4.6: Response of Second Design with Fuzzy Logic Controller 5x5 Rules

The simulation is accomplished, and the microgripper system requires 0.6077 second to rise from 10% to 90% of the final value and its overshoot is 0% and 1.039 seconds settling time. The steady state and overshoot are 0%. The tuning of scaling factor of (G) the system input and (Gce) change of error play an important role in term of reducing the steady state error and reducing the overshoot. Table 4.6 shows the tabulated values of transient response specification.

Table 4.6: Transient response specification of second design 25 rules

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Fuzzy (5x5) rules | 0% | 0.6077s | 1.039s | 0 % |

### 4.4.3 Result of The System with Fuzzy Controller 7x7Rules

Figure 4.7 shows the output result of the gripper with fuzzy. The first 7×7 rules of fuzzy logic controller that have been applied to the microgripper to develop the behavior.

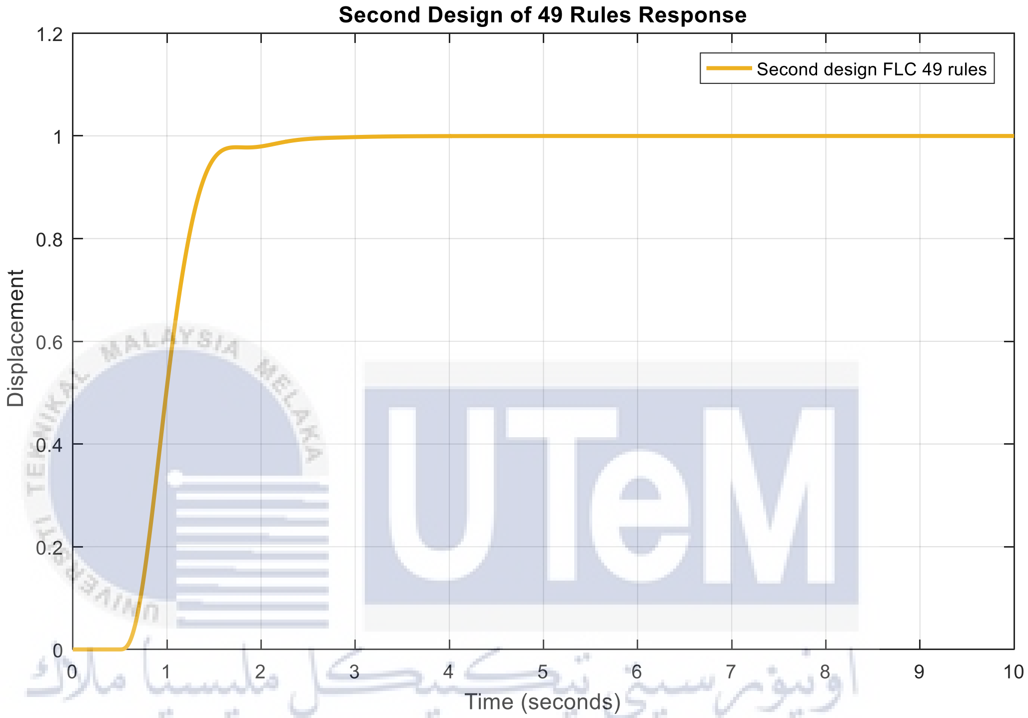


Figure 4.7: Response of Second Design with Fuzzy Logic Controller 7x7 Rules

The simulation is implemented, and the analysis has been done and the controller requires 0.6427 second to rise from 10% to 90% of its final value and 1.517 seconds settling time. The steady state error and overshoot have 0%. The tuning of scaling factor of (G) the system input and (Gce) change of error play an important role in term of reducing the steady state error and reducing the overshoot respectively. The value of transient response specification is shown in table 4.7.

Table 4.7: Transient response specification of second design 49 rules

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Fuzzy (7x7) rules | 0% | 0.6427s | 1.517s | 0% |

## 4.4 Summary

Placing all the controllers in one figure will make the vision clearly and will show the comparison between all controllers and illustrate the most accurate and effective controller to be applied to microgripper. Figure 4.8 illustrate the six controller responses. Solid blue color line state the first design 25 rules fuzzy logic controller, Solid yellow color line goes for the first design 49 rules fuzzy logic controller, Solid red color line represents the first design 9 rules fuzzy logic controller, Solid orange color line represents the second design 49 rules fuzzy logic controller. Dashed red color line goes for the second design 25 rules fuzzy logic controller and the green line represents the second design of 9 rules fuzzy logic controller. As tabulated in Table 4.8 among the performance of all controllers has zero steady state error and zero overshoot that improved by tuning the scaling factors as mentioned in chapter 3. In terms of rise time and settling time after comparation of the six controllers according to Figure 4.8 and Table 4.8. The 9 rules fuzzy logic controller has the best performance since it has fastest response as is requires 0.5397 seconds to rise from 10% to 90% of the final value and takes 0.978 seconds to approach and stay within ± 2% of its final desired value. So, the 9 rules fuzzy logic controller in second design is recommend to be applied and used.

Figure 4.9 illustrate a clear chart of the comparison between the six controllers of the system in term of rise time, settling time, maximum overshoot and steady state error.

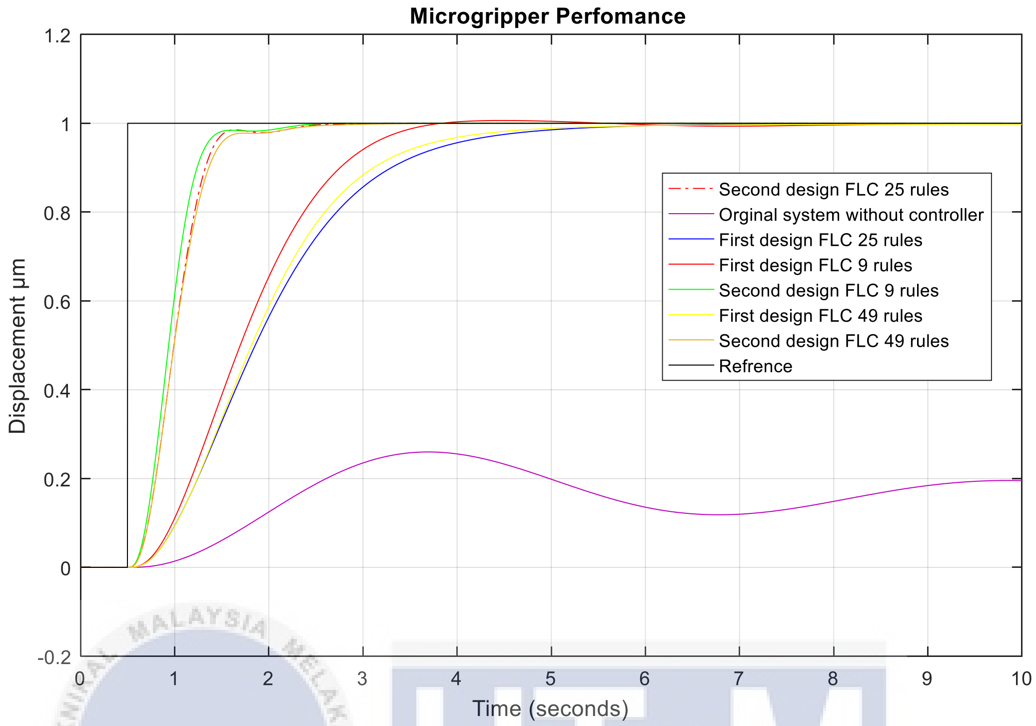


Figure 4.8: Response of All Controllers

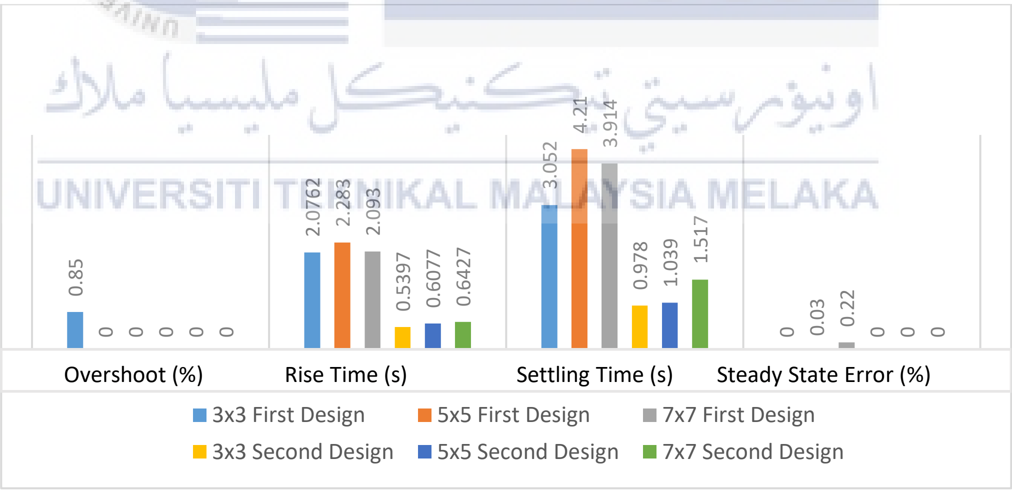


Figure 4.9: Fuzzy Logic Controller Performance Chart

Table 4.8: The output characteristics of the overall systems

| **Controller** | **OS%** | **$T_r$** | **$T_s$** | **$e_{ss}$** |
|---|---|---|---|---|
| Original System | 54% | 1.17s | 19.3s | 83.2% |
| 3x3 First Design | 0.85% | 2.0762 | 3.052s | 0 % |
| 5x5 First Design | 0% | 2.283 | 4.21s | 0.03% |
| 7x7 First Design | 0% | 2.093 | 3.914s | 0.22% |
| 3x3 Second Design | 0% | 0.5397 | 0.978s | 0% |
| 5x5 Second Design | 0% | 0.6077 | 1.039s | 0% |
| 7x7 Second Design | 0% | 0.6427 | 1.517s | 0% |

# CHAPTER 5

# CONCLUSION

In conclusion, it can be concluded that the objectives have been achieved. Micro-gripper system and the importance of the controllers to be applied to the system have been obviously studied. The difference of the different types of micro actuation of micro-gripper has been clearly compared in the literature review. Moreover, the implementation of fuzzy to micro electrostatic micro-gripper have been studied, clarified, explained in detail and shown a promising result. It is proven by the analysis done. Eventually, fuzzy logic controller with (9,25,49) rules have been evaluated and analyzed. The comparison shows the best fuzzy controller is 3x3 with lowest steady state error, percent overshoot, time rise and settling. This proved that it will be benefited the medical field and its application

## RECOMMENDATION

As recommendation is suggested for the future researches, further development of the project is applying the controllers in the real word into hardware development. Since this research works cannot be guaranteed that this applied controller can perform as perfect as it has operated in simulation experiment there might be environment effects. In addition, the system can be improved by implementing the fuzzy logic controller with different types of rules and memberships. On the other hand as further development the fuzzy logic controller can be integrating with other controllers as fuzzy-PID and implementing optimization controller.

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