DEVELOPMENT OF PID-TYPE FUZZY LOGIC CONTROLLER WITH ADAPTIVE INVASIVE WEED ALGORITHM TO CONTROL OF FLEXIBLE ARM SYSTEM

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DECLARATION

I declare that this thesis entitled “DEVELOPMENT OF PID-TYPE FUZZY LOGIC CONTROLLER WITH ADAPTIVE INVASIVE WEED ALGORITHM TO CONTROL OF FLEXIBLE ARM SYSTEM is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ---

Name : ---

Date : ---

APPROVAL

I hereby declare that I have checked this report entitled “DEVELOPMENT OF ADAPTIVE INVASIVE WEED ALGORITHM WITH PID-TYPE FUZZY LOGIC CONTROLLER TO CONTROL OF FLEXIBLE ARM SYSTEM” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

Through this section, I would like to use this opportunity to express my deepest gratitude and special thanks to my supervisor, Dr. Hyreil Anuar who in spite of being busy with his duties but still took time out to hear, guide and keep me on the correct path for my final year project.

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Next, I would like to express my gratitude to my family. Due to the endless support and care, I able to complete my project with confidence.

Finally, I perceive this project as a big milestone in my study. I will strive to use gained skills and knowledge in the best possible way.

ABSTRACT

Flexible robot arm is widely used in the industry nowadays. This is because it is able to handle tasks that are difficult, dangerous or repetitive and variety manufacturing work. Therefore, the flexible robot arm is required to be highly accurate and repeatable in controlling to work like a human’s hand. This project attempts to improve accuracy and repeatability using a PID-type fuzzy logic controller (PID-FLC) and optimize by an invasive weed optimization (IWO) algorithm for a flexible robot arm. The algorithm will be validated with the design of fuzzy logic controller for a single-link flexible arm system. To simulate such system, a PID-type fuzzy logic controller will be designed in the Simulink. The proportional-integral- derivative (PID) acts as scaling gain for the fuzzy logic controller in order to normalize inputs and output and to damp oscilations of the system. Next, the IWO algorithm will be optimised the performance of PID-type fuzzy logic controller by discovering the best value of membership function for fuzzy logic controller. Last but not least, the result of PID-FLC with IWO will be evaluated and validated by inserting different value of iterations for IWO. The performance of PID-FLC is evaluated by comparing and analysing with Ziegler-Nichols tuned PID controller, PD-FLC with IWO and PID-FLC without IWO in term of rise time, overshoot and undershoot, settling time and steady state error. As a result, the most suitable iterations to get the ideal result of PID-FLC with IWO is analysed and obtained. 30 number of iterations able to generate the optimum performance of PID-FLC with less time-consuming and low cost function. Other than that, PID-FLC with IWO has better settling time and overshoot and undershoot compared to Ziegler-Nichols tuned PID controller. PID-FLC shows better performance by improving 11% of lower overshoot at first signal, 27.9% of smaller undershoot at second signal and 0.8% lower overshoot at third signal compared to PD-FLC with IWO. PID-FLC also achieved better overall performance than PID-FLC without IWO in term of rise time, settling time, overshoot and undershoot and teady-state error. However, there are some future works to be done which are comparing the performance of IWO with other biological-based algorithm and apply this optimized control system to the real model of robot arm.

ABSTRAK

Lengan robot fleksibel digunakan secara meluas dalam industri pada masa kini. Ini kerana ia dapat mengendalikan tugas-tugas yang sukar, berbahaya atau berulang dan pelbagai jenis pembuatan. Oleh itu, lengan robot fleksibel dikehendaki menjadi sangat tepat dan boleh mengawal untuk bekerja yang megulangi seperti tangan manusia. Projek ini cuba meningkatkan ketepatan dan pengulangan dengan menggunakan PID-FLC dan mengoptimumkan dengan Invasive Weed Optimization (IWO) algoritma untuk lengan robot fleksibel. Algoritma ini akan digunakan dengan reka bentuk pengawal logik fuzzy untuk sistem lengan fleksibel. Untuk mendapatkan sistem sedemikian, PID-FLC akan direka di dalam Simulink. PID bertindak sebagai penambahan skala untuk FLC untuk mengimbangkan input dan output dan juga untuk mengimbangi sistem. Seterusnya, algoritma IWO akan dioptimumkan prestasi PID-FLC dengan menemui nilai terbaik *membership function* untuk *fuzzy logic controller*. Akhir sekali, keputusan PID-FLC dengan IWO akan dinilai dan disahkan dengan memasukkan nilai *"iteration"* yang berbeza untuk IWO. Prestasi PID-FLC dievaluasi dengan membandingkan dan menganalisis dengan PD-FLC dengan IWO dan PID-FLC tanpa IWO dari segi *rise time, overshoot* dan *undershoot, settling time* dan *steady state error*. Akibatnya, *"iteration"* yang paling sesuai untuk mendapatkan hasil ideal PID-FLC dengan IWO dianalisis dan diperolehi. 30 bilangan *"iteration"* yang dapat menghasilkan prestasi optimum PID-FLC dengan masa yang lebih singkat dan "*cost function"* yang rendah. Di samping itu, PID-FLC dengan IWO menunjukkan *rise time*, *overshoot* dan *undershoot* yang lebih baik daripada *Ziegler-Nichols PID controller*. PID-FLC menunjukkan prestasi yang lebih baik dengan meningkatkan 11% daripada *overshoot* yang lebih rendah pada isyarat pertama, 27.9% daripada *undershoot* yang lebih kecil pada isyarat kedua dan 0.8% *overshoot* yang lebih rendah pada isyarat ketiga berbanding PD-FLC dengan IWO. PID-FLC juga mencapai prestasi keseluruhan yang lebih baik daripada PID-FLC tanpa IWO dari segi *rise time, overshoot* dan *undershoot, settling time* dan *steady state error*. Walau bagaimanapun, terdapat beberapa kerja masa depan yang akan dilakukan seperti membandingkan prestasi IWO dengan algoritma berasaskan biologi yang lain dan menggunakan sistem kawalan optimum ini kepada model robot lengan sebenar.

TABLE OF CONTENTS

		PAGE
DECLARATION		
APPROVAL		
DEDICATIONS		
ACKNOWLEDGEMENTS		**2**
ABSTRACT		**3**
ABSTRAK		**4**
TABLE OF CONTENTS		**5**
LIST OF TABLES		**7**
LIST OF FIGURES		**8**
LIST OF SYMBOLS AND ABBREVIATIONS		**10**
LIST OF APPENDICES		**11**
CHAPTER 1	**INTRODUCTION**	**12**
1.1	Project Background	12
1.2	Motivation	14
1.3	Problem Statement	15
1.4	Objective	16
1.5	Scope of the Project	16
CHAPTER 2	**LITERATURE REVIEW**	**17**
2.1	Introduction	17
2.2	Control System for the Manipulator	17
	2.2.1 Conventional Controller	18
	2.2.2 Fuzzy Logic Controller	20
	2.2.3 Comparison of Different Types of Controller	23
2.3	Biological-based Algorithm	25
2.4	Summary	26
CHAPTER 3	**METHODOLOGY**	**27**
3.1	Introduction	27
3.2	Simulation Tool	31
3.3	Design of Control System	31
3.4	Design of Fuzzy Logic Controller	34
3.5	PID Tuning Method	35
3.6	Invasive Weed Optimization (IWO) Algorithm	36
3.7	Summary	40

CHAPTER 4 RESULTS AND DISCUSSIONS 41
4.1 Introduction 41
4.2 Simulation Results of PID-type Fuzzy Logic Controller with IWO 42
4.3 Comparison of Performance of PID-FLC (IWO) and Ziegler-Nichols tuned PID Controller 46
4.4 Comparison of Performance of PD-FLC (IWO), PID-FLC (IWO) and PID-FLC without IWO 49
4.5 Summary 54

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 55
5.1 Conclusion 55
5.2 Future Works 56

REFERENCES 57

APPENDICES 60

LIST OF TABLES

Table 2.1 Tuning method of a PID controller 18

Table 2.2 Methods of tuning a PID controller (cont.) 19

Table 2.3 The methods of defuzzification [23] 21

Table 2.4 The comparison of IWO and different algorithm in term of performance 25

Table 3.1 Parameter of flexible manipulator 33

Table 3.2 The output of zero order Sugeno FIS 35

Table 3.3 rule-base for flexible manipulator system 35

Table 3.4 The design steps of the basic IWO algorithm [31] 36

Table 3.5 Initial Condition of IWO 39

Table 4.1 The scaling gain value of PID-FLC 42

Table 4.2 Result of PID-type fuzzy logic controller with different iteration 42

Table 4.3 Numerical results of time domain parameters of PID-FLC with IWO 45

Table 4.4 The gain values of PID controller 46

Table 4.5 Numerical results of time domain parameters of Ziegler-Nichols tuned PID controller and PID-FLC with IWO 48

Table 4.6 The scaling gain value of PID-FLC 49

Table 4.7 Simulation Result 50

Table 4.8 Numerical results of time domain parameters of PID-FLC with IWO and PD-FLC with IWO 52

LIST OF FIGURES

Figure 2.1 Blocks of a Fuzzy Controller 20

Figure 2.2 Examples of membership functions. 20

Figure 2.3 The example of whole process of Mamdani and Sugeno inference method [25] 22

Figure 3.1 The flowchart of controller design 30

Figure 3.2 Scheme of control system 31

Figure 3.3 Schematic diagram of flexible manipulator system 32

Figure 3.4 Free body diagram of flexible manipulator system [31] 32

Figure 3.5 Simulink designed block diagram of single-link flexible system 33

Figure 3.6 The membership function of error, ek and change-in-error, $\Delta e(k)$ 34

Figure 3.7 Flowchart of IWO [31] 38

Figure 4.1 The design of control system for PID-FLC 42

Figure 4.2 (a) Hub-angular transient response of PID-FLC (IWO) with 10 iterations, (b) Hub-angular transient response of PID-FLC (IWO) with 20 iterations, (c) Hub-angular transient response of PID-FLC (IWO) with 30 iterations, (d) Hub-angular transient response of PID-FLC (IWO) with 100 iterations 44

Figure 4.3 The design of control system for PID controller in Simulink 46

Figure 4.4 Transient response of Ziegler-Nichols tuned PID Controller 47

Figure 4.5 Transient response of PID-FLC with IWO 47

Figure 4.6 The design of control system for PID-FLC 49

Figure 4.7 (a) Error membership functions of PD-FLC with IWO(b) Change-in-error membership functions of PD-FLC with IWO 50

Figure 4.8 (c) Error membership functions of PID-FLC with IWO (d) Change-in-error membership function of PID-FLC with IWO 51
Figure 4.9 (c) Error membership functions of PID-FLC without IWO (d) Change-in-error membership function of PID-FLC without IWO 51
Figure 4.10 Transient response of PID-FLC with IWO and PD-FLC with IWO 51
Figure 4.11 Transient response of PID-FLC without IWO 52

LIST OF SYMBOLS AND ABBREVIATIONS

PID-FLC	-	PID fuzzy logic controller
PD-FLC	-	PD fuzzy logic controller
FLC	-	Fuzzy Logic Controller
IWO	-	Invasive weed optimization
PID	-	Proportional- Integral- Derivative
PD	-	Proportional- Derivative
PI	-	Proportional- Integral- Derivative
P	-	Proportional
I	-	Integral
D	-	Derivative
PSO	-	Particle Swarm Optimization
SMES	-	Simple Multimembered Evolution Strategy
ICMOA	-	Multi-objective optimization immune algorithm
HIWO	-	Hybrid Invasive Weed Optimization
CCIWO	-	Cooperative co-evolutionary Invasive Weed Algorithm
nFOA	-	Novel Fruit Fly Optimizationa Algorithm
HEDA	-	Hybrid Estimation of Distribution Algorithm
KMEA	-	Knowledge-based Multi-agent Evolutionary Algorithm
ANN	-	Artificial Neural Network
Kd	-	Derivative Gain
Kp	-	Proportional Gain
Ki	-	Integral Gain

LIST OF APPENDICES

APPENDIX A GANTT CHART 61

CHAPTER 1

INTRODUCTION

1.1 Project Background

Traditionally, industrial robot arms are designed based on human's arm which needed to control the location and velocity of the robot's end-effector repeatedly and accurately. Nowadays, robot arms are often used to perform complex tasks which cannot be finished by human which required a robust force control strategies. Position and velocity control in some Degree-Of-Freedom (DOF) are also essential for certain task. Therefore, the method of implementation of stable and accurate force control is an important area of robotics research in order to fulfil those extra demands. Although there are a lot of researches have been worked on enhancing on the controller, however, technological limitations of current controller causes the difficulty to achieve in practice [1]. Yet, current knowledge is applied on the controller to minimize its error as much as possible.

Because of the simple structure and robust performance of proportional- integral-derivative (PID) control in a wide range of operating conditions, PID control which act as a well-known control strategy has been widely used in the industry [6]. According to the thesis that was presented by Sena TEMEL, Semih YAĞLI and Semih GÖREN [7], there are different transient performances of P, P-D, P-I and P-I-D controller.

P controller is mainly used to decrease the steady-state error of the system. However, it cannot eliminate the steady-state error of the system and it probably will causes oscillation and amplifies process noise. P-I controller manage to eliminate the steady-state error but it will be prone to overshooting in the event of large change. P-D controller able to increase the stability of the system as it handles large changes well with minimal overshoot but have poor performance on tracking small changes or errors. For PID controller, it has the optimum control dynamics since it has 3 parameter that including zero steady-state error, fast response, no oscillations and higher stability [7].

In recent decades, a lot of researchers found that nonlinearities in a control system have causes specific phenomena where it had to be taken into account to study. It could be a useful tool to solve the delicate problem of modelling and control of the complex systems

[2]. Fuzzy logic controller (FLC) is one of the tools that able to solve the unknown nonlinearities, time delays, disturbances as well as change in system parameters and reach the desired control performance [3]. FLC a set of linguistic control rules that combine the dual concepts of fuzzy implication is and the compositional rule of inference [4]. Thus, it able to convert the linguistic control strategy according expert knowledge into an automatic control strategy by providing an algorithm.

However, at present, there is no systematic steps to design an FLC or tune the fuzzy logic for best performance. Therefore, biological-based algorithms such as an invasive weed optimization (IWO) are used for benchmark functions and tuning FLC. The design of IWO algorithm is inspired from the phenomenon of colonization of invasive weed in the nature. The colonization of invasive weed means each invading weed will take the unused resources in the field and start to grow. As it grows to a flowering weed, it will start to produces new weeds. The weeds with better adoption to the environment will take more resources and produces more seeds until it spreads over the field. In the end, only the weeds that have better fitness can survive [5]. Therefore, by using its properties, the system will become well adapted and improved over time.

1.2 Motivation

In 1960s, a robotic arm which is developed by Joseph Engelberger [8] is mass produced for factory automation. Robotics manipulators and robotics arms are used in the industry since 1960s. Although the robotics arms were first designed for manufacturing and production process, however, there are a lot of robotics arms have been developed for other purpose nowadays. For example, robot arm that are used for defusing bombs by military and the assistive robotics arm by JACO [9] that able to help individuals with disabilities. Other than that, there are other robotic arms that are used in daily life or help to work in project such as Care-O-bot [10] and also mobile manipulator robot PR2 by Willow Garage [11].

Robotic arms can be found in every field such as manufacturing, military, medical field and so on. This is because it has the ability to work in environments that are inhospitable to human, freedom form human limitation, high accuracy and precision and also high production rate [12]. In this recent years, the rise of China automation demand has push the market into a growth super-cycle of robotics due to China is the largest purchaser of robotic arms. According to the research that done by IDTechEx [13], the rise of the automation demand will emerged a new class of robots that are collaborative, mobile and increasingly intelligent. This new robots will then causes the overall market grow by a factor of nearly 3 and 7 in next 10 and 20 years [13].

In order to let robotic arm performs and complete tasks more precisely, accurately and efficiently, thus, a good quality of system is needed. First of all, more researches of the controller of robotic arm system are done to obtain more knowledge and information that enhance the quality of the system as well as the performance of robotic arm.

The main purpose of this project is to design a PID-type fuzzy controller (PID-FLC) with invasive weed optimization (IWO) to enhance the quality of robotic arm system in term of accuracy and its performance will be compared. MATLAB is used for simulation of the controller.

1.3 Problem Statement

Proportional- integral- derivative (PID) controller is the one of the most common type of controller that can be found in the industry. PID controller is used to control dynamic processes with variable at wide limits parameters and uncontrolled violations in the process control systems.

However, PID controller required a calibration procedure, level of knowledge of dynamics of the controlled process in order to choose the correct parameters of the regulator. It becomes a main problem to the most of regulators that have been used in the industry due to lack of knowledge of finding correct parameters for the regulator [14]. It also causes each regulator only capable to do one task because of unable to adjust the parameters of the regulator.

Although fuzzy logic controller (FLC) is getting popular to replace PID controller, but it also faced with a problem of the tuning. Due to it implies the handling of a great quantity of variables such as the shape, number and range of the membership function, the percentage of overlap among them need to be determined and rule base need to be designed as well. The problem will become more complicated when it need to control multivariable systems [15].

Therefore, the main efforts of this project is focused on design the FLC for automatic adjustment of regulators. The problem of tuning of the fuzzy logic also need to be solved throughout this project. Finally, the controller will be analysed and compared to show its improvement.

1.4 Objective

1. To design PID type fuzzy logic controller for flexible arm system

2. To validate the performance of PID type fuzzy logic controller with IWO for flexible arm system.

3. To compare the performance of the designed PID-type fuzzy logic controller with IWO with Ziegler-Nichols tuned PID Controller, PD-type fuzzy logic controller with IWO and PID-type fuzzy logic controller without IWO.

1.5 Scope of the Project

There are few scopes of this project. First and foremost, the construction of the flexible arm system is only focused on one-link flexible robot arm. Besides, the rotation of flexible arm system is limited in between -90 degree to 90 degree. This project will cover the comparison of the result of PID-FLC with IWO with Ziegler-Nichols tuned PID controller, PD-FLC with IWO and PID-FLC without IWO. All the result from simulation will be done by using Matlab and Simulink. Therefore, there is no hardware configuration for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

After discovering the problem of control system to control flexible robot arm and motivation on developing better solution for flexible robot arm, a review of previous related works will be discussed and compared each other to find a better method to optimize the controller. In this chapter, the background of controller will be briefly explained for a better understanding. Besides, researches that have been done also can obtain useful information by synthesizing their works to make this project successful.

2.2 Control System for the Manipulator

A control system for the manipulator is necessary in order to move the robot with planned trajectory or maintain a robot in a desired dynamic behaviour. The forming of the controlled variable will causes the different of accuracy of motion along on the output of the system required. Therefore, there are different methods are used to overcome the control problem of manipulators as well as increase its accuracy. Generally, proportional- integral-derivative (PID) controller is used in most of the manipulators due to its effectiveness on the torque calculation. However, this method required a time-consuming process and level of knowledge of dynamics of the controlled process to derive the model of the manipulator system.

Hence, artificial intelligence technique such as fuzzy logic and neural network are applied on the controller to replace the PID controller. Fuzzy logic allows the system to make definite decisions based on imprecise or ambiguous data but it is difficult to define the fuzzy parameter. For artificial neural network (ANN), there are some factors has to be considered which are the complexity models of the system which will make the learning process harder and choosing the suitability of learning algorithm to the models [16].

2.2.1 Conventional Controller

During the 1930, PID controller become popular and gained widespread in industrial acceptance due to the benefits of this controller such as simplicity, robustness and wide applicability. After that, there are many various tuning methods for this controller have been proposed. The purpose of tuning a PID controller is to gain a better control system response based on desirable control objectives such as percent of overshoot, rise time, settling time, manipulated variable behaviour and steady state error. Table 2.1 is tabulated to show different tuning methods a PID controller and compare their performances.

Table 2.1 Tuning method of a PID controller

<table>
<tr><th>Tuning Method</th><th>Explanation</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Closed-loop Ziegler-Nichols Method [20]</td><td>is a trial and error tuning method based on sustained oscillations
Obtain the ultimate gain, Ku and frequency, Pu
Apply gain to the controller setting, the controller parameters can be obtained.
controller setting:
<table>
<tr><th>Controller</th><th>k_c</th><th>τ_I</th><th>τ_D</th></tr>
<tr><td>P</td><td>$0.5k_{cu}$</td><td>-</td><td>-</td></tr>
<tr><td>PI</td><td>$0.45k_{cu}$</td><td>$P_u/1.2$</td><td>-</td></tr>
<tr><td>PID</td><td>$0.6k_{cu}$</td><td>$P_u/2$</td><td>$P_u/8$</td></tr>
</table></td><td>do not require the process model</td><td>time – consuming, force the system to margin if instability, not applicable for unstable open loop processes</td></tr>
<tr><td>Tyreus – Luyben Method [20]</td><td>similar steps as Ziegler- Nichols method but different controller parameter setting
Only for PI and PID controller
controller setting:
<table>
<tr><th>Controller</th><th>k_c</th><th>τ_I</th><th>τ_D</th></tr>
<tr><td>PI</td><td>$k_{cu}/3.2$</td><td>$2.2P_u$</td><td>-</td></tr>
<tr><td>PID</td><td>$k_{cu}/3.2$</td><td>$2.2P_u$</td><td>$P_u/6.3$</td></tr>
</table></td><td>lesser settling time, overshoot and wildness than Z-N method</td><td>time-consuming and force the system to margin if instability</td></tr>
</table>

Table 2.2 Methods of tuning a PID controller (cont.)

<table>
<tr><th>Tuning Method</th><th>Explanation</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Damped Oscillation Method [20]</td><td>obtain the parameters of Gd and Pd.
Gd = Proportional gain at decay ratio of ¼
Pd= Period of oscillation
Apply gain to controller setting and obtain the controller parameter
controller setting:
<table>
<tr><th>Controller</th><th>k_c</th><th>τ_I</th><th>τ_I</th></tr>
<tr><td>P</td><td>$1.1G_d$</td><td>-</td><td>-</td></tr>
<tr><td>PI</td><td>$1.1G_d$</td><td>$P_d/2.6$</td><td>-</td></tr>
<tr><td>PID</td><td>$1.1G_d$</td><td>$P_d/3.6$</td><td>$P_d/9$</td></tr>
</table></td><td>solve the problem of marginal stability</td><td>more suitable for first order system</td></tr>
<tr><td>Cohen- Coon Method [21]</td><td>process reaction curve by first order plus dead time model
determining of three parameters of km , τm and d
Apply to the Cohen –Coon controller setting to get the controller parameter
Cohen –Coon controller setting:
<table>
<tr><th>Controller Type</th><th>k_c</th><th>τ_I</th><th>τ_D</th></tr>
<tr><td>P</td><td>$\frac{1}{K_m}\frac{\tau_m}{d}(1+\frac{d}{3\tau_m})$</td><td>-</td><td>-</td></tr>
<tr><td>PI</td><td>$\frac{1}{K_m}\frac{\tau_m}{d}(\frac{9}{10}+\frac{d}{12\tau_m})$</td><td>$d\frac{30+3d_m/\tau_m}{9+20d_m/\tau_m}$</td><td>-</td></tr>
<tr><td>PD</td><td>$\frac{1}{K_m}\frac{\tau_m}{d}(\frac{5}{4}+\frac{d}{6\tau_m})$</td><td>-</td><td>$d\frac{6-2d/\tau_m}{22+3d/\tau_m}$</td></tr>
<tr><td>PID</td><td>$\frac{1}{K_m}\frac{\tau_m}{d}(\frac{4}{3}+\frac{d}{4\tau_m})$</td><td>$d\frac{32+6d/\tau_m}{13+8d/\tau_m}$</td><td>$d\frac{4}{11+2d/\tau_m}$</td></tr>
</table></td><td>provides a good approximation to process reaction curve and fast ast response</td><td>less robust than Z-N method</td></tr>
</table>

As mentioned before, P controller is mainly used to decrease the steady-state error of the system but unable to eliminate the steady-state error of the system. P-I controller manage to eliminate the steady-state error and tracking small change error but lead to high overshoot of the system. P-D controller able to increase the stability of the system as it handles large changes well with minimal overshoot but have poor performance on tracking small changes or errors. For PID controller, it has the optimum control dynamics since it has 3 parameter that including zero steady-state error, fast response, no oscillations and higher stability.

2.2.2 Fuzzy Logic Controller

The blocks of a FLC is shown in Figure 2.1. Each of the block has its own characteristic.

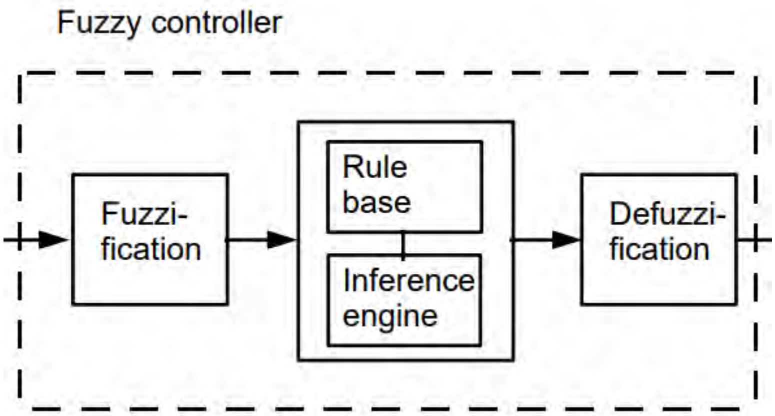

Figure 2.1Blocks of a Fuzzy Controller

The first block inside the controller is fuzzification which used to converts every input data to degrees of membership by a lookup in one or more membership functions [19]. The fuzzification block will then compare the input data with the conditions of the rules to determine the fitness of each rule into the particular input instance [19]. However, there are several typical shapes of membership functions which is shown in Figure 2.2. The suitable form of membership function need to be selected for certain problem in order to achieve the best performance.

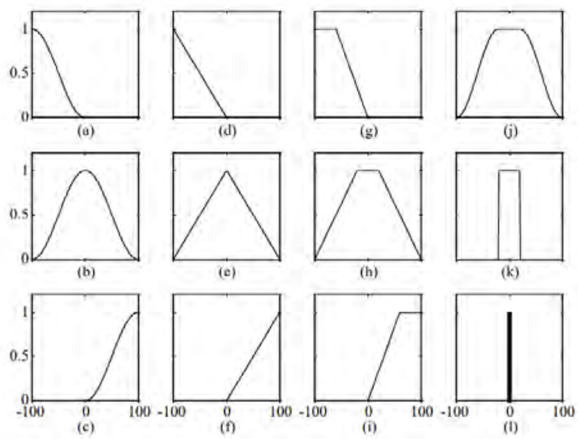

Figure 2.2Examples of membership functions.