FUZZY LOGIC CONTROLLER SIMULATION

FOR

WATER TANK LEVEL CONTROL

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Specially dedicated to

My beloved family and those people who have guided and inspired me

throughout my journey of education

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ABSTRACT

In control systems there are a number of generic systems and methods which are encountered in all areas of industry and technology. From the dozens of ways to control any system, it turns out that fuzzy is often the very best way. The only reasons are faster and cheaper. One of successful application that used fuzzy control is water tank level control. The purpose of this project is to design a simulation system of fuzzy logic controller for water tank level control by using simulation package which is Fuzzy Logic Toolbox and Simulink.in MATLAB software. In order to find the best design to stabilize the water level in the system, some factors will be considered. For this project, the water level was controlled by using three rules of membership function which then extended to five rules and seven rules for verification purpose and further improvement of the system. Besides that, several of different methods also been used in order to design the most stabilize system and this project was focused to the software part only. By doing some modification of this project, the design will be very useful for the system relates to liquid level control that widely use in industry nowadays.

ABSTRAK

Dalam industri masa kini terdapat banyak kaedah yang digunakan dalam aplikasi sistem kawalan. Daripada senarai tersebut, masih ramai yang memilih sistem *"fuzzy"* sebagai kaedah yang terbaik memandangkan sistem ini mudah dan rendah kos. Salah satu contoh aplikasi sistem ini adalah untuk mengawal aras air dalam sistem tangki air. Objektif utama projek ini adalah untuk membina satu sistem simulasi yang mengawal aras air dalam sesebuah sistem tangki air berasaskan sistem *"fuzzy"* dengan menggunakan *"Fuzzy Logic Toolbox"* dan *"Simulink"* dari perisian MATLAB. Beberapa faktor telah dipertimbangkan dalam usaha membina sistem yang stabil untuk mengawal aras air tersebut. Untuk projek ini, aras air dikawal oleh tiga peraturan. Seterusnya lima dan tujuh peraturan diambil kira untuk tujuan pembuktian dan mempertingkatkan kestabilan sistem. Selain itu, beberape kaedah lain juga diguna pakai untuk mencari sistem yang terbaik dalam mengawal aras air di dalam tangki and projek ini juga hanya tertumpu kepada bahagian simulasi sahaja. Dengan membuat sedikit pengubahsuaian pada projek ini, dijangkakan ianya amat berguna dalam aplikasi pengawalan aras cecair yang banyak digunakan di industri masa kini.

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ABBREVIATIONS

FLC   -   Fuzzy Logic Controller

PID   -   Proportional, Integral and Derivative

SPC   -   Smith Predictor Controller

ANFIS   -   Adaptive Neuro-Fuzzy Inference System

GUI   -   Graphical User Interface

MIMO   -   Multiinput Multioutput

FARMA   -   Fuzzy Auto-Regressive Moving Average

CHAPTER 1

INTRODUCTION TO FUZZY LOGIC

1.1   Overview

Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions [1]. Computers can interpret only true or false values but a human being can reason the degree of truth or degree of falseness. Fuzzy models interpret the human actions and are also called intelligent systems.

Fuzzy or multi-valued logic was introduced in the 1930s by Jan Lukasiewicz, a Polish philosopher [2]. While classical logic operates with only two values 1(true) and 0(false), Lukasiewicz introduced logic that extended the range of truth values to all real numbers in the interval between 0 and 1. He used a number in this interval to represent the possibility that a given statement was true or false.

Later in 1937, Max Black published a paper called "Vagueness; an exercise in logical analysis". In this paper, he argued that a continuum implies degrees. He accepted vagueness as a matter of probability.

Fuzzy system was first proposed by an American professor, Lotfi A. Zadeh, in 1965 when he presented his seminal paper on "fuzzy sets"[1]. Zadeh showed that

fuzzy logic unlike classical logic can realize values between false (0) and true (1). Basically, he transformed the crisp set into the continuous set. Zadeh extended the work on possibility theory into a formal system of mathematical logic, and introduced a new concept for applying natural language terms, and he became the Master of fuzzy logic. Fuzzy sets thus have movable boundaries. The elements of such sets not only represent true or false values but also represent the degree of truth or degree of falseness for each input.

Although an American professor introduced the fuzzy logic theory where it was first implemented in the control of cement kilns in Denmark in 1977 but the Japanese were successful in applying fuzzy logic in commercial goods like automobiles and washing machines and their current fuzzy logic market is estimated around 2 billion dollars[2]. America has been left behind in the implementation of fuzzy logic to real world problems.

For the application of fuzzy logic, it mostly been applied to control systems field. Fuzzy control systems interpret the expert human and replace them for performing certain tasks such as control of a power plant. Fuzzy controllers apply decision rules (if-then rules) by making use of critical variables to interpolate the output between the crisp boundaries.

Fuzzy logic is not logic that is fuzzy, but logic that is used to describe fuzziness. Fuzzy logic is the theory of fuzzy sets, sets that calibrate vagueness [3]. It is based on the idea that all things admit of degrees. In other words, fuzzy logic is a set of mathematical principles for knowledge representation based on degrees of membership. Fuzzy logic reflects how people think. It attempts to model our sense of words, our decision making and our common sense. As a result, it is leading to new, more human, intelligent systems.

While modern control theory has made modest inroad into practice, fuzzy logic control has been rapidly gaining popularity among practicing engineers. This increased popularity can be attributed to the fact that fuzzy logic provides a powerful vehicle that allows engineers to incorporate human reasoning in the control algorithm.

As opposed to the modern control theory, fuzzy logic design is not based on the mathematical model of the process. The controller designed using fuzzy logic implements human reasoning that has been programmed into fuzzy logic language (membership functions, rules and the rule interpretation). It is interesting to note that the success of fuzzy logic control is largely due to the awareness to its many industrial applications.

Industrial interests in fuzzy logic control as evidenced by the many publications on the subject in the control literature have created an awareness of its increasing importance by the academic community. Starting in the early 90s, the Applied Control Research Lab. at Cleveland State University, supported by industry partners, initiated a research program investigating the role of fuzzy logic in industrial control [2].

1.2   Objective

The aim of this project is to perform a design simulation of fuzzy logic controller for stabilizing the water tank level control which is done by using MATLAB/Simulink, Fuzzy Logic Toolbox packages and MATLAB programming. This is a simple and easy approach to know more about water level system, including its level movements, valve setting, data consistency and also about the rules of the variables. The purpose of this project is to provide a feasibility study on the water level control simulation based on Fuzzy Logic expert system.

In order to achieve the project main objectives, there are some tasks that have to be done. The overall structure of the project will basically based on following:

1.   Understand the foundation of fuzzy logic which covers the introduction to the general concepts.

2.   Study and familiar with the fuzzy inference system which consists of methods of fuzzy inference used in the Fuzzy Logic Toolbox. Since the

field of fuzzy logic uses many terms that do not yet have standard interpretations, so this step should be considered to become familiar with the fuzzy inference procedures and process.

3. Building system with the Fuzzy Logic Toolbox which goes into detail about the step taken to build and edit the fuzzy system using the toolbox.

4. Building the system with Fuzzy Logic Controller with Rule Viewer blocks using Simulink and integrates it with Fuzzy Logic Toolbox.

5. Evaluate the result obtained from the simulation.

This project will be discussing and analyzing the result obtained to verify below mentioned items:

1. Run the system using different numbers of rules to prove that the more accurate result can be obtained by adding the number of rules.

2. Use several different methods and fuzzy membership functions to find the best method that should be used for the system to get the most accurate result as required.

1.3   Scope

The scope of project is to encode the fuzzy sets, fuzzy rules and procedures. Then perform fuzzy inference into the expert system (Fuzzy Logic Toolbox). The task is to design and display the simulation of the fuzzy logic controller for water level tank control and the result of the simulation will be display by using Rule Viewer and Surface Viewer which are parts of the graphical user interface (GUI) tools in Fuzzy Logic Toolbox in MATLAB programmed. This project is designed to make use of the great advantages of the Fuzzy Logic Toolbox and integrate it with SIMULINK which is also in MATLAB programmed. The Fuzzy Logic Toolbox has

the ability to take fuzzy systems directly into Simulink and test them out in a simulation environment.

The simulation will display the animation of the water tank level that controlled based on the rules of fuzzy sets. This project covers the processes of developing the application of fuzzy expert system in water tank level control. It starts from the theory until it implemented into the simulation environment.

In addition, this project also makes the analysis of the variety results that obtained from system. Different numbers of rules that used in the system will give the different result, so the analysis for results will be conducted.

Besides that, this system will be also tested by using different types of methods and membership functions. The purpose is to find the best way to get the result as close as the requirement for stability of the level control for the water tank system.

1.4   Problem Statement

Combined water tank systems are used in many resident areas. Most of the time they are functioning well, but there are some condition that the system faces the problem of overflows because of the system cannot detect whether the water level have properly reach the desired level or the flow-in rate of the water are not proportional with the flow-out rate. It can cause the water tank system empties faster than it fills up. Consequently, the pressure of the water cannot support the distribution of the water to the resident area.

Construction of new tank, valve or system could be the solution to completely eliminate the problems. However, such schemes are expensive and can also be extremely disruptive because the system networks may extend across wide geographical areas. Alternatively, controlling the flow between parts of the system which are under different loading can reduce the overflow spills. Actuated valve can be opened or closed to control the flow past a certain point.

The implementation of the Fuzzy Logic Controller in water tank level control system can be used to overcome this problem. By doing some modification of this project, the problem can be solved in the simplest and cheapest possible controller for a given application. The basic idea is still the same and the modification will be made depends on the design expectation.

One interesting features of this water tank system is that the tank empties much more slowly than it fills up because of the specific value of the outflow diameter pipe. It can deal with this by setting of the valve membership function.

Although this project only focusing on software simulation not really on the hardware, but this is the best step that should be considered before any implementation of the system be constructed. By testing the system in this simulation area, the expected output from the input can be set earlier based on the rules set. The uses of MATLAB card is most required in order to integrate the software and hardware parts of the system and the cost of MATLAB card is quite high. Besides that, the hardware implementation of the simulated design is also requires a longer time. Those are the reasons why this project will be concentrate on the software simulation part only.

1.5   Thesis Organization

This thesis consists of five chapters including this chapter. The content of each chapters are outlined as follows:

Chapter 2introducing about the Fuzzy Logic Toolbox. This chapter will describing all the terms that been used in the toolbox.

Chapter 3 introducing the background knowledge and literature review of Fuzzy Logic Toolbox and Simulink in MATLAB programmed software.

Chapter 4, will be including the project methodology. This will explain how the project is organized and the flow of simulation design including the steps on how the system is build.

Chapter 5, where the result for the system will be discussed and analyzed.

Chapter 6, will discussed about the conclusion that can be made of all about the project that have been completed.

CHAPTER 2

INTRODUCTION TO FUZZY LOGIC TOOLBOX

2.1   Introduction

Fuzzy Logic Toolbox allows several things to be done, but the most important things are to be a place where a fuzzy inference system can be created or edited. These systems can be created by using graphical tools or command-line functions, or even can be automatically generated by using either clustering or adaptive neuro-fuzzy techniques.

The fuzzy system that has been accessed to Simulink can be easily tested in a block diagram simulation environment. The toolbox also allows the stand-alone C programs to be run without the need of Simulink. This is made possible by a stand-alone Fuzzy Inference Engine that reads the fuzzy systems saved from a MATLAB session. The stand-alone engine can be customized in order to build fuzzy inference into code.
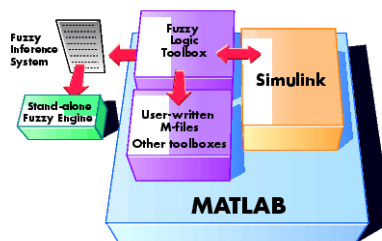

Figure 2.1   Figure above shows how MATLAB packages can be linked

2.2   Foundation of Fuzzy Logic

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary [13]. It can contain elements with only a partial degree of membership. Unlike classical set theory that classifies the elements of the set into crisp set, fuzzy set has an ability to classify elements into a continuous set using the concept of degree of membership. The characteristic function or membership function not only gives 0 or 1 but can also give values between 0 and 1.

A fuzzy set is a set with fuzzy boundaries. In fuzzy logic, the truth of any statement becomes a matter of degree. Any statement can be fuzzy. A value between 0 and 1 represents the degree of membership, also called membership value. For this water tank level control simulation system, the fuzzy boundaries can be considered according to the rules that are going to be used. As the numbers of rules increased, the degree of membership will become more accurate.

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (degree of membership) between 0 and 1 [13]. The input space is sometimes referred to as the universe of discourse. The only condition a membership function must really satisfy is that it must vary between 0 and 1. The function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency. A classical set might be expressed as

$$A = \{x \mid x > 6\}$$

A fuzzy set is an extension of a classical set. If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs.

$$A = \{x, \mu_A(x) \mid x \in X\}$$

$\mu_A(x)$ is called the membership function (or MF) of x in A. The membership function maps each element of X to a membership value between 0 and 1.

The Fuzzy Logic Toolbox includes 11 built-in membership function types. These 11 functions are built from several basic functions which are piecewise linear functions, the Gaussian distribution function, the sigmoid curve, quadratic and cubic polynomial curves.

There is a very wide selection to choose from these membership functions. Membership function can be created in Fuzzy Logic Toolbox, but for this project, only three out of these 11 membership functions will be used which are triangular, trapezoidal and Gaussian. These three membership function are chosen because of the simplicity and based on the parameters used for this system. A membership function associated with a given fuzzy set maps an input value to its appropriate membership value.

The most important thing to realize about fuzzy logical reasoning is the fact that it is a superset of standard Boolean logic. In other words, if the fuzzy values are kept at their extremes of 1 (completely true), and 0 (completely false), standard logical operations will hold. As an example, consider the standard truth tables below.

Table 2.1   Truth tables for AND, OR and NOT

Fuzzy logic is the truth of any statement is a matter of degree [14]. The input values can be real numbers between 0 and 1. The tables now can be altered by replacing the AND truth table with *min* operation. That will resolve the statement A AND B, where A and B are limited to the range (0,1), by using the function *min(A,B)*. Using the same reasoning, we can replace the OR operation with the *max*

function, so that *A* OR *B* becomes equivalent to *max(A,B)*. Finally, the operation NOT *A* becomes equivalent to the operation *1-A*. Notice how the truth table above is completely unchanged by this substitution.

Table 2.2 Truth tables for AND, OR and NOT after substation.

Moreover, since there is a function behind the truth table rather than just the truth table itself, the values other than 1 and 0 now can be considered. The next figure uses a graph to show the same information. The truth table have been converted to a plot of two fuzzy sets applied together to create one fuzzy set. The upper part of the figure displays plots corresponding the two-valued truth tables above, while the lower part of the figure displays how the operations work over a continuously varying range of truth values A and B according to the fuzzy operation that have defined before.
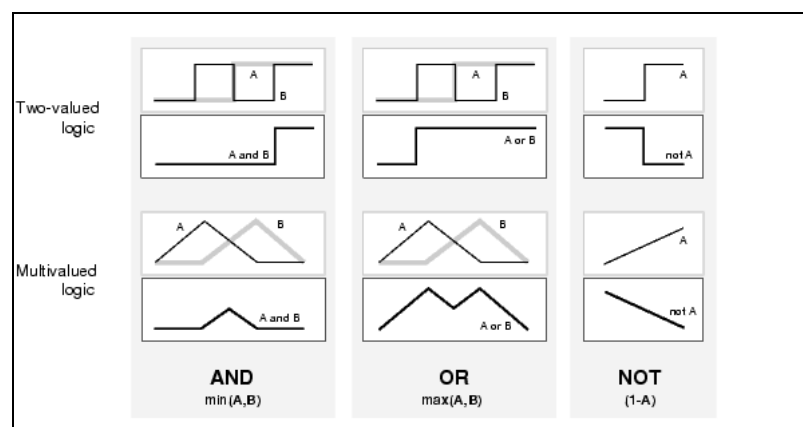

Figure 2.2 Figure shows the two-valued and multivalued logic for AND, OR and NOT

Given these three function, any construction now can be resolved by using fuzzy sets and the fuzzy logical operation AND, OR and NOT. That is how the fuzzy operator will be used in this system. After making some studies on this part, only one fuzzy logical operation is considered suitable for this water tank level control system. AND operation is used to get the minimum value of multivalued logic. More information will be discussed on this part in next chapter.

Fuzzy sets and fuzzy operators are the subjects and verb of fuzzy logic. These if-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule assumes the form

if x is A then y is B

where A and B are linguistic values defined by fuzzy sets on the range X and Y. The if-part of the rule "x is A" is called the *antecedent* or premise, while the then-part of the rule "y is B" is called the *consequent* or conclusion.

In general, one rule by itself doesn't do much good. What needed are two or more rules that can play off one another. The output of each rule is a fuzzy set. The output fuzzy sets for each rule are then *aggregated* into a single output fuzzy set. Finally the resulting set is *defuzzified*, or resolved to a single number.

2.3   Fuzzy Inference System

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces which are membership functions, fuzzy logic operators, and if-then rules. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined.