Development of Fuzzy Logic Water Bath Temperature Controller using MATLAB

Norhaslinda Hasim
Department of Control and Automation, Faculty of
Electrical Engineering, Universiti Teknikal Malaysia
Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka,
Malaysia.
norhaslinda@utem.edu.my

Mohd Zamzuri Ab Rashid
Department of Mechatronics, Faculty of Electrical
Engineering, Universiti Teknikal Malaysia Melaka, Hang
Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
zamzuri@utem.edu.my

Mohd Shahrieel Mohd Aras
Department of Mechatronics, Faculty of Electrical
Engineering, Universiti Teknikal Malaysia Melaka, Hang
Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
shahrieel@utem.edu.my

Anuar Mohamed Kassim
Department of Mechatronics, Faculty of Electrical
Engineering, Universiti Teknikal Malaysia Melaka, Hang
Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
anuar@utem.edu.my

Dr Shahrum Shah Abdullah
Department of Electric and Electronics,
Malaysia-Japan International Institute of Technology,
Universiti Teknologi Malaysia, International Campus Jalan Semarak,
54100 Kuala Lumpur, Malaysia
shahrum@ic.utm.my

Abstract— **In this paper, the development of a water bath temperature system to control the liquid's temperature in the water bath will be presented. In order to develop the water bath temperature control system, MATLAB fuzzy logic toolbox will be utilized. The Fuzzy Logic Controller (FLC) is designed to control water temperature based on the input acquired from the thermal transducer sensor. The inference engines that are used are; Max-min (Mamdani) method and centre of gravity technique for defuzzification. The 4 x 4 matrix rules for the controller will be used in this project. In addition, the USB NI-DAQ card will be used as xPC target to link the MATLAB software and real time application. The real time output temperature is validated based on the simulation's temperature which is initially set by user. It can be concluded the performance of real time study is in par with the simulation result.**

Index Terms- Temperature Control; fuzzy logic controller; Water bath System

I. INTRODUCTION

Water baths are used in industrial clinical laboratories, academic facilities, government research laboratories environmental applications as well as food technology and wastewater plants[1][3-5]. Because water retains heat so well, using water baths was one of the very first means of incubation. Applications of water bath include sample thawing, bacteriological examinations, warming reagents; coli form determinations and microbiological assays [6][10- 11].

The first thing to consider when purchasing a water bath is the electronics part. Digital control systems provide greater temperature uniformity, stability and control. Constant temperature digital water baths are suited to a host of applications, including bacteriological examinations, food processing/QC procedures and microbiology assays, just to name a few [9].

In this paper, the system will be designed using MATLAB fuzzy logic toolbox for a fuzzy logic control system based on temperature (water) to output the temperature of water bath. When the water level in water tank is full, the heater should turn to the highest temperature. The level sensor on the water bath not implemented yet and using manual to control the level of water in the water bath system. The schematics of water bath control system shown in Figure 1.

The design of this system will mainly based on assumption of initial water temperature and the initial amount of water. The output of the water bath temperature is based on people's need. It is also depends on the surrounding temperature whether it has a cold surrounding or hot temperature. Therefore, the objective of this system is to control the water bath temperature according to the needs of people.

This paper is organized as follows. Section 1 and 2 describe brief introduction of water bath system. Section 3 describes simulation results using the MATLAB software and hardware implementation with field testing results. Finally, section 4 shows the final remarks.
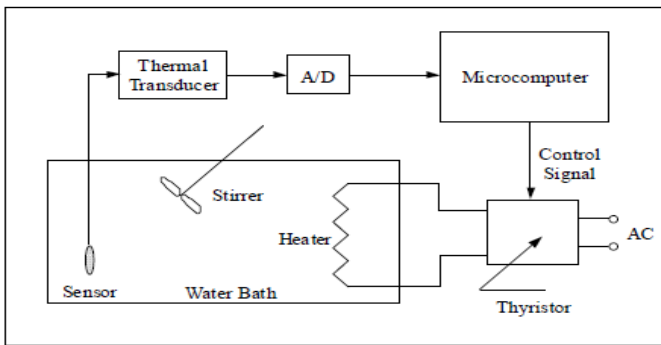
Figure 1: Schematic of water bath control system

II WATER BATH SYTEM

The primary objective of this project is to setup a water bath, interfacing system and the server in the lab located in University Teknikal Malaysia Melaka. The water bath consists of the water tank itself, a temperature sensor (RTD), a heater and a stirrer[1]. An interface system will also be mounted so that the water bath can be controlled through the server computer using the GUI module developed. The development of GUI module can be referred to [1]. Figure 2 shows the water bath wiring system.
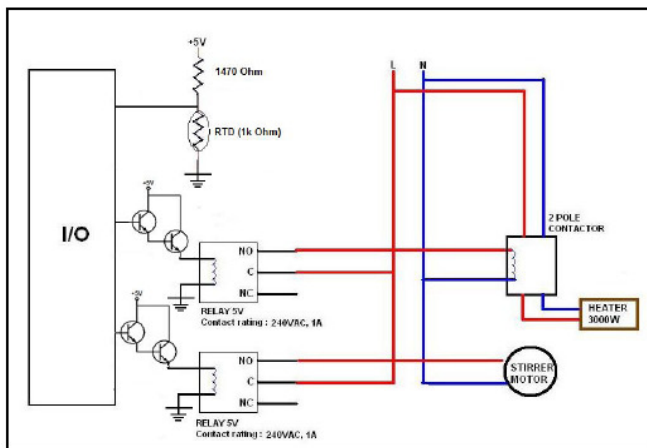
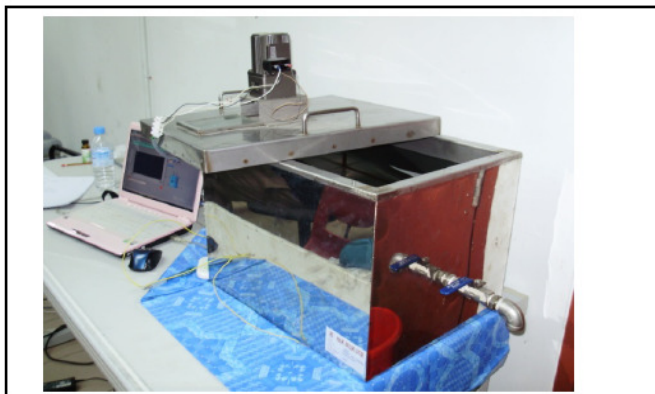Figure 2: Water bath wiring system

Figure 3: Complete of Water bath System

Figure 4: Motor 12V for stirrer

Figure 5: Controller module using USB NI-DAQ card

Figure 6: Inside of water bath system (Sensor, Heater and Stirrer).

The complete system of water bath system are shown in Figure 3 until Figure 6. Figure 3 shows the complete system of water bath while Figure 4, 6 shows the components of water bath system. Figure 5 shows the control and data acquisition card using NI DAQ 6009.

III SYSTEM DESIGN CONCEPT

This system will be design using MATLAB fuzzy tools using FIS (Fuzzy Inference System) and M-file in this paper. The design on the MATLAB itself is using the FLC (Fuzzy Logic Controller) to exert a block diagram based on the problem.

A. Main Idea FLC

In this section, the main ideas underlying the FLC will be presented. To highlight the issues involved, Figure 7 shows the basic configuration of an FLC, which comprises four principal components: a *fuzzification interface, a knowledge base*, *decision making logic,* and a *defuzzification interface*.[2]
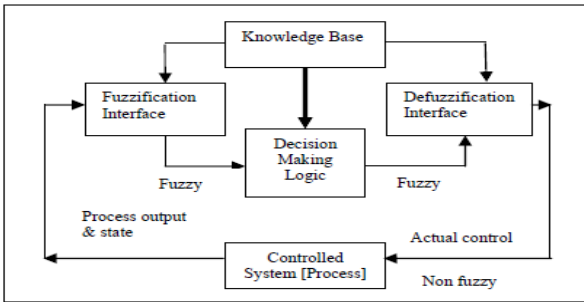
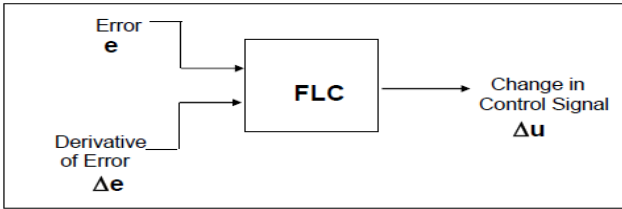Figure 7: Block diagram for Fuzzy Logic Architecture

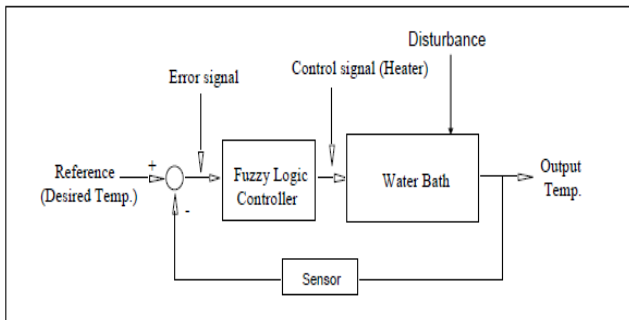Figure 8: Block Diagram of system design concept

Figure 9: Block diagram of the water bath temperature control system

There are two inputs and single output will be design in FLC system as shown in Figure 8. The inputs is the error and the change of error while the output is the change in control signal. The main idea is highlighted in Figure 9. The FLC system will be implemented on water bath system through Fig 9.

IV   DESIGN METHODOLOGY

Input 1 is the error (temperature). It will divided into 3 triangular membership functions and 1 trapezium membership function which named as normal, warm, hot and very hot. Input 2 is the change of error (water level in the tank) into 4 triangular membership functions as well which named as low, medium, high and very high. This 2 inputs will output a triangle membership function which is the control signal (water temperature of a water bath). The output is divided into 4 membership functions as well which are normal, warm, hot, and very hot. This system will be using Mamdani inference engine. There will be 16 rules applied between input 1 and input 2. The rules that will be includes in the system are shown in Figure 11.
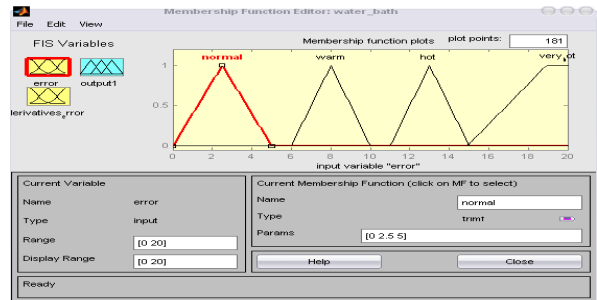
(a) Input variable - error temperature
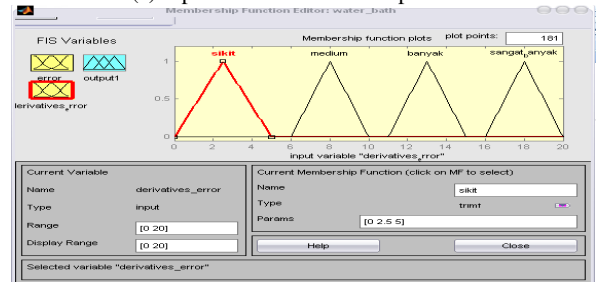
(b) Input variable - change of error
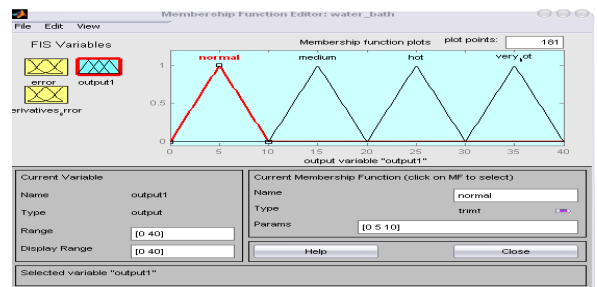
(c) Output Variable
Figure 10: Input and output membership functions

Figure 11: Rules Matrix

From Figure 10, the input and the output is designed in triangular membership function and no overlap between them. This is because the system is more accurate and no doubtful when defuzzification is applied.

A.   *MATLAB M-File*

Other than using MATLAB GUI (graphic user interface) which is FIS, MATLAB also able to create a fuzzy logic controller using M-file which coding is only what needed in this method and its will all result after debugging the M-file. However, the result is the same as using MATLAB GUI but this design method is slow compare to FIS.

B.   *Labview Software*

The block diagram of the water-bath control system for this project is shown in Figure 12. The desired temperature can be selected by key in the desired values. In addition, the current temperature can be monitored through the indicator shown. The response between the set point and process variable can be monitored in the waveform graph. Figure 13 shows the rule base for the control system. From the Rulebase Editor front panel, the defuzzification method and inference method can be selected. In this case, Center of Gravity defuzzification and Max-min inference method are chosen.
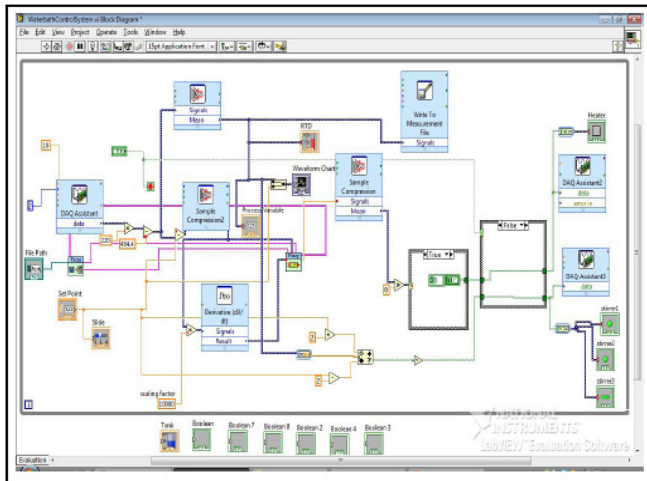
Figure 12: Labview Software

Figure 13: Rules based set up on LabView

VI.   RESULT

The expected result of the whole system can be simplified and categorized as the following table;

Table 1: Summarize the system expected result

Very hot	$31-40$
Hot	$21-30$
Warm	$11-20$
Normal	$0-10$

Output (Water Temperature)

Table 2: Rules for Output

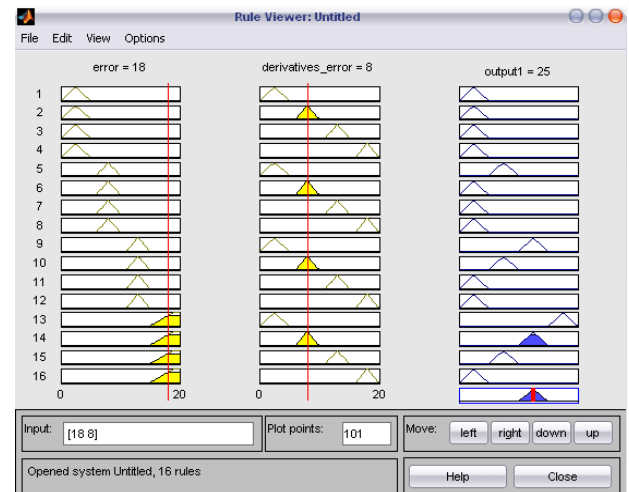| Input 2 \ Input 1	$0-5$ (Normal)	$6-10$ (Warm)	$11-15$ (Hot)	$16-20$ (Very hot)
$0-5$ (Low)	$0-10$	$11-20$	$21-30$	$31-40$
$6-10$ (Medium)	$0-10$	$0-10$	$11-20$	$21-30$
$11-15$ (High)	$0-10$	$0-10$	$0-10$	$11-20$
$16-20$ (Very High)	$0-10$	$0-10$	$0-10$	$0-10$

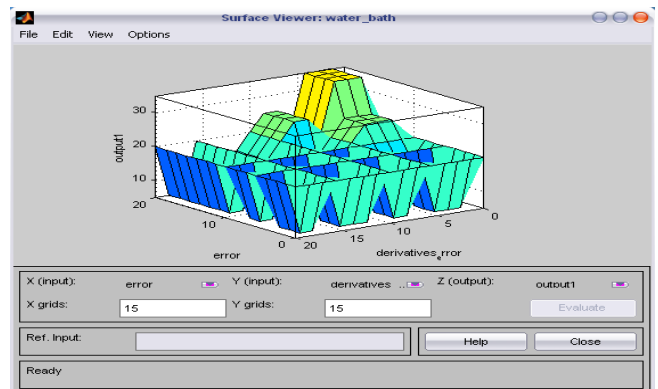Figure 14: Rules and result of the system on MATLAB rules viewer.

Figure 15: Surface viewer of the system.

The summary of rules and result can be output in MATLAB rules view of the FIS tools. The overall of the result can be shown in surface viewer of MATLAB surface viewer. The waveform signal when the set point was 50ºC is depicted in Figure 16. The figure shows temperature versus number of data taken during the experiment. From the waveform, it can be seen that the initial temperature was a room temperature which is 30°C. After the set point was set to 50ºC, the fuzzy controller is trying to reach the set point and after 24 minutes, the desired temperature is achieved.

Figure 17 shows the signal waveform when the process set point was 40ºC. After five minutes the system reaches its set point, then the user change the set point to 60ºC. From 40ºC to 60ºC, generally, it takes about 10 to 15 minutes to the system to achieve its new set point. Set point of 70ºC and 80ºC were set, and the waveform is as depicted in Figure 18. Initially the temperature inside the water bath was 60ºC. But after the set point is set to 70ºC, the fuzzy controller tries to reach 70ºC and it can be clearly seen that the readings is stagnant for a while after it achieves 70°C. Then, when the set point was changed to 80ºC, the fuzzy controller was then again tries to achieve it and it goes stagnant once the desired temperature is achieved.
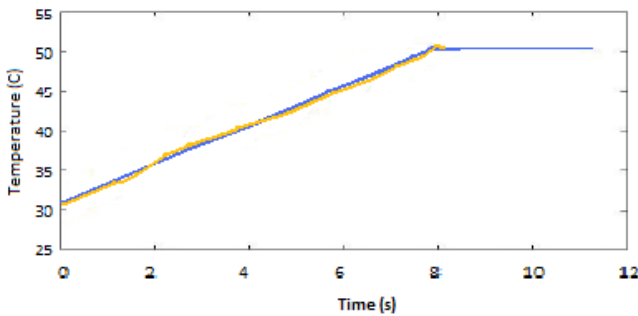

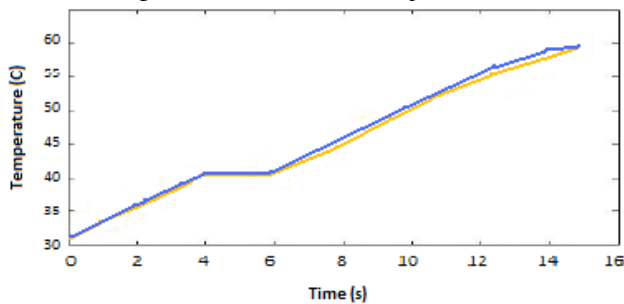Figure 16: Waveform when setpoint 50 ºC
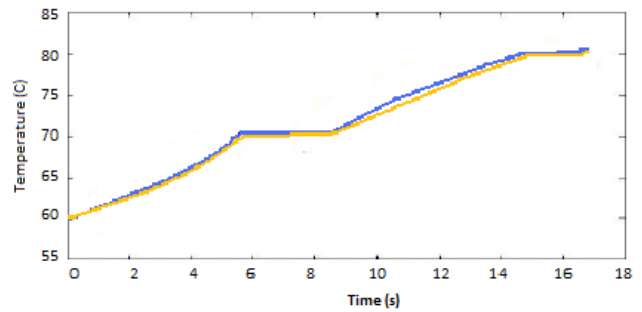

Figure 17: Waveform when setpoint 40 ºC

Figure 18: Waveform when setpoint 70 ºC

VII. SUMMARY

Overall, this paper describes water bath temperature control system development by using FLC. This system is produced through MATLAB software and 16 rules are utilized to obtain the optimized result for the system. From the observation, it is shown that the outputs for the control system are depended to the input that has been initially declared. Last but not least, the FLC controller is easily programmed and can be implemented to make the system achieves more accurate result and saves the energy of the water bath system.

In the next development, this FLC controller scheme can be compared with other controller such as PID controller, Neuro-fuzzy controller, Neural- Network controller, Sliding Mode controller and adaptive controller and the comparison are done through the experimental studies. By conducting comparison studies between these controllers, it is hoped that a robust controller can be acquired to control this water bath control system.

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