FUZZY LOGIC IN TWO NON-INTERACTING TANKS IN SERIES

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CHEMICAL ENGINEERING
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by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATE OF APPROVAL

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Approved by,

____

(Ir Dr Abdul Halim)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ABDULLAH HAJI ABU BAKAR

ABSTRACT

Two Non-Interacting Tanks is commonly used in the petrochemical industry especially when it involves chemical reaction. Most chemical reaction needs optimum time to achieve the target conversion rate, so precise and controlled retention time of the chemicals in the tanks/reactors is very essential. This leads to the development of my project where I will compare fuzzy logic control, an advance control system and compare it with the conventional controller, which is the PID controller. Fuzzy Controller is basically a controller that mimics a human in term of decision making by installing a range of human "decision" based on condition that we have introduced to the controller. PID Controller however is a controller based on the mathematical process modeling of the system & it will measure the error of the system from the set-point and perform a calculation for corrective action based on the PID equation. The results of the simulation will be compared based on the settling time, overshoot peak and maximum level at steady state of the tanks

ACKNOWLEDGEMENT

First of all I would like to say thank you god for giving me strength and perseverance for me to complete my final year project. I would also like to give my thanks to my supervisor Ir. Dr. Abdul Halim for his endless guidance and teachings. It is not an exaggeration to say that the project would not finish successfully without his help. I am also thankful for the help given to me by my previous supervisor, Mr. Nasser who is currently pursuing his studies. I feel thankful for the support given to me by my parents and fellow friends that have helped e throughout this project. I hope from this project, it will help develop our country's industries as a whole.

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INTRODUCTION

1.1 Background Study

Modelling of systems is a very essential concept in developing an effective control system in which will reflect the simulation of the physical processes. Fuzzy logic concept is a very distinct idea in developing models of physical processes as the fuzzy models themselves are less complex, easy to understand and easy to be executed. Furthermore, fuzzy models also are very suitable to be deployed for non-linear processes for which models with fewer rules are more advantageous. The process chosen for this project is Water Tank Level Control. As we all know, level control can be found in almost everywhere especially in Oil & Gas industry. Hence, by developing Fuzzy Model, we can analyze and produce an alternate solution for level control system.

1.2 Problem Statement

Why do we need to control two non-interacting tanks? It is simply because that these system is commonly used in the industry especially plants that involves chemical reaction. Two non-interacting tanks provide more retention time to increase the rate of a reaction.We need to control the level of the tanks to control the retention time. Thus leads to the need to control the level of the tank. There is a lot of level control system available in the industry and fuzzy logic is one of the most recent developed tank level control systems. This project is mainly to simulate the fuzzy logic system in controlling two non interacting tanks and compare the results with PID control. By doing so, we can help optimize processes and reduce as many failure during operation. Level Controllers in Malaysia's offshore platform are mainly using PLC and PID controller. This in an old technology installed from the beginning of the fabrication of the platform itself. If we can prove Fuzzy Control to be better than PID, we can have the option to replace controllers in offshore platforms with fuzzy controller.

As of year 2009, there is no further research on the effectiveness of fuzzy logic control against PID control on two noninteracting tanks in series.

1.3 Objective

To conduct studies and evaluates the best two tank in series level control system by simulation using fuzzy logic and then comparing the results with PID control system. The simulation for the control system will be performed by using Matlab 7.1 software

1.4 Scope of Study

The scope of project will at least cover the components below:

- Develop a model system to be used for level control simulation
- To develop a fuzzy logic control system so that it can be used as an alternative control strategy for level control system
- Analyze the effectiveness of Fuzzy logic control when confronting level control problem.
- To study the behaviour of fuzzy logic controller (FLC) compared to conventional PID controller.
- To compare the control responses between FLC and conventional PID or PI Controller.

The above list will cover the basic features of the proposed project. Additional features may be added if deemed feasible to increase the value and quality of the project throughout its development period.

CHAPTER 2

LITERATURE REVIEW

2.1 Non Interacting System

Non interacting system is a system in which a variation of any one reference input quantity will cause only the one corresponding controlled output variable to change. For this system, the input variable is the flow rate of the outlet from both Tank1 & Tank 2 and the corresponding output variable is the level of water in the tank.

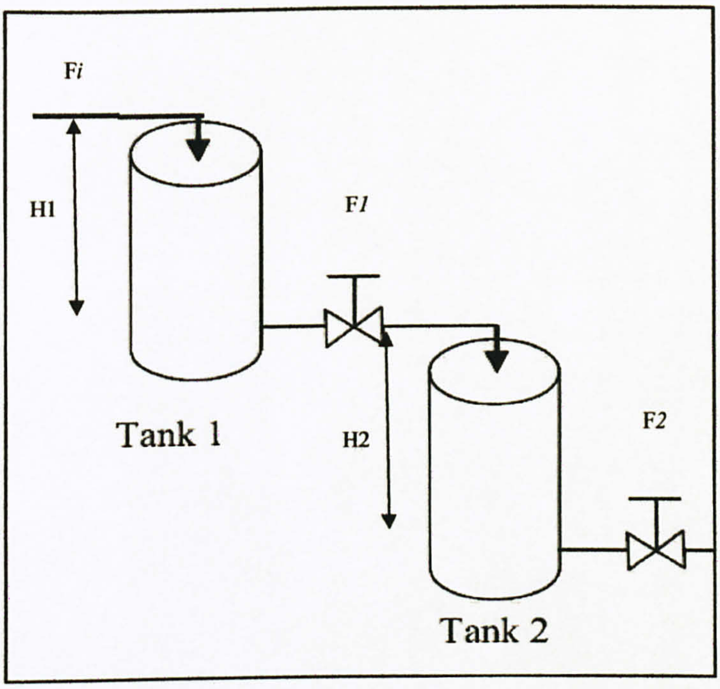


Figure 1: *Two Non Interacting Tanks in Series*

The basic model equation of noninteracting two tank system is given by:

Tank1

$$Fi(t) - F1(t) = A1\frac{dh1(t)}{dt}$$

- F*i* (t) is tank1 inflowing liquid (m3/s)
- F*1* (t) tank1 out flowing liquid (m3/s)
- A*1* area of the tank1 (m2)
- H1 liquid level in tank1 (m)

Tank2:

$$F1(t) - F2(t) = A2\frac{dh2(t)}{dt}$$

- F*1*(t) is tank1 inflowing liquid (m3/s)
- F*2* (t) tank1 outflowing liquid (m3/s)
- A2 area of the tank2 (m2)
- H2 liquid level in tank2 (m)

2.2 PID Control

Now, more than half of the controllers used in the industry are PID controllers. In the past, many of controllers used were analog. However, vast numbers of today's controllers uses computers and digital signal. When a mathematical model of a system is available, the parameters of the controller can be explicitly determined. However, when a mathematical model is unavailable, the parameters must be determined experimentally. Controller tuning is the process of determining the controller parameters to produce the desired output control. Controller tuning allows for optimization of a process and minimizes the error between the variable of the process and its set point.(Process Dynamics and control, Dale, 2004)

There are a few types of controller tuning methods include the trial and error method, and process reaction curve methods. The most common and widely used controller tuning methods are the Ziegler-Nichols and Cohen-Coon methods. These methods are often used when the mathematical model of the system is not available. The Ziegler-Nichols method can be used for both closed and open loop systems, while Cohen-Coon is typically used for open loop systems. A closed-loop control system is a system which uses feedback control. In an open-loop system, the output is not compared to the input. (Advance PID Control byAtrom, Karl J, 2008)

The equation below shows the PID algorithm.

$$u(t) = K_c\left(\epsilon(t) + \frac{1}{\tau_i}\int_0^t \epsilon(t')\,dt' + \tau_d\frac{d\epsilon(t)}{dt}\right) + b$$

1. u is the control signal and ε is the control error.
2. b is the set point value of the signal, also known as bias or offset.
3. Kc is the gain for a proportional controller.
4. τi is the parameter that scales the integral controller.
5. τd is the parameter that scales the derivative controller.
6. t is the time taken for error measurement.

The experimentally obtained controller gain which gives stable and consistent oscillations for closed loop systems, or the ultimate gain, is defined as Ku. Kc is the controller gain which has been corrected by the Ziegler-Nichols or Cohen-Coon methods, and can be input into the above equation. Ku is found experimentally by starting from a small value of Kc and adjusting upwards until consistent oscillations are obtained, as shown below. 14. (Loop Tuning Fundamentals, Van, Doren, Vance J, July 1, 2003)

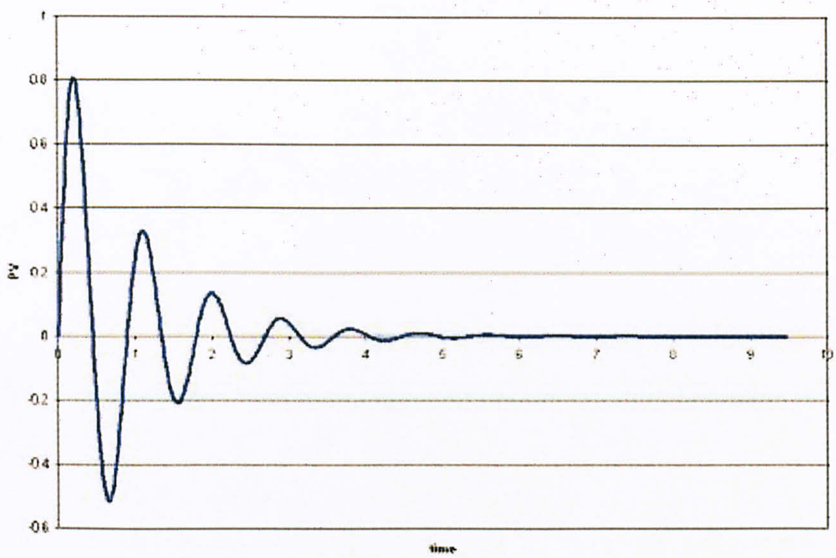


Figure 2a: *Graph PV vs. time*

If the gain is too low, the output signal will be damped and attain equilibrium eventually after the disturbance occurs as shown below.

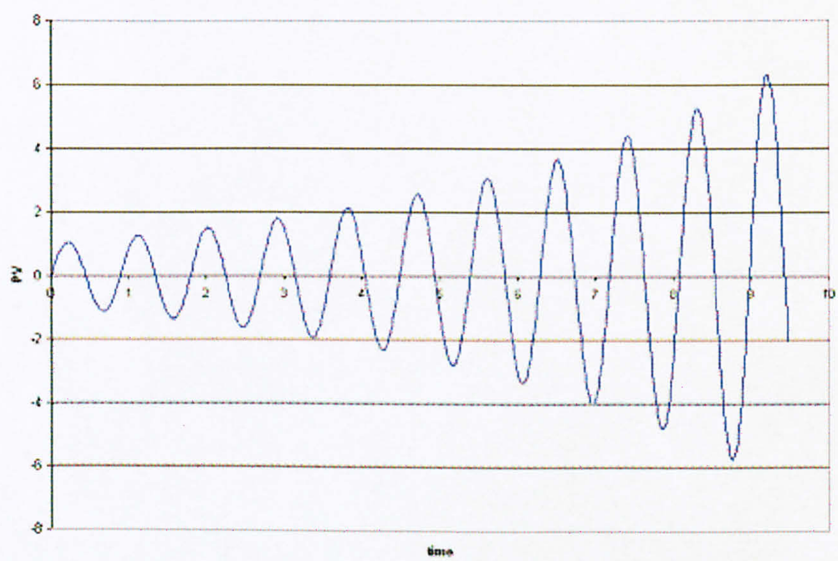


Figure 2b: *Graph PV vs. time*

By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the setpoint and the degree of system oscillation. (A Real Time Approach to Process control, by Svrcek, 2^{nd} Edition)

2.3 Cohen-Coon PID Tuning

The Cohen-Coon method of controller tuning corrects the slow, steady-state response given by the Ziegler-Nichols method when there is a large dead time (process delay) relative to the open loop time constant; a large process delay is necessary to make this method practical because otherwise unreasonably large controller gains will be predicted. This method is only used for first-order models with time delay, due to the fact that the controller does not instantaneously respond to the disturbance (the step disturbance is progressive instead of instantaneous).

The Cohen-Coon method is classified as an 'offline' method for tuning, meaning that a step change can be introduced to the input once it is at steady-state. Then the output can be measured based on the time constant and the time delay and this response can be used to evaluate the initial control parameters.(Instrument Engineers Handbook, Liptak, Bela, 2005)

The process in Cohen-Coon turning method is the following:

1. Wait until the process reaches steady state.
2. Introduce a step change in the input.
3. Based on the output, obtain an approximate first order process with a time constant t delayed by tDEL units from when the input step was introduced.
4. The values of t and tDEL can be obtained by first recording the following time instances: t0 = time at input step start point t2 = time when reaches half point t3 = time when reaches 63.2% point

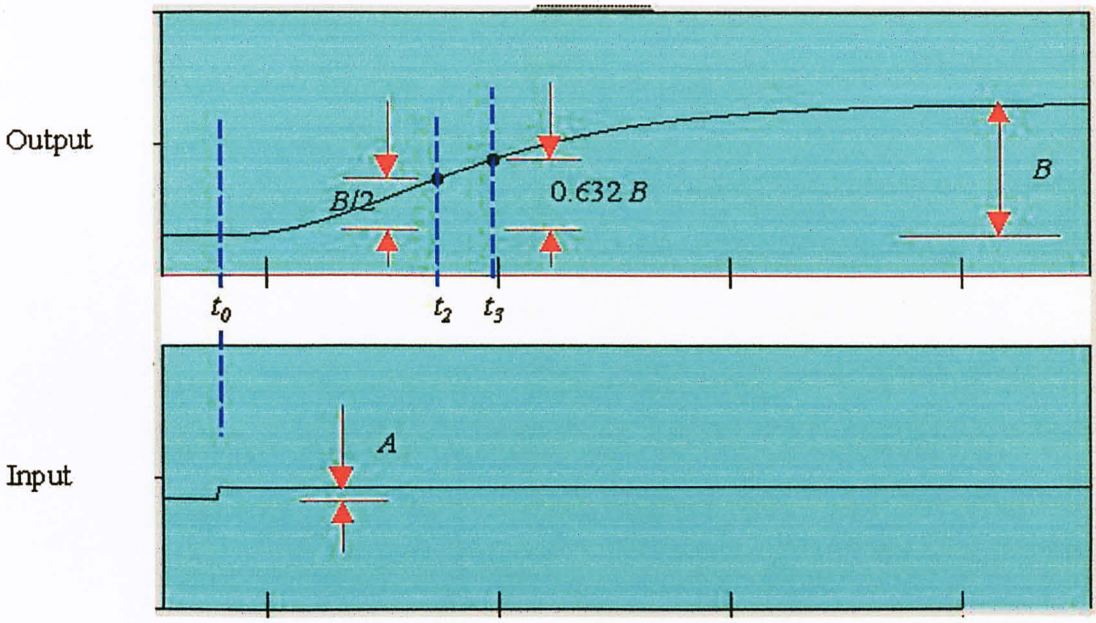


Figure 3a: *Cohen-Coon Tuning Parameters*

5. Using the measurements at t0, t2, t3, A and B, evaluate the process parameters: t, tDEL, and K.
6. Find the controller parameter based on t, tDEL, and K.

	K_c	t_I	t_D
P	$\frac{1}{K \cdot r} \cdot \left(1 + \frac{r}{3}\right)$		
PI	$\frac{1}{K \cdot r} \cdot \left(0.9 + \frac{r}{12}\right)$	$\tau_{DEL} \cdot \frac{30 + 3 \cdot r}{9 + 20 \cdot r}$	
PID	$\frac{1}{K \cdot r} \cdot \left(\frac{4}{3} + \frac{r}{4}\right)$	$\tau_{DEL} \cdot \frac{32 + 6 \cdot r}{13 + 8 \cdot r}$	$\tau_{DEL} \cdot \frac{4}{11 + 2 \cdot r}$

where $r = \frac{\tau_{DEL}}{\tau}$

Figure 3b: *Cohen –Coon Tuning Parameters*

2.4 Fuzzy Logic

Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. In binary sets with binary logic, in contrast to fuzzy logic named also crisp logic, the variables may have a membership value of only 0 or 1. Just as in fuzzy set theory with fuzzy logic the set membership values can range (inclusively) between 0 and 1, in fuzzy logic the degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth values {true (1), false (0)} as in classic predicate logic and when linguistic variables are used, these degrees may be managed by specific functions. (Fuzzy System.., by Witold Pedrycz, 1994)

2.5 History of Fuzzy Logic

The term "fuzzy logic" emerged as a consequence of the development of the theory of fuzzy sets by Lotfi Zadeh. A paper introducing the concept without using the term was published by R.H. Wilkinson in 1963 and thus preceded fuzzy set theory. Wilkinson was the first one to redefine and generalize the earlier multivalued logics in terms of set theory. The main purpose of his paper, following his first proposals in his 1961 Electrical Engineering master thesis, was to show how any mathematical function could be simulated using hardwired analog electronic circuits. He did this by first creating various linear voltage ramps which were then selected in a "logic block" using diodes and resistor circuits which implemented the maximum and minimum Fuzzy Logic rules of the INCLUSIVE OR and the AND operations respectively. He called his logic "analog logic". In 1965 Lotfi Zadeh developed fuzzy set theory, thereby creating the set-theoretical equivalent of the "analog logic" of Wilkinson. Fuzzy logic has been applied to diverse fields, from control theory to artificial intelligence.

2.6 Fuzzy Control

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.The processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". Typical fuzzy control systems have dozens of rules.

One of the examples from the book "Fuzzy Systems Engineering Toward Human Centric Computing" by Witold Pedrycz and Fernando Gomide(1994) can help us further understand fuzzy control. We may qualify an indoor environment as comfortable when its temperature is kept around 20C. If we observe a value of 19.5C, it is very likely that we still feel quite comfortable. The same holds if we encounter 20.5C humans usually do not discriminate changes in temperature within the range of 1C. A value of 20C would be fully compatible with the concept of comfortable temperature, yet 0C or 30C would not. In these two cases, as well as for temperatures close to these two values, we would describe them as being cold and warm, respectively. We could question whether the temperature of 25C is viewed as warm or comfortable or, similarly, if 15C is comfortable or cold. Intuitively, we know that 25C is somehow between comfortable and warm, whereas 15C is between comfortable and cold. The value 25C is partially compatible with the term comfortable and warm, and somewhat compatible or, depending on observer's perception, incompatible with the term cold temperature. Similarly, we may say that 15C is partially compatible with the comfortable and cold temperature, and slightly compatible or incompatible with the warm temperature. In spite of this highly intuitive categorization of environment temperatures into the three classes, namely cold, comfortable, and warm, we note that the transition between the classes is not instantaneous and sharp. Simply when moving across the range of temperatures, these values become gradually perceived as cold, comfortable, or warm. As you can see, Fuzzy Logic is all about improving decision making.

Some of known advantages of Fuzzy Logic Control System are listed below:

- Fuzzy logic is flexible

  With any given system, it's easy to modify it or layer more functionality on top of it without starting again from scratch.

- Fuzzy logic is conceptually easy to understand

The mathematical concepts behind fuzzy reasoning are very simple. The simplicity of its approach and its far reaching complicity is what makes Fuzzy Logic a great system

- Fuzzy logic is tolerant of imprecise data

Everything is imprecise in the control system if we look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.

- Fuzzy logic can be blended with conventional control techniques

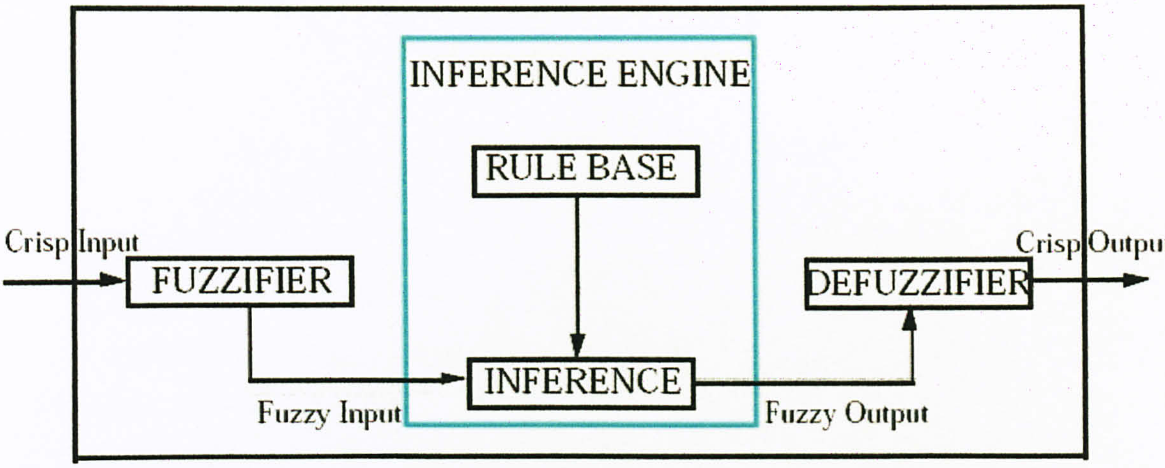
Fuzzy systems don't necessarily replace conventional control methods. In many cases fuzzy systems augment can be used to simplify their implementation.

- Fuzzy logic is based on natural language:

The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic.

2.7 Mamdani Type Fuzzy Control

One of the long standing problems of fuzzy control consists in the high number of choices necessary to define the fuzzy controller (tuning). If the designer does not dispose of some general criteria to follow, then the fuzzy controller is characterised by some arbitrariness. The designer must choose the type of fuzzification , the number of membership functions, the functional forms of the membership functions, the parameters of the membership functions (fixed or tuned during a training procedure), the conjunction operator and the type of defuzzification (centroid, maxima, height). This demonstrates the richness of fuzzy controllers but also the need for some guidelines for their practical design. (Metamathematics of fuzzy, Kluwer, 1998)



This project shall always refer to a Mamdani-type fuzzy controller (Fig. 1) with one or more inputs and one output, characterised by a singleton fuzzifier. Furthermore, the controlled system will be single input - single output. For this project, only single input will be implemented into the rule base for the fuzzy controller i.e; IF (condition) THEN (action).

2.8 RESULT & DATA REPRESENTATION

Upon the completion of the project, most of the results and data obtained from the experiment are displayed in term of graph of tank water level versus time. The comparison between PID and Fuzzy controller will be based on the settling time and oscillation of the water level.

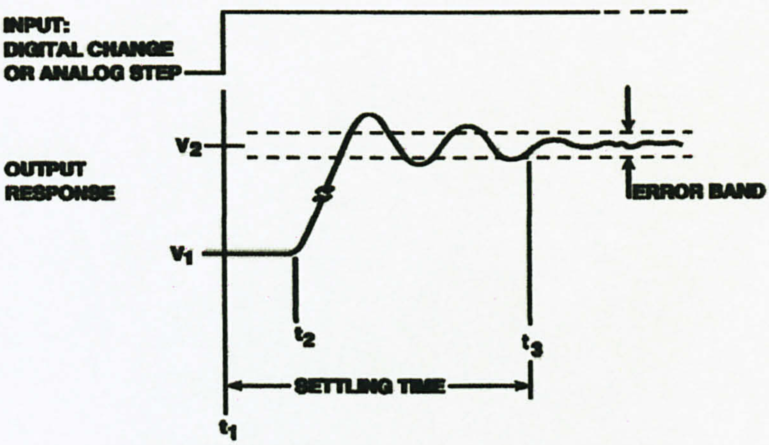


Figure 5: *Settling Time Data Representation*

2.9 Matlab Software

MATLAB is a numerical computing environment and fourth generation programming language. Developed by The MathWorks, MATLAB allows matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. Although it is numeric only, an optional toolbox uses the MuPAD symbolic engine, allowing access to computer algebra capabilities. An additional package, Simulink, adds graphical multidomain simulation and Model-Based Design for dynamic and embedded systems.

MATLAB (meaning "matrix laboratory") was invented in the late 1970s by Cleve Moler, then chairman of the computer science department at the University of New Mexico.[3] He designed it to give his students access to LINPACK and EISPACK without having to learn Fortran. It soon spread to other universities and found a strong audience within the applied mathematics community. Jack Little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983. Recognizing its commercial potential, he joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded The MathWorks in 1984 to continue its development. These rewritten libraries were known as JACKPAC.[citation needed] In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK[4].

MATLAB was first adopted by control design engineers, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved with image processing. (The Origins of MATLAB, Cleve Moler, April 15 2007)

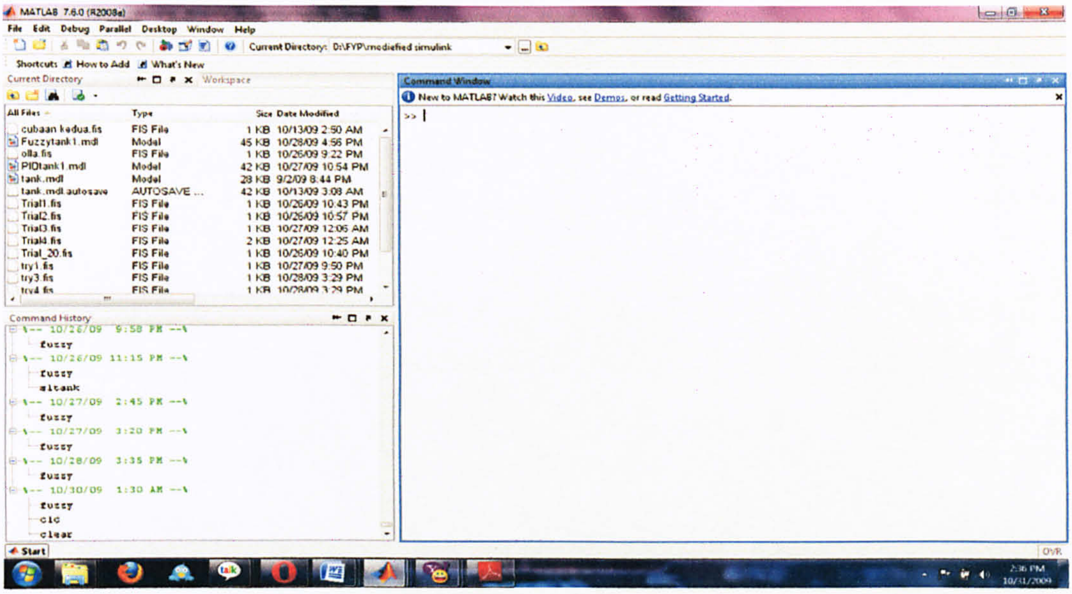


Figure 6: *Matlab Software 7.6.0 (R2008a)*

CHAPTER 3
METHADOLOGY

3.1 PROJECT MILESTONE

The milestone of this project comprise of six chapters, three chapters for this semester (semester July 09) and three chapters for last semester (semester Jan 09). For this semester, FYP II is focusing more on the development of the fuzzy controller and PID controller itself. For last semester (semester Jan 09), the studies were focused on literatures and simulating the process system.

SEMESTER JAN 09	STATUS
<u>Chapter 1: Introduction</u> ➢ Background of study ➢ Problem statement ➢ Objective ➢ Scope of study	Completed
<u>Chapter 2: Literature Review</u> ➢ Non Interacting System ➢ PID Control ➢ Cohen-Coon PID Tuning ➢ Fuzzy Logic ➢ History of Fuzzy Logic ➢ Fuzzy Control ➢ Fuzzy Control Mamdani Method ➢ Result and data representation ➢ Matlab Software	Completed

Chapter 3 : Methodology ➢ Project milestone ➢ Gant Chart and Project Flow ➢ Process Parameter ➢ Process Simulation ➢ Performance Criterion ➢ Design of PID Controller ➢ Design of Fuzzy Logic Control	Completed

Table 1a: *Project Milestone Jan09*

SEMESTER JULY 09	STATUS
Chapter 4: Controller Design & Simulation ➢ Simulate PID Control into Process Simulation ➢ Simulate Fuzzy Control into Process Simulation	Completed
Chapter 5: Result & discussion ➢ Result obtained from the simulation was recorded in tables and represented in graph.	Completed
Chapter 6 : Conclusion ➢ The Conclusion of the experiment	Completed

Table 1b: *Project Milestone July09*

3.2 GANT CHART & PROJECT FLOW

Gant Chart illustrates the start and finish dates of the terminal elements and summary elements of a project. Terminal elements and summary elements comprise the work breakdown structure of the project. The breakdown of the project is shown on the Gant Chart below:

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■						Mid-semester break							
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				●											
4	Seminar 1 (optional)					■	■	■								
5	Project Work					■	■	■								
6	Submission of Progress Report									●						
7	Seminar 2 (compulsory)										■	■	■	■		
8	Project work continues									■	■	■	■	■		
9	Submission of Interim Report Final Draft														●	
10	Oral Presentation															●
			●	Suggested milestone												
			■	Process												

Table 2a: *Gant Chart for Project Completion for Semester Jan 09*

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■												
2	Submission of Progress Report 1															
3	Project Work Continue				■	■	■	■								
4	Submission of Progress Report 2															
5	Seminar (compulsory)										■	■	■			
5	Project work continue								■	■	■	■	■			
6	Poster Exhibition															
7	Submission of Dissertation (soft bound)															
8	Oral Presentation															
9	Submission of Project Dissertation (Hard Bound)															
				Suggested milestone												
			■	Process												

Table 2b: *Gant Chart for Project Completion for Semester July 09*

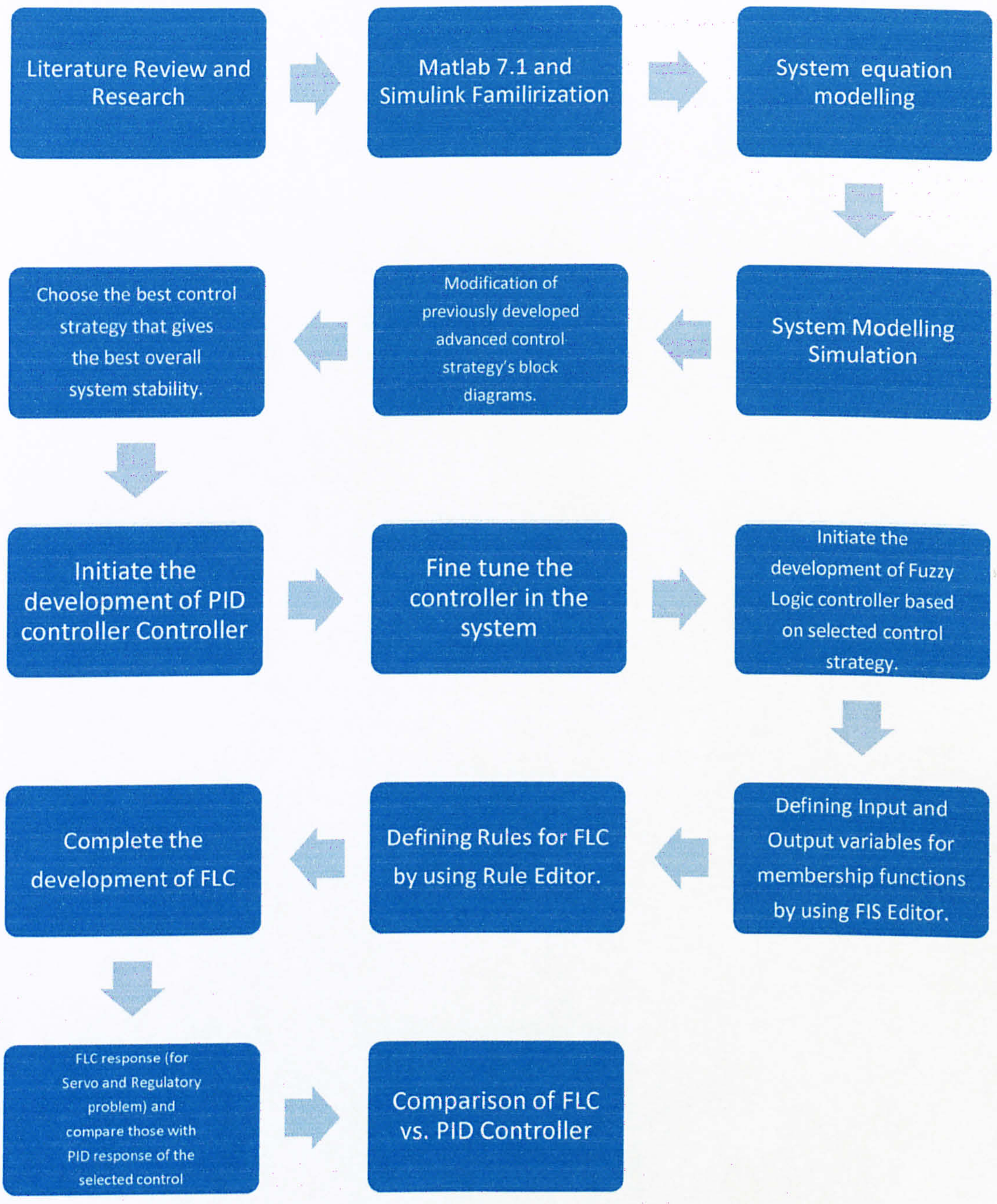


Figure 7: *Project Flowchart*

3.3 Process Parameter

The manipulated variable (MV) in the system is the level of water tank1 and tank 2. This is where the water level will be measured and analyse the response of the water level based on the control of the control system. The Fuzzy Logic Control and PID Control System will control the flow rate of tank1 and tank2 outlet flow, hence will become the Controlled Variable (CV) of the system. For the sake of simplicity of the project, the disturbance variable (DV) is only considered at Fi, the inlet of tank 1. Disturbance will be set to $1m^2/s$ at f(i) at t=100s.

<u>Water Flow Equation:</u>

$$F1(t) = Cv1\sqrt{h1}$$

$$F2(t) = Cv2\sqrt{h2}$$

<u>Where</u>

$A_1=10m^2$	$C_{v1}=2.2$	$fi(t)=5m^3/s$
$A_2=10m^2$	$C_{v2}=3.2$	

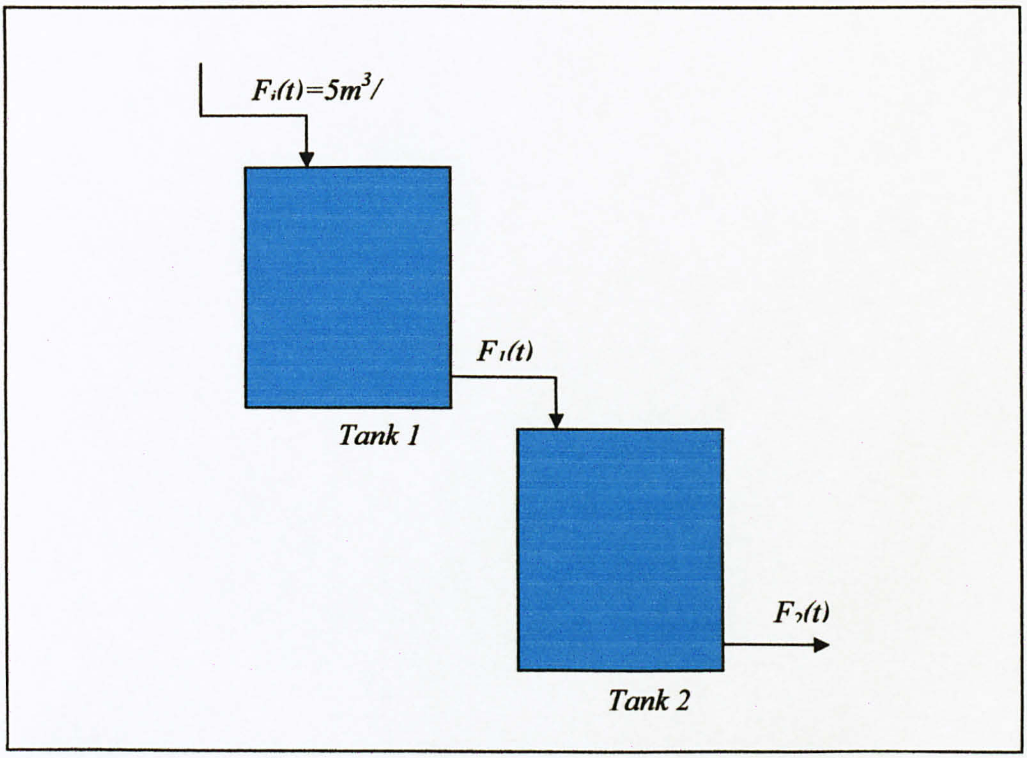


Figure 8: *Two Tanks in Series Non Interacting System*

3.4 Simulation

The two in series noninteracting tanks will be simulated using computer software Matlab®Simulink toolbox. Simulink, developed by The MathWorks, is a commercial tool for modeling, simulating and analyzing multidomain dynamic systems.

3.5 Performance Criterion

The function of a PID & Fuzzy control system is to ensure that the system has desirable dynamic and steady-state response characteristics. Ideally, it is good if the system to satisfy the following criteria:

1. The open-loop system must be stable.
2. The effects of disturbance are minimized, providing good disturbance rejection.
3. Rapid, smooth responses to set-point changes are obtained, thaht is, good set-point tracking.
4. Steady-state error (offset) is eliminated.
5. Excessive control action is avoided.
6. The control system is robust, that is, insensitive to changes in process conditions and to inaccuracies in the process model.

In typical applications, it is not possible to achieve all of these goals simultaneously because they involve inherent conflicts and tradeoffs. The tradeoffs must balance two important objectives, performance and robustness. A control system exhibits a high degree of performance if it provides rapid and smooth responses to disturbance and set-point changes with little, if any, oscillation. A control system is robust if it provides satisfactory performance for a wide range of process conditions and for a reasonable degree of model inaccuracy. Robustness can be achieved by choosing conservative controller settings (typically, small values of Kc and large value of t_i), but this choice tends to result in poor performance. Thus, conservative controller settings sacrifice performance in order to achieve robustness.

3.6 Design of PID Controller

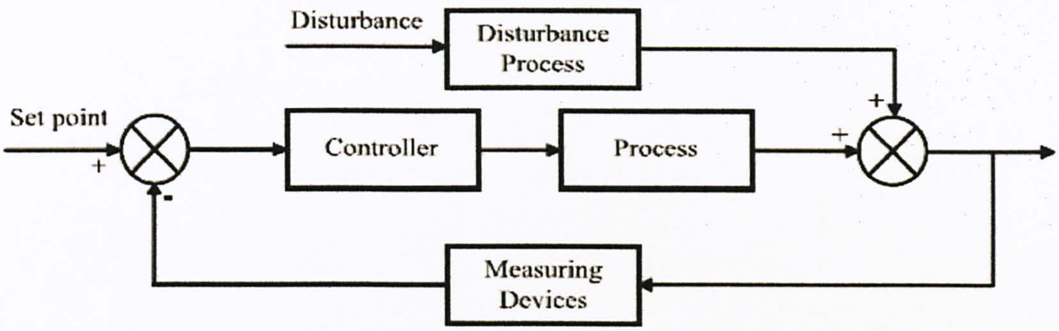


Figure 9: *Block Diagram for the system*

A typical block diagram of feedback control system is shown in Fig. 1. The output of the process is measured and its value is compared with the current set point to generate the error signal. The controller acts upon this error to generate a corrective action. The controller output and the error can be related by the following ways:

(i) The controller output is proportional to the error;

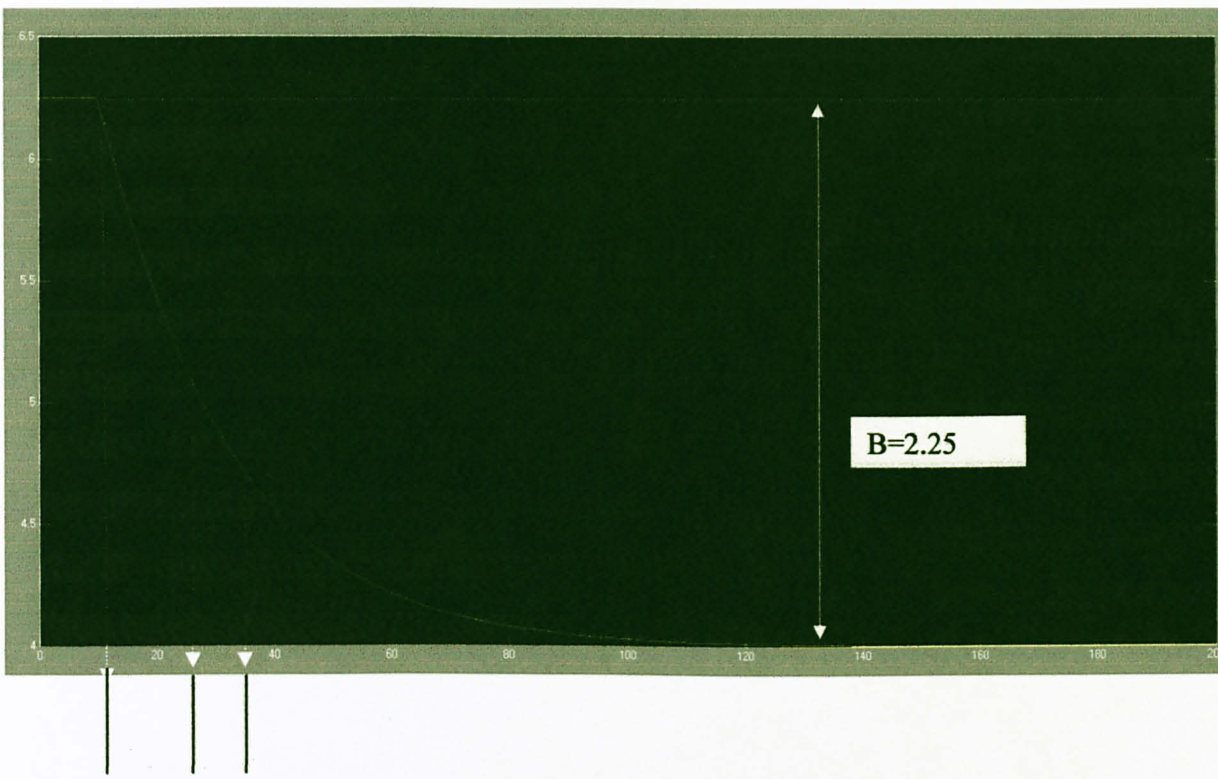
(ii) The controller output proportional to the integral of the error;

(iii) The controller output proportional the derivative of the error.

The servo response of the noninteracting two tank system is obtained and analyzed under P, PI, and PID controllers.

3.7 Step Response Analysis

Cohen Coon PID tuning method will be used to tune the PID control for this process. A step change of 1 m^3/s is introduced as a disturbance at the input of the process (*fi*). Based on the output, an approximate first order process with a time constant t delayed by tDEL units is obtained from when the input step was introduced. Below is an example of calculation for PID control at *f1* at tank 1 outlet



t0 t2 t3 Figure 10: *Step Test Method Analysis (Water Level vs. Time)*

t0	=	time when input step was initiated
t2	=	time when half point occurs
t3	=	time when 63.2% point occur

From the Graph

t_0=10; t_2=26; t_3=32;

A=1; B=2.25

Based on the step test: t0, t2, t3, A and B, the following process parameters is evaluated:

t1 = (t2 - ln(2) t3)/(1 - ln(2)) = 6.7045

t = t3 - t1 = 16.2955

tDEL = t1 - t0 = 7.3527

K = B/A = 2.25

Based on the parameters K, t and tDEL, the following controller parameters formulas is prescribed Kc, tI and tD

For PID Controller

K_c = 1.9

t_I = 3.166

t_D = 0.47

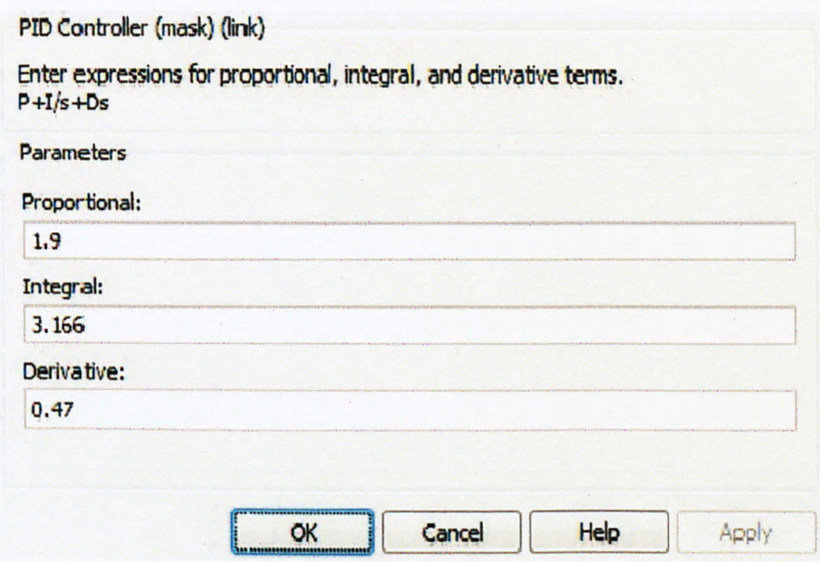


Figure 11: *PID Control Toolbox*

Fill in the PID details as calculated earlier into the Simulink PID Control Toolbox

3.8 Design of Fuzzy Logic Control

In an attempt to study the effectiveness of an intelligent fuzzy logic based controller is studied through computer simulation. The development of fuzzy logic control consists of the following steps:

1. Specify the range of controlled variable and manipulated variables;
2. Divide these ranges into fuzzy sets and attach linguistic labels which can be used to describe them
3. Determine the rules (rule base), which relate the manipulated variable and controlled variable, to specify control action;
4. Application of a suitable defuzzification method.

The number of necessary fuzzy sets and their ranges were designed based upon the experience gained on the process. The standard fuzzy set consists of three stages: Fuzzification, Decision-Making Logic and Defuzzification

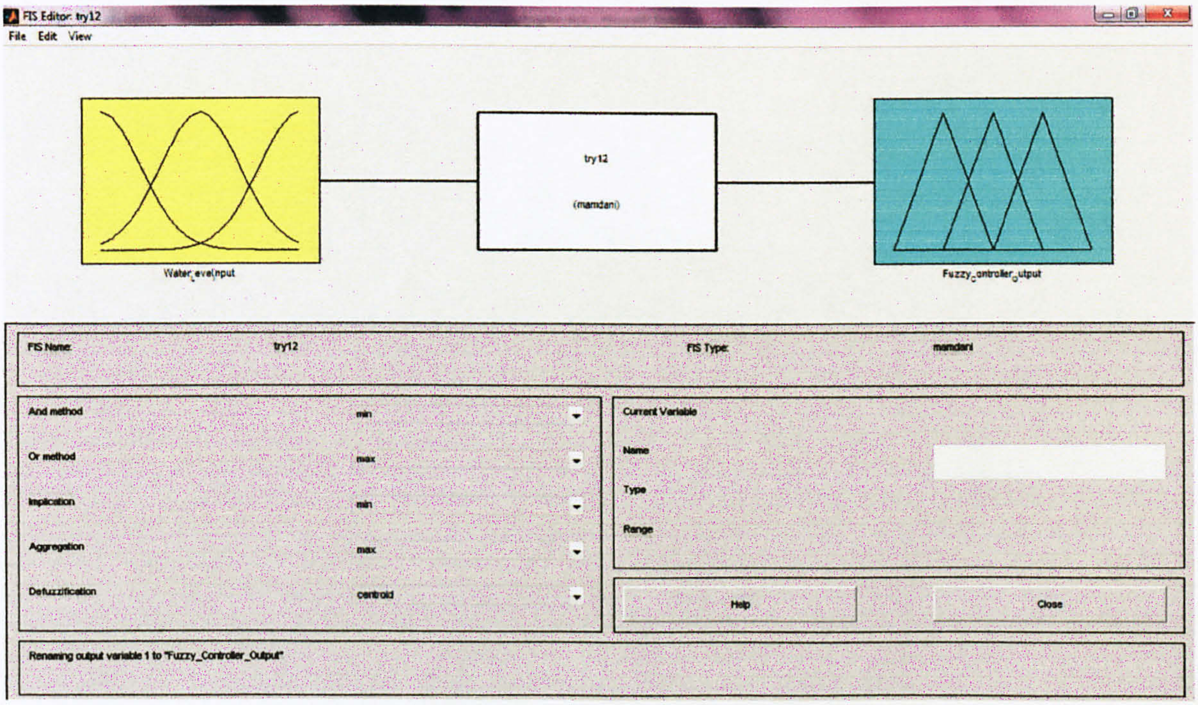


Figure 12: *Mamdani type Fuzzy Control FIS Editor*

Only one input will be considered which are the water level of the tanks, while the output of the controller for outlet tank flow, F_1 and F_2.

3.8.1 Architecture of a Fuzzy Logic Control

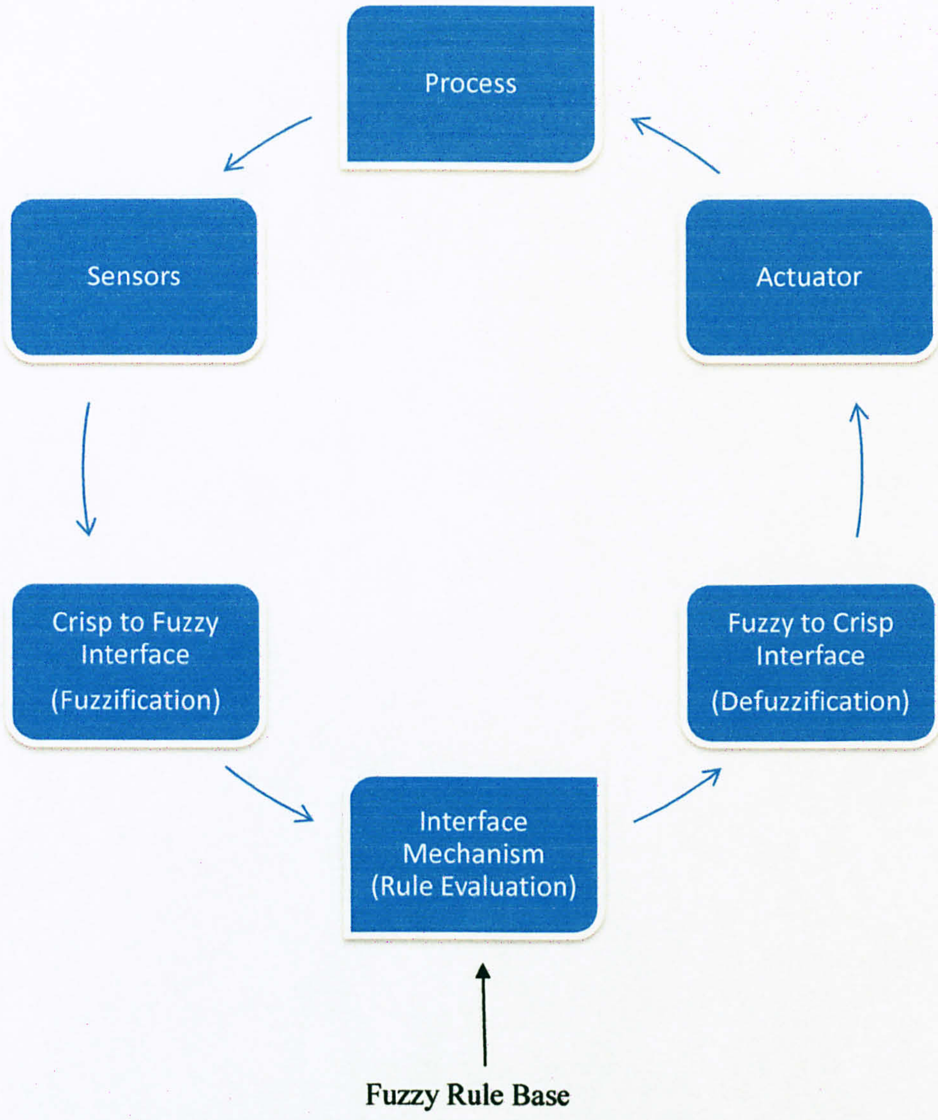


Figure 13: *Fuzzy Control Architecture*

3.8.2 Fuzzification stage

This stage converts a crisp number into a fuzzy value within a universe of discourse. The triangular membership functions with seven linguistic values for Water Level. Range of input used is from -5 to 5

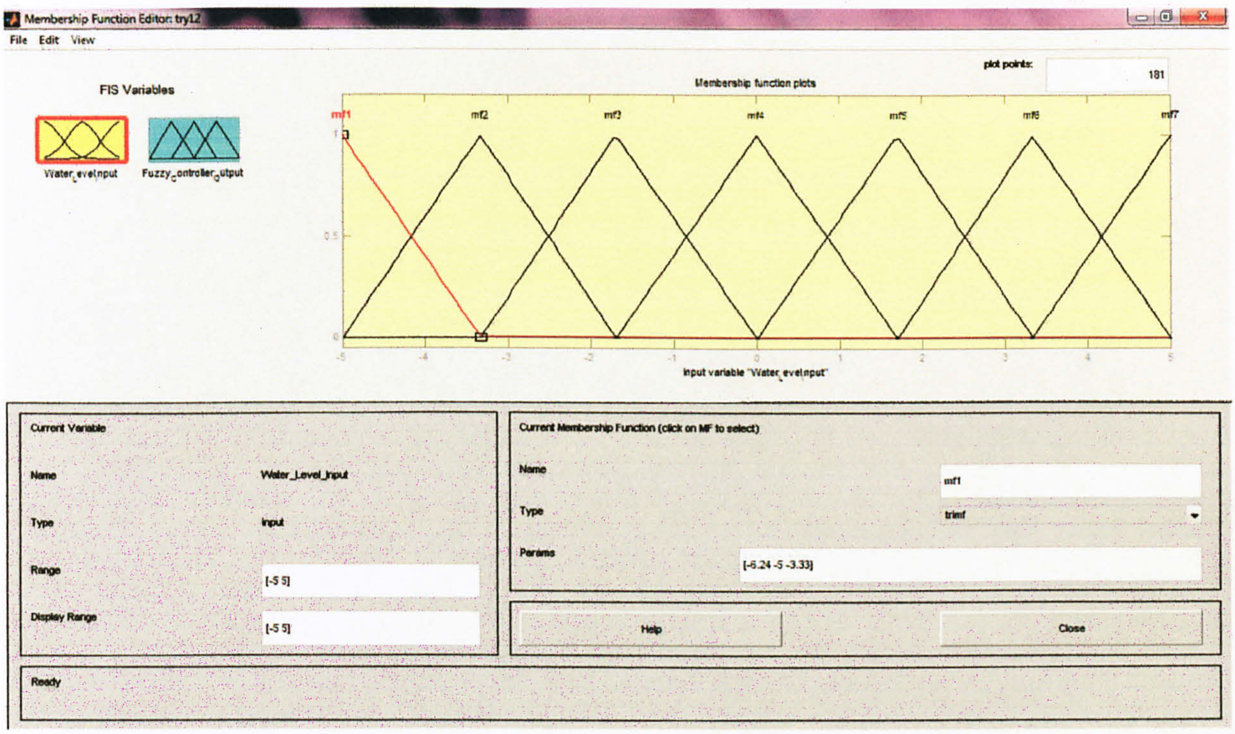


Figure 14: *Membership functions for Water Level*

3.8.3 Decision Making Stage

This stage consists of fuzzy control rules which decide how the fuzzy logic control works. This stage is the core of the fuzzy control and should be constructed from expert knowledge and experience in real life practice. The fuzzy logic control base rule for this fuzzy controller is shown below.

IF (Water_level_input is NB) THEN (Fuzzy_Controller_Output is NB)

IF (Water_level_input is NM) THEN (Fuzzy_Controller_Output is NM)

IF (Water_level_input is NS) THEN (Fuzzy_Controller_Output is NS)

IF (Water_level_input is ZO) THEN (Fuzzy_Controller_Output is ZO)

IF (Water_level_input is PS) THEN (Fuzzy_Controller_Output is PS)

IF (Water_level_input is PM) THEN (Fuzzy_Controller_Output is PM)

IF (Water_level_input is PB) THEN (Fuzzy_Controller_Output is PB)

3.8.4 Defuzzification Stage

The purpose of this stage is mainly to convert fuzzy value into crisp value. In other words, this stage will convert fuzzy value into a value that is recognizable by the controller to perform the error correction. As a basis for the value that will be used in range for the output of the defuzzification, data obtained from the PID controller and calculation from the mathematical modeling will be used to be adjusted to achieve the best controller setting. In this study, centre of area method is used. The triangular shaped membership function with seven linguistic values is used and it is shown in Fig. 5c. The range of error and the controller output are made on the basis of practical experience. For this fuzzy controller, the output range is from -9.5 to 9.5

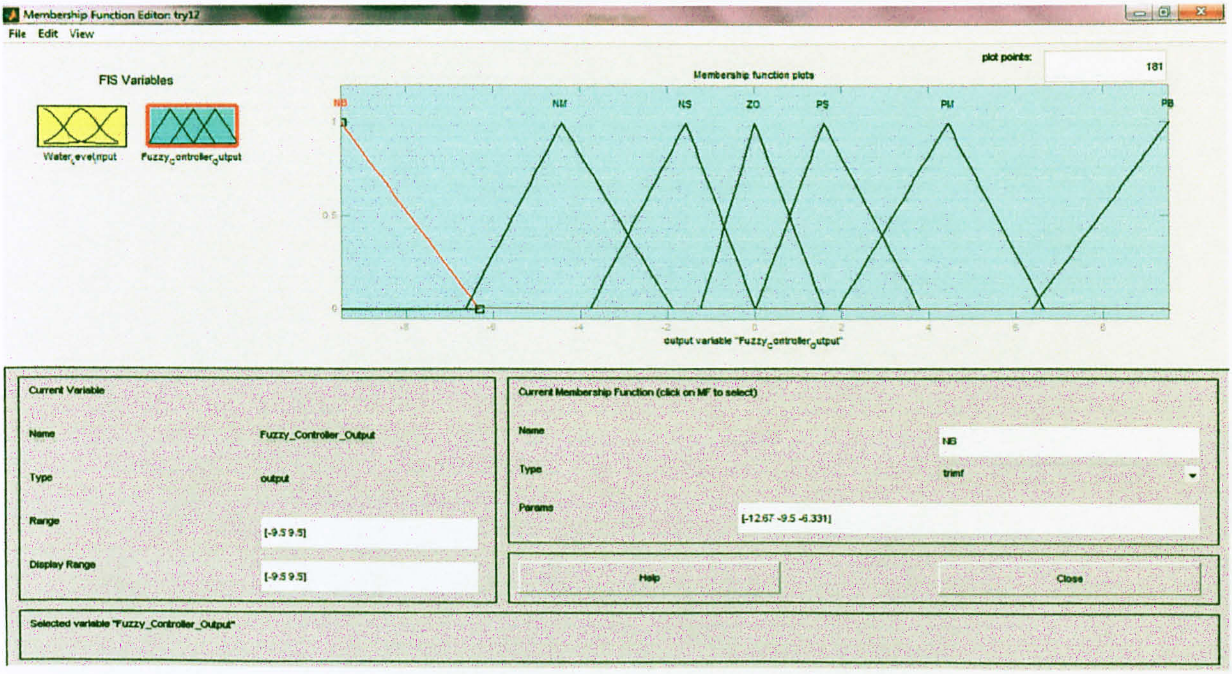


Figure 15: *Membership function for Output.*

CHAPTER 4
RESULTS & DISCUSSION

4.1 Simulation of Process via Matlab Software

Based on the mathematical equations that have been formulated earlier, the simulation for two noninteracting tanks in series is shown below

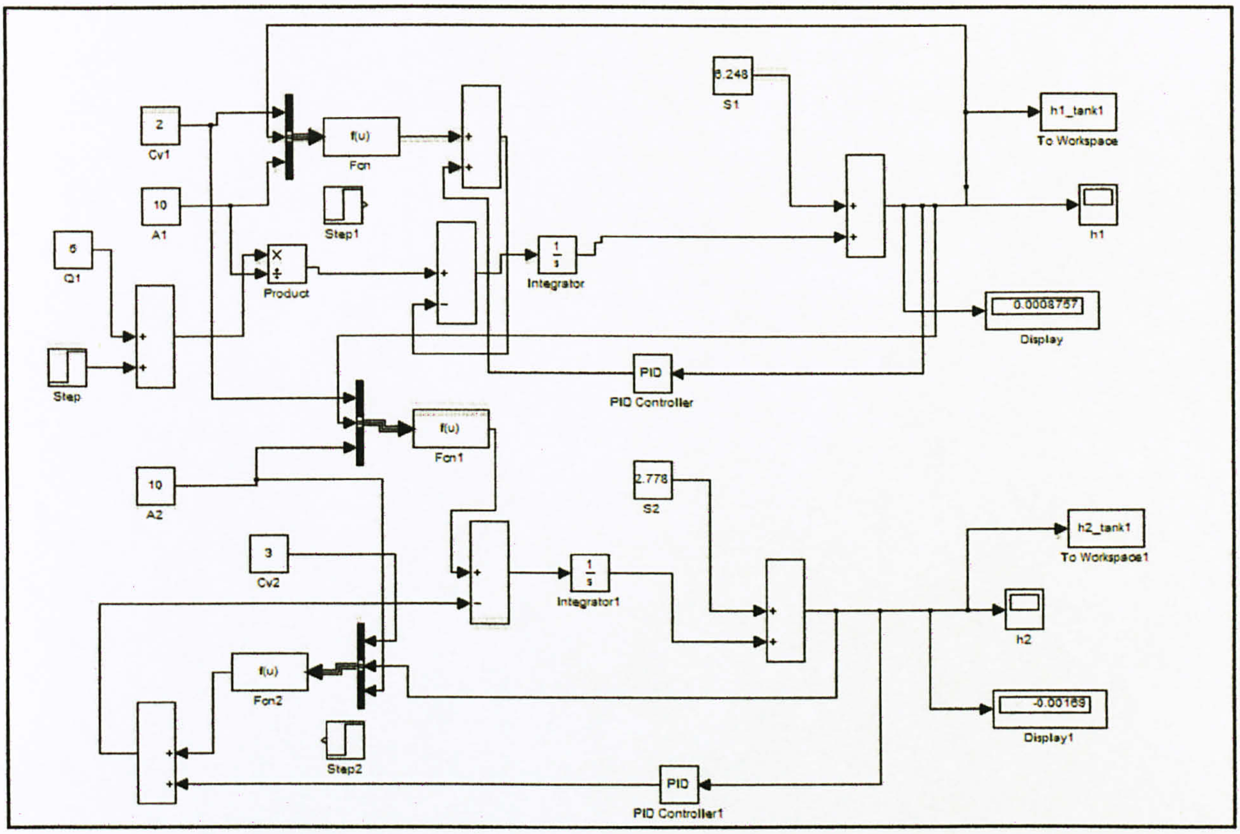


Figure 16: *Two Tanks in Series Non Interacting Block Diagram with PID Controller*

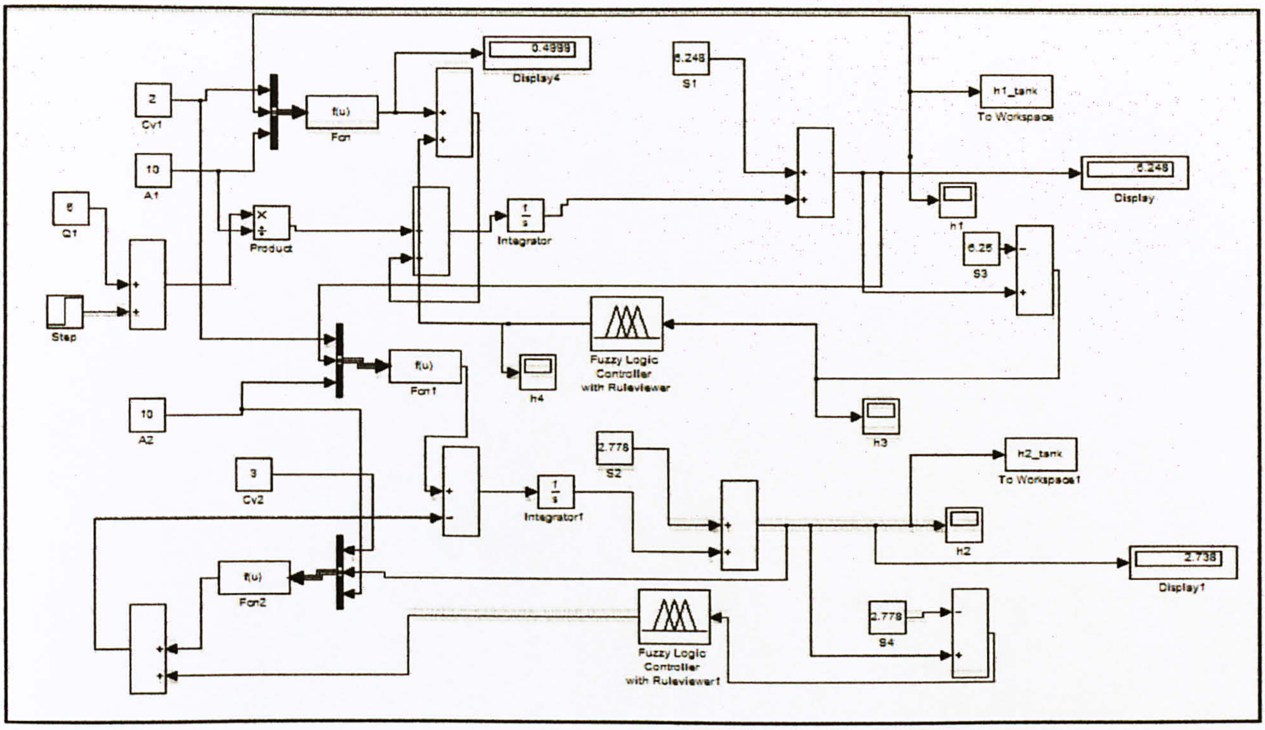


Figure 17: *Two Tanks in Series Non Interacting Block Diagram with Fuzzy Controller*

4.2 Data Representation

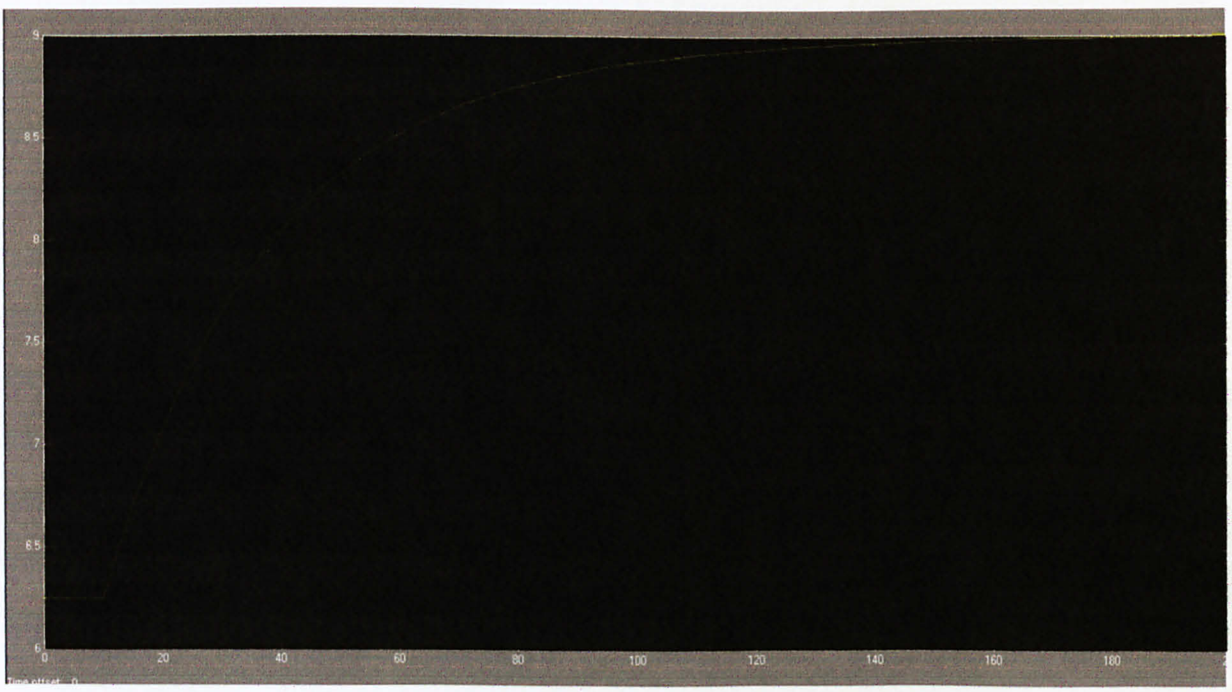


Figure 18: *Tank1 disturbance=1 with no Controller*

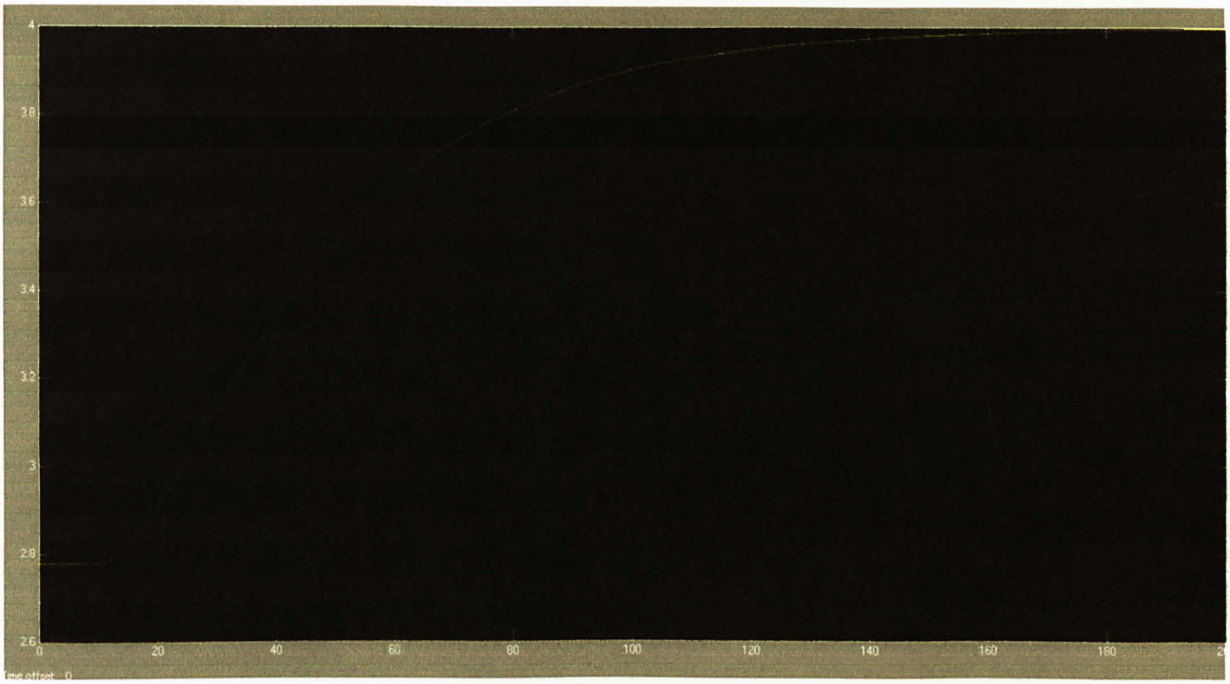


Figure 19: *Tank2 disturbance=1 with no Controller*

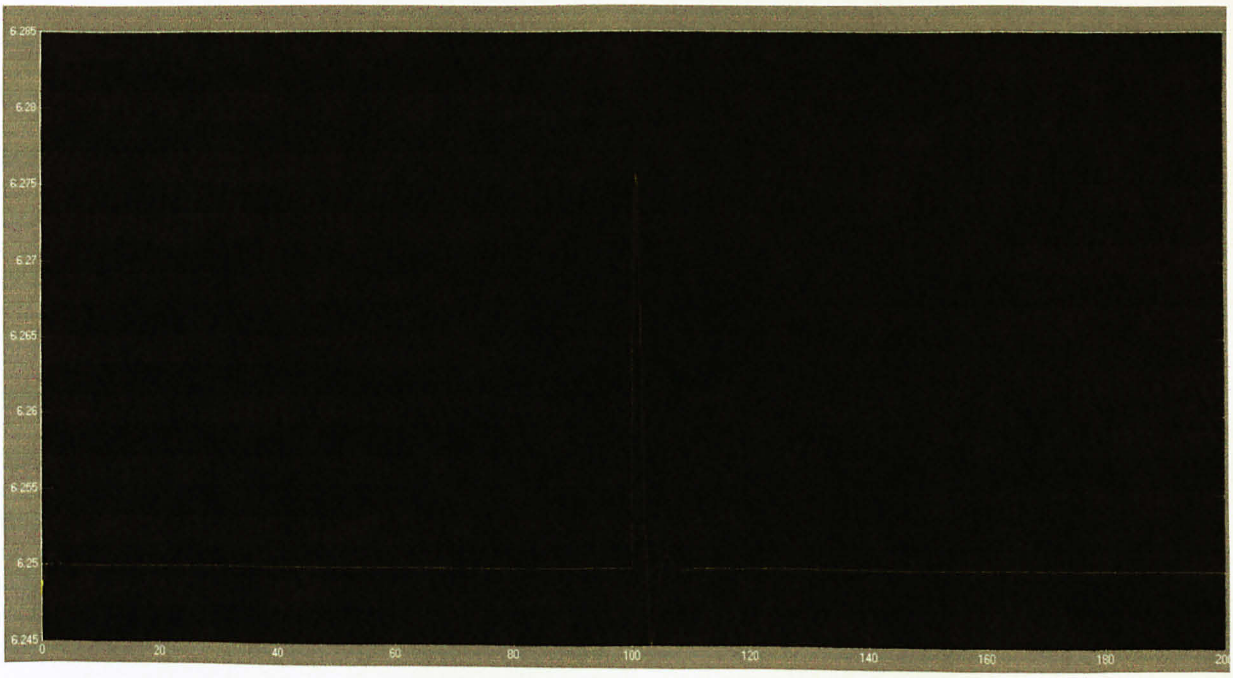


Figure 20: *Graph of Tank1 after PID Control Implementation*

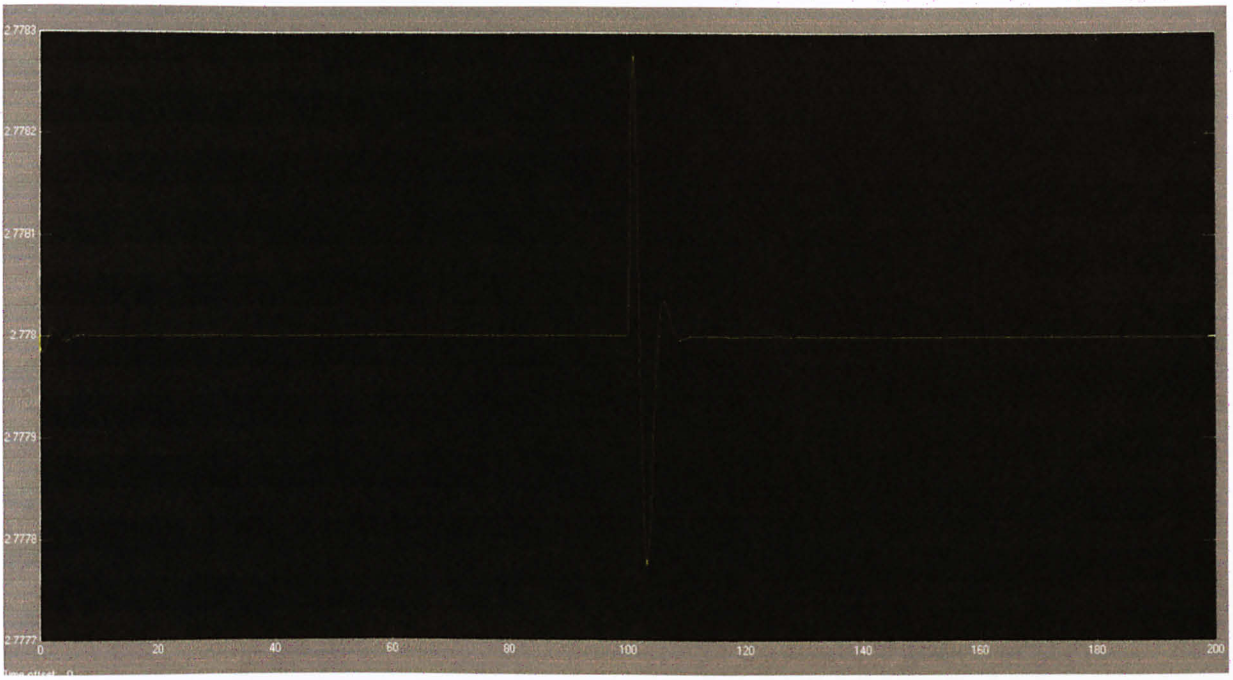


Figure 21: *Graph of Tank2 after PID Control Implementation*

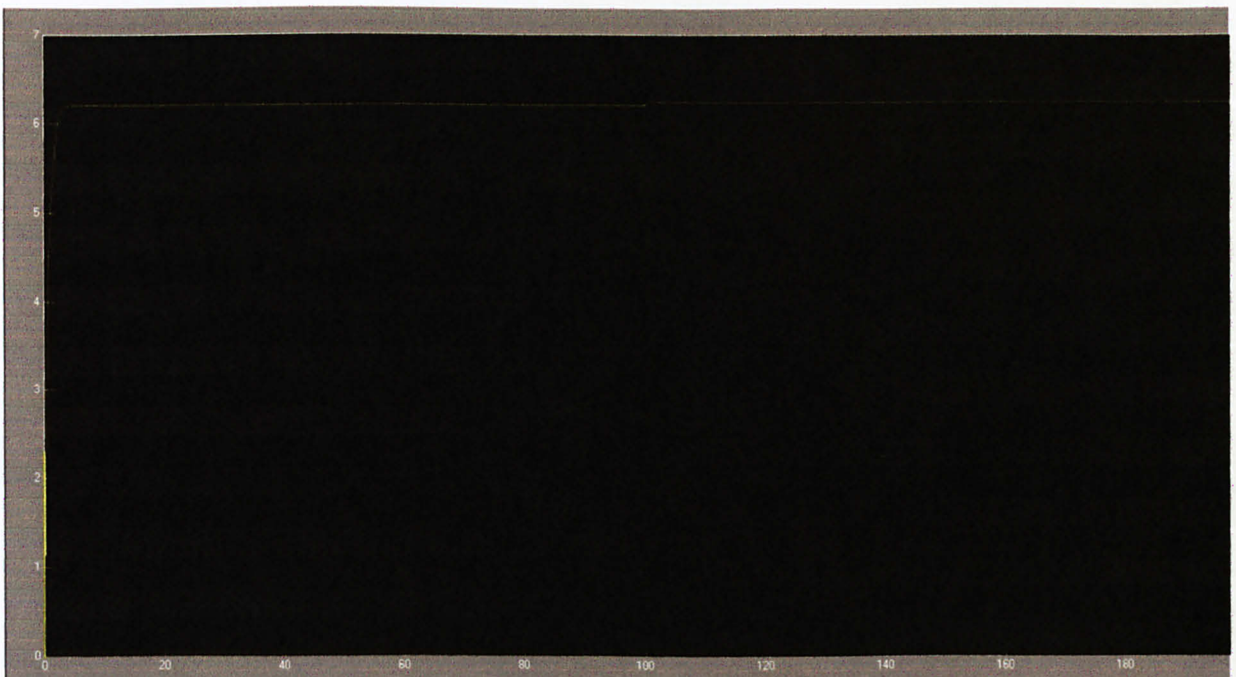


Figure 22: *Graph of Tank1 after Fuzzy Control Implementation*

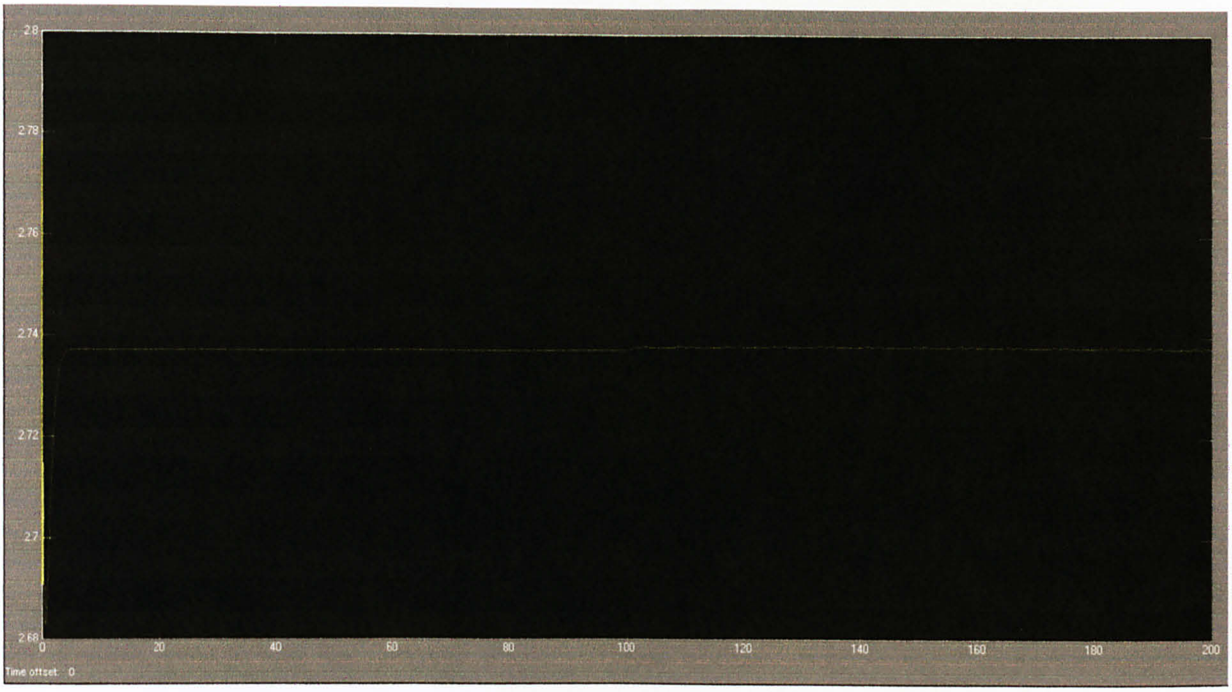


Figure 23: *Graph of Tank2 after Fuzzy Control Implementation*

Controller / Data	Tank 1 with no Control	Tank 1 with PID Control	Tank1 With FLC	Tank 2 with no Control	Tank 2 with PID Control	Tank2 With FLC
Water Level Peak (m)	8.955	6.25	6.25	3.995	2.738	2.738
Overshoot Peak(m)	-	6.276	6.273	-	2.778	2.740
Settling time (s)	180	10	3	200	10	8

Table 3: *Water Level at Steady State & Overshoot Peak*

4.3 Data Comparison Analysis

The servo responses of PID & Fuzzy control system for two non interacting tanks in series system are shown in Figure 20, 21, 22, and 23. The quantitative comparison of the responses of the selected system is presented in terms of water level peak, maximum peak overshoot, and settling time. Comparison of the two controllers as on table 3 is elaborated below

1. Water Level Peak

The set point for tank1 is 6.25m while the set point for tank2 is 2.738. On the 100 second, a disturbance is introduced to the system, an increase in inlet flow rate from $5m^2/s$ to 6m/s which cause an increment in the water level. For tank1, the water level is to 8.955, an increment of 2.705 from the set point. Whereas for tank2 increases to 3.955, an increment of 1.217. Both PID & Fuzzy controller implemented in the outlet flow stream of both tank have manage to reject the disturbance and control the water level of the tanks back to the set point.

2. Overshoot peak

For this project, the overshoot peak is the highest amount water level after a disturbance is set on the system with the water level controller implemented into the system. For tank1, PID controller have higher amount of overshoot peak compared to fuzzy controller. Fuzzy controller overshoot peak is virtually none, the water level is controlled very quickly to reach the set point. For a control system, lesser overshoot peak is preferred

3. Settling time

The settling time for fuzzy controller for both tanks is faster compared to PID. While the PID controller settling time is virtually similar in both tank. PID controller depends on the complexity of the process and the tuning of parameters of proportional, integral and derivatives to perform better where as Fuzzy controller only needs to have a better base rules, which can be improved and add anytime.

Based on the analysis, fuzzy logic control is a better performer for two non interacting tanks in series. All 3 aspects of comparison are on favour to fuzzy control. The mathematical concept of fuzzy controller is very simple compared to PID. Complex calculation by PID control leads to more time to process a control output. Fuzzy logic is a more intuitive approach without the far-reaching complexity. As long as we understand the concept of the mathematic model of the problem, to solve would not need much of complex calculation. Fuzzy logic can also be integrated with conventional control techniques. So it can actually enhance an existing controller in the system instead of replacing it which will cost more.

The basis for fuzzy logic is the basis for human communication. So it easier to determine the output because it is based on our language like cold, hot, long, short and so on thus making fuzzy logic easy to use.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

As a conclusion, it is proven that fuzzy controller perform better than PID controller in two non-interacting tanks in series.

5.2 Recommendation

There are a few recommendations that might be suitable for this project for improvement

- Increase the number of membership function so that the controller can sustain higher amount of disturbance
- Introduce different type of disturbance signal to see study more on the characteristics of the controller
- Compare with other type of controller instead of PID such as feed forward, cascade controller and etc.
- Integrate PID Controller with Fuzzy Controller to see if Fuzzy logic is capable to increase the performance of PID controller
- Use other type of PID tuning such as Zeigler-Nichols for comparison

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APPENDICES

Appendix 1: Mfile coding to produce graph

```
tank
subplot(3,2,1),plot(tout_tank,h1_tank)
xlabel('time (s)')
ylabel('height (m)')
subplot(3,2,3),plot(tout_tank,h2_tank)
xlabel('time (s)')
ylabel('height (m)')
subplot(3,2,5)
plot(tout_tank,h1_tank,'m')
hold on
plot(tout_tank,h2_tank,'b')
xlabel('time (s)')
ylabel('height (m)')
legend('Tank 1', 'Tank 2')
hold off

tank1
subplot(3,2,2),plot(tout_tank1,h1_tank1)
xlabel('time (s)')
ylabel('height (m)')
subplot(3,2,4),plot(tout_tank1,h2_tank1)
xlabel('time (s)')
ylabel('height (m)')
subplot(3,2,6)
plot(tout_tank1,h1_tank1,'m')
hold on
plot(tout_tank1,h2_tank1,'b')
xlabel('time (s)')
ylabel('height (m)')
```