# DEVELOPMENT AND IMPLEMENTATION OF FUZZY LOGIC CONTROLLER FOR FLOW CONTROL APPLICATION

ELANGESHWARAN PATHMANATHAN

ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
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# DEVELOPMENT AND IMPLEMENTATION OF FUZZY LOGIC CONTROLLER FOR FLOW CONTROL APPLICATION

By

ELANGESHWARAN PATHMANATHAN

**FINAL DISSERTATION**

Submitted to the Electrical & Electronics Engineering Programme

in Partial Fulfillment of the Requirements

for the Degree

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Universiti Teknologi Petronas

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

**CERTIFICATION OF APPROVAL**

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Approved by:

Dr. Rosdiazli Ibrahim

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

## 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.

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ELANGESHWARAN PATHMANATHAN

# ABSTRACT

Flow measurement and control are essential in plant process control. This paper aims to shed some light on the Development and Implementation of Fuzzy Logic Controller for Flow Control Application. The development will be done onto the *PcA SimExpert Mobile Pilot Plant SE231B-21 Flow Control and Calibration Process Unit*. This mobile plant contains flow measurement instruments such as Coriolis, Vortex and Orifice Flow meters. Currently, control and tuning is done via *KONICS* PID Controller that is mounted on the local control panel. This project aims to develop a control strategy using a fuzzy based controller as an alternative to the existing PID controller and to design a DCS-HMI interface using MATLAB/Simulink for this pilot plant. Some of the required tools are the USB-1208 FS Personal Measurement Device and MATLAB Product Family. The Fuzzy Inference System (FIS) are developed using the Mamdani [1] approach. This involves designing and tuning of the membership functions, input/output rules, and the defuzzification technique. Overall, this project has shown that a fuzzy logic controller is a good alternative to a PID controller, and a complete DCS-HMI architecture could be developed using MATLAB/Simulink.

# ACKNOWLEDGEMENTS

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Lastly, the author would like to thank friends, family and all parties who were directly or indirectly involved in making this final year projects a success.

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| | |
|---|---|
| PID | Proportional Integral Derivative |
| PI | Proportional + Integral |
| PD | Proportional + Derivative |
| PMD | Personal Measurement Device |
| FLC | Fuzzy Logic Controller |
| FIS | Fuzzy Inference System |
| DAQ | Data Acquisition |
| PC | Personal Computer |
| ANFIS | Adaptive Neuro Fuzzy Inference System |
| PT | Pressure Transmitter |
| LS | Level Switch |
| TT | Temperature Transmitter |
| FT | Flow Transmitter |
| HV | Hand Valve |
| CV | Control Valve |
| PIC | Pressure Indicator Controller |
| P&ID | Process and Instrumentation Diagram |
| RTW | Real Time Workshop |
| FLT | Fuzzy Logic Toolbox |
| FODT | First Order with Dead Time |
| KB | Knowledge Base |
| MF | Membership Function |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background of Study

Automation via feedback control is not new in the industry. This has begun since the dawn of the Industrial Revolution since the 1800s. This is when the agricultural industry was literally being replaced by the mass manufacturing industry. Focus shifted to large scale production and assembly. With so much emphasis on productivity, human operators just do not cut it and industrial automation became a vital part of any manufacturing or process plant.

Process control is a sub discipline of automatic control. Virtually all consumer products in the market like petrol, detergents, cars or even microprocessor chips go through some form of process or manufacturing plants. A typical single feedback loop consists of a controller, control element, plant, and sensors. The stability of a feedback loop depends on all of the elements mentioned before, however only the controller can be modified easily to adjust the control performance of the plant. Hence to maintain the stability and ensure good response, a good controller is vital.

Flow control commands particular attention in plant process control and measurement because; among other applications controlling flow in a plant is important to [2]:

- Regulate the amount of feed to a reactor.
- Regulate the amount of heating fluid through a shell and tube type heat exchanger and due to that, controlling the temperature of the product.
- Regulate the level of a tank if either the flow in or flow out could be controlled.

### 1.2 Problem Statement

Measuring and controlling flow rate in process plants presents challenges of its own. Both gas and liquid flow can be measured in volumetric or mass flow rates, such as litres per second or kilograms per second. These measurements can be converted between one another if the fluid density is known. The density for a liquid is almost independent of the liquid conditions; however, this is not the case for gas, the density of which depends greatly upon pressure, temperature and to a lesser extent, the gas composition [2]. With so many different variables that could affect flow rate, flow measurement and control is susceptible to disturbances. Because of this, flow controllers need to be robust in order to optimize the performance of a plant. Fuzzy Logic Controller is proposed to replace the conventional PID controller due to its superior applicability and robustness [3]. Apart from that, the current PID controller is mounted on the Local Control Panel, and there is no Human Machine Interface from where the data trend can be viewed ***(Refer to Appendix C – Plant Devices and Instruments)***. This makes monitoring, controlling and tuning of the controller quite cumbersome. To overcome this problem the new controller must have access from a remote PC for easy monitoring, control and tuning.

### 1.3 Objectives and Scope of Study

- To investigate, design and develop a fuzzy logic controller for Flow Control of the Process Unit.
- To implement the advanced control strategy in the Flow Control of the Process Unit by means of DAQ Card and a remote PC.
- To analyze the controller performance between the conventional PID controller and the advanced Fuzzy Logic Controller.

## 1.4 Significance, Relevancy and Feasibility of the Project

The feasibility of the project lies in its minimalistic approach. The physical implementation is quite simple and straightforward. All that needed are a compatible workstation (Laptop) and the USB – 1208 FS Personal Measurement Device. The project's significance is amplified by the fact that the pilot plant is fabricated according to real-world industrial standards and conditions. Hence the input output (feed - product) relationship, as well as the disturbances such as unmeasured noise, feed pressure and outflow of the tank are well captured. Hence the successful design and implementation of a Fuzzy Logic Controller for this plant would mean that it could be applied to the Industry. With some meticulous planning and scheduling, this project has the feasibility to be completed within the time frame and scope of work.

## CHAPTER 2

## LITERATURE REVIEW

## 2.1 Foundations of Fuzzy Logic

### *2.1.1 Fuzzy Sets*

Fuzzy logic begins with the idea of a fuzzy set. A *fuzzy set* is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership [4]. To understand what a fuzzy set is, first the definition of a *classical set* must be considered. A classical set is a set that wholly includes or excludes any given element. The following diagrams attempts to classify the weekend days, as an example to differentiate between fuzzy sets and classical sets.

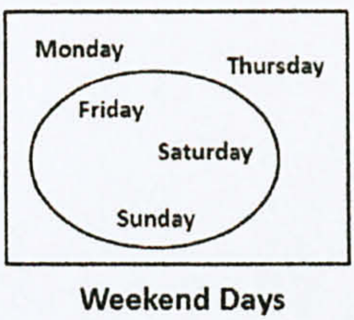


Figure 2-1: Classical Set

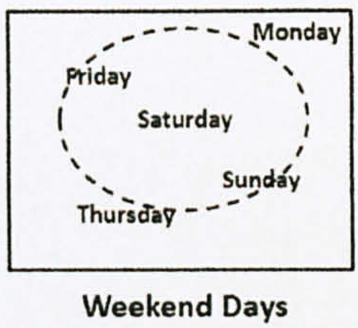


Figure 2-2: Fuzzy Set

As shown above, the classification using fuzzy logic sets is almost like how a human perceives the weekend days, as opposed to simple-minded classifications that is defined in dictionaries. In fuzzy logic, the truth of a statement becomes a matter of degree [5], this is the major advantage of fuzzy reasoning is the ability to answer to a simple yes-or-no question with a not-quite-yes-or-not-quite-no answer. This is exactly how humans think, and now it is possible to be applied to machines and computers.

### *2.1.2 Membership Functions*

A *membership function* (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the *universe of discourse* [6]. Taking the above example, some may perceive certain days to be more like a weekend, while other days are not. This shows that subjective interpretations are built into fuzzy sets. The following example shows the difference between a classical reasoning (degree of membership is either 0 or 1) and fuzzy reasoning (degree of membership is *between* 0 and 1).

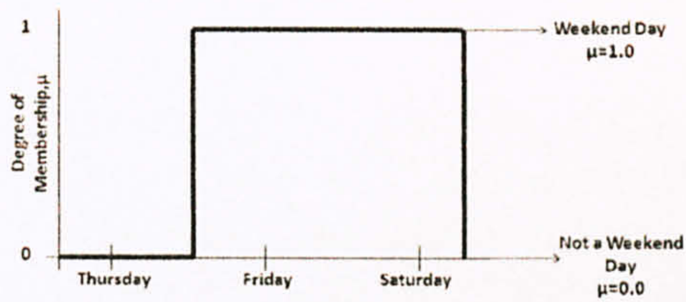


Figure 2-3: Sharp Edged Membership Function for Weekend Days

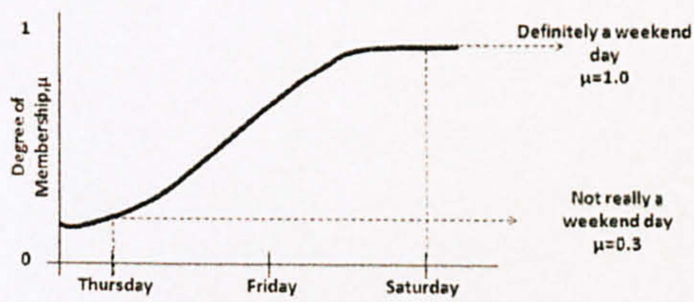


Figure 2-4: Continuous Membership Function for Weekend Days

### *2.1.3 Fuzzy Logic Control*

Controls of processes through fuzzy logic have been demonstrated in 1974 by E.H Mamdani and S. Assilian [7]. They have used the fuzzy if/then rules to regulate a model steam engine; and with that a great number of fuzzy control applications have been deployed. The core of a fuzzy controller is a linguistic description prescribing appropriate action for a given state [8]. From the basic structure of a Fuzzy Logic Controller (FLC), it is understood that it has input interface, linguistic description and output interface. The input and output interfaces handles fuzzification and defuzzification as well as normalization, scaling, smoothing and quantization. The inference mechanism emulates the expert's decision making in interpreting and applying knowledge about what is best to control the plant.

### *2.1.4 Fuzzy Logic Applications*

Fuzzy logic is widely applied in control engineering and sciences. The works of E. H. Mamdani [7] and his students in 1972 was seen as an important milestone. Apart from Fuzzy control, fuzzy logic is applied to other fields. From L. A. Zadeh [9], it is understood that Fuzzy logic has high power of cointensive precisiation which is required in human-centric fields such as economics, conflict resolution, psychology and medicine. An application of Fuzzy logic in the field of psychology is exemplified by Sripada et al [10], where the conscious and unconscious relations of the scientific observer are studied.

### *2.1.5 Mamdani FIS*

FIS is Fuzzy Inference System that is the medium between the parameter ($K_P$ and $T_I$ or $T_D$) or the set point and the output to the PID Controller. To use the Gain – Scheduling method in Fuzzy PID Controller design, one can apply either Mamdani FIS rules or Sugeno FIS rules. This section aims to explain the differences, advantages and disadvantages of the two.

This FIS was built in 1975 by Ebrahim Mamdani [7] to control a steam engine and boiler combination by using synthesis on the experiences by operators and developing linguistic controls based on that synthesis. Mamdani FIS was one of the first and most widespread methodologies in designing control systems using fuzzy controllers. Like most fuzzy logic developments, Mamdani based his idea on Zadeh's [11] paper on fuzzy algorithms for complex systems and decision-making processes.

The output of a Mamdani style FIS are fuzzy sets and hence its development is unique and depends heavily on the type of applications. The following figure exemplifies the Mamdani style FIS.

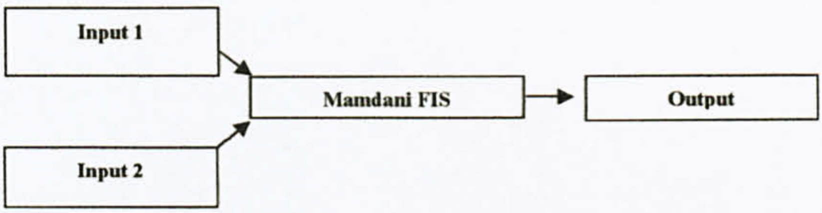


Figure 2-5: Mamdani Style FIS

### *2.1.6 Sugeno FIS*

Michio Sugeno [12] developed the Segeno FIS; it differs from the Mamdani FIS in terms of the output. In Sugeno FIS, the output is singleton or expected to be defuzzified before fed to the PID Controller. Constant or linear equations are obtained from the output variables (although input still remains the same with Mamdani FIS). Actual input value is needed for the linear equations' computations:

Constant $y = k$ , $k$ is measured experimentally or calculated

Linear $y = m_1 x_1 + m_2 x_2 + ... + m_n x_n + c$

Where, $m_1, m_2, ... m_n$ are the gradient to the nth input

$x_1, x_2, ... x_n$ are input variable value to the nth input

$c$ is the y-intercept and $y$ is the output variable

Some of the advantages of Sugeno style FIS are:

- Computationally efficient
- Works well with linear techniques
- Works well with optimization and adaptation techniques
- Guaranteed continuity of the output surface
- Well adapted to Mathematical analysis
- Can be implemented in ANFIS
-

Mamdani style FIS also has its own advantages:

- Its intuitive
- It has widespread acceptance
- It's well suited to the human decision making process

## 2.2 Fuzzy Control Approaches

Fuzzy Logic Controllers have been applied to industrial control by means of emulating the PID Controller. From the proposal of Mamdani [13], there ought to be two input PI or PD to the Fuzzy Logic Controller (FLC); and the output from these FLCs will be fed to the PID Controller. Thus far research for a full-fledged P-I and D FLC is still being conducted. From Mann et al [14], this can be done through separation of fuzzy rules in two stages, linear and non-linear and then this will then be tuned separately. For this project, there will be two possible approaches; Gain-Scheduling and ANFIS. Gain scheduling looks at implicitly defining the fuzzy relationship between the inputs against $K_P$ and $T_I$ or $T_D$ using Mamdani or Sugeno FIS rules. ANFIS however is much simpler, according to Clodoaldo et al [15], the FLC will replace PID once it's completely able to imitate the PID's responses. By using ANFIS approach, the IF-THEN rules and the Membership Function (MF) need not to be defined explicitly, instead; the Fuzzy Controller will be "trained" automatically using the data imported from the PID controller response.

### *2.2.1 Fuzzy Emulation of a PID Controller*

P-I-D like fuzzy controllers is designed basically to overcome the disadvantages of linear PID Controllers [16]. A simple PID controller is defined by the following equation:

$$u(t) = K_P e(t) + K_I \frac{1}{T}\int_0^t e(t)dt + K_D \frac{de(t)}{dt}$$

And in discreet time domain it would be represented as such:

$$u(k) = K_P e(k) + K_P \frac{T_d}{T_I} e(i) + K_P \frac{T_D}{T_d}[e(k) - e(k-1)]$$

Essentially, there are three variants [6] of fuzzy PID Controller, as described by the three figures below:


Figure 2-6: Variant A Fuzzy PID Controller

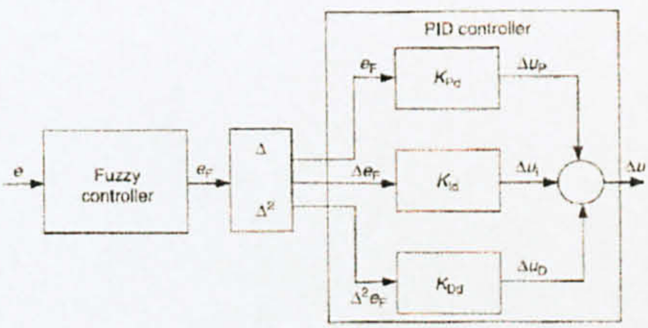


Figure 2-7: Variant B Fuzzy PID Controller

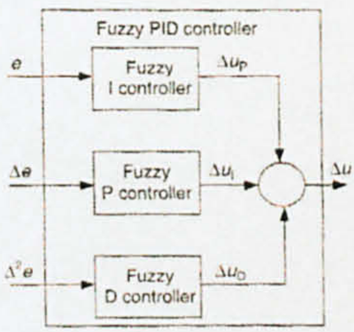


Figure 2-8: Variant C Fuzzy PID Controller

From the above it is deducted that there are three variants that could be implemented:

- Variant A: a single fuzzy PID controller with three inputs $e$, $\Delta e$ and $\Delta^2 e$ and one output, $\Delta u$
- Variant B: a single fuzzy PID controller comprised of a linear PID Controller and a SISO fuzzy controller with $e(k)$ and $e_F(k)$ as input and output.
- Variant C: a fuzzy PID Controller composed of fuzzy P + fuzzy I + fuzzy D controllers having $e$ and $\Delta u_P$, $\Delta e$, $\Delta u_I$, $\Delta^2 e$ and $\Delta u_D$ as received inputs and outputs.

### *2.2.2 Adaptive PID Fuzzy Logic Control*

A new approach proposed by Eker et al [17] aims to improve the performance of not only the conventional fuzzy controller, but also the PID, PI, and PD controllers for the dynamic responses of the closed loop drive system. An improved controller is needed especially to control non-linear and complex systems and many controllers that are developed are purely based on the mathematical model of systems which does not fully describe the complexity of the non-linearity of the system [18]. Electrical drive systems which are used in this research paper have large uncertainties and nonlinearities, and over the years there have been many methods to develop a nonlinear controller such as the self-tuning control [19] and sliding mode control [20]. These methods are complicated and difficult to implement, which contradicts with the core of a fuzzy controller which is based on simple human heuristics instead of complex mathematics. For conventional FLC, there are bound to be some steady state error due to the lacking of an inherent integrating property [21]. To improve on this many methods have been proposed; one of which is the PI-type FLC which generates incremental control output via an integrator at the output. It is also more practical because it reduces overshoot and settling time. Nevertheless, PI-FLC is known to give poor performance in transient response [22]. Lately there have been some significant developments in PID-FLC in order to improve the transient characteristics of the

PI-FLC controller [23]. The following figures exemplify the conventional, PI and PID type FLCs:

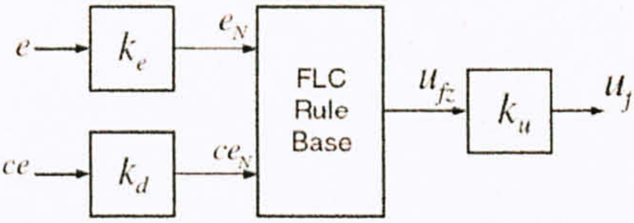


Figure 2-9: Conventional FL controller diagram

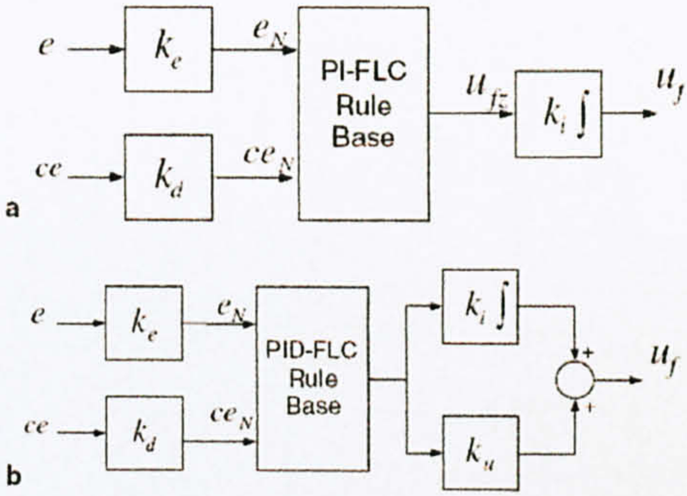


Figure 2-10: Fuzzy PID control diagram (a) for PI-FLC and (b) for PID-FLC.

Nevertheless, with highly nonlinear and uncertain controlled plants, adaptive FLC are shown to give better performances in many cases and applications [24]. Several adaptive fuzzy techniques developed for FLC, among others [17]:

- Membership function tuning
- Input or output scaling factors tuning
- Linguistic rules tuning

In their paper Eker et al [17] have developed the adaptive FLC based on the tuning of the scaling factors because it's more effective and simpler implementation of the control policy. What results is an adaptive FLC whose control actions changes according to plant operation. The tuning is done based on error and the changes in error, hence the scaling factors; $k_i = f(e_N)$ and $k_d = g(e_N)$. This is shown below:

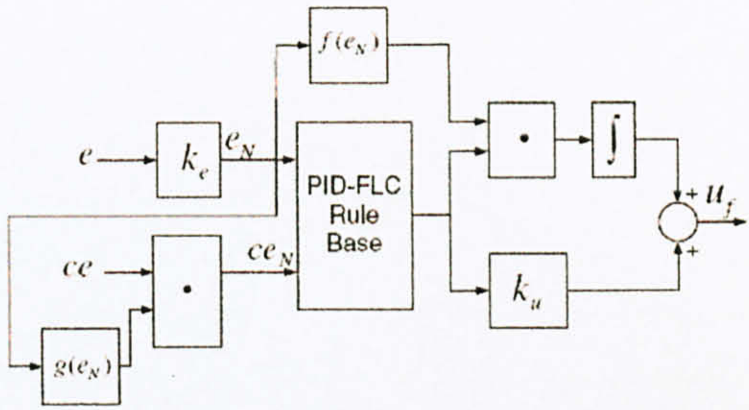


Figure 2-11: Adaptive PID-FLC Diagram

Where;

$f(e_N) = a_1 \times (a_2 + a_3 \times |e_N(k)|)$

$g(e_N) = b_1 \times (b_2 - b_3 \times |e_N(k)|)$

And $a_1, a_2, a_3, b_1, b_2$, and $b_3$, are all positipve and real constants.

### *2.2.3 PD-Fuzzy Controller without Steady State Error*

This project is developed mainly on the basis of a PD-Fuzzy architecture; where the inputs to the FLC are error, E and the differentiation of the process variable delPV. The reason why PD fuzzy architecture is chosen over a PI fuzzy is because the former produces quicker response with less oscillation [25]. Even though a FLC is superior in terms in robustness and applicability [26], PI fuzzy and PD fuzzy do posses some main characteristic as a PI and PD controller. The PI controller adds damping to the system and reduces steady state error, but it lengthens the rise and settling times, meanwhile the PD controller adds damping and it's able to predict large overshoots; however it doesn't improve the steady state error. Some works have been done to improve the PD fuzzy controller by fine tuning the rule base, performing parameter optimization and increasing and number of rules [27]. The PI fuzzy controller is able to solve the steady state error problem, however to improve the rise time and oscillatory behaviour techniques such as scaling factor adjustments, rule modifications and membership functions shifting are required [28].

The main tool used to tune a FLC are by scaling factor (SF) adjustments, however issues such as modifications of the poles of the overall transfer function and it's zeros [29] could lead to a dramatic influence on the dynamics of the overall dynamics of the control loop. This calls for a more standardized method of tuning SF's. Some existing methods [30] require control performance information prior to tuning which proves to be troublesome because an acceptable controller is needed before any tuning could be performed. Another popular method is via gradient based Back Propagation (BP) algorithm similar to the methods from neural network based fuzzy systems [31]; however the drawbacks is that it is very time consuming to take hundreds of learning epochs to train so many parameters in fuzzy neural networks. The proposed Self – Tuning Controller (STC) proposed by the Chao et al [25] has the following architecture:

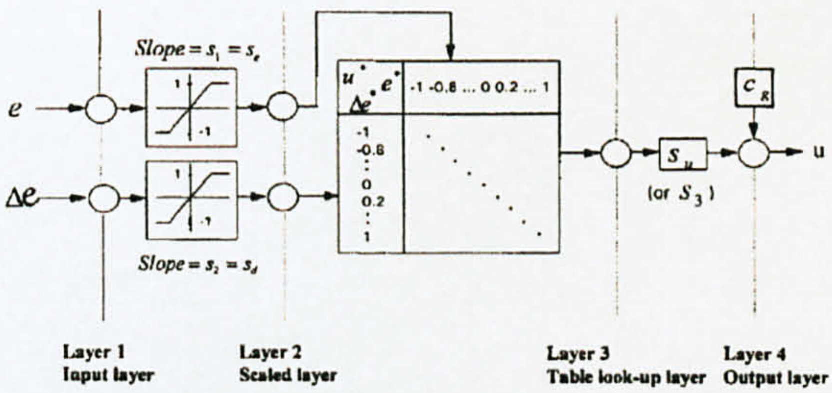


Figure 2-12: The Network Structure of the STFC

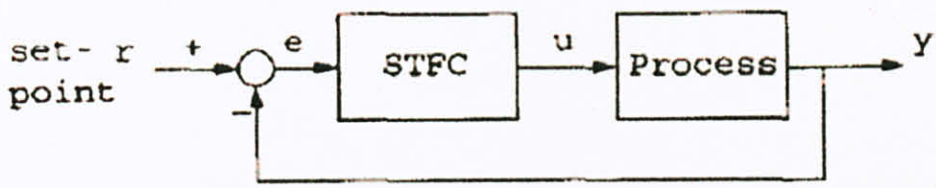


Figure 2-13: Block Diagram of a basic Feedback Control System

## 2.3 Advances, Robustness and Stability of Fuzzy Control

In the paper Application of Fuzzy Logic Control in Industry, van der Wal [32], suggested many ways of which fuzzy logic can be used to improve the industry is explained. In one of the works, it is shown that by incorporating fuzzy logic with existing PID Controller, it could be fine tuned by the operator without any prior knowledge regarding the system. A case study regarding the ES100 industrial controller is done by van der Wal and Mattaar [33]. In this study, the classical PID Controller is combined with a feed forward and a fuzzy expert system for fine-tuning the ES100 OMRON Controller. From this study, the clear advantages qualities of fuzzy logic, which is the incorporation of tuning knowledge of a human control expert and the merging of human observations and the operator's decision to optimize the behaviour of the system under control, are fully obvious. This combination of Fuzzy-PID controller architecture will be implemented in this project. The article "Why is Fuzzy Control Robust" by Pok and Xu [34] was the initial wayward that sets the path towards the study of the robustness and stability of fuzzy logic control. In their paper, the derivation of conditions for asymptotic stability and robustness are carried out by considering system trajectories in phase space and making a number of assumptions.

The simplistic derivation starts with two-input fuzzy controller consisting of only four rules:

*IF (E = P) and (R = P) then U = P;*

*IF (E = P) and (R = N) then U = Z;*

*IF (E = N) and (R = P) then U = Z;*

*IF (E = N) and (R = N) then U = N;*

From above, $P$ and $N$ and $Z$ represent the linguistic values 'positive', 'negative' and 'zero' respectively. The fuzzy variable $E$ and $R$ represents the weighted error and weighted rate of change of the error represented by two linear membership functions *(P,N)* each on a bounded universe of discourse. The controller output variable $U$ have three linguistic values *(N,Z,P)* and can be represented by three triangular MF's (Membership Functions). This elementary fuzzy controller to stabilize a second order linear process with damping ratio of 0.1 and unity gain; and by simulation it is shown that even when the damping ratio is varied from 0 to 1.5, and the process gain from 1 to 3, the controller is still capable of stabilizing the system. System response is virtually identical under these variations, indicating the controller's robustness. The stability analysis is also straightforward, using the Lyapunov theory; however it's quite laborious because many different regions in phase space have to be considered. Another analysis to show that the fuzzy controller effectively operates as a variable structure controller with a boundary layer of varying thickness is shown [35]. From the thickness of the boundary layer, the robustness and steady-state accuracy (i.e. stability) of the controller can be expressed.

## 2.4 Modelling of a Coupled Industrial Tank System with ANFIS

The importance of having a good model of a system to be simulated on prior to implementation of an intelligent control system is exemplified by Engin et al [36]. In this section a non-linear coupled tank system will be modelled using ANFIS (Adaptive-Network-Based Fuzzy Inference System), of which it will be used to develop a fuzzy-PID control for this system. The modelled system should reflect the whole characteristic of the real system that is to be controlled. As described in previous literatures, there are two ways of which modelling of a plant system can be done; mathematical modelling and system identification (otherwise known as empirical modelling). Empirical modelling is preferred especially if the plant or process involves extremely complex physical phenomenon or have some nonlinearities. Mathematical modelling is normally very tedious and requires a in depth understanding of the plant's physical characteristics; lately researches done by Jang, 1993 [37], have shown that combining the linguistic description of fuzzy logic and the mathematical self learning of artificial neural network, an accurate model of a plant system can be achieved based only on some inputs and outputs to and from the plant. System parameters should first be determined in system identification and in this modelling technique using ANFIS, the Takagi-Sugeno [38] fuzzy modelling technique are used, and with a hybrid learning procedure ANFIS can learn input-output mapping by combining some features from artificial neural network (NARX model):

$$\phi = [u(t-k),..u(t-n), y(t-k)...y(t-m)]$$

## 2.5 Generation and Tuning FLC Knowledge Base

A research done by Sultan et al [39] of Mentalogic Systems Inc (MSI) has shed some light a new method to tune and design a fuzzy based controller. An automated station for automated design of fuzzy controller application is developed on the basis that it will support functions such as automated knowledge base (KB) generation and tuning. The need for such an automated station stemmed from the need to solve some of the known difficulties in obtaining the fuzzy controller:

- Difficulties in obtaining the FLC's KB and Membership Functions (MF)
- Difficulties to comply with the requirements for fast and multivariable control
- Difficulties in tuning and obtaining stable controller. The trial and error method is still basic in tuning a FLC.

Sultan and the team from MSI are developing an Automated Fuzzy Controller Design Station (AFCDS) to allow the rapid development of FLC based applications. The AFCDS has the following systems incorporated:

- Fuzzy Modelling System
- Automatic Fuzzy Knowledge Base Generator
- Fuzzy Tuning System

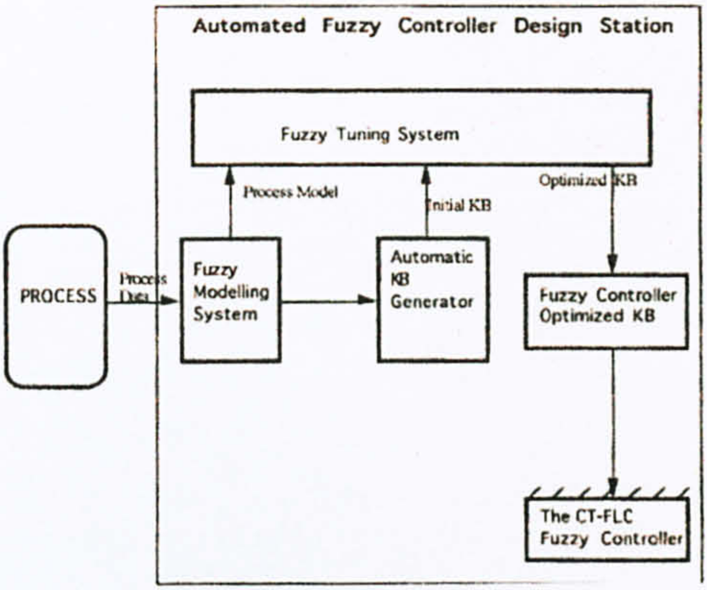


Figure 2-14: The Block Diagram of AFCDS

## 2.6 Flow Rate Measurement

### *2.6.1 Coriolis Flowmeter*

Coriolis Flowmeter measures flow rates based on mass of the fluids. This flowmeter measures mass flow directly, independent of temperature and pressure. The accuracy of these flowmeters is remarkably accurate, typically 0.02% to 0.5% of total flow rate. According to G. Bobovnik [40], the sensitivity of the flowmeter can be affected by the various flow conditions, i.e. fully developed flow, asymmetry flow and swirl flow. The flowmeter operates based on the Coriolis force principle, where a sine wave is applied to an electromagnetic drive which causes the internal flow tube to oscillate perpendicular to the flow. This oscillation is at resonances frequency which also provides information about the density of the fluid [41]. When process fluid flows through the tube, the vibration causes a slight angular rotation at its centre, the flow movement towards the centre aids the tube rotation. The resultant force produces the measured sine wave which is measured and converted to the mass flow reading.

### 2.6.2 *Vortex Flowmeter*

Vortex flowmeters uses a principle involving the formation of a vortex swirls (vortices) downstream of an obstruction placed in a flowing stream. When fluid passes by an object or obstruction, oscillation can occur (e/g: flag waving in wind). Vortex shedding flowmeters uses a bluff body obstruction and the higher the flow rate, the higher the frequency of oscillation. A sensor detects this frequency and an electronic transducer/ transmitter generates flow measurement signal. The ideas of vortex flowmeters that are to be used to measure mass flow rate have been developed by Y. Huang et al [42]. Vortex shedding is detected at the vortex shedder using the differential pressures at the downstream and upstream sides. To reduce noise disturbance, vortex frequency and pressure are measured simultaneously.

### 2.6.3 *Orifice Flowmeter*

An orifice plate assists in measuring flow through differences in pressure from the upstream side to the downstream side of a partially obstructed pipe. A DP Cell provides the measurement of the difference in pressure at the upstream side (unobstructed) and the downstream side (obstructed). The greater the flow, the greater the difference in pressure. Orifice plates flowmeters are generally cheaper to purchase and install compared to other devices. A specialized type of orifice flowmeter is the variable area type, where a bluff body is inserted symmetrically inside the orifice. Design analyses performed by S.N Singh et al [43] on the bluff body showed that the ideal characteristics of flowmeter of constant differential pressure have not been achieved; hence further research regarding the insertion and design of the bluff body is required.

## 2.7 Fuzzy Logic in Level Control

According to Niimura et al [44] water level control in Hydro Generating Plants needs to be strictly monitored by feedback control, hence in their paper; they have proposed the usage of Fuzzy Logic Controller to control the water level to the reservoir. According to them, the IF-THEN rules are highly adaptable to the human logic and the conditions for water level can be expressed in terms of fuzzy sets and reasoning that provides multi-attribute decision making. From simulations, it is proven that fuzzy logic control is suitable to maintain the water level to a certain limit, while allowing other operational goals of the plant to be achieved. In a different paper, Aydogmus [45], has shown that water level control in a tank is indeed possible with the usage of the Sugeno type fuzzy algorithm. MATLAB/Simulink has been used to implement the controller. One of the main reasons FLC is chose over conventional PID is that the latter adjusts system parameters on the basis of a set of differential equations which is the model of the system dynamics. However, by using fuzzy logic, these adjustments are handled by a fuzzy rules-based expert system. This paper also proves that to design a fuzzy logic controller, there is no need for a precise model of a system, fuzzy controller demonstrates better results than conventional PID in terms of response time, settling time and robustness.

# CHAPTER 3
# METHODOLOGY

## 3.1 Procedure Identification

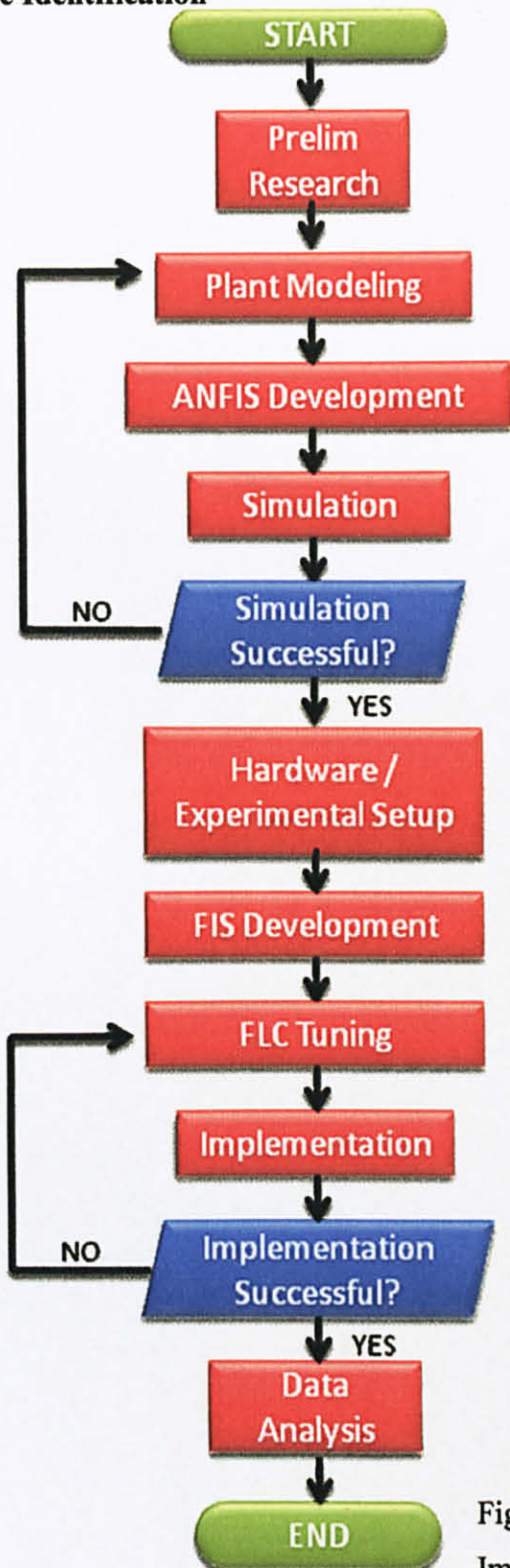


Figure 3-1: Flow Chart of Project Implementation

## 3.2 Project Activities

Table 3-1: Elaboration on each Step of the Flow Chart

| Activity | Description |
|---|---|
| **Preliminary Research** | Performing initial ground work in obtaining information regarding the project and its elements like hardware, software and model verifications. Also includes critical literature survey to enhance knowledge about advances in Fuzzy Logic and Control, among others. Reference Empirical and Mathematical Model will be obtained |
| **Plant Modelling** | Plant modelling is performed via the Empirical modelling method. The resultant model is the first order with dead time (FODT). Next, the mathematical modelling method is also employed to compute the plant model. |
| **ANFIS Development** | Using ANFIS method under the Fuzzy Logic Toolbox, the plant will be modelled. At this stage the FLC is to be used with PID Controller in order for it to mimic the PID responses. |
| Simulation | The simulation involves FIS which are developed using ANFIS method, and the empirical model of the plant. This is done to understand the behaviour of the FLC and how it interacts with the plant model. |
| Hardware/Experimental Setup | Preparation for implementation is done at this stage. The Data Acquisition cards (DAQ) are used to interface between the plant and computer. Termination of cables, jumpers and resistors are done to ensure that interfacing is possible. |
| FIS Development | At this stage, the FIS is developed from scratch. Using reference from several literatures; the membership functions, input fuzzification and output defuzzification techniques are designed. |
| FLC Tuning | To ensure the best control performance, the controller is fine-tuned. Some of the methods used are input/output scaling and membership function tuning. |
| Implementation | To implement completely the fuzzy controller onto the process plant. The controller is subjected to random set |

| | |
|---|---|
| | point changes, and also disturbances. At this stage the DCS-HMI architecture will also be developed. |
| Data Analysis | The control performances of the FLC and PID controller are compared to determine which one is superior. |

### 3.3 Tools and Equipments Required

Some of the hardware and software required are listed below. Also refer to ***Appendix D – Project set up.***

- A Laptop PC
- DAQ Cards (USB-1208FS)
- MATLAB with Real Time Workshop, Control System, Fuzzy Logic Toolboxes, Simulink and ANFIS.
- Smaller components such as 250Ω resistors, and jumper cables

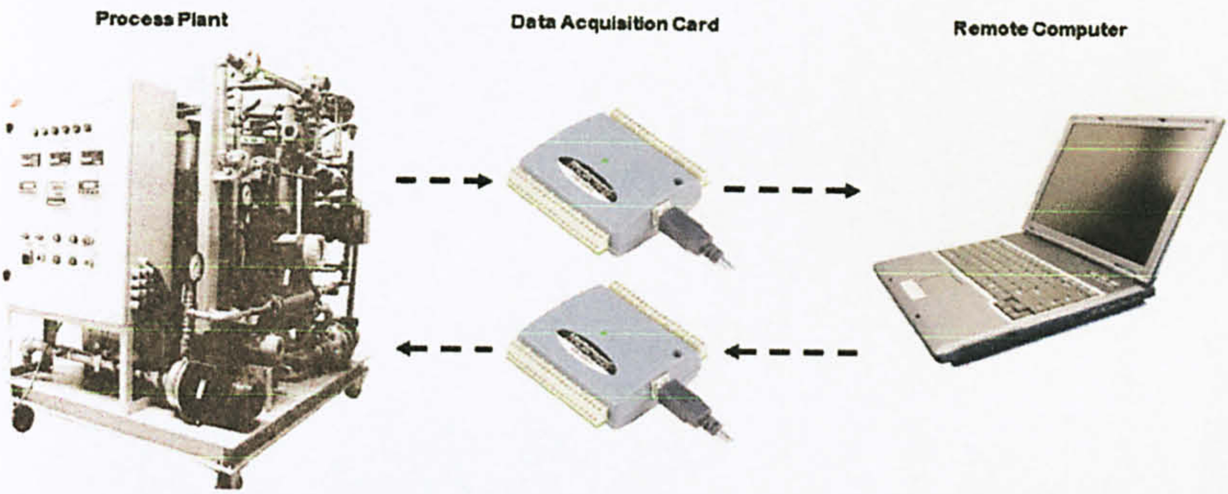


Figure 3-2: System Overview

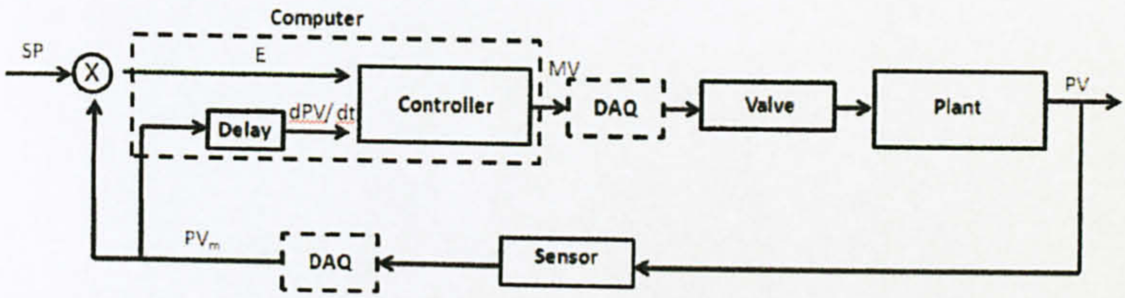


Figure 3-3: Block Diagram Implementation

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 Plant Process and Instrumentation Diagram

The P&ID of the *PcA SimExpert Mobile Pilot Plant SE231B-21 Flow Control and Calibration Process Unit* are as below; the symbols and numbering standards are referred [46].

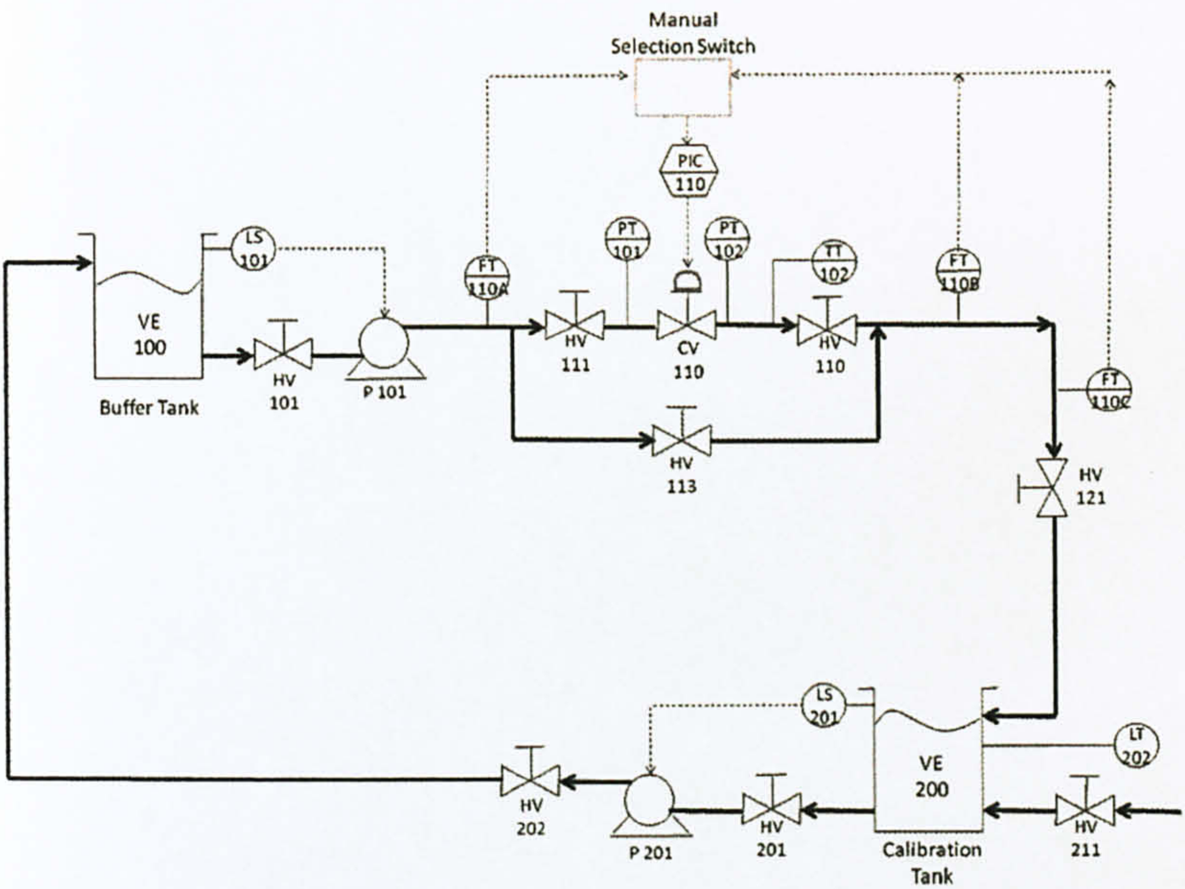


Figure 4-1: P&ID of the Plant

## 4.2 Plant Process Description

Based on the P&ID, it is observed that this process is fairly simple. This plant's objective is to transfer the fluid (water) from the Buffer Tank (VE-100) to the Calibration Tank (VE-200); while controlling the flow of the fluid in between these two tanks. The flow must be controlled in such a way that the level in both tanks does not overflow and can be maintained at a steady predetermined level. The main feedback loop in this plant is controlled by PIC – 110, of which the flow inside the pipe will be measured by either one of the three available flow meters and fed back to the controller. The controller then will then send an output signal in order to control the opening of the Control Valve (CV-110). CV-110 has causal relationship with the flow of the fluid from VE-100 to VE-200. The three flow meters (FT-110A, FT-110B and FT-110C) can be used interchangeably by selecting either one using the Manual Selection Switch. Besides that, there are two other feedback loops; the level switch (LS-101) to the pump (P-101) and level switch (LS-201) to pump (P-201). Both of these feedback loops have the same objective, which is to protect the pumps and their respective tanks. It is used as a fail-safe measure to ensure that whenever the level in the tank gets too low, the pump will be shut down, so that it won't be damaged. The pressure transmitters (PT-101 and PT-102) are used to determine the before and after pressures of the line that goes through CV-110. There is also a Level Transmitter to indicate the level in the tank, a temperature transmitter (TT-102) which is useful to determine the density of the fluid. There are several hand-valves installed; these are used to ON and OFF certain lines; depend on the task at hand.

## 4.3 Plant Modelling Techniques

### *4.3.1 Mathematical Modelling*

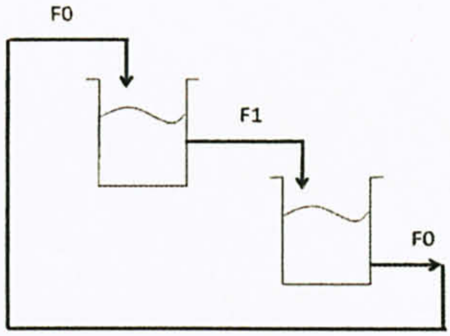


Figure 4-2: Simplified Two Tank System

In order to do Mathematical Modelling for any process, the following steps are used [46]:

1. Define Goals
    a. Specific Design Decisions
    b. Numerical Values
    c. Functional Relationships
    d. Required Accuracy
2. Prepare information
    a. Sketch process and identify system
    b. Identify variables of interest
    c. State assumptions and data
3. Formulate model
    a. Conservation balances
    b. Constitutive equations
    c. Rationalize (combine equations and collect terms)
    d. Check degrees of freedom
    e. Dimensionless form
4. Determine solution
    a. Analytical
    b. Numerical

5. Analyze results
    a. Check results for correctness
        i. Limiting and approximate answers
        ii. Accuracy of numerical method
    b. Interpret results
        i. Plot solution
        ii. Characteristics behaviour like oscillations or extrema
        iii. Relate results to data and assumptions
        iv. Evaluate sensitivity
        v. Answer "what if" question
6. Validate model
    a. Select key values for validation
    b. Compare with experimental results
    c. Compare with results from more complex model

In order to model the tank, the density of the liquid, $\rho$ is considered to be constant, and since the tank is cylindrical, the cross section of the tank doesn't change with the height of the tank. The available data is as follows:

- Cross section of the tank, $A = 551.55cm^2$
- Diameter of the tank is $26.5cm$
- The height of liquid at 100% level is $83cm$
- The initial steady state condition is the tank's level, $L$

The level depends on the total amount of liquid in the tank; thus the conservation equation is selected is an overall material balance of the system;

$$\frac{d(mass)}{dt} = \rho F_i(t) - \rho F_o(t)$$

From the above equation, it can be said that the level of liquid in the tank is equals to the difference in the inflow to the tank and the outflow from the tank. This is depicted in the following equation:

$$F_i(t) - F_o(t) = A\frac{dL(t)}{dt}$$

The out-flow rate of liquid in a pipeline is given by the following equation:

$$F_o = C_d a\sqrt{2gL} = k_{Fo}L^{0.5} \text{ where } k_{Fo} = C_d a\sqrt{2g} = 39.23$$

$F_o$ is the flow rate of the liquid out of the tank $cm^3/\sec$

$C_d$ is the discharge coefficient of the tank outlet = 0.7

$a$ is the area of the tank outlet = $1.266cm^2$

$G$ is the gravitational constant = $9.8m/s^2 = 980cm/s^2$

Combining all the equations, the system can be described by a single first order differential equation:

$$F_i - k_{Fo}L^{0.5} = A\frac{dL}{dt}$$

Subtracting the linearized balance at steady state conditions and noting that input is a constant step, we have the following equation:

$$\Delta F_i(t) - (0.5k_{Fo}L_s^{-0.5})L' = A\frac{dL'}{dt}$$

The linearized Differential Equation can be rearranged and solved as before:

$$\tau\frac{dL'}{dt} + L' = \frac{\tau}{A}\Delta F_i \text{ With } \tau = \frac{A}{19.26L_s^{-0.5}}$$

$$\text{And } K_p = \frac{\tau}{A} = \frac{1}{19.26L_s^{-0.5}}$$

Transforming the above equation using Laplace transform to obtain a transfer function whereby the input is the in-flow and the output is the liquid level, we obtain the following:

$$L'(s) = \frac{K_p}{\tau s + 1} F_i'(s)$$

The transfer function above is a general one, because it depends on the initial level of the liquid as it affects the flow rate of the outlet.

### *4.3.2 Empirical Modelling*

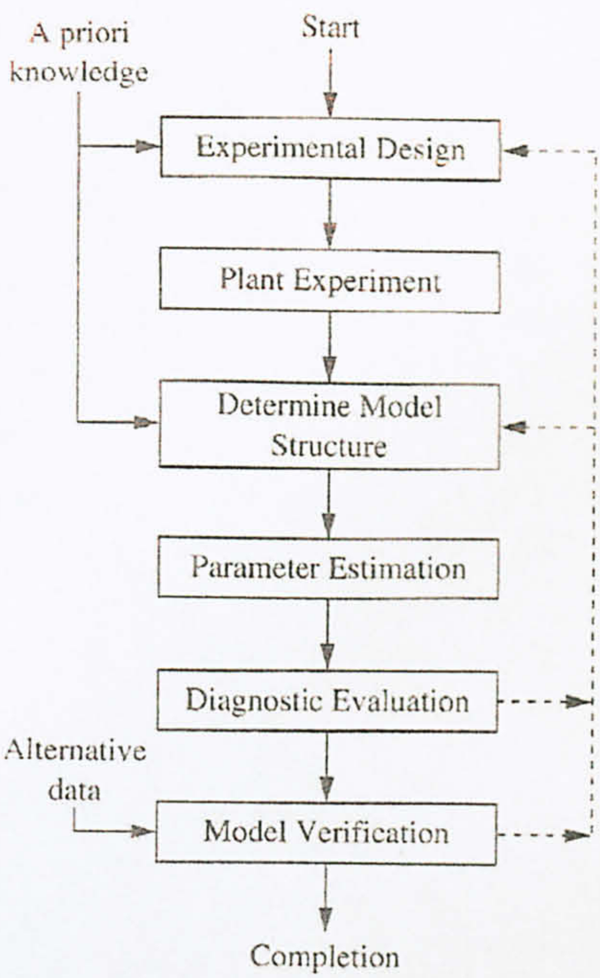


Figure 4-3: Empirical Modelling Technique Flow Chart

The above flow chart shows the typical steps taken in order to determine an Empirical Model of the Process plant. Typically Empirical Modelling has two methods; Method I use the slope to determine time constant, while Method II uses the time at 28% and 63% to determine the time constant. The parameter estimation step is normally chosen as Method II, especially when the signal has high frequency noise [46]. There are several reasons why Empirical Modelling are preferred over Mathematical Modelling, the main reasons being its simplicity and Empirical Modelling places a greater emphasis on the human cantered construction of models that has the elements of observations and experimentations [47].

The Empirical Modelling is done through plant experimentation to obtain the Process Reaction Curve, and by using the Cohen – Coon open loop tuning method, the PID Parameters were obtained:

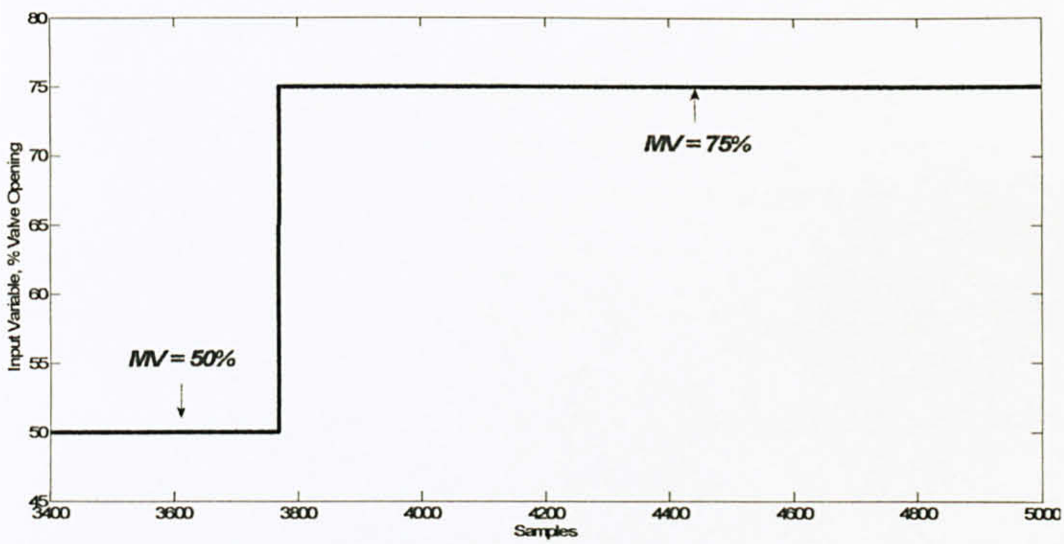


Figure 4-4: Process Reaction Curve (changes in MV – Valve Opening)

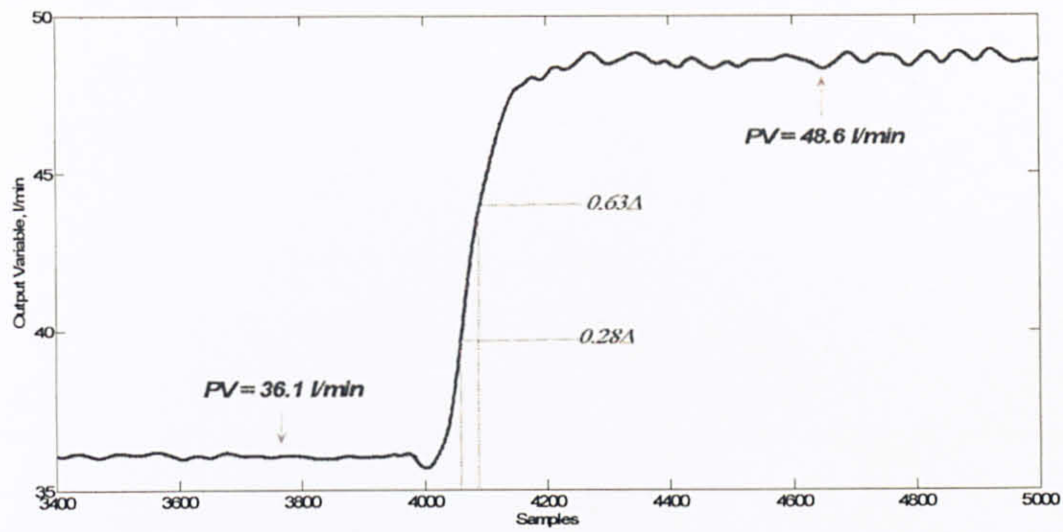


Figure 4-5: Process Reaction Curve (changes in PV – Flow Rate)

The PRC above is acceptable, because of the following factors:

- The input (MV) magnitude is large enough to give an output (PV) signal to noise ratio greater than 5.
- The experiment duration is long enough, it is longer than $\theta + 4\tau$.
- The input change is a perfect step change.
- The model is obtained matches the First Order with Dead Time process model.
- There are no significance disturbances that can strongly degrade the accuracy.
- From the simulations (see next section) the diagnostics shows that the model is acceptable.

The graphical calculations are shown below, note that the sampling rate is $100 samples/\sec$.

$\sigma = 25\%$

$\Delta = 12.5l/\min$

$K_P = \Delta/\delta = (12.5l/\min)/(25\%) = 0.5$

$\delta = 25\%$

$0.63\Delta = 43.93 l/\min$

$$t_{63\%} = (4090 smpl - 3796 smpl)/(100 smpl/\sec) = 3.21\sec$$

$0.28\Delta = 39.60 l/\min$

$$t_{283\%} = (4059 smpl - 3796 smpl)/(100 smpl/\sec) = 2.90\sec$$

$$\tau = 1.5(t_{63\%} - t_{28\%}) = 1.5(3.21 - 2.90) = 0.465\sec$$

$$\theta = t_{63\%} - \tau = (3.21 - 0.465) = 2.75\sec$$

Table 4-1: Results for Process Reaction Curve

| Measurement | Value |
|---|---|
| Change in perturbation / MV, $\sigma$ | 25% |
| Change in output / PV, $\Delta$ | 12.5 *l/min* |
| Maximum slope, $S$ | - |
| Apparent dead time, $\theta$ | 2.75 *sec* |
| **Calculations** | **Value** |
| Steady State Process Gain, $K_P = \Delta/\sigma$ | 0.5 |
| Apparent time constant, $\tau = \Delta/S$ or $\tau = 1.5(t_{0.63\Delta} - t_{0.28\Delta})$ | 0.465 *sec* |
| *Fraction dead time, $R = \theta/\tau$ | 5.91 |

Table 4-2: Tuning Constants

| Tuning Parameters: | P-only | PI | PID | PD |
|---|---|---|---|---|
| Proportional Gain, $K_c$ | 1.005 | 0.471 | 0.951 | 0.756 |
| Integral Time, $T_I$ (minutes/repeat) | | 0.659 | 2.083 | |
| Derivative Time, $T_D$ (minutes/repeat) | | | 0.482 | -0.403 |

The tuning constants above were obtained using Cohen Coon open loop correlations ***(Refer to Appendix I)***. From the process reaction curve, the First Order wit Dead Time (FODT) model was obtained;

$$G_p(s) = \frac{0.5e^{-2.75s}}{0.465s + 1}$$

### 4.4 Preliminary Simulation Results

Using this model, several simulations have been conducted using MATLAB and Simulink. The steps to develop the Fuzzy Logic Controller in MATLAB are as follows:

1. Develop control model using PID Controller
2. Train the Fuzzy Logic Controller to emulate PID's response using ANFIS
3. Implement the FIS in the Fuzzy Logic Controller block
4. Compare results from both controllers.

*Step 1: Develop control model using PID Controller*

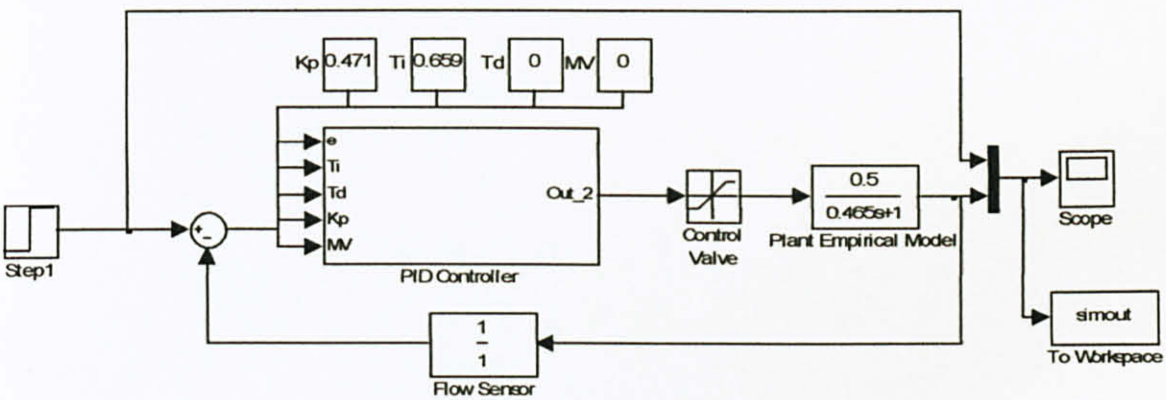


Figure 4-6: Plant Model using PID Controller

*Step 2: Train the Fuzzy Logic Controller to emulate PID's response using ANFIS*

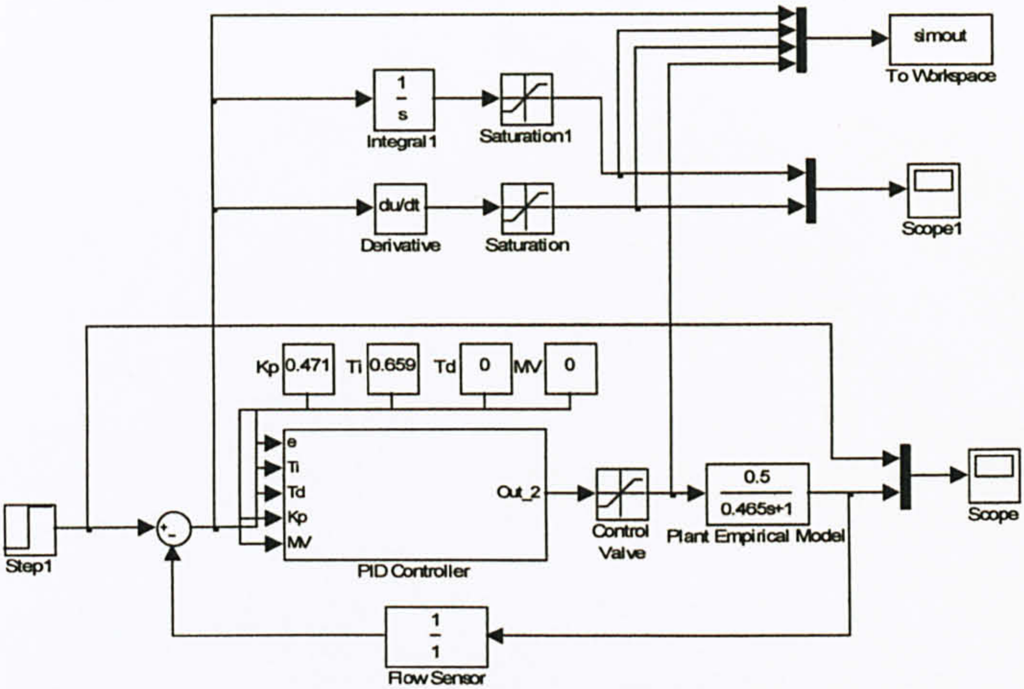


Figure 4-7: Export Simulation Data to Workspace

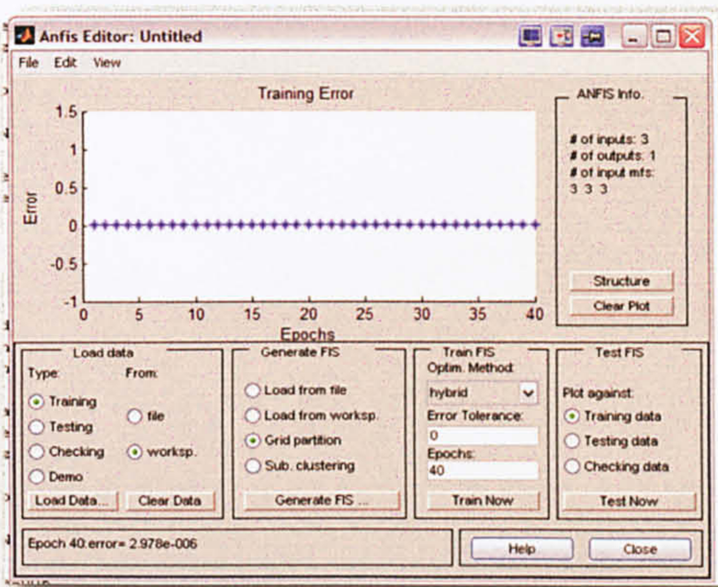


Figure 4-8: ANFIS Training to Generate FIS

*Step 3: Implement the FIS in the Fuzzy Logic Controller block*

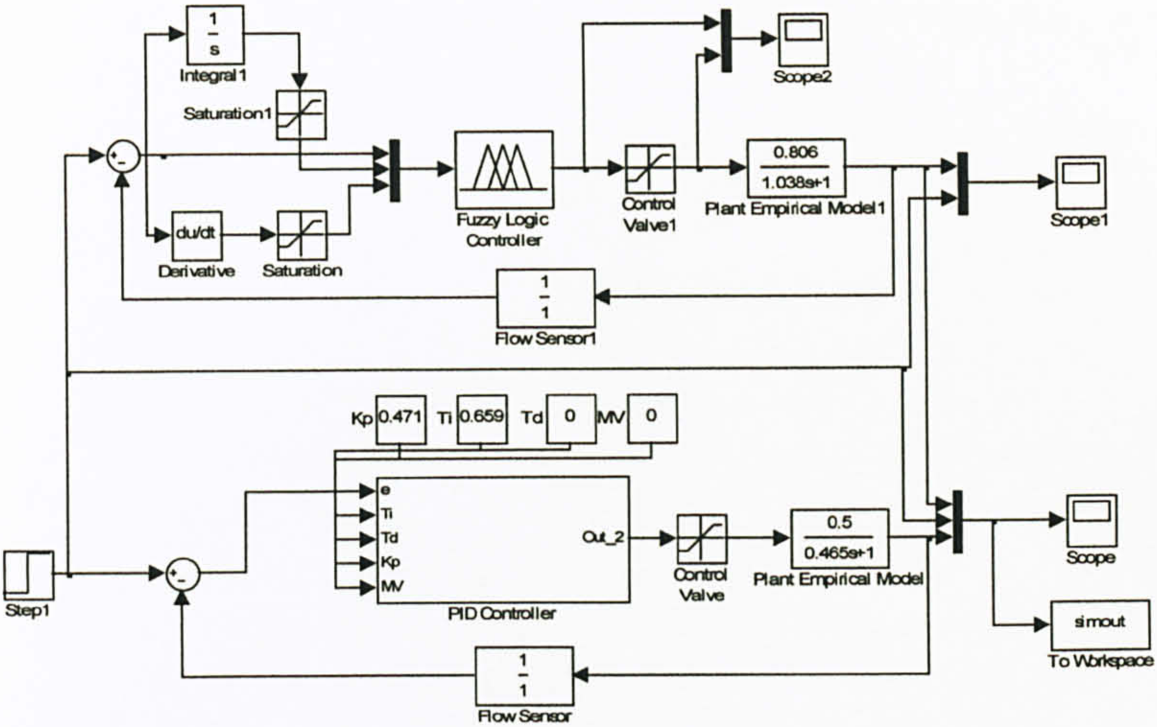


Figure 4-9: Plant Model with both PID and FLC Controller

*Step 4: Compare results from both controllers.*

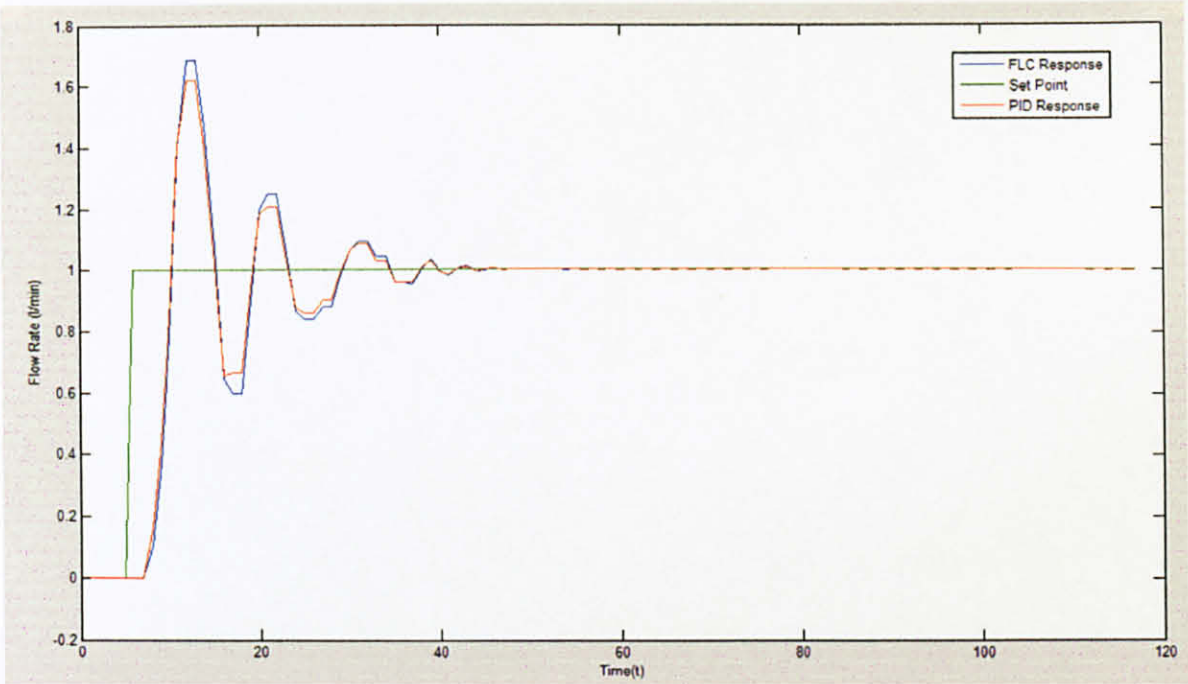


Figure 4-10: Comparative Controller Response between PID and FLC

From the above figure, the comparative response from the PID Controller and the Fuzzy Controller can be demonstrated. Following are some of the findings from this preliminary simulation:

- The Fuzzy controller has successfully emulated the response of the PID Controller for a step change input
- The ANFIS Training has some drawbacks, whereby the Fuzzy controller that has been trained can respond effectively only towards the input that it has been trained with earlier. The fuzzy controller would not be able to control the system optimally should there be any other inputs like random numbers or sine wave.
- To counter this problem there can be two possible solutions; the first is to train the Fuzzy controller for different types of inputs like sine waves or random numbers. Secondly is by defining the IF-THEN rules and Membership Functions (MF), as suggested by Niimura [44] and Aydogmus [45]. With this, Fuzzy Controller which is more robust and quicker can be developed.

## 4.5 Fuzzy Logic Controller Development and Implementation

### *4.5.1 Designing a Fuzzy Inference System*

Another way to design the FLC is by using the Fuzzy Logic Toolbox in MATLAB. Keeping in mind that this FLC will be used to control the flow of liquid in the plant; the Fuzzy Inference System (FIS) is designed to have two inputs i.e. the error, $E$ and the rate of change of flow which is, $delPV$. The reason why the derivative of the process variable is taken instead of the derivative of error is because the derivative mode amplifies the sudden changes in controller input signal and cause large variation in the controller output. For example, derivative of a step change goes to infinity and practically this may completely open/close the control valve. Hence, by taking the derivative of the process variable, this could reduce the extreme variation in the manipulated variable [46]. The output is the control signals to the control valve, hence the manipulated variable $mv$. The relationship between the inputs and output are shown in Table 4-3. The input-output relationships are used to develop the IF-THEN rules for the fuzzy inference system. A total of 81 rules can be developed. There are 81 rules in total; the reason why such a large number of rules are applied is to ensure better control performance, with better accuracy especially at smaller errors

Table 4-3: Relationship between Input and Output

| E/delPV | NL | NI | NM | NS | Z | PS | PM | PI | PL |
|---|---|---|---|---|---|---|---|---|---|
| NL | NL | NL | NL | NL | NL | NL | NL | NL | NL |
| NI | NM | NM | NS | NI | NI | NI | NS | NM | NM |
| NM | Z | NM | NM | NM | NM | NM | NM | NM | Z |
| NS | PS | Z | NS | NI | NS | NI | NS | Z | PS |
| Z | Z | Z | Z | Z | Z | Z | Z | Z | Z |
| PS | NS | Z | PS | PI | PS | PI | PS | Z | PS |
| PM | Z | PM | PM | PM | PM | PM | PM | PM | Z |
| PI | PM | PM | PS | PI | PI | PI | PS | PM | PM |
| PL | PL | PL | PL | PL | PL | PL | PL | PL | PL |

With that, the inputs, $E$ and $delPV$ the output *mv* each has nine membership functions; negative large (NL), negative intermediate (NI) negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), positive intermediate (PI) and positive large (PL).The figures below shows the membership functions of the two inputs and output. As observed below in the membership functions (*Figure 4-13 and Figure 4-14*), the range of the first input, $E$ is taken from [-50 50], this is because the range of operation for this plant is set from 15*l/min* to 45*l/min*. From the valve characteristics below (*Figure 4-17*), it can be concluded that the valve is non-linear in nature; the range with best linearity is from 15*l/min* to 45*l/min*. The error wouldn't exceed $\pm 30$*l/min*, because the largest set point change $\Delta SP$ would be 30*l/min*. This is the exact reason why a limit of [-50 50] is chosen as the $E$ input range. For the second input $delPV$, a range of [-20 20] is chosen because at the empirical modelling stage, the change in flow rate is found to be averaging around $\pm 20$*l/min/sec* when there is a step change in the set point. Looking at the MF's for the output *(Figure 4-15)*, the range is set at [-0.15 0.15]. From the Simulink model for plant implementation *(Figure 4-18)*, the output from the FLC is accumulated and then it's fed to the valve/plant. If the output range is too large the control would be too aggressive, and if it's too small the control would not have enough "kick" and response would be slow. Hence from fine tuning, it is found that the best control performance is achieved with an output range of [-0.15 0.15].

The surface viewer (*Figure 4-16*) shows the relationships between the two inputs and output. It can also be looked at as a graphic representation of the above rules (*Table 4-3*). The rules are set based on a few key ideas, explained below:

- If E is large and delPV is small then valve opening/closing must be quick
- If E is large and delPV is large then valve opening/closing must be moderate
- If E is small and delPV is small then valve opening/closing must be small
- If E is small and delPV is large then valve opening/closing must be small in the opposite direction

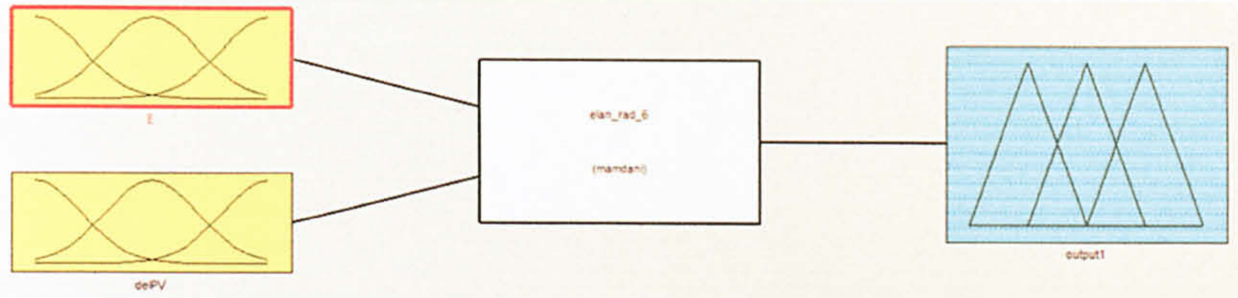


Figure 4-12: Input, Inference Engine and Output

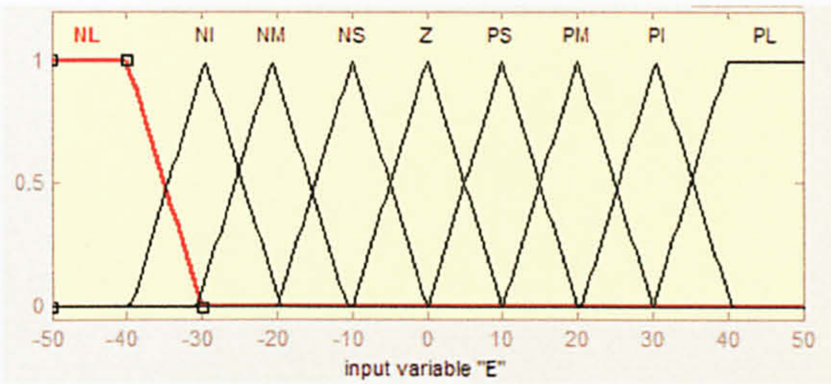


Figure 4-13: MF's for E

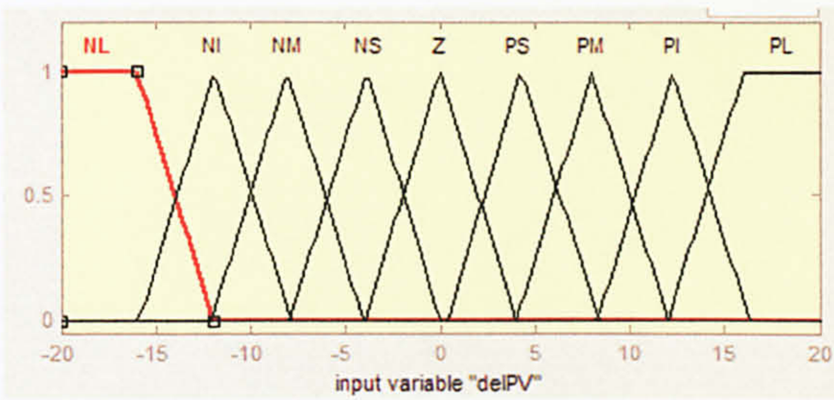


Figure 4-14: MF's for delPV

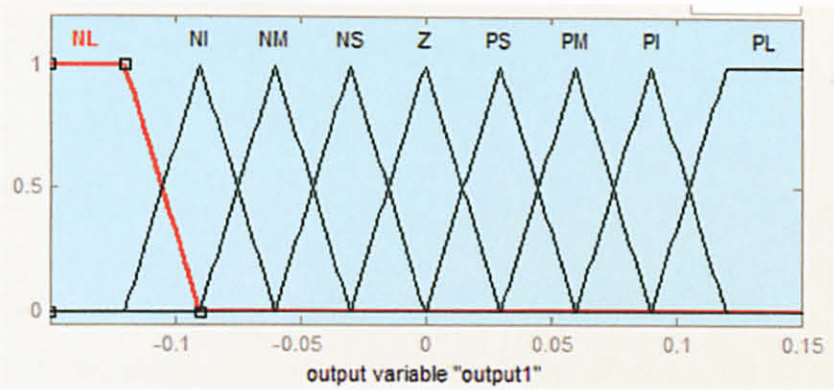


Figure 4-15: MF's for output

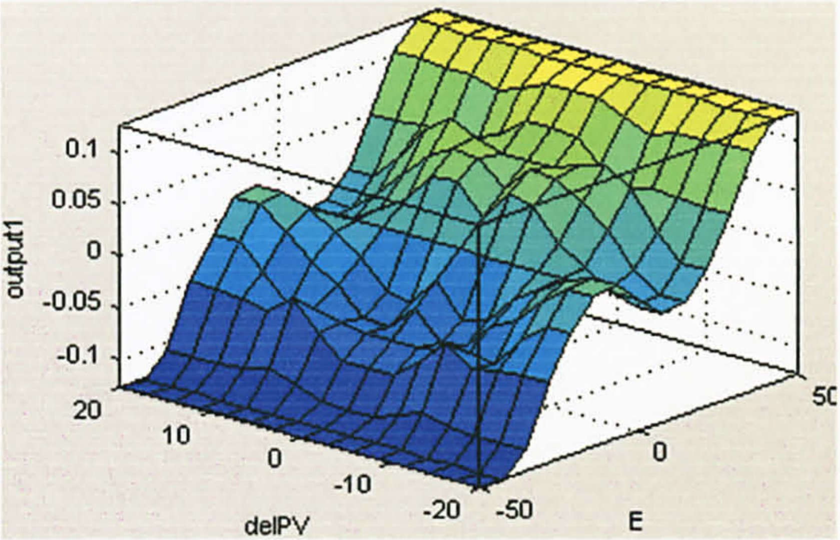


Figure 4-16: Surface View of FIS

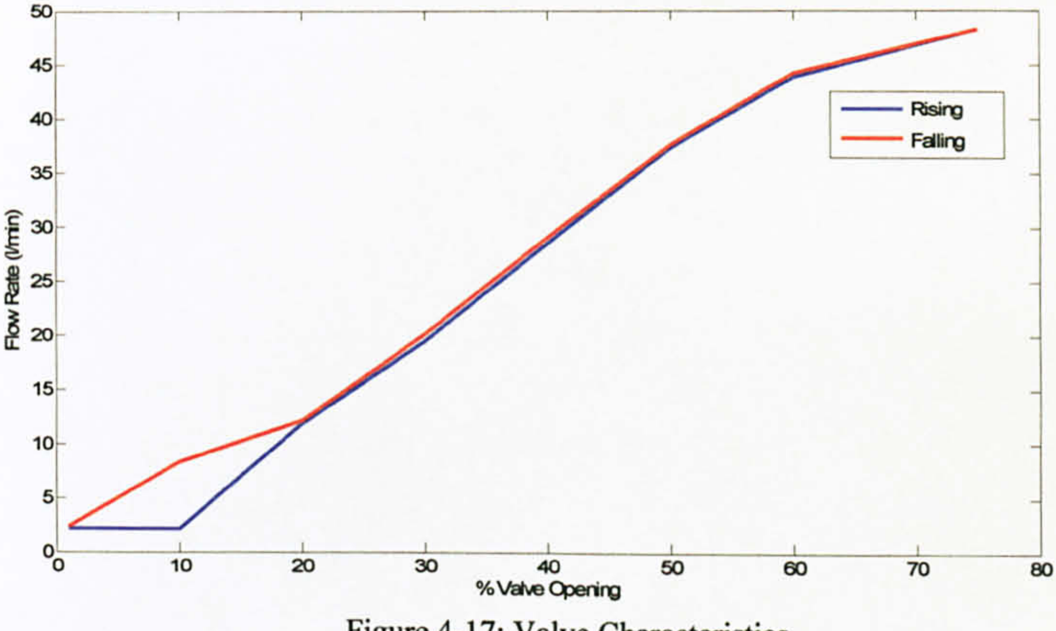


Figure 4-17: Valve Characteristics

### *4.5.2 Controller Implementation on Pilot Plant*

The goal of this section is to show that the FLC developed can be used to control the operation of a pilot plant, and compare its control performance to the conventional PID controller. The implementation is done via two data acquisition cards (by Measurement Computing), Data Acquisition and Fuzzy Logic Toolboxes from MATLAB/Simulink. The model below shows how the FLC and the PID Controller will be used to control the plant. For details of each subsystem refer to ***Appendix F – Simulink Model Subsystems.***

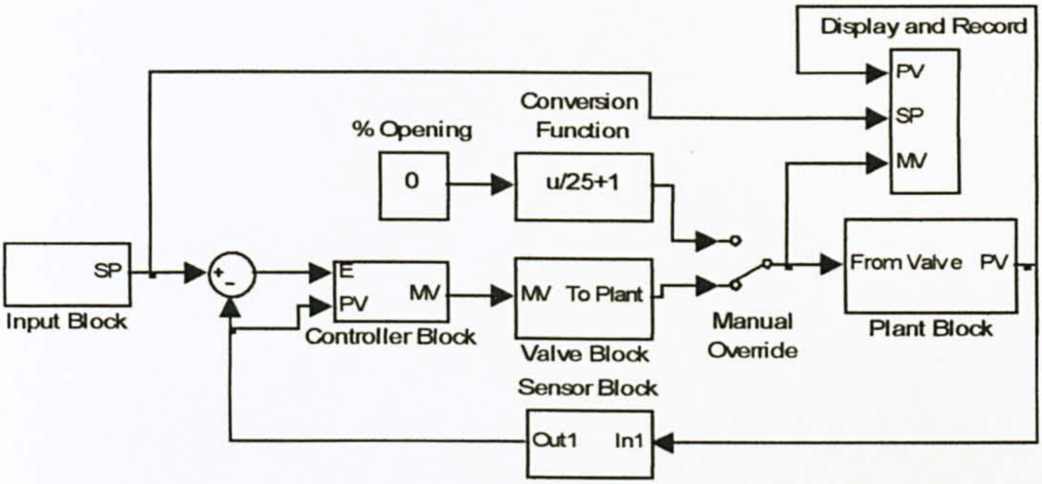


Figure 4-18: Simulink Model for Controller Implementation

Some of the features of the Simulink model are:

- DCS-like HMI feature with scopes to show real time data on PV, MV and SP
- User friendly approach where the operator can input the set point and change from auto to manual with just a click
- Engineering Units are used, where the SP and PV are handled in l/min while the MV are shown in percentage (%) opening
- Data can be collected over a very long period of time and saved to the workspace or file
- Gaussian filter is used to ensure only clean signal from the plant is fed back to the controller.

- The valve subsystem includes a memory block and it is included in the model to act as an accumulator that adds up the controller output over time.

*A. Results and Findings*

To evaluate the robustness, these controllers have been subjected to random set point changes using the "uniform random number" block in Simulink. Since the operating range of the plant is set from 15*l/min* to 45*l/min*, the mean is set at 30*l/min*, with an interval time of 20 seconds. This shall give the controller ample time to settle to steady state. Refer to the figures below for results.

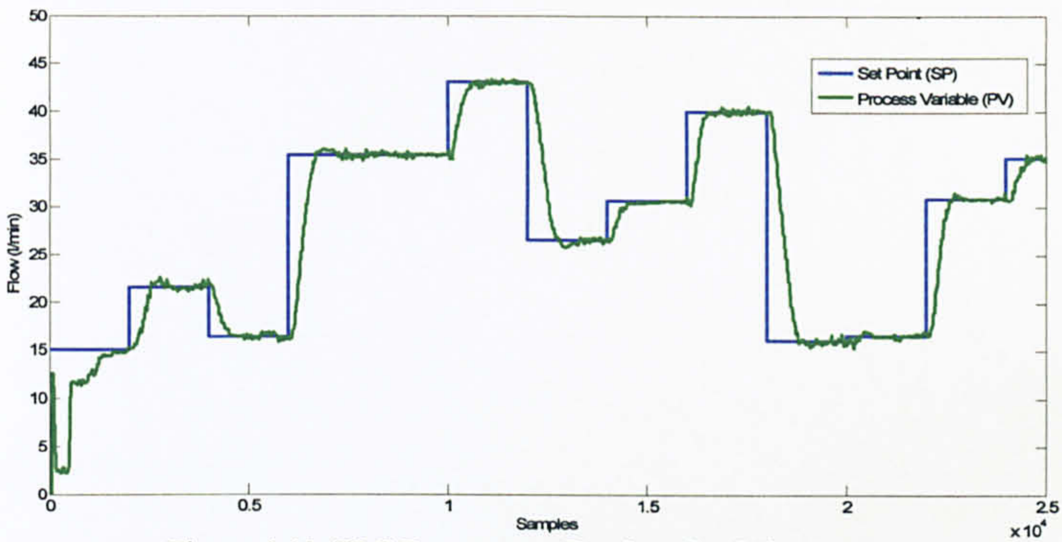


Figure 4-19: FLC Response to Random Set Point Input

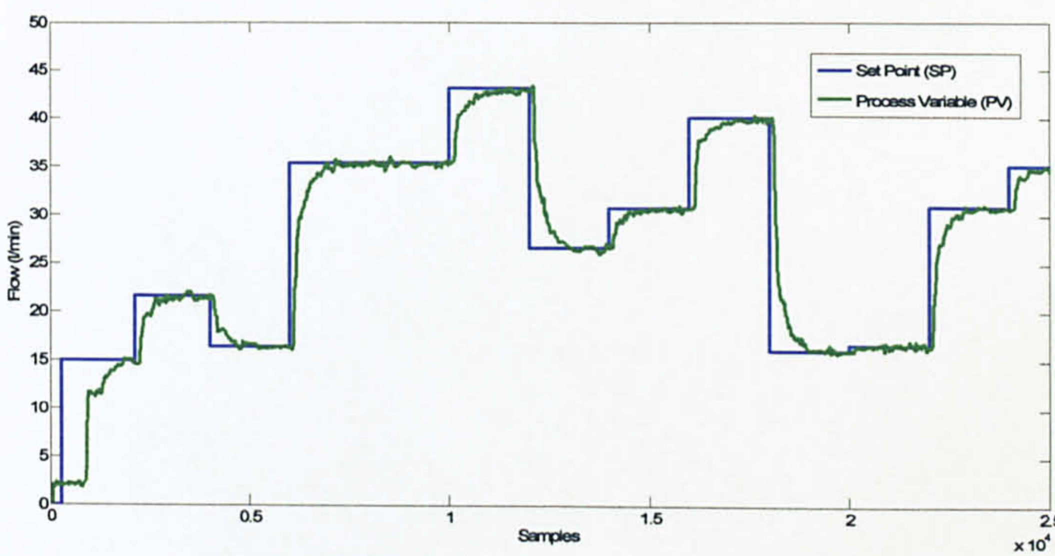


Figure 4-20: PID Response to Random Set Point Input

At a glance, it is obvious that FLC provides better control performance at random set points. Although some overshoot can be seen at certain set points in the FLC response, this is justifiable because the overshoot is only 2.90%. Generally, the FLC response is quicker in terms of rise times and settling times with zero steady state error that is better than PID controller where steady state exists at almost all set points. A more detailed study of the control performance is explained in the next section. The PID controller and FLC controller are then subjected to the same conditions and a set point change from 16.41 *l/min* to 35.37 *l/min* is introduced to the system. The controller responses are exemplified in the figures below:

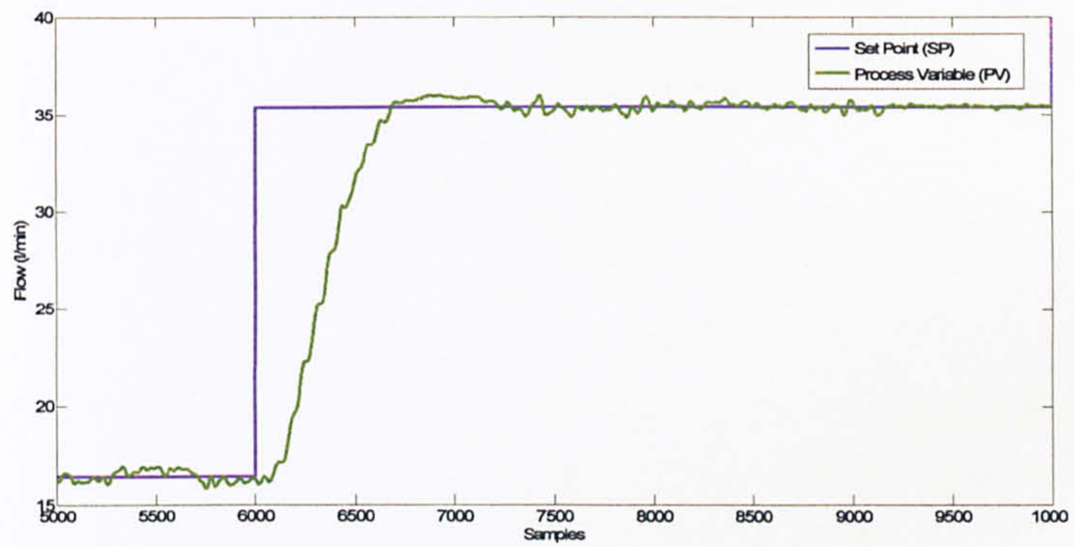


Figure 4-12: FLC Response to a Step Change

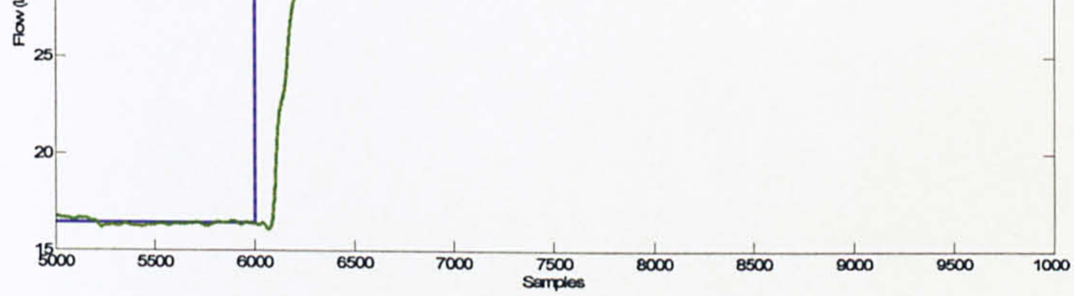


Figure 4-22: PID Controller Response to a Step Change

From the process reaction curves above, the control performance can be studied; from which it can be concluded that the FLC's response is more favorable compared to PID controller's response. This is due to better control performance of the FLC where it gives a better settling time, smaller integral of the absolute value of error (IAE), smaller decay ratio, and small MV overshoot means that final elements will not be damaged [46]. Refer to Table 2 below:

Table 4-4: Control Performance Comparison

| Control Performance | PID | FLC |
|---|---|---|
| IAE | Intermediate | Very Small |
| Rise Time | 9.49 sec | 6.83 sec |
| Settling Time | 9.49 sec | 6.83 sec |
| Decay Ratio | 0.00 | 0.00 |
| Steady State Error | Acceptable | ~0.00% |
| %Over Shoot | 0.00% | 2.90% |

### *4.5.3 Bubble Noise Effect*

One of the common disturbances that affect the flow meters is the bubbling effect. Bubble noise is due to the superposition of single pulses generated by individual bubbles which are randomly distributed in the liquid [48]. The effect of bubbles in the liquid flow on the output signal and control performance of the fuzzy controller is investigated in this section. The bubbling effect is simulated by feeding air through a tube to the bottom of the tank ***(refer to Appendix E – Bubbling Effect set up)***. Some bubbles will escape to the process lines and cause disturbances to the flow meters. The following diagrams *(Figure 4-23 & 4-24)* show the controllers' performance under bubbling noise effect for two different set point changes. PID controller output exhibits slight ripples, due to the sensitive derivative mode. It may be also due to the erratic disturbances from the bubbles in the process lines. Due to these bubbles the readings from the flow meter fluctuates and may be erroneous. The fuzzy controller's output however is more stable even under bubbling noise disturbances. It exhibits no overshoot and gives a faster response compared to PID controller.

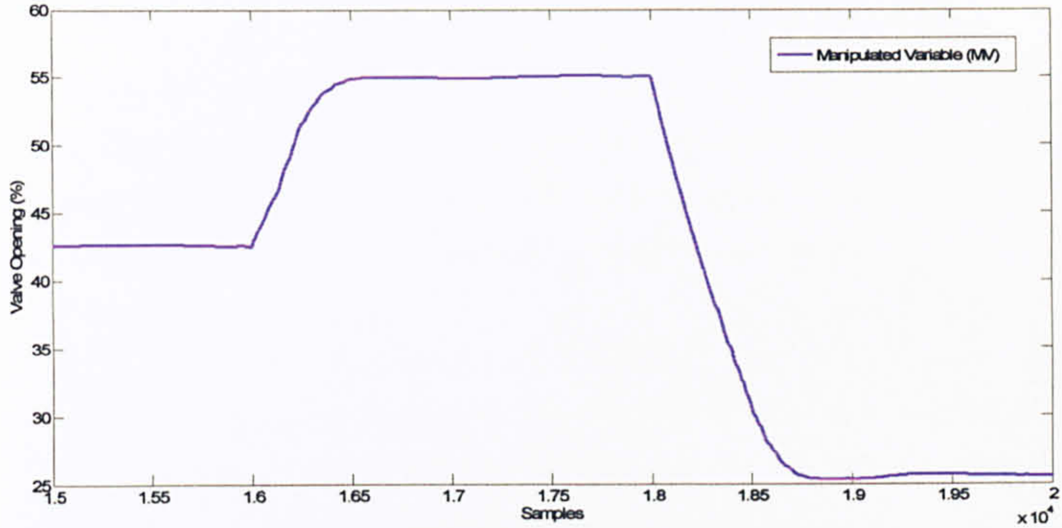

Figure 4-23: FLC Output Response with Bubbling

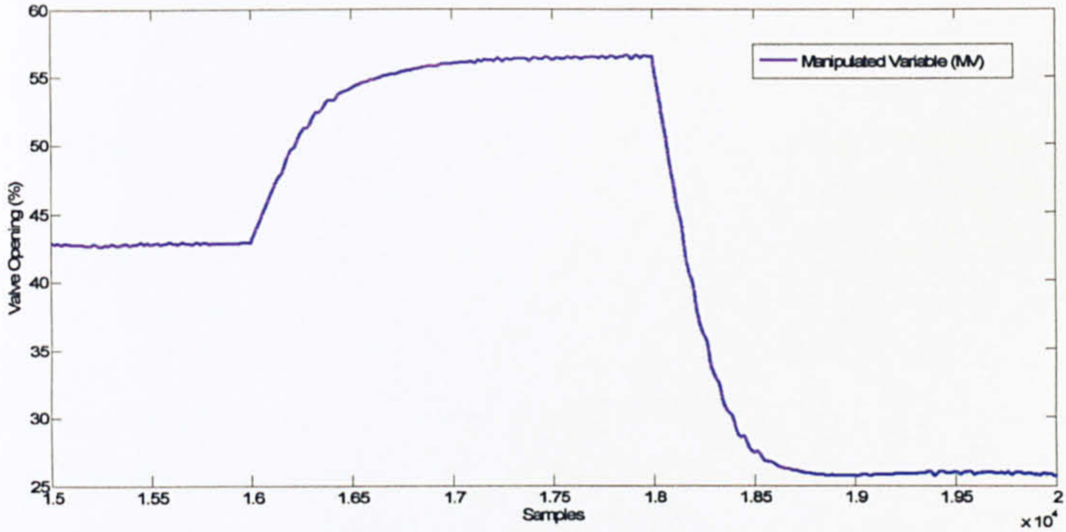

Figure 4-24: PID Controller Output Response with Bubbling Effect

## 4.6 Fuzzy Logic Controller for Level Control

This section is beyond the scope and objective of this project. Fuzzy controller for level control was initially planned to be implemented for the future. However, some groundwork has been done towards its implementation. Here the initial FIS design and results from the abovementioned groundwork are shown.

### *4.6.1 FIS Development*

Level control is not as straightforward as flow control; it is because level depends on both the inflow and outflow of the tank. Referring to the P&ID diagram, in order to maintain a stable level at the calibration tank (VE-200), HV-202 must be maintained at 30% opening, while CV-110 is maintained at 50% opening. Since only CV-110 can be controlled by the controller, the outflow now poses as a disturbance. Therefore if the level of the liquid in the tank were to be increased, CV-110 must be opened more than 50%. If the level of the liquid in the tank were to be reduced, CV-110 must be reduced to less than 50% opening. This is the core idea to develop the FIS for level control. The input to the FLC is just the error *(E)* and the output is the *(mv)* or valve opening. The input-output relationship shown *(Figure 4-28)* below is highly non-linear, this is because at errors larger than $\pm$ 50mm the valve is opened or close at its maximum. Only at small errors will the control action be sensitive to error changes. This is to ensure zero steady state offset/error. The membership functions *(Figures 4-26 and 4-27)* are designed based on the input/output rules shown below *(Table 4-5)*. Most of the MFs are close to zero; this is to guarantee a close performance at small errors.

Table 4-5: Input and Output Rules

| E | NL | NI | NM | NS | Z | PS | PM | PI | PL |
|---|---|---|---|---|---|---|---|---|---|
| **Output** | NL | NI | NM | NS | Z | PS | PM | PI | PL |

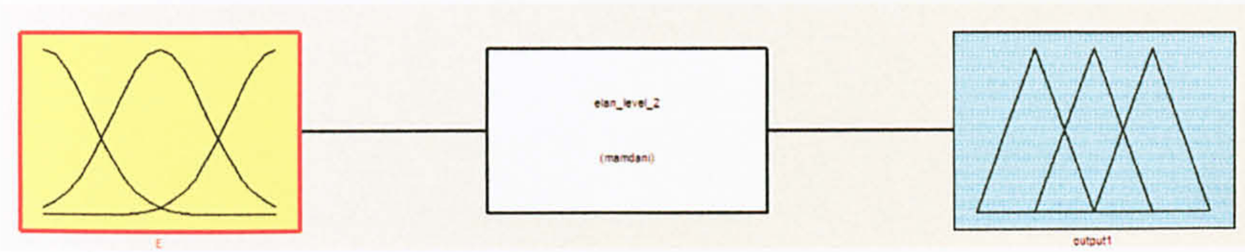

Figure 4-25: Input, Inference Engine and Outputs

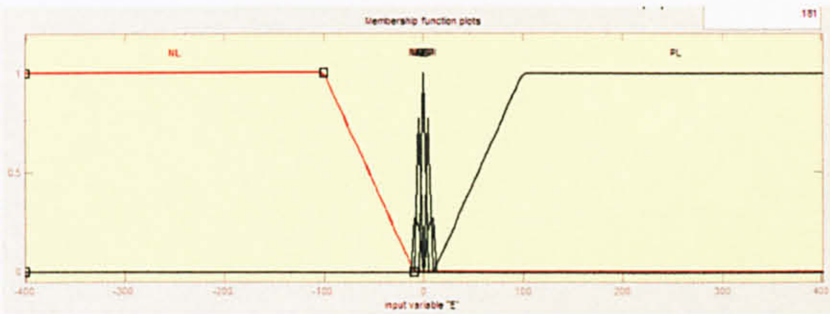

Figure 4-26: MF's for E

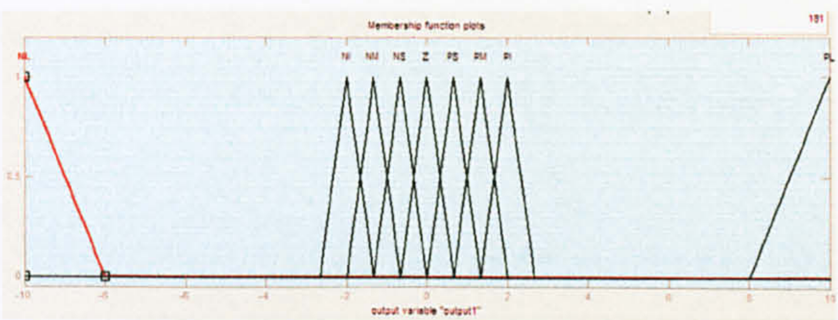

Figure 4-27: MF's for output

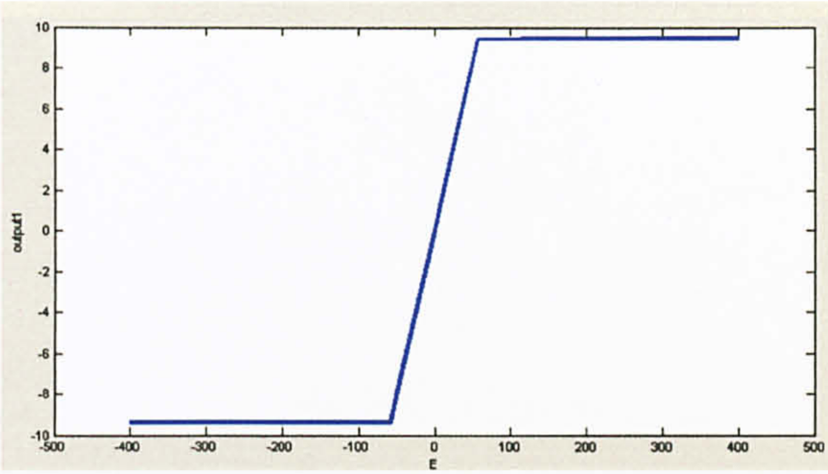


Figure 4-28: Relationship between Input and Output

### *4.6.2 Results and Analysis*

Both PID and fuzzy level controllers are subjected to random set point changes. Following are the results obtained:

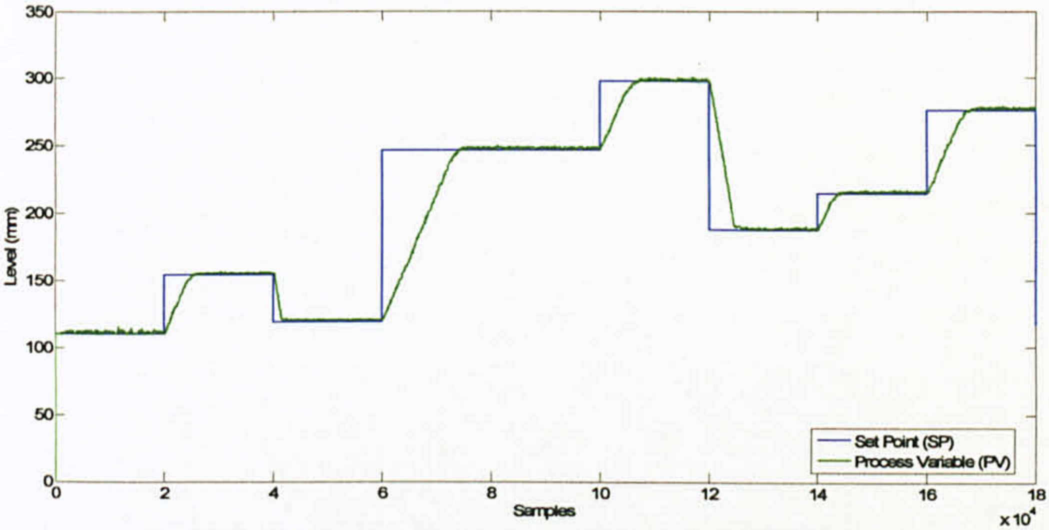


Figure 4-29: FLC Response to Random Set Point Change

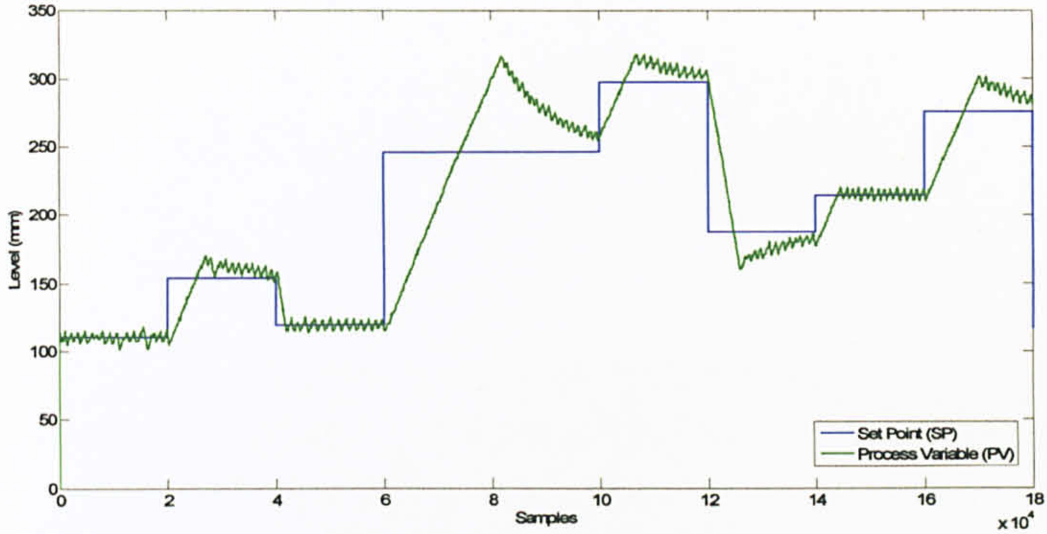


Figure 4-30: PID Response to Random Set Point Change

From the results obtained above, it is quite obvious that FLC could track changes in the set point better than PID controller. FLC response is stable with zero steady state offset. The reason behind this is that with FLC, it is possible to set the valve opening where tank level will be constant. Therefore at zero error, FLC simply brings the control valve to 50% opening. With a PID controller, the response is seen to be oscillatory. At small errors the PID controller will bring the control valve to 0%, instead of the required 50%. At 0%, the level will drop, causing the PID controller to open the valve to 100%. This is why the output response is unable to settle at the set point. A single PID controller is not able to control a process with significance disturbance; in this case the outflow of the tank. To be able to control the level of the tank, more than one PID controller is needed with advanced control techniques such as cascade. However with fuzzy logic controller, only a single controller is needed to control a complex process like level control.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Overall the project's feasibility lies in the simplicity of its implementation. The advantages of a fuzzy based controller over a PID controller are derived from the implementation and simulation results. Better control performance, robustness and overall stability can be expected from the fuzzy controller. Fundamentally, the fuzzy concept is merely a representation of the human cognitive and decision making process hence developing and tuning of the FIS is more intuitive than the PID controller. The development of this project is also parallel with industrial needs and applications, therefore the fuzzy logic controller could be used to replace the conventional controllers currently being used in the industry. Besides, the DCS-HMI developed could be beneficial as it is more economical compared to the standard DCS architecture. The objectives of this project which are to develop a fuzzy logic controller, develop a DCS-HMI system and to compare the performances of FLC and PID controller have been achieved successfully.

## 5.2 Future Work and Recommendations

In the future, the performance of different flow meters (cariolis, vortex and orifice) will be compared. Besides that, other methods for fuzzy control will be explored such as sliding mode control, self tuning control, and adaptive PID-fuzzy control in order to optimize the current performances.

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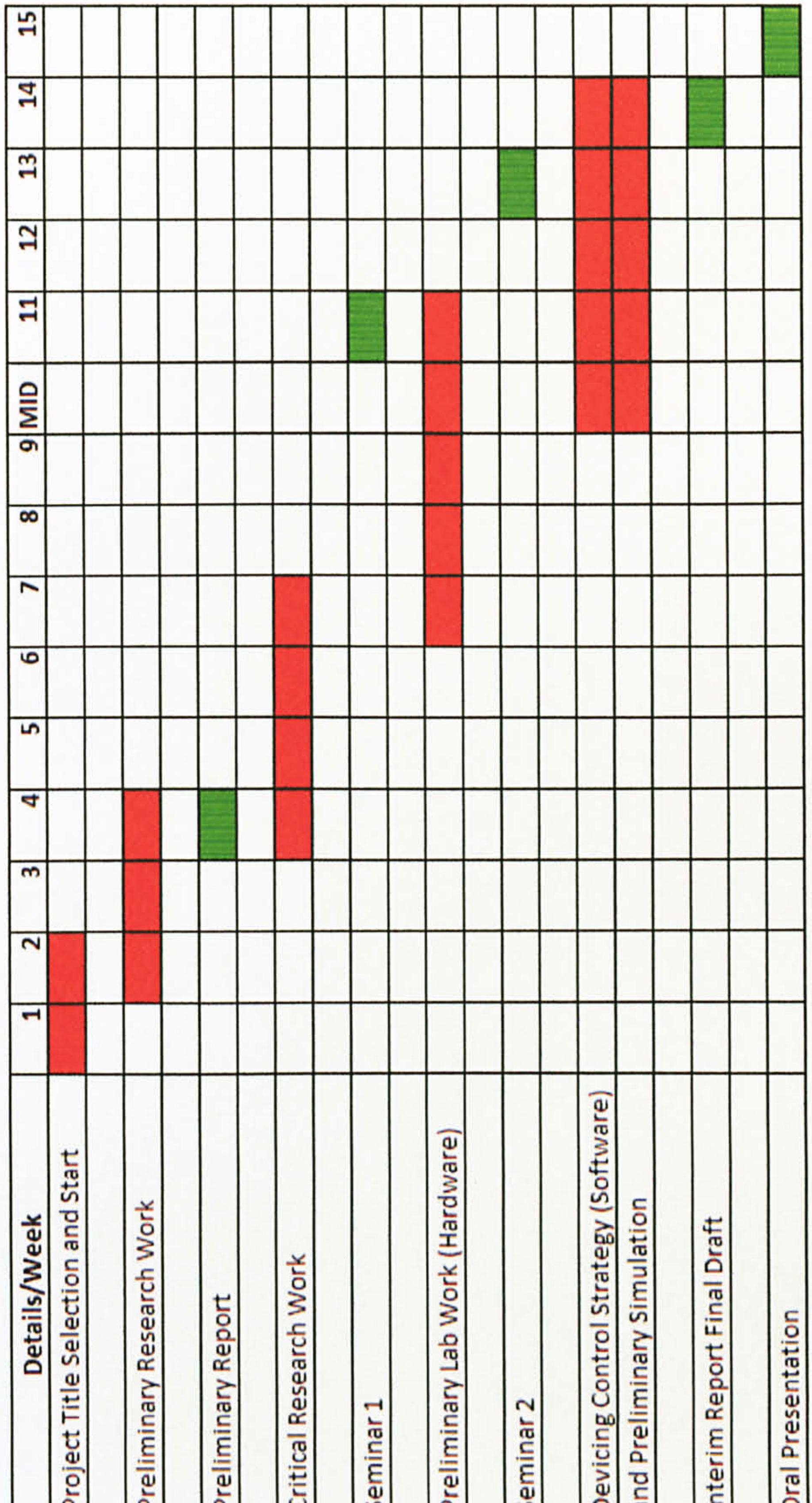
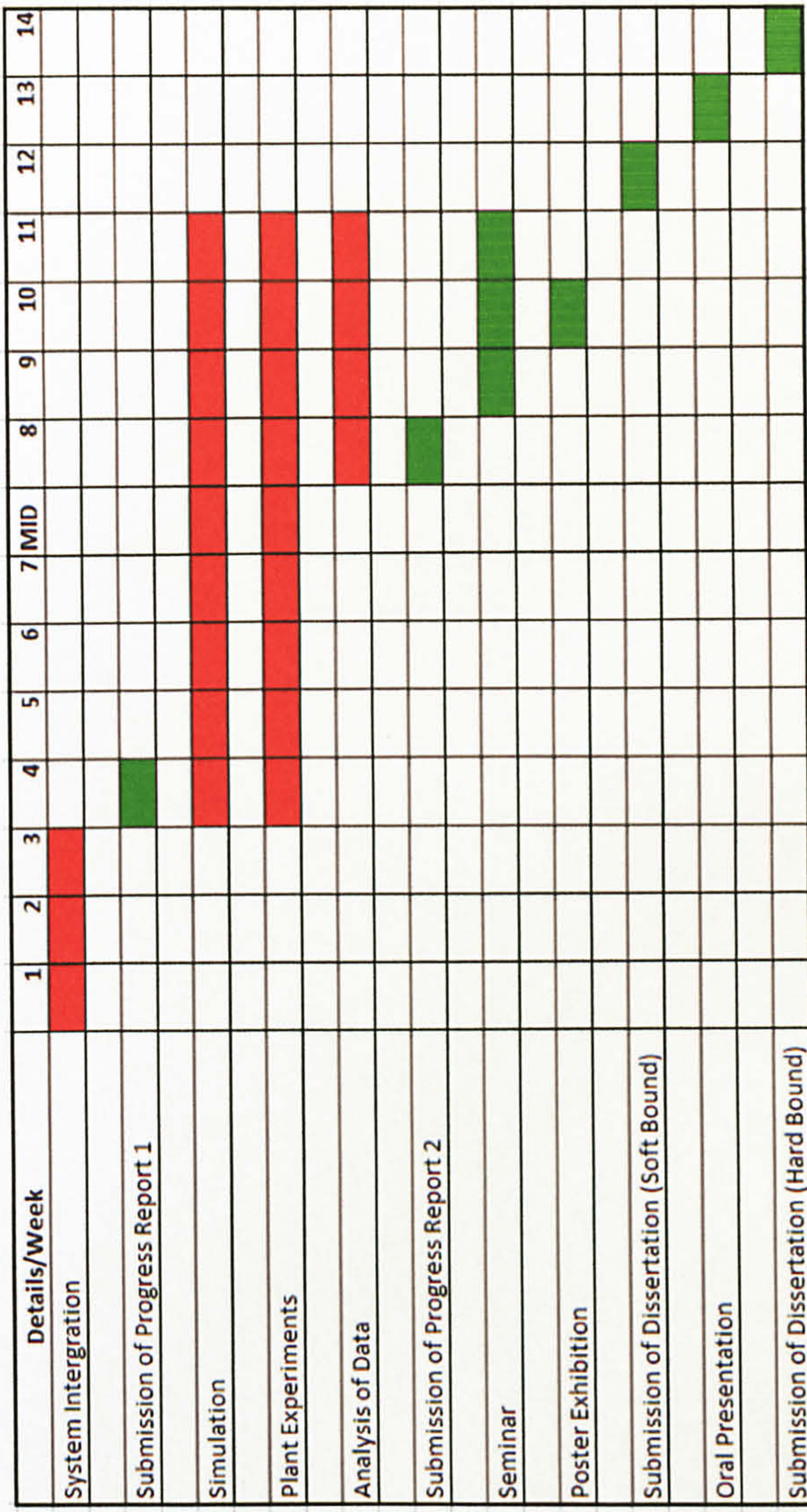
# APPENDIX A – MILESTONES FOR FYP1

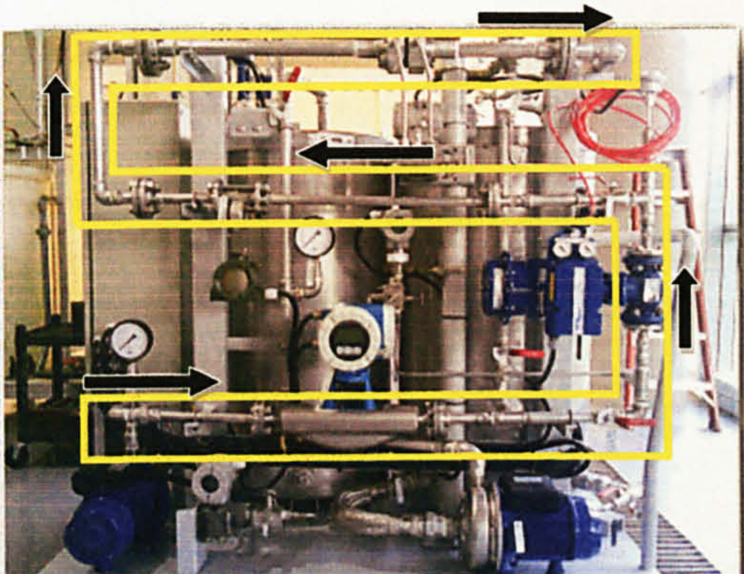


# APPENDIX B – MILESTONES FOR FYP2



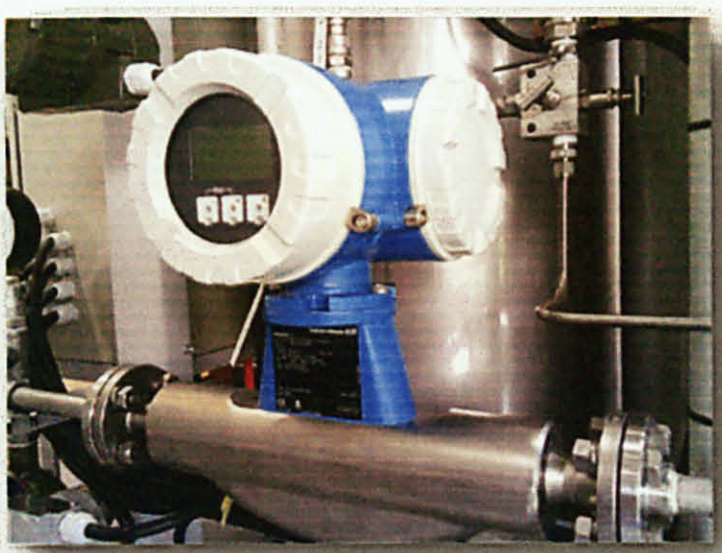
# APPENDIX C – PLANT DEVICES AND INSTRUMENTS

Pilot Plant

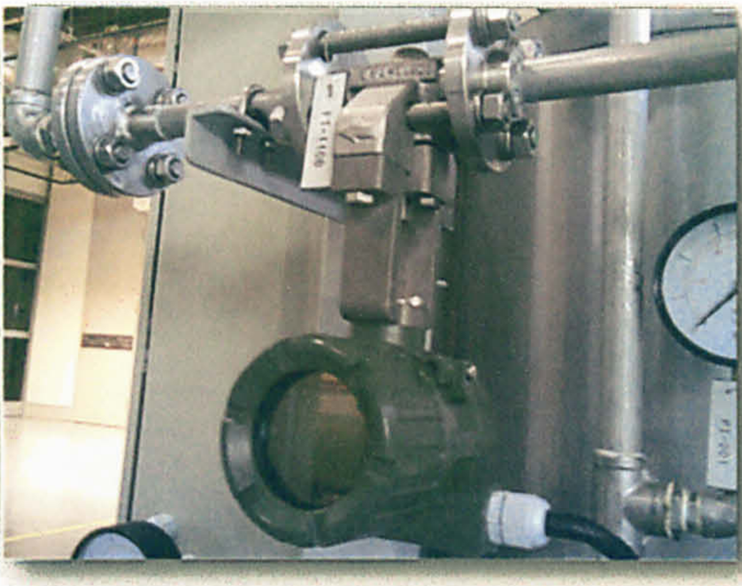


Main Line

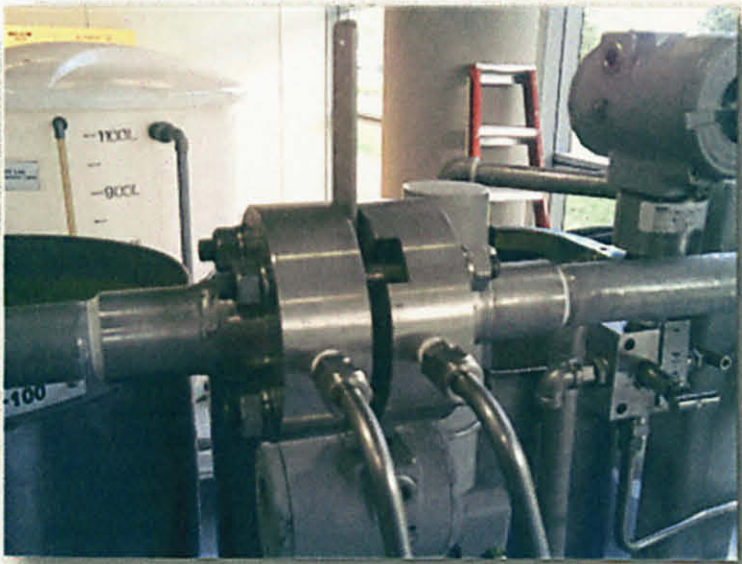
Calibration Tank (Left) and Buffer Tank (Right)



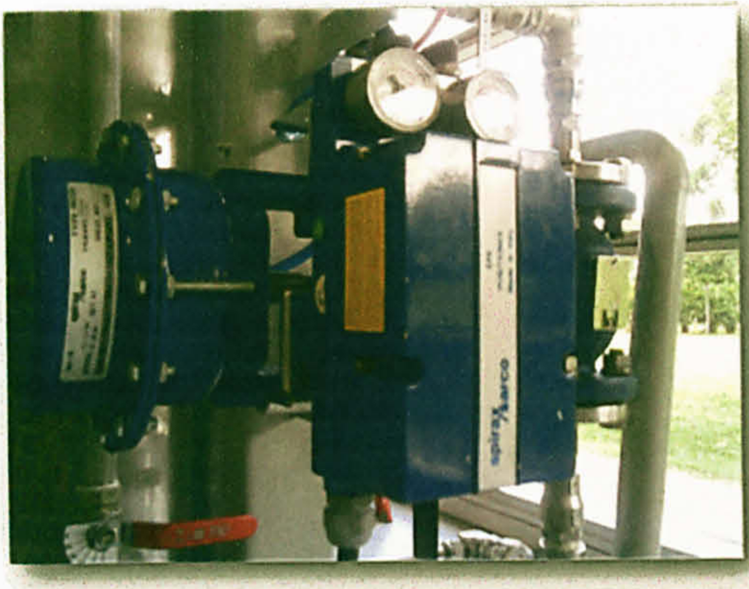
Coriolis Flowmeter



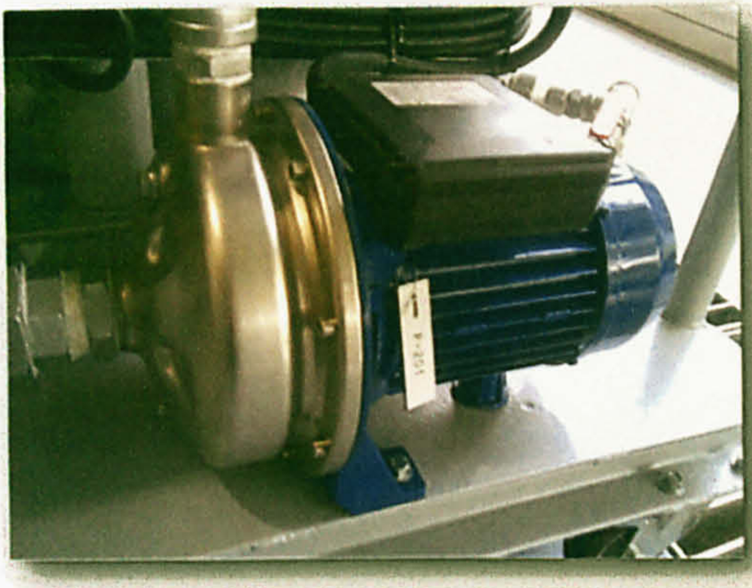
Vortex Flowmeter



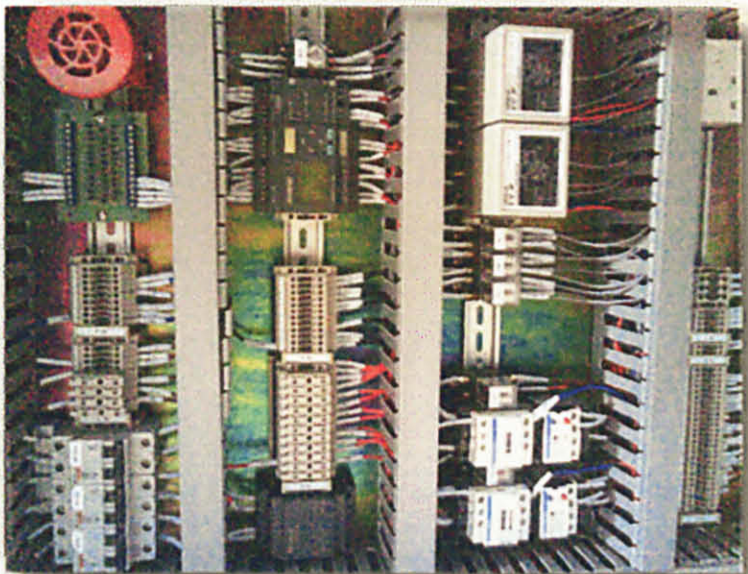
Orifice Plate Flowmeter



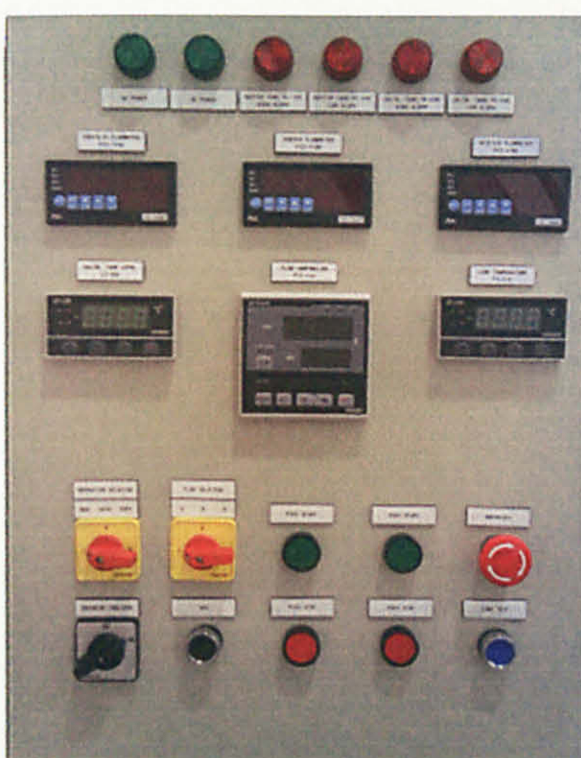
Pneumatic Control Valve



Liquid Transfer Pump

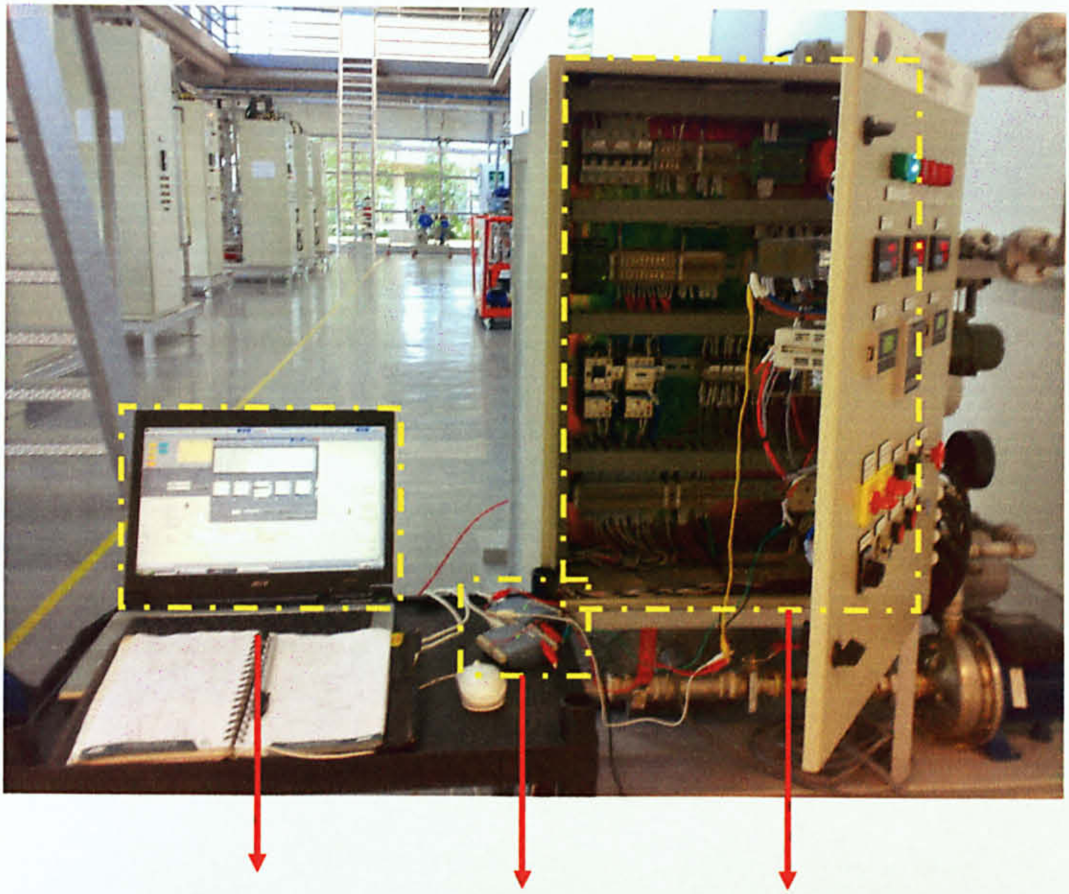


MCB, Termination Box, and PLC inside Local Control Panel



Front of Local Control Panel

# APPENDIX D – PROJECT SET UP



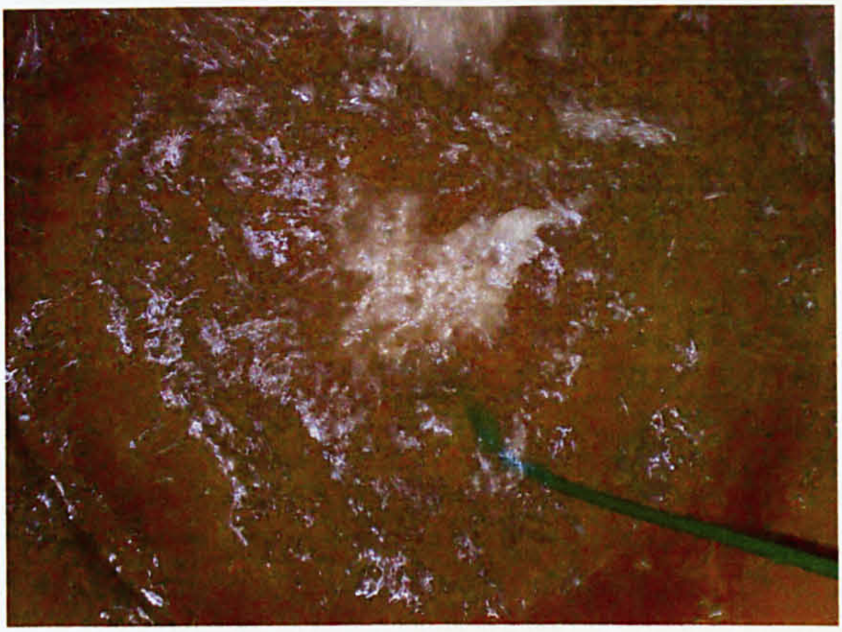
Laptop

DAQ Cards

Plant Control Panel

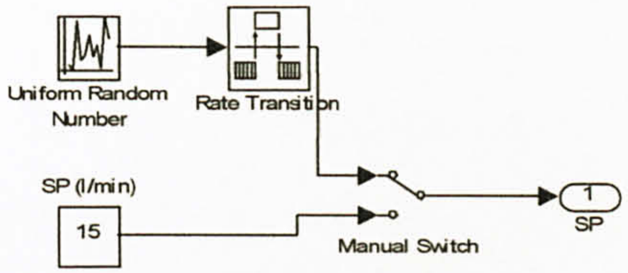
# APPENDIX E – BUBBLING EFFECT SET UP

Regulators to Control the Amount of Bubbles

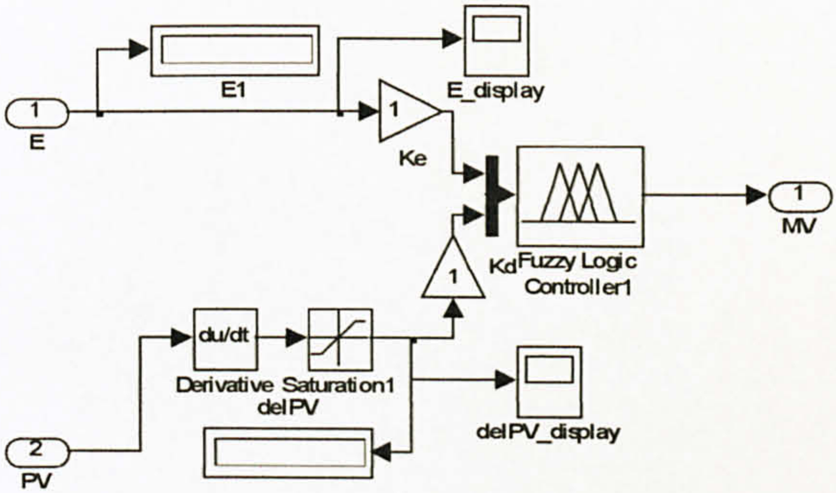


Bubbles are created at Tank Bottom

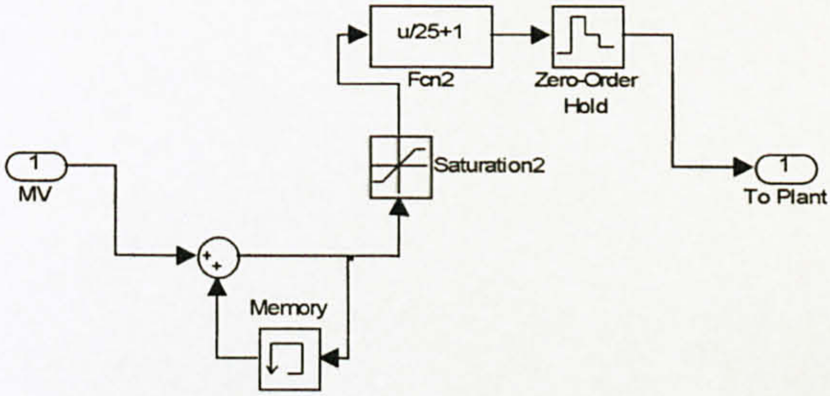
# APPENDIX F – SIMULINK MODEL SUBSYSTEMS



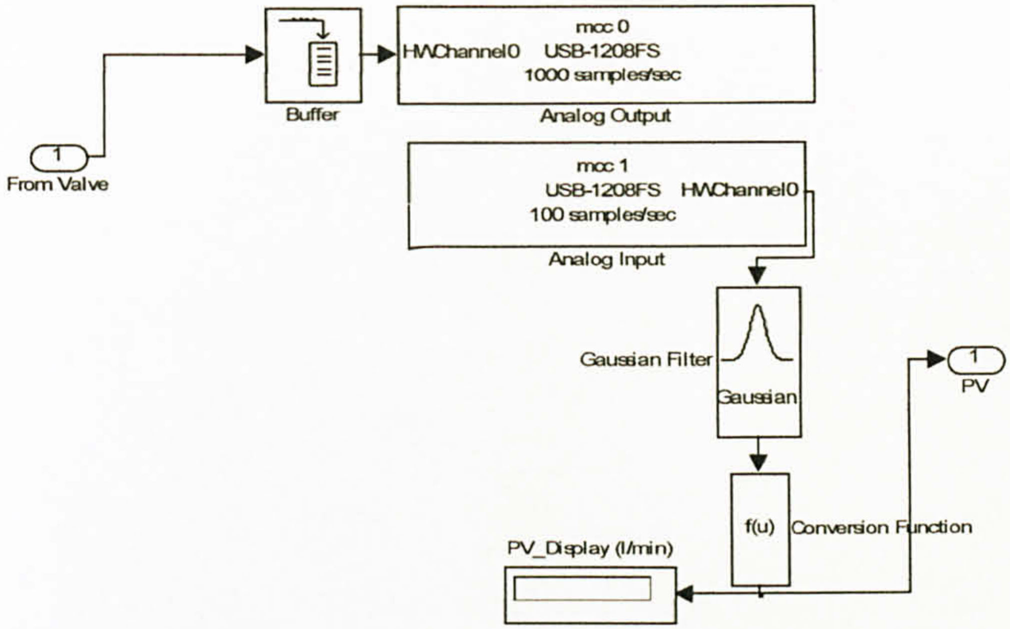

Input Subsystem



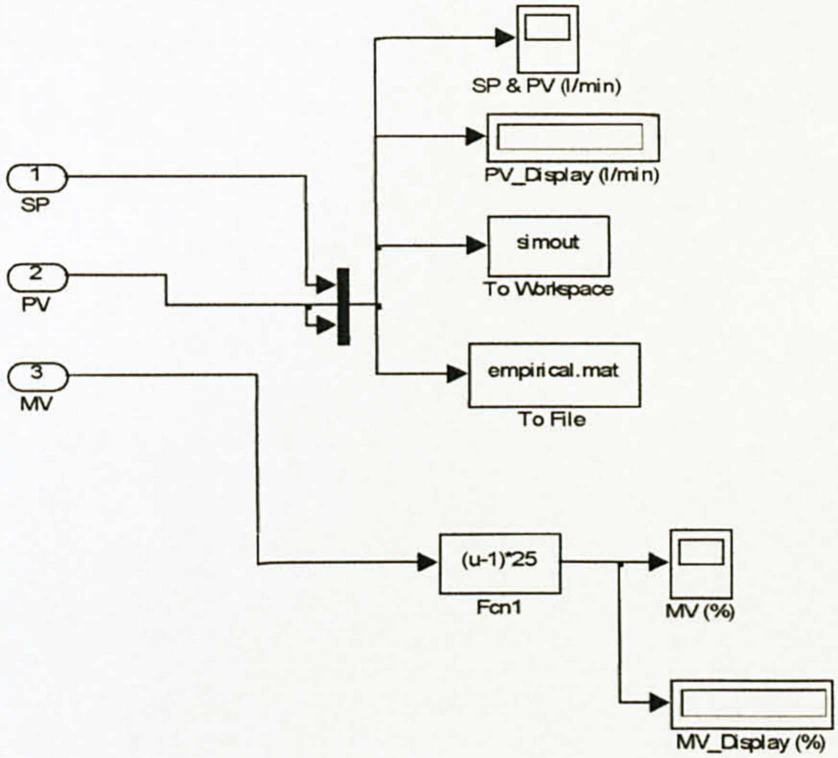

Controller Subsystem




Valve Subsystem




Plant Subsystem




Display and Record Subsystem

# APPENDIX G – USB-1208FS SPECIFICATIONS

## Analog input section

Table 4-1. Analog input specifications

| Parameter | Conditions | Specification |
|---|---|---|
| A/D converter type | | Successive approximation type |
| Input voltage range for linear operation, single-ended mode | CHx to GND | ±10 volts (V) max |
| Input common-mode voltage range for linear operation, differential mode | CHx to GND | -10 V min, +20 V max |
| *Absolute maximum input voltage* | *CHx to GND* | *±28 V max* |
| Input current (Note 1) | Vin = +10 V | 70 microamperes (µA) typ |
| | Vin = 0 V | -12 µA typ |
| | Vin = -10 V | -94 µA typ |
| Number of channels | | 8 single-ended / 4 differential, software selectable |
| Input ranges, single-ended mode | | ±10 V, G=2 |
| Input ranges, differential mode | | ±20 V, G=1<br>±10 V, G=2<br>±5 V, G=4<br>±4 V, G=5<br>±2.5 V, G=8<br>±2.0 V, G=10<br>±1.25 V, G=16<br>±1.0 V, G=20<br>Software selectable |
| Throughput (Note 2) | Software paced | 250 samples per second (S/s) typ, PC-dependent |
| | Continuous scan | 50 kilosamples per second (kS/s) |
| Channel gain queue | Up to 16 elements | Software configurable channel, range, and gain |
| Resolution (Note 3) | Differential | 12 bits, no missing codes |
| | Single-ended | 11 bits |
| CAL accuracy | CAL = 2.5 V | ±0.05% typ, ±0.25% max |
| Integral linearity error | | ±1 least significant bit (LSB) typ |
| Differential linearity error | | ±0.5 LSB typ |
| Repeatability | | ±1 LSB typ |
| CAL current | Source | 5 milliamperes (mA) max |
| | Sink | 20 µA min, 100 µA typ |
| Trigger source | Software selectable | External digital: TRIG_IN |

**Note 1:** Input current is a function of applied voltage on the analog input channels. For a given input voltage, $V_{in}$, the input leakage is approximately equal to $(8.181 * V_{in} - 12)$ µA.

**Note 2:** Maximum throughput scanning to PC memory is machine dependent. The rates specified are for Windows XP only. Maximum rates on operating systems that predate XP may be less and must be determined through testing on your machine.

## Analog output section

Table 4-8. Analog output specifications

| Parameter | Conditions | Specification |
|---|---|---|
| Resolution | | 12-bits, 1 in 4096 |
| *Output range* | | *0 – 4.096 V, 1 mV per LSB* |
| Number of channels | | 2 |
| Throughput (Note 4) | Software paced | 250 S/s single channel typical, PC dependent |
| | Single channel, continuous scan | 10 kS/s |
| | Dual channel, continuous scan, simultaneous update | 5 kS/s |
| Power on and reset voltage | | Initializes to 000h code |
| Output drive | Each D/A OUT | 15 mA |
| Slew rate | | 0.8 V/microsecond (µs) typ |

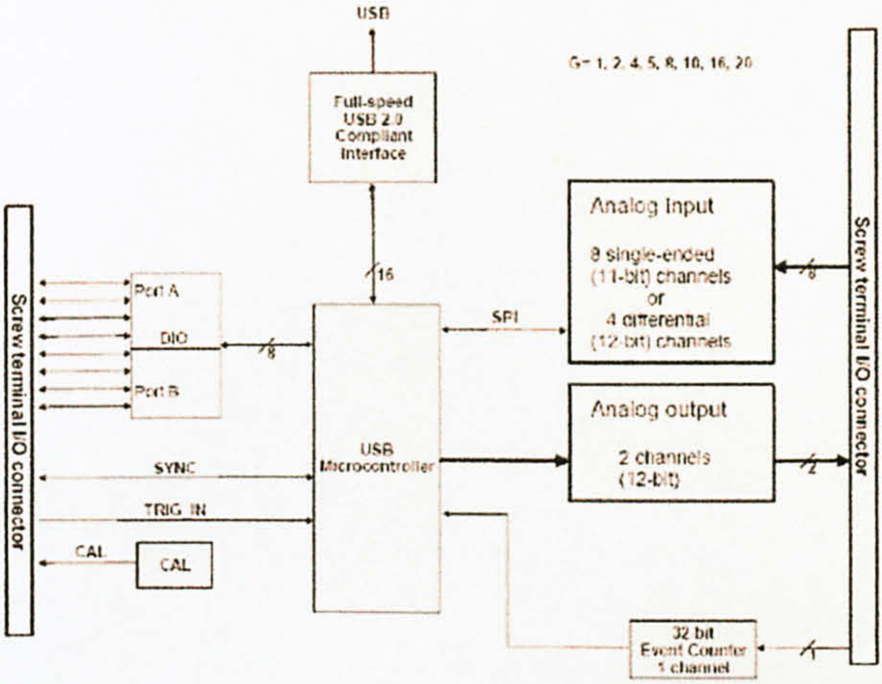
**Note 4:** Maximum throughput scanning to PC memory is machine dependent. The rates specified are for Windows XP only. Maximum rates on operating systems that predate XP may be less and must be determined through testing on your machine

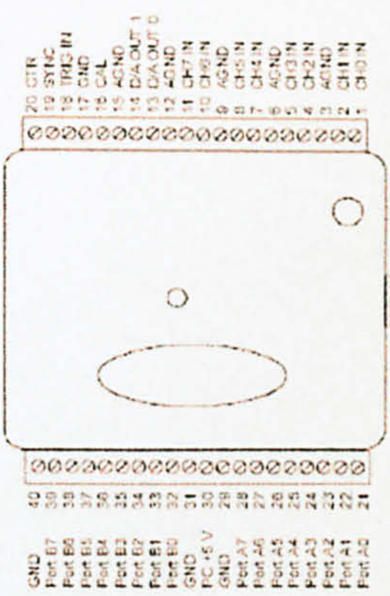
## Digital input/output

Table 4-11. Digital I/O specifications

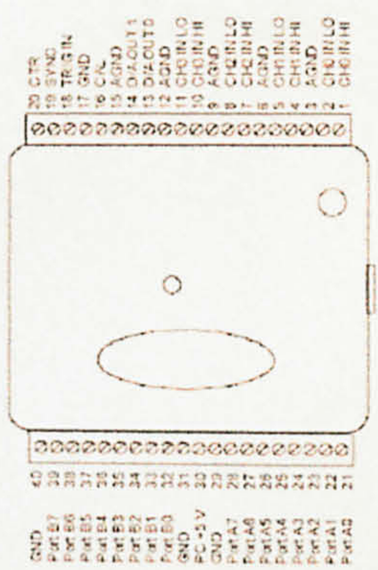
| | |
|---|---|
| Digital type | CMOS |
| Number of I/O | 16 (Port A0 through A7, Port B0 through B7) |
| Configuration | 2 banks of 8 |
| Pull up/pull-down configuration | All pins pulled up to Vs via 47 K resistors (default). Positions available for pull down to ground. Hardware selectable via zero ohm (Ω) resistors as a factory option. |
| Input high voltage | 2.0 V min, 5.5 V absolute max |
| Input low voltage | 0.8 V max, -0.5 V absolute min |
| Output high voltage (IOH = -2.5 mA) | 3.8 V min |
| Output low voltage (IOL = 2.5 mA) | 0.7 V max |
| Power on and reset state | Input |

# APPENDIX H – USB-1208FS BLOCK DIAGRAM AND PINOUTS



8-channel single-ended mode pin out



4-channel differential mode pin out

# APPENDIX I – COHEN-COON OPEN LOOP CORRELATIONS

| Control Modes | Parameters |
|---|---|
| P only | $K_C = \left(\frac{1}{RK_P}\right)\left(1+\frac{R}{3}\right)$ |
| P + I | $K_C = \left(\frac{1}{RK_P}\right)\left(\frac{9}{10}+\frac{R}{12}\right)$ |
| | $T_I = \theta\frac{(30+3R)}{(9+20R)}$ |
| P + I + D | $K_C = \left(\frac{1}{RK_P}\right)\left(\frac{4}{3}+\frac{R}{4}\right)$ |
| | $T_I = \theta\frac{(32+6R)}{(13+8R)}$ |
| | $T_D = \theta\frac{4}{(11+2R)}$ |
| P + D | $K_C = \left(\frac{1}{RK_P}\right)\left(\frac{5}{4}+\frac{R}{6}\right)$ |
| | $T_I = \theta\frac{(6-2R)}{(22+3R)}$ |