pH Neutralization Control System

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Presented in partial fulfillment of the requirements for Bachelor degree in Computer Engineering.

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Date: April, 30, 2014

Acknowledgment

We would like to express our gratitude to all those who have supported us, to our parents, who gave us all kinds of support, to our friends.

Special thanks to Dr.Raed Alqadi, Dr.Ashraf Armoush and Dr. Abdalraheem Abu Alsafa who encouraged us to go ahead with our project, we are also so grateful for the Computer Engineering Department stuff.

At last but not least we would like to thank Eng. Nidal Mari for helping us to write the fuzzy logic rules.

Firas & Hafiz

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GUI: Graphical User Interface.

PID: Proportional Integrator derivative Controller.

FLC: Fuzzy Logic Controller.

Abstract

In this project, we developed a microcontroller based system to control the pH degree of a solution, composed of Acid and base. We based our control algorithm on Fuzzy logic. We also used MatLab to act like the system controller.

Our system consists of three microcontrollers: the first one is a master while the two other are slave. The three microcontrollers are inter connected using I2C bus. One of salves is connected to Acid tank and controls a pump based on level and flow sensor. The Second one is connected to Base tank. The master controller collects data from two slave and transfers its to MatLab running on PC. The master serves as mediator between the Fuzzy logic controller (MatLab) and the two slave microcontrollers to control Acid and Base pumps to get the central pH.

Chapter 1: Introduction

The main objective of this graduation project is to design and construct a control system to adjust the flow rate influent stream and control the pH of the resulting mixture in a stirred tank.

In the chemical industry, the control of pH is a well-known problem that presents difficulties due to the large variations in its process dynamics and the static nonlinearity between pH and concentration. pH control requires the application of advanced control techniques such as linear or nonlinear adaptive control methods. Unfortunately, adaptive controllers rely on a mathematical model of the process being controlled, the parameters being determined or modified in real time. Because of its characteristics, the pH control process is extremely difficult to model accurately. (E.Huang 1997)

In our project, we designed a Fuzzy Logic Controller to control the flow rate of two pumps that pour acid and base on the mixing tank, the controller built using MATLAB program, and this program should read all sensors as an input to the Fuzzy logic controller and the output from the controller is the pump speed of the two tanks (Acid and Base).

By using MATLAB, it is possible in the future to change the controller easily, without need to an expert in software engineering, it is just changing the parameters of the controller and run the system.

We used Level sensor, flow sensor, pH sensor, gas sensor, temperature sensor.

Chapter 2: Constraints, Standards/ Codes and Earlier course work

In this project we faced with several constraints, we did our best to get the best result under these constraints. In the following paragraph we will describe these constrains.

The first constrain that we search about material that will bear chemicals especially for the sensors and pumps, so we use the car water pumps because it was from material that bear chemicals.

The second one is how we can get the required sensors because the limitation of choices in the local, to solve it we have two choices go to global market or make the sensors using simple components. We choose to bring sensors from global market because making the sensors needs a lot of time more than getting it from global market. Also we had to learn a Fuzzy logic and some chemical equation in a relatively short time but we able to do in time and developed the system.

The third one is the I2C, we wrote a specific protocol that uses I2C, but the problem is if we want to send more than 8 bits, some delay occurs until this byte has been sent, but this amount of delay is still acceptable.

Earlier course:

66111 Computer programming

66426 Micro-controllers.

66332 Digital Electronic Circuits.

66417 Artificial Intelligence.

Chapter 3: Literature Review

3.1 pH Neutralization Process

A brief review of the definition of pH, the pH scale, and some of the chemistry involved in pH Adjustment systems is provided below. For some this may be trivial, yet for many others this may be useful. The information provided below is typical of the background information we provide in our training classes and seminars.

By definition pH is the measure of free hydrogen activity in water and can be expressed as:

$$\mathbf{pH= -log[H^+]}$$

In more practical terms (although not technically correct in all cases) pH is the measure of free acidity or free alkalinity of water. Measured on a scale of 0-14, solutions with a pH of less than 7.0 are acids while solutions with a pH of greater than 7.0 are bases. In very simple terms bases are used to neutralize acids, while acids are used to neutralize alkalis (the term caustic, alkaline, alkali, or base, although not truly synonymous, are often used interchangeably). The byproducts are normally salts (which may or may not be soluble) and water. (pH Adjustment 2012)

The task of any pH adjustment system is to adjust the pH of the process stream into the defined acceptable discharge range.

3.2 Fuzzy Logic:

Fuzzy logic is a logic that describes fuzziness. As fuzzy logic attempts to model humans' sense of words, decision making and common sense, it is leading to more human intelligent machines.

The fuzzy logic use fuzzy sets and fuzzy rules.

The fuzzy set maps the crisp value that comes from the environment to a member ship degree. This value between 0 and 1. Depending on the member ship function, the crisp value will convert to a fuzzy logic value.

Then depending on the rules, the system will produce the outputs.

Fuzzy rules are used to capture human knowledge. A fuzzy rule is a conditional statement in the form:

IF x Is A

THEN y is B

There are 4 steps that the fuzzy logic system should execute to produce the output:

1- Fuzzification
2- Rule Evaluation
3- Aggregation of the rule outputs
4- Defuzzification.

3.3 I2C Protocol

The I2C (Inter-IC) bus is a bi-directional two-wire serial bus that provides a communication link between integrated circuits (ICs). Phillips introduced the I2C bus 20 years ago for mass-produced items such as televisions, VCRs, and audio equipment. Today, I2C is the de-facto solution for embedded applications.

There are three data transfer speeds for the I2C bus: standard, fast-mode, and high-speed mode. Standard is 100 Kbps. Fast-mode is 400 Kbps, and high-speed mode supports speeds up to 3.4 Mbps. All are backward compatible. The I2C bus supports 7-bit and 10-bit address space devices and devices that operate under different voltages. (I2C bus (Inter-IC bus) 2005)

3.4 MATLAB Program

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, Simulink, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems.

In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises.

3.5 Microcontrollers

PIC18F4620

PIC microcontrollers (Programmable Interface Controllers), are electronic circuits that can be programmed to carry out a vast range of tasks. They can be programmed to be timers or to control a production line and much more. They are found in most electronic devices such as alarm systems, computer control systems, phones, in fact almost any electronic device. (technology student 2010)

Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. (arduino 2014)

3.6 Sensors

eTap Level Sensor:

Description

The eTape sensor is a solid state, continuous (multi-level) fluid level sensor for measuring levels in water, non-corrosive water based liquids and dry fluids (powders). The eTape sensor is manufactured using printed electronic technologies which employ additive direct printing processes to produce functional circuits. (Std_eTape_Datasheet 2014)

Theory of Operation

The eTape sensor's envelope is compressed by hydrostatic pressure of the fluid in which it is immersed resulting in a change in resistance which corresponds to the distance from the top of the sensor to the fluid surface. The eTape sensor provides a resistive output that is inversely proportional to the level of the liquid: the lower the liquid level, the higher the output resistance; the higher the liquid level, the lower the output resistance. (Std_eTape_Datasheet 2014)

Flow Sensor

The flow sensor is device that used to measure the steam of liquid. And will use the changing of level to measure the flow.

PH Sensor

PH sensor is device that used to get the pH degree for liquid. This sensor will give a voltage range 0 – 1.4V based on the pH level.

Chapter 4: Methodology

This project contains two parts, software part and hardware part.

Hardware part contains 3 microcontrollers connected together using I2C, there is one master microcontroller and two slaves microcontrollers,

The master microcontroller should read the value of the pH sensor, Temp sensor, level sensor of the mixing tank, and the gas sensors. Also it should send a commands to the MATLAB program and to send packets to other slave microcontrollers.

The main objective of using master and slave microcontrollers is if the user in the future decided to add another tank, it is done easily by connecting the new controller to I2C bus and the master is going to scan the bus before it starts the process.

We wrote a simple protocol to send and receive packets between master and slaves on the I2C bus, also we wrote another protocol to send and receive packets between MATLAB program and the master.

In the next sections, we will find the descriptions of the MATLAB program and how it was designed, the I2C protocol, Serial Protocol, and how the hardware circuit was built.

4.1 System Main Components

As we mentioned before, the system contains 3 level sensors one of them for mixing tank and the others for the tanks, also each tank has flow sensor to measure the flow in the pipe, the following picture show you the main components and sensors that was used in this project.

System Main Components

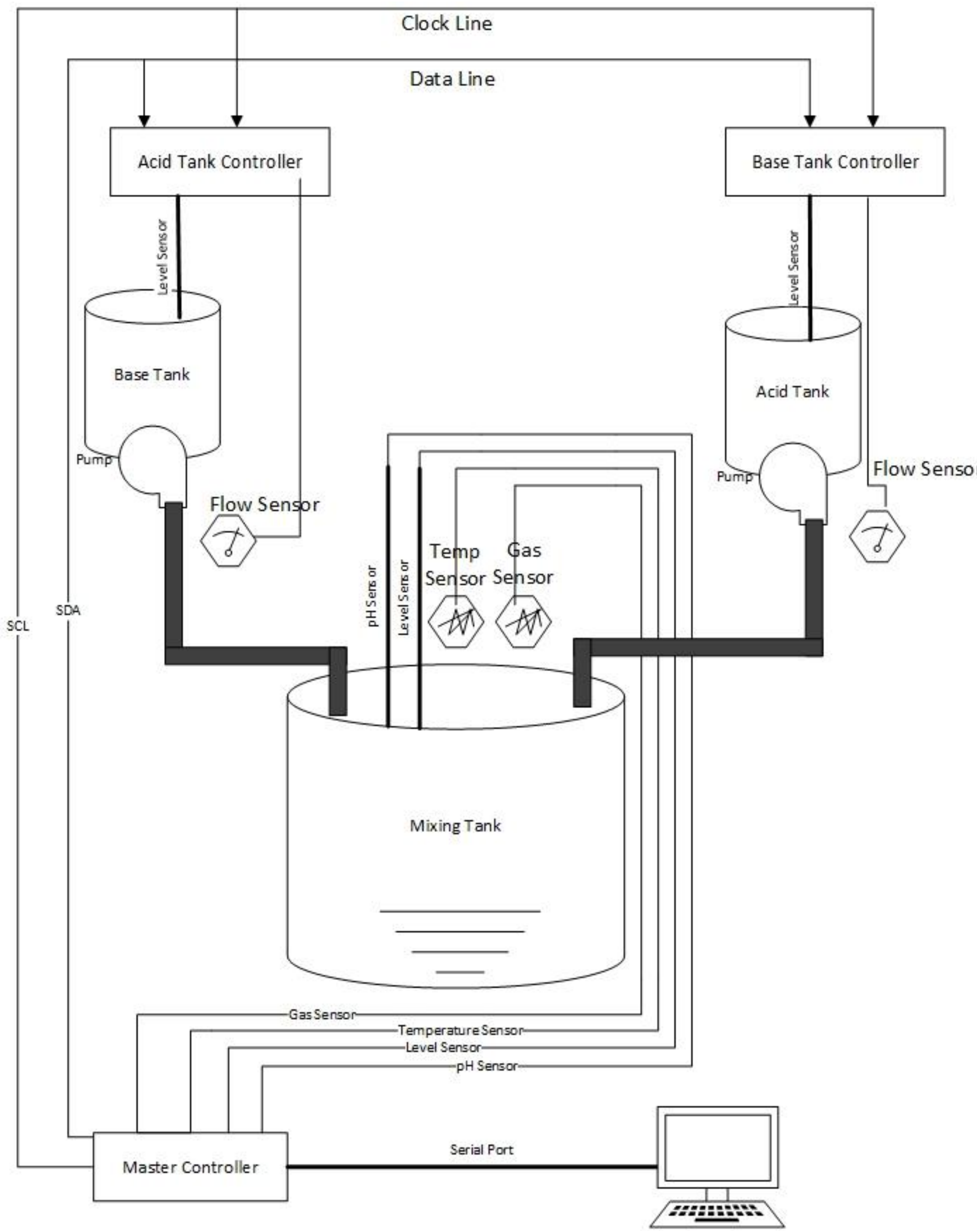

Figure 4.1 System Components

4.2 System Operation

Before the system start running, there are some parameters that should be checked.

First of all, the system should be connected to the master controller, and a handshake message should be sent to the master controller to start the program.

Then the system should handshake acid and base tank controller, if any of them did not do the handshake, the system will stop the operation until the handshake acknowledgment received from that tank.

If the all controllers did handshake, the system will ask the user to enter pH set point, then the system check if there is enough amount of acid and base to do the mixing. Unfortunately, it's very difficult to calculate the amounts of acid and base that should get in the reaction to produce the desired pH value.

The level of the acid and base tanks should be larger than a specific value, the user will enter this value to the program.

When the system ensure that all the previous parameters were successfully done, it will be ready to start pH regulation. The system starts reading the flow sensor of acid and base tank and the pH sensor, then the system will run the fuzzy logic controller and load these values to it. The fuzzy logic controller will produce the acid and base pump speed. This speed depends on the fuzzy logic rules, we will find the fuzzy logic rules in section 4.3.

The system also read the Gas sensor and temperature sensor, if their values was larger than the threshold value, the system will stop the whole operation. We check these sensors, because chemical reactions could produce gases and high temperature that can cause dangerous. This is for safety reasons.

When the pH degree reached the desired value, the system will stop the operation.

The following picture show you the system architecture.

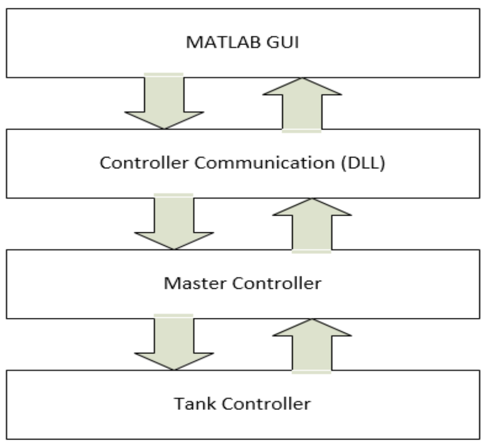

Figure 4.2 System Architecture

The following sequence diagram shows you the process of setting the speed of the pump

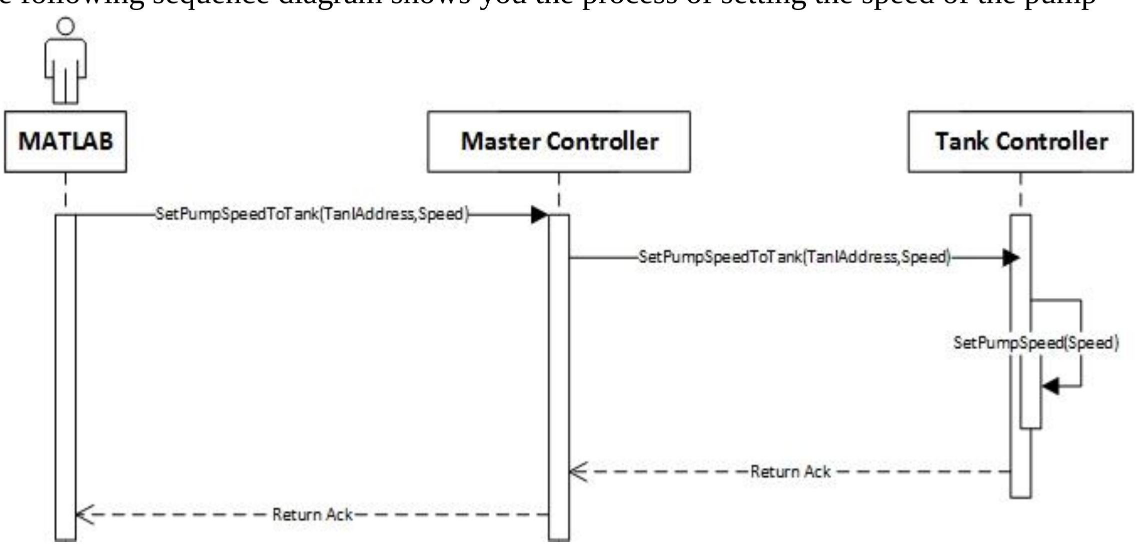

Figure 4.3 Set Pump Speed Sequence Diagram

Instead of requesting each sensor's value alone, we can request them at one time, the following sequence diagram show you the process of reading level and flow sensor from the tank.

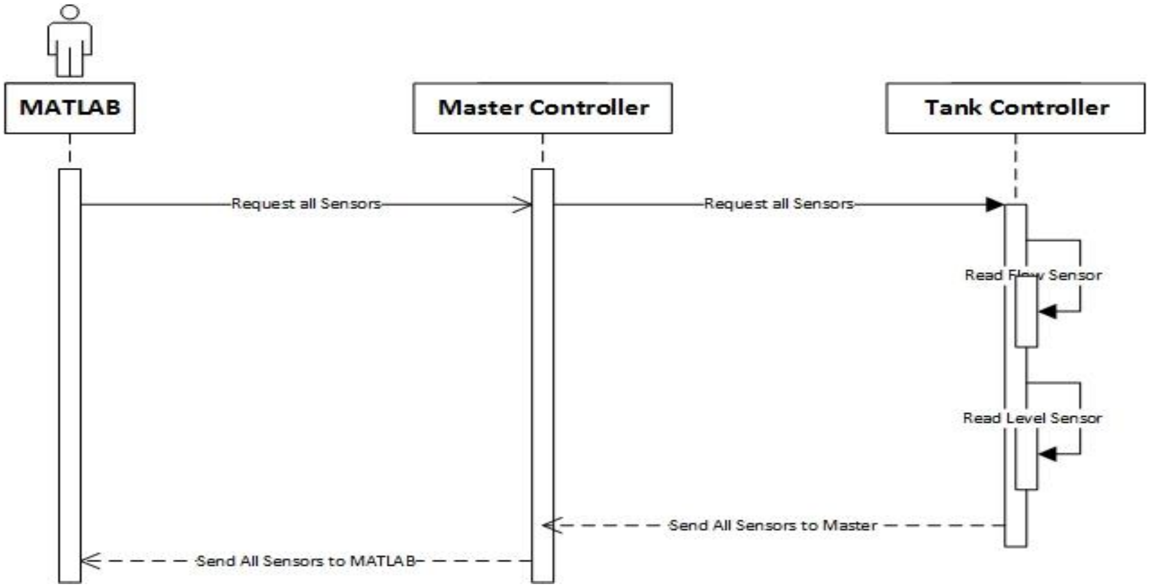

Figure 4.4 Requesting all sensors Sequence Diagram

Figure 4.2 show you the flowchart of the system operation.

The following picture shows you the handshake process between MATLAB and Master and Master and Tank Controller.

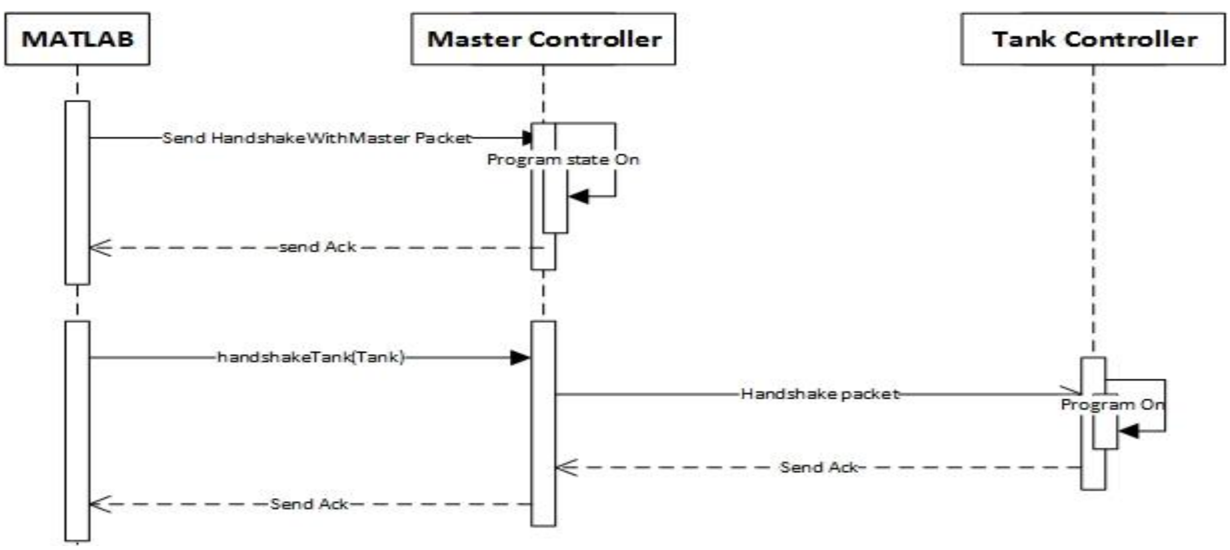

Figure 4.5 Handshake Process

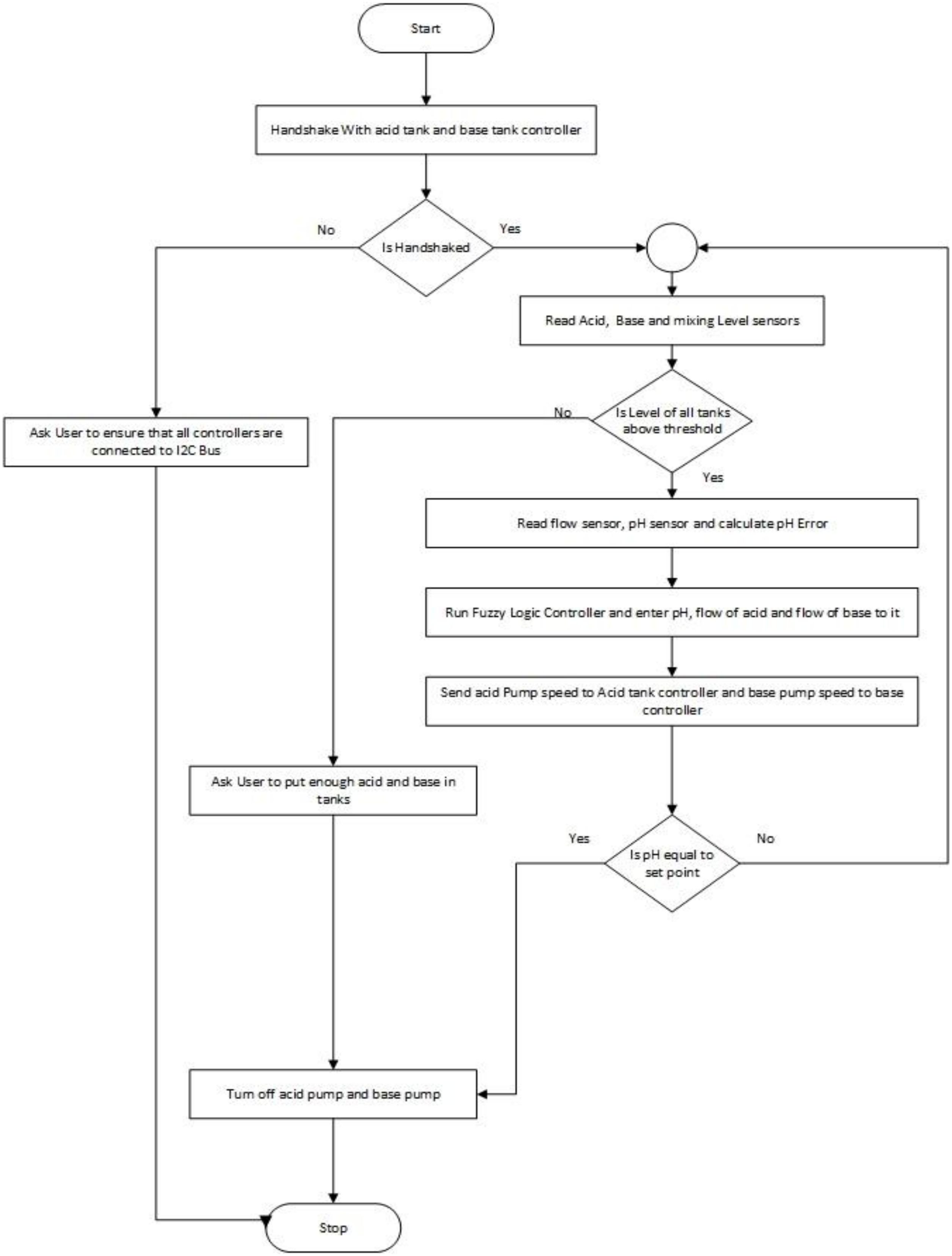

Figure 4.6 System Flowchart

4.3 MATLAB Program

The most powerful thing in this project is anyone can modify the controller and change its parameters easily without changing any code, but we have used fuzzy logic because it gives a good performance rather than other controllers like PID.

This controller has 3 inputs and 2 outputs, these inputs are flow of acid tank, flow of base tank, the pH value of the mixing tank.

The outputs are the pump speed of the acid and the base tank.

Depending on the Fuzzy logic rules, the system will produce the outputs to control the pumps, these values are sent throw serial port to the master controller and the maser controller send them again to the tank controller.

4.3.1 Fuzzy sets

In this section, we will find the fuzzy sets of the inputs and outputs to the fuzzy logic controller.

The inputs are the flow of the acid and base tank and the pH error, these values will get into the flow and pH fuzzy set, the MATLAB will produce the membership degree and load it to the fuzzy rules to produce the output. This operation called Fuzzification.

The following picture shows you the fuzzy logic controller in MATLAB

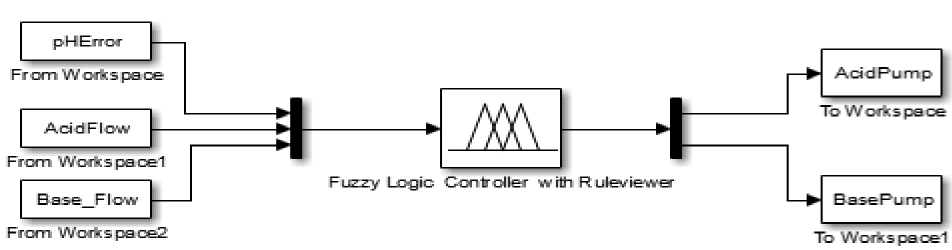

Figure 4.7 Fuzzy Logic Controller

The following picture show you the member function for pH Error.

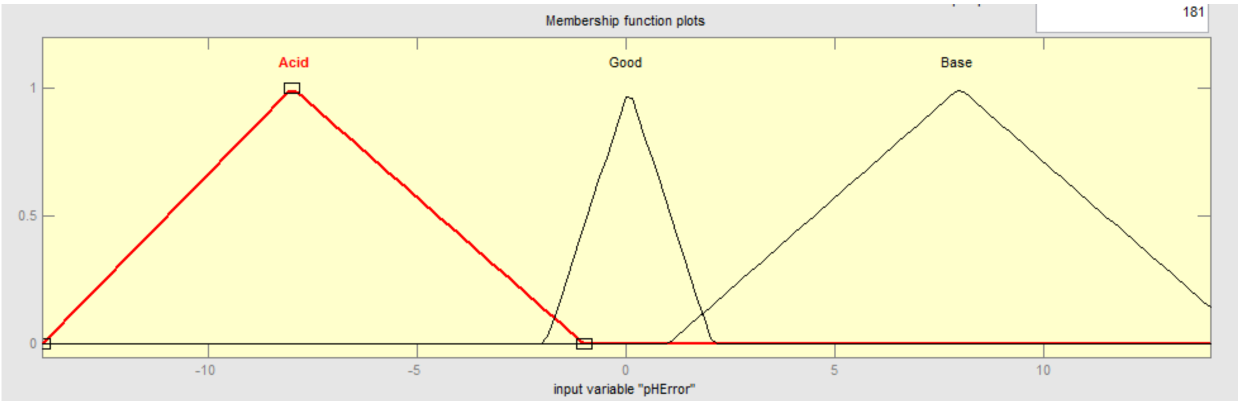

Figure 4.8 Member Function for pH Error

The following picture shows you the member function for the Acid and Base flow.

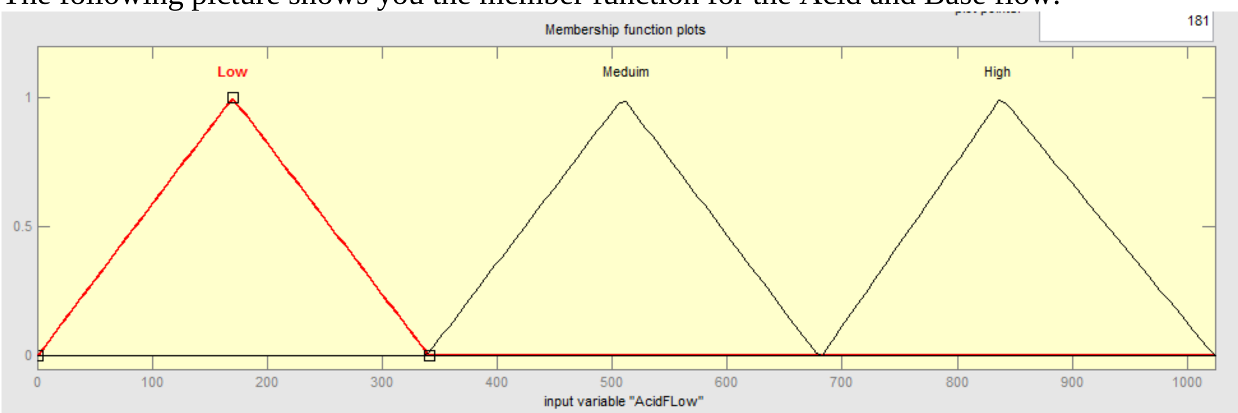

Figure 1.9 Acid and base Member function

The following picture shows you the pump speed member function

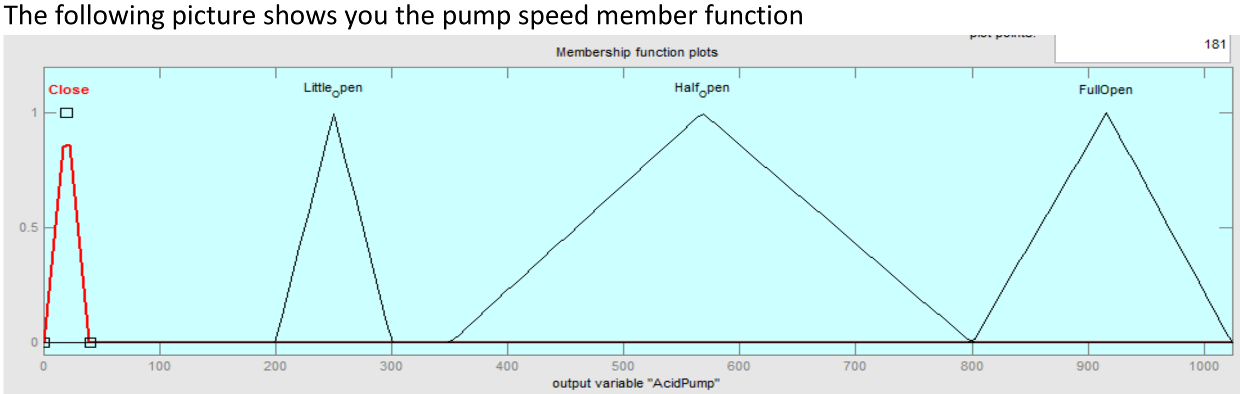

Figure 4.10 pump speed member function

Note that the inputs and outputs member functions maybe change to improve the performance in the system.

4.1.2 Fuzzy Logic Rules

In this section, you will find the rules that the system will use them to run the fuzzy logic controller.

Depending on these rules, the system is going to produce the pumps speed.

Also these rules could change to improve the performance.

The following picture shows you the rules that was used in this system.

IF			Then	
pH Error	Flow Acid	Flow Base	Acid pump	base Pump
Acid	Low	Low	close	Littlie
Acid	Low	Medium	close	Littlie
Acid	Low	High	close	Littlie
Acid	Medium	Low	close	half
Acid	Medium	Medium	close	half
Acid	Medium	High	close	half
Acid	High	Low	close	full
Acid	High	Medium	close	full
Acid	High	High	close	full
Good	Low	Low	close	close
Good	Low	Medium	close	close
Good	Low	High	close	close
Good	Medium	Low	close	close
Good	Medium	Medium	close	close
Good	Medium	High	close	close
Good	High	Low	close	close
Good	High	Medium	close	close
Good	High	High	close	close
Base	Low	Low	Littlie	close
Base	Low	Medium	half	close
Base	Low	High	full	close
Base	Medium	Low	Littlie	close
Base	Medium	Medium	half	close
Base	Medium	High	full	close
Base	High	Low	Littlie	close
Base	High	Medium	half	close
Base	High	High	full	close

Table 4.1 Fuzzy Logic Rules

4.3.3 The GUI

The GUI of the system is going to control the whole system, connecting to master microcontroller and handshake with it, and also read all sensors, and produce the output, to control the pumps speed.

The following picture shows you the GUI of the system.

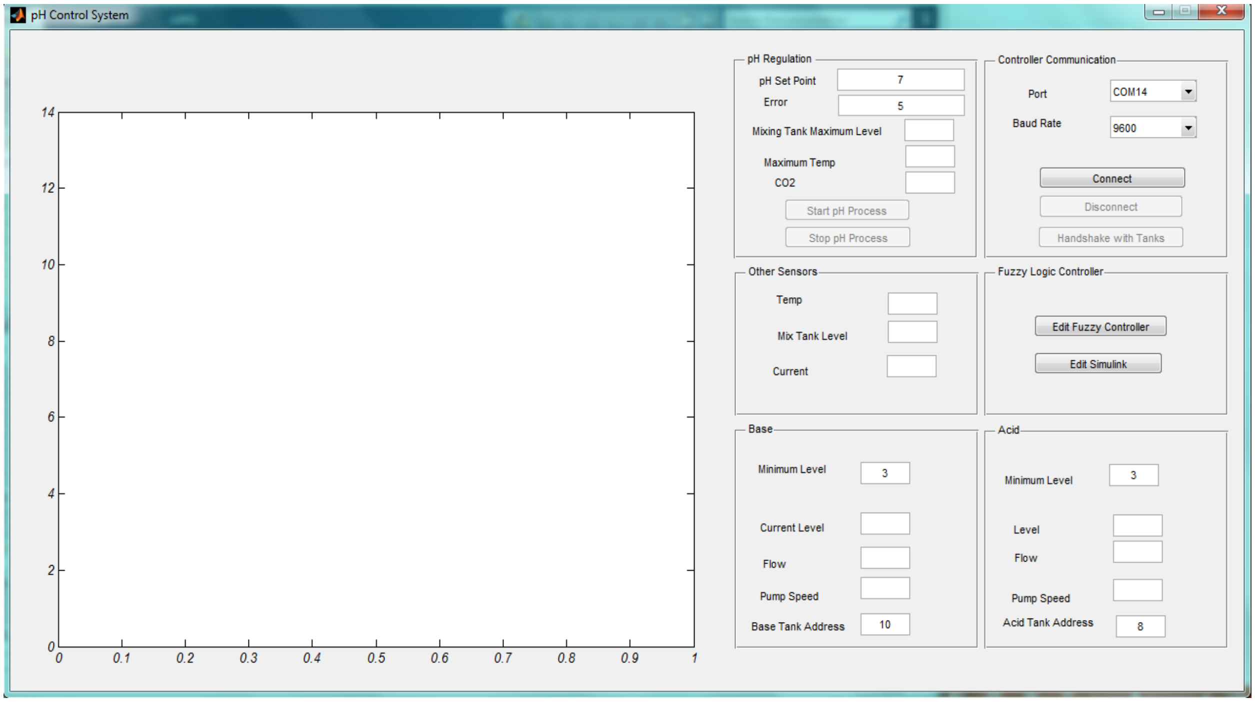

Figure 4.11 System GUI

The user can edit the fuzzy logic rules by clicking on Edit Rules button, and edit the Simulink.

4.4 I2C Protocol

The main purpose of this protocol is to ensure the reliability of data communications between the master and the slaves.

Each slave should hold an address on the I2C bus, and the master does not have any address, the communications between the master and slave is done by the master, that means, the slave cannot send anything to the master without the master request it, there is two operations that the master can do is send data and request data from slave, the slave cannot send anything to master without request, so in our implementation, the slave is running like state machine, the next sequence diagram show us how is the communication between them,

The data communication contains from the packet, the size of the packet is 6 bytes, the first filed is the packet type, the other 4 fields is the data, and the 6^{th} byte is the check sum.

We have 9 primary types of packets, the following table describe them briefly.

Packet Type	Description
TYPE_HANDSHAKE_TANKS	To handshake between master and slave
TYPE_DISCONNECT_PC	if the PC is disconnected, shut down the program
TYPE_ACK	Acknowledgment
TYPE_REQUEST_FLOW	To request the flow sensor
TYPE_REQUEST_LEVEL	To request the level sensor
TYPE_BAD_PACKET	If the check sun is incorrect
TYPE_REQUEST_ALL_SENSORS	To request all sensors
TYPE_SET_PUMP_SPEED	To set the pump speed
TYPE_NACK	Negative acknowledgment

Table 4.2 I2C Packets Description

The first thing is the master should send a handshake packet to the slave in order to respond to any incoming packets, if the slave is not handshake, the slave will send negative acknowledgment to the master.

4.5 Serial Communication Protocol

In order to send and receive packets correctly between MATLAB program and maser microcontroller, we wrote another simple protocol to communicate between the MATLAB and the master controller.

Using MATLAB APIs to communicate with serial port is too bad, so that, we implement a dynamic link library (DLL) which was written in C# to communicate with the serial port, this DLL was opened by MATLAB to use our APIs to use this protocol.

The structure of the packet contains 6 bytes, the first one is the packet type, the next 4 bytes is the data, and the 6^{th} one is the check sum.

There are several types of packets, the following table describe each one briefly

Packet Type	Description
TYPE_PACKET_HANDSHAKE_PC	To handshake with PC
TYPE_HANDSHAKE_TANKS	To handshake with tanks
TYPE_DISCONNECT_PC	To tell the microcontroller that the program wants to disconnect
TYPE_ACK	Acknowledgement
TYPE_NACK	Negative Acknowledgement
TYPE_REQUEST_FLOW	To request flow sensor
TYPE_REQUEST_LEVEL	To request level sensor
TYPE_REQUEST_GAS	To request Gas Sensor
TYPE_REQUEST_pH	To request pH sensor
TYPE_REQUEST_TEMP	To request Temp
TYPE_BAD_PACKET	If the check sum is incorrect
TYPE_REQUEST_ALL_SENSORS	To request all sensors from all microcontrollers
TYPE_SET_PUMP_SPEED	To set pump speed to one of the controllers
TYPE_REQUEST_SCAN_I2C	To scan I2C bus

Table 4.3 Serial Packets type Description

4.6 Hardware components

We need two voltage sources. One is 5V source that will use for microcontroller circuit and other one is 9V that will be used in sensors circuit.

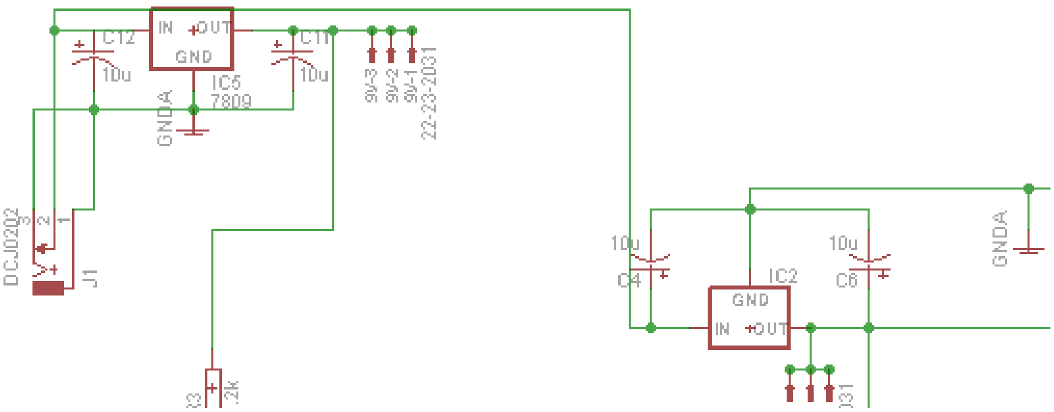

Figure 4.12: Power circuit

As we know in pervious chapter we talk about level sensors. And we know the changing in liquid level will reflect as resistive, so we will need to build interface to microcontroller. To make this we use a resistor 1.2 KΩ to connect it with the sensor as shown in the figure.

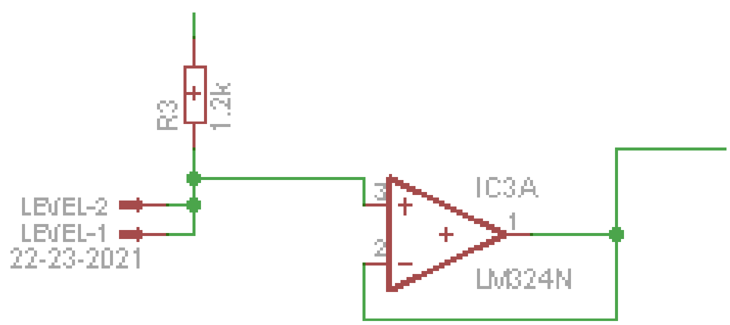

Figure 4.13: Senor Interface circuit

We choose 1.2KΩ in this circuit because we use a 9V power supply to feed this circuit and the sensors will give 1500Ω to 300Ω using the voltage division theory will get a voltage range from 5V to 1.8V. The output from this circuit will connect to puffer circuit.

We connect a DC pump to pump the liquid for transferring it to mixed tank. To control speed of pumps we use a Pulls with Modulation (PWM). We need a driver circuit to do the controlling so we use Optokoppler that flow with power transistor as shown.

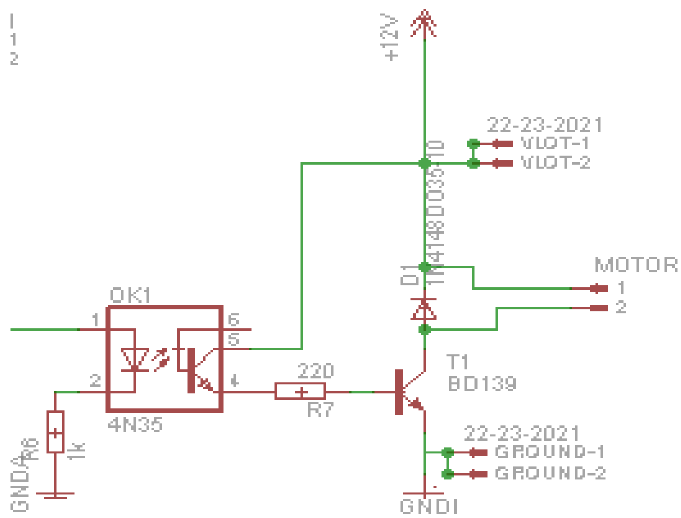

Figure 4.14: Pumps drive circuit.

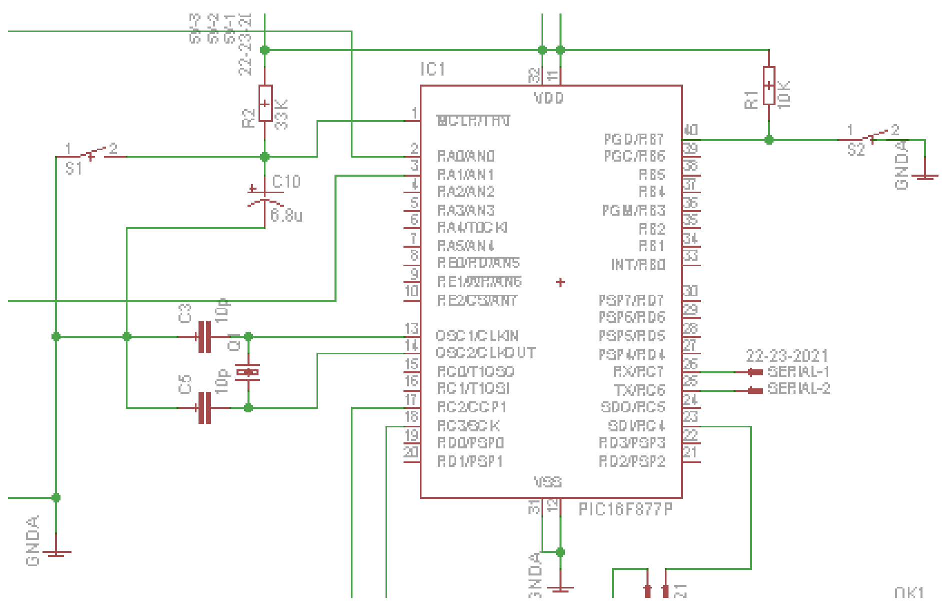

Figure4.15: Microcontroller circuit.

This circuit will give a 1.5A and the pumps that we used in the project need 400mA to 800mA.

And we use a 12V power supply to pumps circuit.

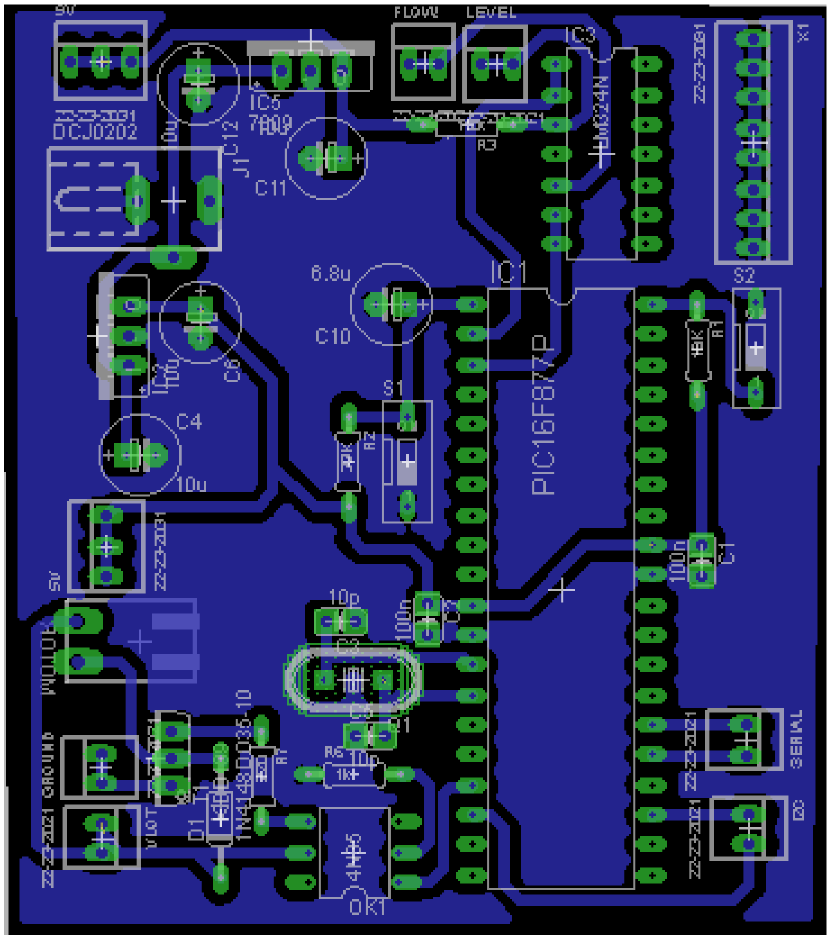

Figure4.16: Board Layout

In the microcontroller circuit we use a PIC18F4620 and run it on crystal 20MHz.

This Microcontroller we used to control pump speed and will read the sensors that connected with source tank. Also the circuit has an interface for I2C.

Chapter 5: Results and Analysis

We simulate the system using MATLAB and we obtains the following result shows in the following figure.

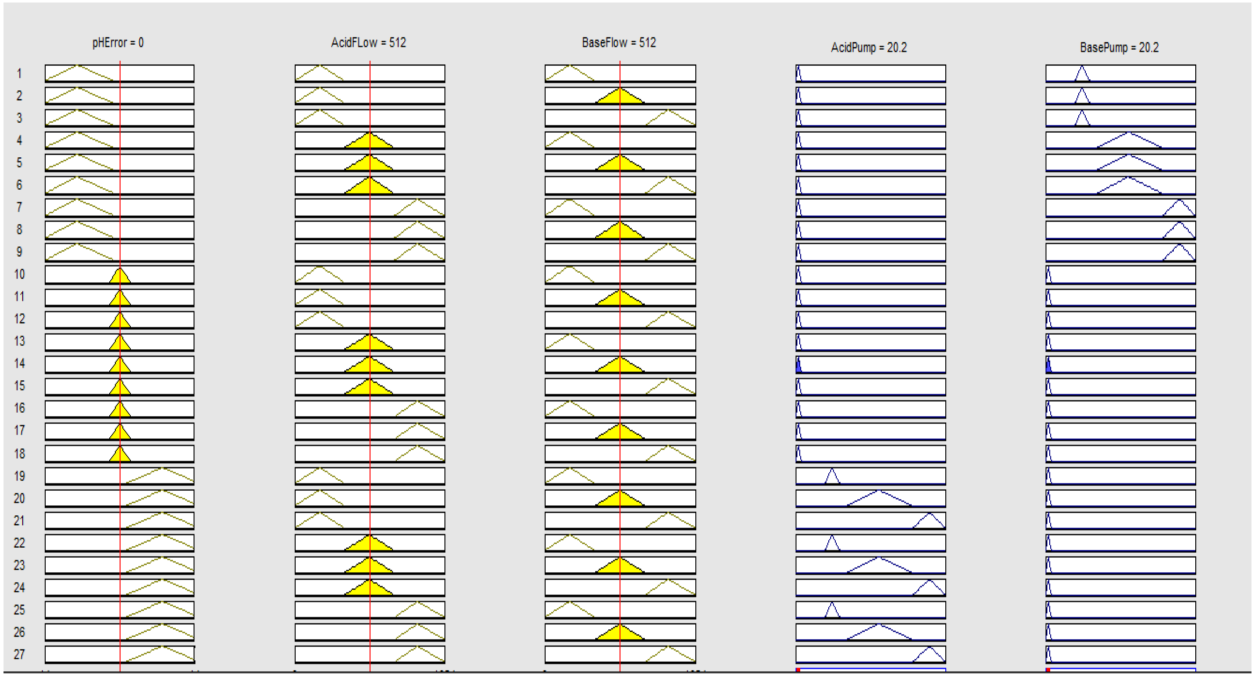

Figure 6.1 MATLAB fuzzy logic Rules Viewer

And if we change the value of the pH error and the flow, we will obtains the pump speed to control the pump on the simulation.

We also connect this Simulink to hardware to send and receive data, and we obtain similar results.

We made a simulation experiment and we obtained sensors values and they were read correctly, also the program successfully controlled the speed of the pump.

We test this application on real chemical liquids acids and bases HCL + NAOH and we got a very good results.

The following image show you the results, the solution pH is 10 and the set point is 7.

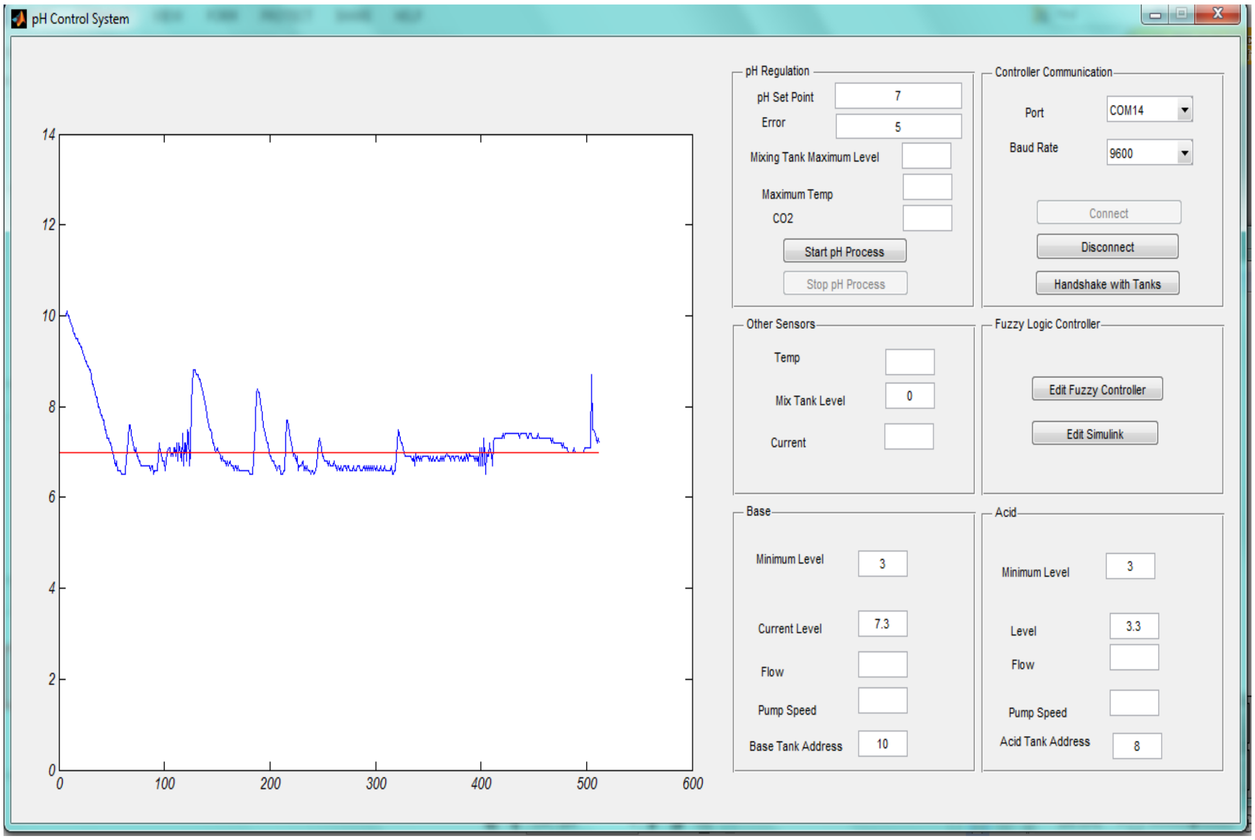

Figure 6.2 Testing Results

Chapter 6: Conclusions and Recommendation

This project was built using fuzzy logic controller, it is possible to have some error in the performance, and we could improve this result by changing the fuzzy logic rules and member ship function. This done by try and test to tune the system to maximum performance.

Our future work is to add more tanks to be involved in this process. In order to get better performance, we are planning to get more accurate sensors. Also, another microcontroller with powerful features could be used.

DISCLAIMER

This report was written by students at the Computer Engineering Department, Faculty of Engineering, An-Najah National University. It has not been altered or corrected, other than editorial corrections, as a result of assessment and it may contain language as well as content errors. The views expressed in it together with any outcomes and recommendations are solely those of the students. An-Najah National University accepts no responsibility or liability for the consequences of this report being used for a purpose other than the purpose for which it was commissioned.

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