Design and Implementation of a Water Level Controller using Fuzzy Logic

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***Abstract* - This paper analyzes the effectiveness of water level control using fuzzy logic. The water level in the tank is sensed using transistor switching principle. The level sensed is fed to the PIC16 microcontroller. The user provides the set point to the microcontroller through serial communication using the COM development port software, Terminal. It computes the error as the difference between the set point and the process variable. The fuzzy logic programmed in the microcontroller is applied which controls the water level in the tank using the drain and the feed pumps. Once the set point has been reached, the message along with the present level is sent back through serial communication to the user interface on a PC. Thus, the water level in the tank is controlled according to the set point given by the user. The implementation of a fuzzy level controller has many applications such as boiler drum level control, reverse osmosis plant, demineralisation plant etc.**

Keyword - Water level control, Fuzzy logic, PIC16 microcontroller, Terminal, Embedded C programming

I. INTRODUCTION

The use of water level control is extensive and varied. The main uses are in chemical plants, power plants etc where a slight deviation can lead to major accidents and huge losses in revenue. Hence, it has become necessary to develop a control system which is far more accurate and also cost effective. Fuzzy logic idea is similar to the human being's feeling and inference process. Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control [1]. Hence, fuzzy logic provides a better, more stable and accurate control for wider ranges of set points. Further, the water level control can be made cost effective by using simple sensing principle like transistor switching. Final control elements such as pumps can be operated by using discrete outputs in such a way that can almost fulfill the requirements of an actuator of a control valve. In today's industry there is a widespread use of microcontrollers because they are simple, cheap and easy to program. The fuzzy controller can be easily implemented by programming the microcontroller effectively [2]. This paper aims to design and implement such a cost effective and accurate system.

II. OBJECTIVE

The objective of the paper is to control the water level in the tank according to the set point given by the user through the user interface by measuring the present level, computing the error, applying fuzzy logic and thereby draining or feeding water into the tank accordingly. The simplified functional block diagram of the complete closed loop control system [3] is shown in Fig. 1.

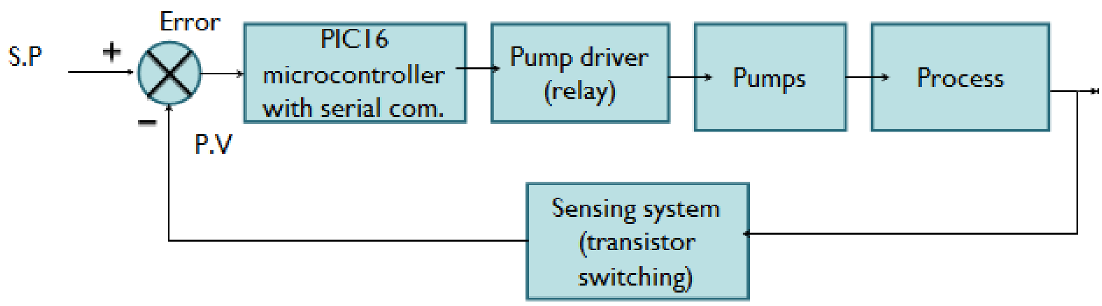

Fig. 1. The Functional Block Diagram of the Closed Loop Control System

III. METHODOLOGY

A. Development of the sensing system

The sensing system used is based on transistor switching principle. The base of a transistor, connected to a resistor, is given at a certain level inside the tank. A 5V power supply is connected to the collector of the transistor and this line is given to the base of the tank. The emitter of the transistor is grounded. When the water level has not reached the level at which the transistor base line is attached, the circuit is open and hence, there is no current to the base. The transistor is now in cut off condition with no collector current and the entire voltage is across the transistor. When the water comes in contact with the base line of the transistor, the switch is closed and collector to emitter voltage becomes negligible and there is a collector current. This change in voltage is considered by the microcontroller and the current level is sensed. In order to detect the various levels across the tank, 8 such circuits are present to detect 8 different levels. It should be noted that the number of levels can be increased or decreased as and if required. Fig. 2 shows the circuit diagram for sensing one level. The same circuit has been developed eight times for eight levels. Fig. 3.1 shows the various levels inside the tank which come from the base lines of 8 transistors. Fig. 3.2 shows the sensing system circuitry.

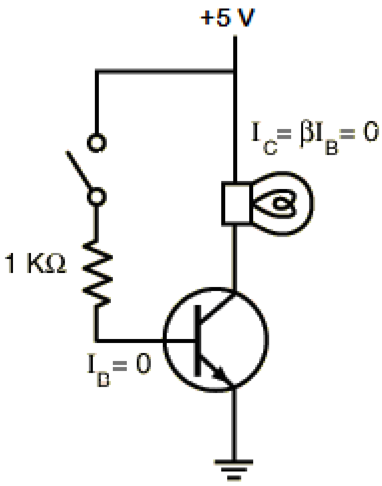

Fig 2.1 Transistor Switching:
When switch is open

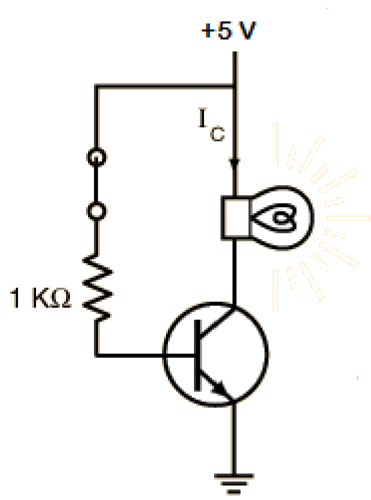

Fig. 2.2 Transistor Switching:
When switch is closed

Fig. 2. Circuit Diagram for sensing one level

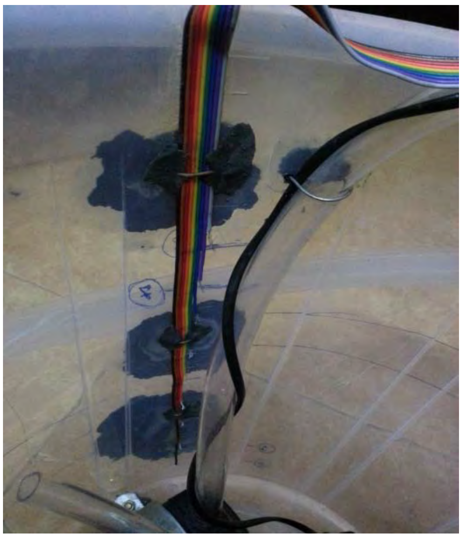

Fig. 3.1 Levels inside the tank

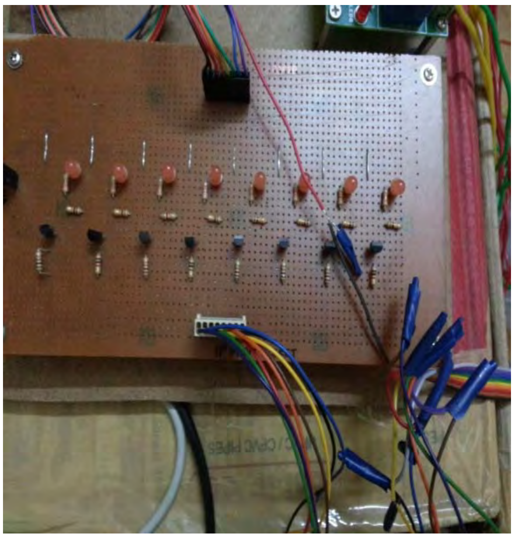

Fig.3.2 The sensing system circuitry

Fig. 3. The complete sensing system

B. *Microcontroller design and programming*

There are 3 steps in fuzzy logic implementation: Fuzzification, Development of Rule Base, Defuzzication. The following sections deal with each of them separately.

1) Fuzzification: The following Table I, Table II and Table III provide the ranges for the input and output membership functions respectively. The Fig. 4 shows the graphical representation of the membership functions. The error (set point - process variable) ranges are the input membership functions [9]. The percentage closing of the control valves (drain and feed) are given as the two output membership functions [6, 7].

TABLE I
Input membership functions

Error	Tag name
-80 to -50	VLN (very large negative)
-60 to -30	LN (large negative)
-40 to -10	N (negative)
-20 to 10	SN (small negative)
0 to 30	VSP (very small positive)
20 to 50	SP (small positive)
40 to 70	P (positive)
60 to 80	LP (large positive)

TABLE II
Output membership functions of the feed valve

Percentage closing of valve	Tag name
0 to 30	OVF1 (open very fast)
20 to 50	OF1 (open fast)
40 to 70	O1 (open)
60 to 90	OS1 (open slowly)
80 to 100	OVS1 (open very slowly)

TABLE III
Output membership functions of the drain valve

Percentage closing of valve	Tag name
0 to 30	OVF2 (open very fast)
20 to 50	OF2 (open fast)
40 to 70	O2 (open)
60 to 90	OS2 (open slowly)
80 to 100	OVS2 (open very slowly)

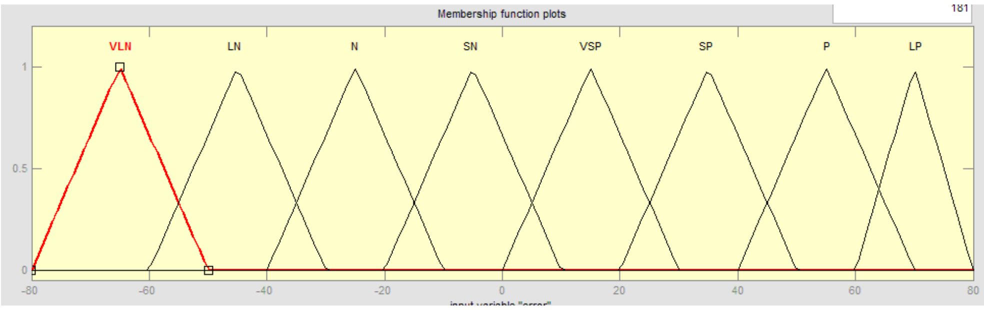

Fig. 4.1 Input membership functions

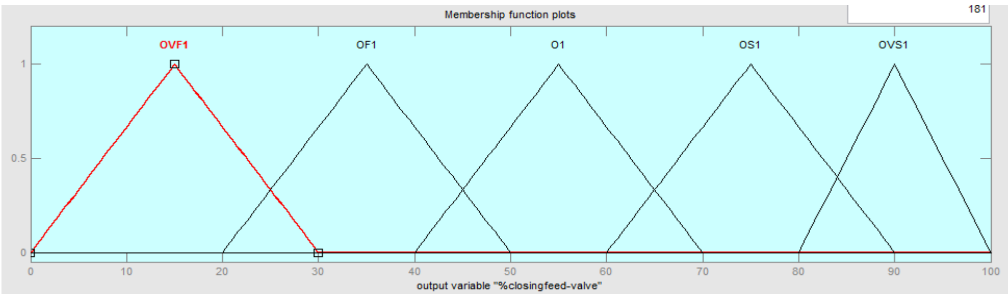

Fig. 4.2 Output membership functions of feed valve

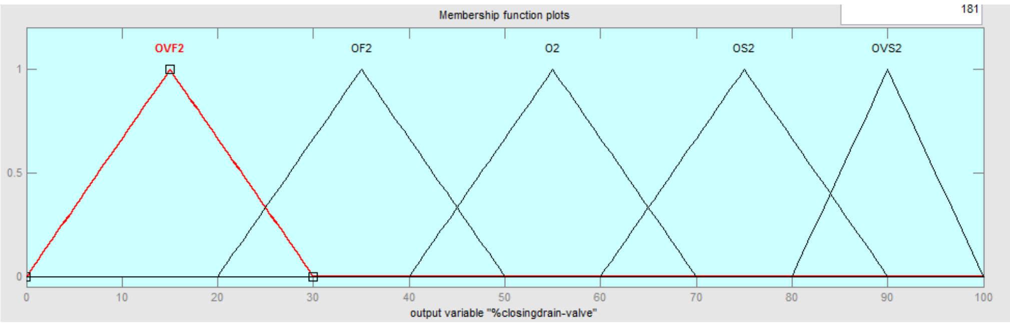

Fig. 4.3 Output membership functions of drain valve
Fig. 4. Membership functions

2) Rule base: There are 8 fuzzy rules [5] which relate the input and output membership functions.

These do not conflict such that one output is picked for each possible input combination [11]. The rules are as follows:

1. If (error is VLN) then ((drainvalve is OVF2) and (feedvalve is OVS1))
2. If (error is LN) then ((drainvalve is OF2) and (feedvalve is OVS1))
3. If (error is N) then ((drainvalve is O2) and (feedvalve is OVS1))
4. If (error is SN) then ((drainvalve is OS2) and (feedvalve is OVS1))
5. If (error is VSP) then ((feedvalve is OS1) and (drainvalve is OVS2))
6. If (error is SP) then ((feedvalve is O1) and (drainvalve is OVS2))
7. If (error is P) then ((feedvalve is OF1) and (drainvalve is OVS2))
8. If (error is LP) then ((feedvalve is OVF1) and (drainvalve is OVS2))

3) Defuzzification: The defuzzification method used is mean of maximum (MOM) method. This method computes the average of those fuzzy outputs that the highest degree. It can be computed using the following formula:

$$\mathrm{MOM}(y) = \frac{\sum_{x' \varepsilon T} x'}{T} \qquad (1)$$

$$T = \{x' \,|\mu y(x')=\text{Support } \mu\ y(x)\} \qquad (2)$$

The fuzzy conclusion is: x is providing y and T is the set of output *x* that has the highest degrees in the set y[1]. In order to make the implementation more cost effective, the defuzzified outputs of the two valves is converted in discrete form using four drain pumps (D.P) and four feed pumps (F.P) [8]. Hence, drain and feed pumps can now be used as the final control elements instead of drain and feed control valves with actuator. The conversion is done as shown in the table IV.

TABLE IV
Conversion of valve outputs to pump on-off controls

% closing-drain valve	**% closing-feed valve**	**Functionality of the pumps**	
		ON	**OFF**
0 to 20	90 to 100	D.P. 1, 2, 3, 4	F.P. 1,2,3,4
20 to 40	90 to 100	D.P. 1,2,3	D.P.4 F.P. 1,2,3,4
40 to 60	90 to 100	D.P. 1,2	D.P. 3,4 F.P.1,2,3,4
60 to 90	90 to 100	D.P. 1	D.P. 2,3,4 F.P. 1,2,3,4
90 to 100	60 to 90	F.P. 1	F.P. 2,3,4 D.P. 1,2,3,4
90 to 100	40 to 60	F.P. 1,2	F.P. 3,4 D.P. 1,2,3,4
90 to 100	20 to 40	F.P. 1,2,3	F.P. 4 D.P. 1,2,3,4
90 to 100	0 to 20	F.P. 1,2,3,4	D.P. 1,2,3,4

The entire fuzzy implementation along with the conversion of the defuzzified valve outputs to pump on-off controls is coded in PIC16 microcontroller in Embedded C programming language [4].

4) PIC16 Microcontroller Circuit Design: The microcontroller circuit diagram is given in Fig. 5. The microcontroller majorly has 5 ports, namely A, B, C, D, E. The ports A and E are generally used for analog to digital data conversion. The port D is generally used for data and control functions of LCD. The port B has internal pull up resistors and hence there is no need to connect any more resistors with it. This port is used as the input port for the eight level transistor switching sensing system. This port is by default high, and hence is activated by ground signals. The port C has eight pins, of which pin 5, 6 are used for serial communication for transmission and reception respectively. The port D is used as the pump driver (relay) inputs.

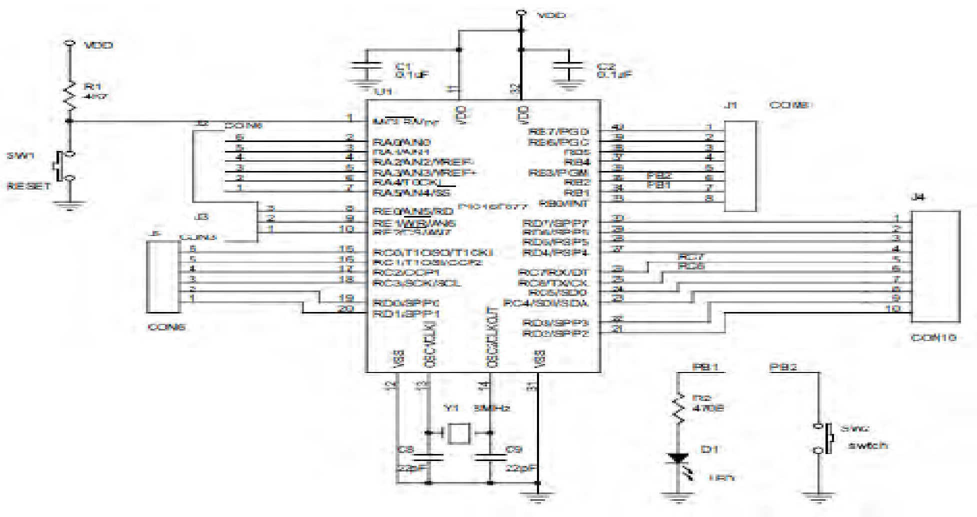

Fig.5. The PIC16 microcontroller circuit diagram

5) Microcontroller Power Supply Circuit Design: The microcontroller power supply circuit diagram is given in Fig.6. A 12V AC/DC jack (Part number MIC W10) goes to a bridge rectifier. The 1000µF capacitor which is connected to output of bridge rectifier is used for voltage regulation and supports load current of maximum 1A. In general, for every 1A, 1000µF capacitor is used for voltage regulation. A 470µF capacitor can also be used but voltage regulation will not be proper. A 5V voltage regulator, LM7805 (range of 7V to 40V) takes this 12V input and converts it to 5V for usage in the microcontroller VDD and VSS. A 0.1µF capacitor is used for smoothening minor fluctuations in the output.

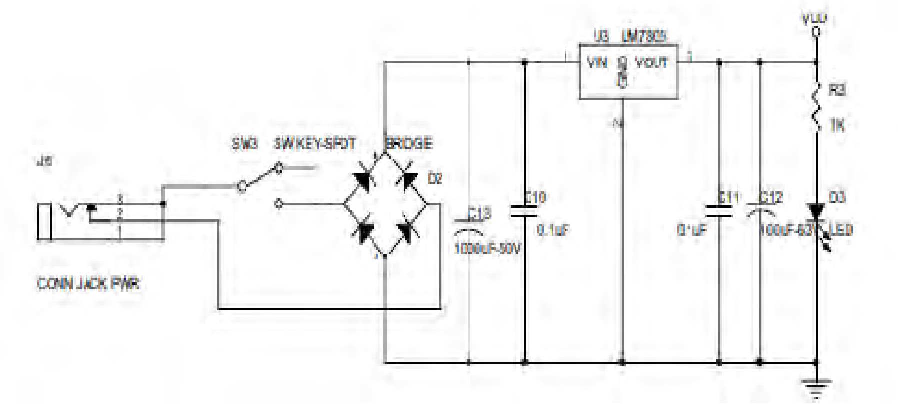

Fig.6. Microcontroller Power Supply Circuit Diagram

6) Serial Communication and User Interface: For serial communication, CP2102 is used which converts the TTL serial communication to USB protocol. Hence the circuit now can be directly connected to a PC using a USB cable. The COM port development emulation program, Terminal, is used as a user interface. Its applications include communication with various devices such as modems, routers, embedded µC systems, GSM phones etc. It is also very helpful as a debugging tool for serial communications.

C. Pumps and Pump Driver

The four feed and four drain pumps are controlled by a 8-channel relay board. The input of the relay board comes from the port D of the microcontroller. The output of each relay has 3 pins, namely NO (normally open), C (common), NC (normally closed). One of the wires of the power supply of each pump is connected to NO of each relay. The other wires of the power supply of all the pumps are connected together and this provides a connection for one of the pins of a two pin plug which is connected to AC mains. The other pin of the two pin plug provides connection for all the C pins of all the relays. When a relay receives an input from the microcontroller, the coil inside it gets energized, which then closes the contact pin NO and the circuit is complete. The 8 channel relay board and the 4 drain pumps (exactly similar to 4 feed pumps fitted in the sump) are shown in Fig. 7 and Fig.8.

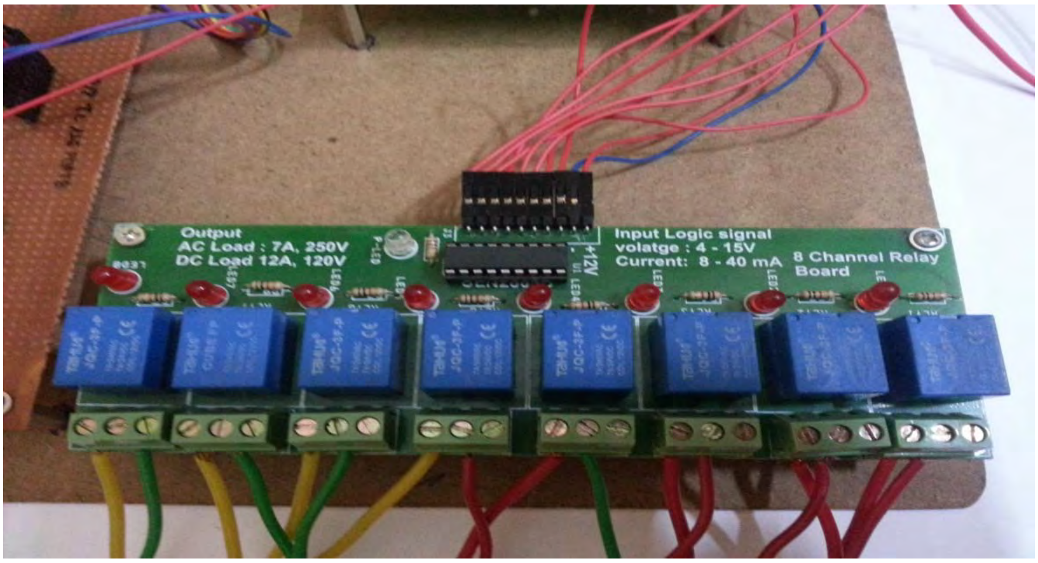

Fig.7. The 8-channel relay board

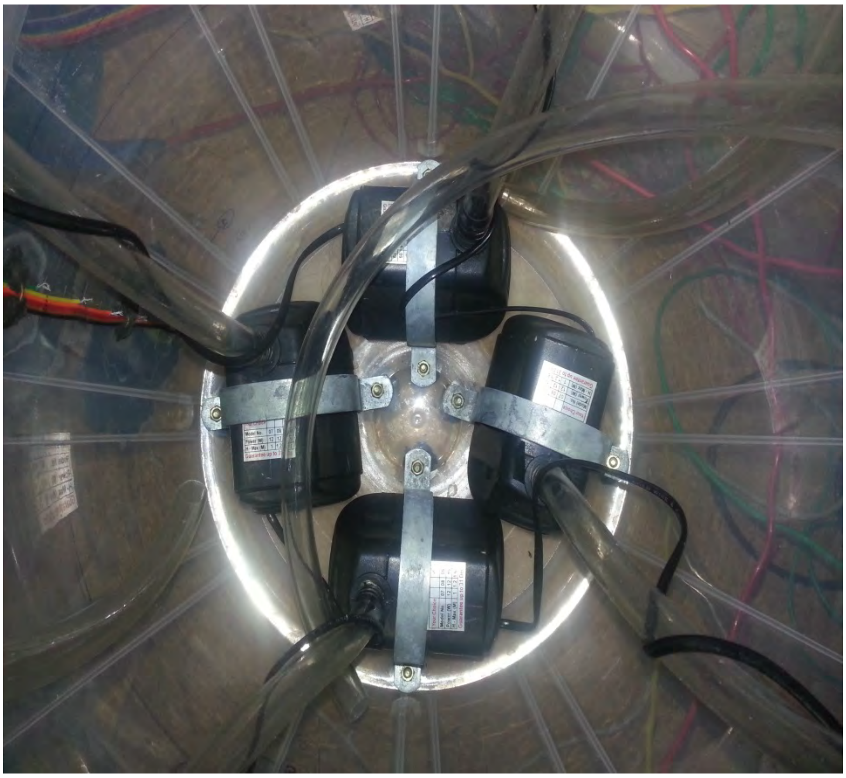

Fig. 8. The 4 drain pumps

The complete circuit system is shown in the Fig.9. This circuit system is connected to the tank with the pumps and the PC for user interface.

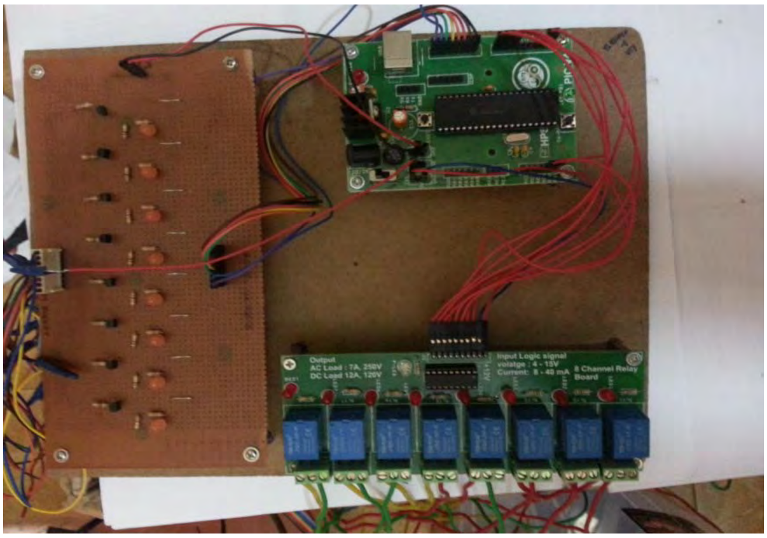

Fig.9. The complete circuit system of the water level controller

IV. RESULTS

The user interface helps the user to monitor and control the system effectively. It is made user friendly as it displays various messages to the user displaying the current state of the system. The Fig.10 (10.1 and 10.2) shows the screen-shots of the user interface. The efficiency of the system is also calculated by measuring the level in the tank manually with the help of a measuring tape and is shown in the Table V. The table shows that the control system controls the water level accurately. The error obtained is due to the water in the tubes connected to the pump which rises before the pumps are off but falls into the tank after the pump are turned off by the microcontroller.

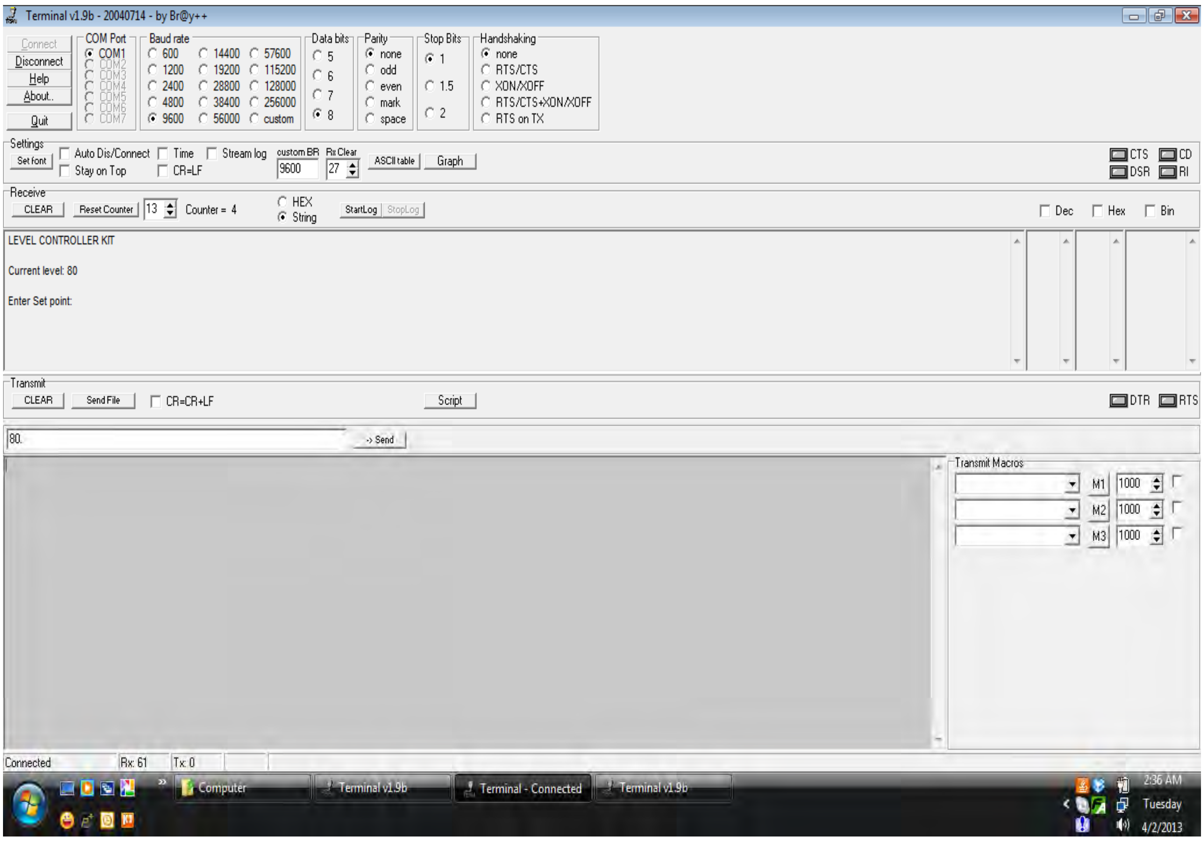

Fig.10.1 Screenshot 1 of the user interface

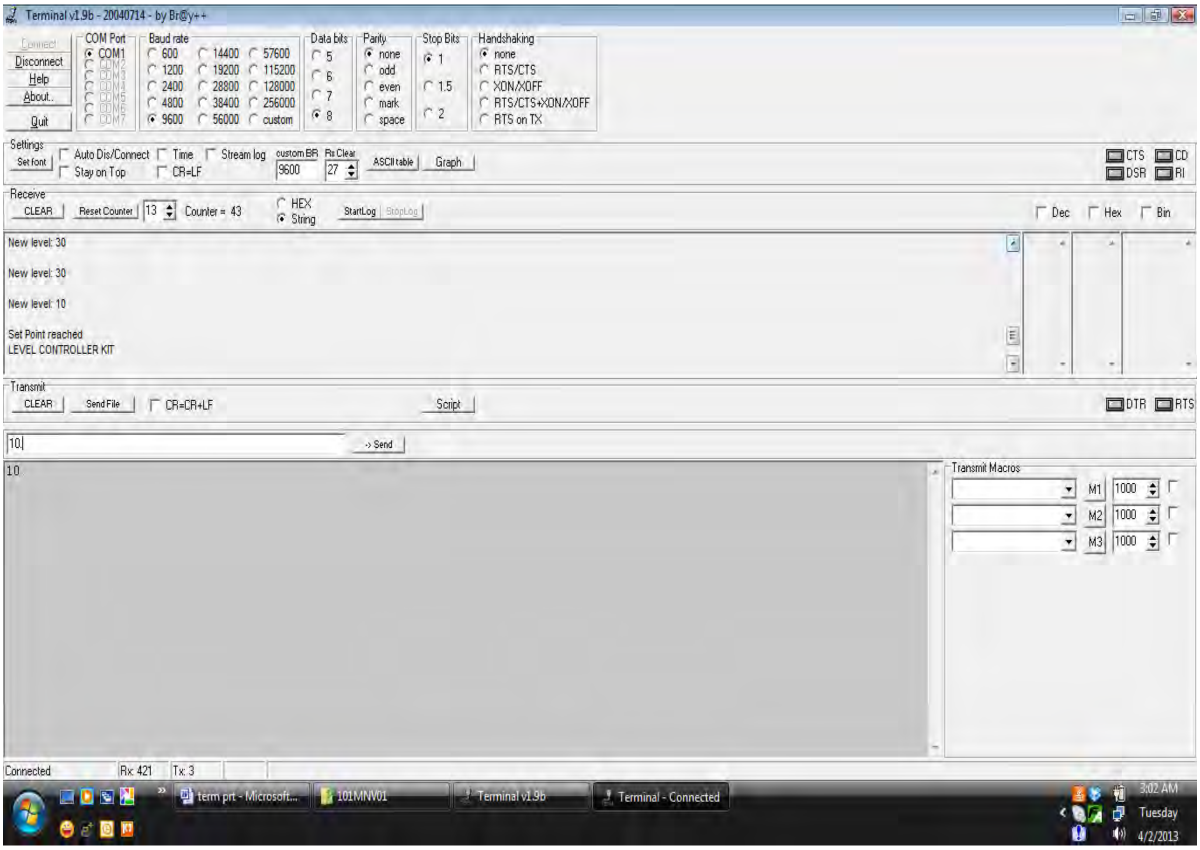

Fig 10.2 Screenshot 2 of the user interface
Fig.10. User Interface

TABLE V
Calculation of the efficiencies

Sl No.	Set point Entered (inch/10)	Level in the tank (manually checked) (inch/10)	Error (inch/10)	Percentage Efficiency (%)
1.	10	11	1	90
2.	20	21	1	95
3.	30	31	1	96.67
4.	40	42	2	95
5.	50	51.5	1.5	97
6.	60	62.5	2.5	95.83
7.	70	72	2	97.14
8.	80	81.5	1.5	98.13

V. CONCLUSIONS

In this paper, the fuzzy control of the water level has been implemented. This approach was chosen mainly because fuzzy logic is more accurate and stable for a wide range of set points. The water levels were reached accurately and the time taken to reach the set point depends proportionately upon the value of the error. The levels chosen in this paper was eight in order to maintain simplicity. However, further research can be done by increasing the number of water levels as per the wish of the researcher. The fuzzy membership functions can also be selected differently and the work can be further improved by selecting better membership functions. The same work can also be extended by designing a PID controlled water level system in a similar manner and by comparing their efficiencies.

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