A Simplified Fuzzy Logic Liquid Level Control System

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ABSTRACT: *This paper describes the design of a simple fuzzy logic liquid level controller. The proposed controller takes the liquid quantity as its input and generates appropriate flow rate on the output. The controller is tested on a cylindrical shaped tank with inlet and outlet valves. The liquid in the tank is sensed with the help of an ultrasonic sensor mounted above the tank. On entering the required liquid quantity with the help of keypad, fuzzy logic controller adjusts the valve opening and closing in order to supply the desired liquid amount. The performance of the controller is also compared with the proportional control and it is found that fuzzy logic controller is better choice owing to its smoothness and accuracy. The experimental setup can be used to teach various fuzzy inference systems in real time.*

Key words: Liquid level, Fuzzy logic controller, Ultrasonic sensors, 89C51 Microcontroller

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1. Introduction

Conventional and modern control theories are being used to control various industrial processes in real time [1,2]. However, these techniques require the mathematical model of the complete process to become effective which in most cases is difficult to build due to the nonlinearities present in the system such as dead zones, saturation, delays, unmeasured and frequent disturbances etc [3,4]. The solution lies in the selection of intelligent controllers which can cope up with these nonlinearities of the processes and produce a smooth desired response. The evolvement of soft computing paradigms has provided a powerful tool to design controllers for non-linear processes. Amongst various techniques in this domain, fuzzy logic presents a promising solution.

Fuzzy Logic was introduced in 1965 by Lofti Zadeh [5,6] and since then it has been widely used in a variety of applications ranging from consumer products to complex industrial plants in operation [4]. An excellent review of applications of fuzzy logic control is reported by Lee et. al. [7]. Fuzzy logic controller (FLC) based on fuzzy set theory is a heuristic control law that uses human experience in the form of rule base to generate desired error free response. This ability of human like reasoning has resulted in application of fuzzy logic controller in existing traditional control systems to make them more intelligent and efficient [8-10].

This paper applies fuzzy logic single input single output (SISO) controller to control the liquid level in a tank. The liquid quantity to be drawn from the tank acts as input to the fuzzy logic controller and its output controls the valve to transfer the desired amount of liquid. The controller is designed using fuzzy logic toolbox of MATLAB® and is implemented in real time using AT89C51 microcontroller. Experimental results have proved the effectiveness of the proposed controller for liquid level control system.

2. Brief Overview of The Method

In industrial processes, it is often desirable to have a system act like a human being. Traditional logic is based on two values, one (true) and zero (false). This is inadequate for approximating the human decision making process. Fuzzy logic uses the entire interval between zero and one and can therefore be used to closely mimic human reasoning [8,9]. The design process of a fuzzy logic system can be divided into three stages:

- Fuzzification,
- Fuzzy Inference Engine, and
- Defuzzification

In fuzzification stage, a quantified numerical control variable is converted into a qualitative value like *small*, *medium* or *large* known as linguistic variables. These linguistic variables are described by a membership function which has a value between zero and one. The computationally less intensive membership functions are triangular and trapezoidal. Once the inputs are fuzzified, they are fed to fuzzy inference engine. This engine consists of two sub-blocks namely fuzzy rule base and fuzzy implication. The fuzzy rule base is a set of *if-then* statements known as linguistic rules which describes the behavior of the robot for a particular set of inputs. Fuzzy implication evaluates the set of rules to compute a qualitative output result for the controller. The commonly used implication method is Mamdani implication. This stage plays a key role on the fuzzy controller operation as its rules model the whole behavior of the robot. Finally, the qualitative value is converted into numerical value in defuzzification stage. There are many defuzzification methods available. Among them, Center of Area (COA) method is easy to implement and has a fast execution time.

3. Fuzzy Controller Design

A single input, single output fuzzy logic controller is designed for liquid level control system. The input to the fuzzy controller is described by:

$$LQ = US - (I.V - R.V) \quad (1)$$

where,
L Q = Liquid Quantity
U.S = Ultrasonic Sensor Value
I.V = Initial Value (amount) of liquid in tank
R.V. = Required Value to be entered from keypad

The output from the fuzzy logic controller is the PWM signal to control the position of the valve to control the flow rate. MATLAB® Fuzzy Logic Toolbox is used to aid in FLC design. The toolbox contains functions, graphical user interfaces and data structures that allow the user to quickly design, test, simulate and modify a fuzzy inference system [11]. The block diagram of system is shown in Fig. 1. The steps involved in fuzzy controller design are described in this section.

3.1 Fuzzification

The input to FLC i.e., the liquid quantity (LQ) given by (1), is described by two fuzzy sets: SMALL and LARGE, the universe of discourse being from 0 to 1000 (The number 1000 corresponds to maximum capacity of the liquid tank i.e., 10 liters). The description of these fuzzy sets is shown in Table 1.

Fuzzy Set	Description
SMALL	The desired liquid level in tank is about to reach (Error between set point and current level is small)
LARGE	The desired liquid level in tank is far to reach (Error between set point and current level is large)

Table 1. Fuzzy Sets Defined For Input

The membership functions for LQ, as shown in Fig. 2, are described by the expressions:

$$\mu_{LQ,\,SMALL} = \begin{cases} -1_q + 100, & 0 \le 1_q \le 100 \\ 0, & 1_q > 100 \end{cases} \tag{2}$$

$$\mu_{LQ,\,LARGE} = \begin{cases} 0, & 1_q \le 20 \\ 1_q - 20 & 20 \le 1_q \le 120 \\ 100, & 1_q \le 120 \end{cases} \tag{3}$$

In these expressions, degree of belongingness of linguistic variable is scaled in range [0, 100] to prevent floating point storage and calculations. Also, triangular membership function (MF) is used for all fuzzy sets because of limited computational resources of microcontroller.

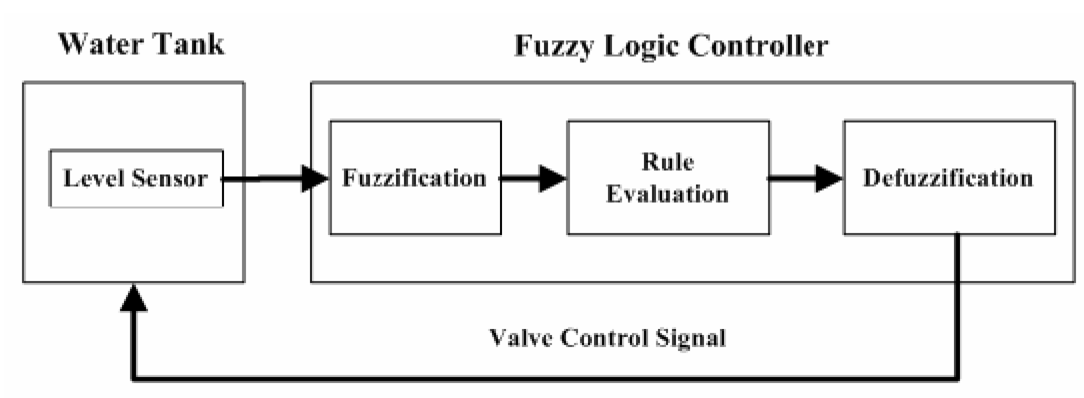


Figure 1. Fuzzy Controller Block Diagram

Fuzzy Set	Description
SLOW	The flow rate of liquid out of tank is slow (Duty cycle of PWM signal is small)
FAST	The flow rate of liquid out of tank is fast (Duty cycle of PWM signal is large)

Table 2. Fuzzy Sets Defined For Output

The outputs of FLC i.e., liquid flow (LF) is described by two fuzzy sets: Slow and Fast; the universe of discourse being from zero (minimum) to hundred (maximum) which describes the duty cycle of PWM signal to control the valve. The description of these sets is shown in Table 2.

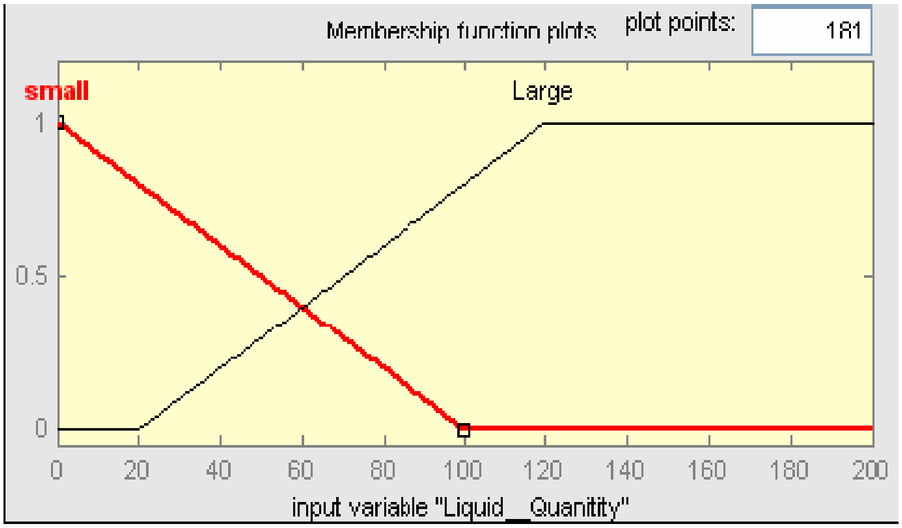


Figure 2. Input Membership Function

The membership functions for LF, as shown in Fig. 3, are described by the expressions:

$$\mu_{LF, SLOW} = -1_f + 100, \qquad 0 \le 1_f \le 100 \qquad (4)$$

$$\mu_{LF, FAST} = 1_{f,} \qquad 0 \le 1_f \le 100 \qquad (5)$$

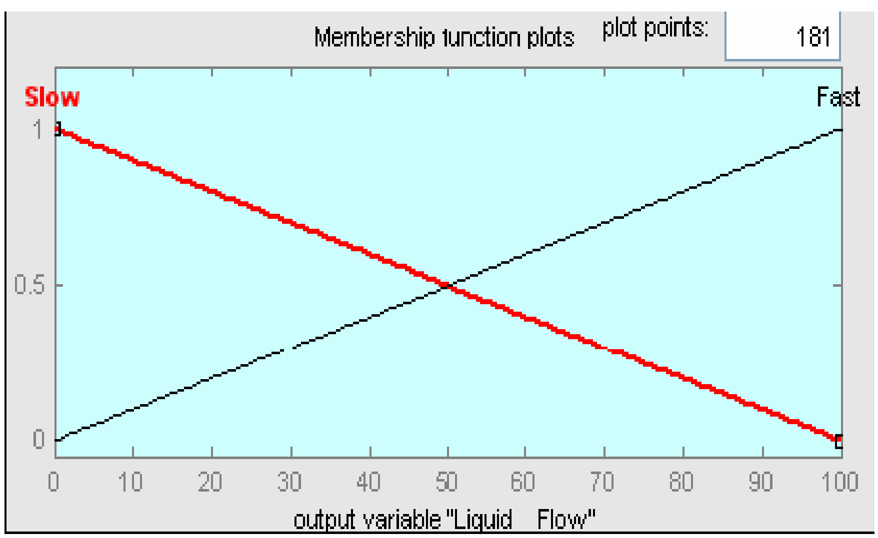


Figure 3. Output Membership Function

3.2 Fuzzy Rule Base

Two rules are designed to control the liquid flow rate given the liquid quantity. These rules establish the relation between liquid quantity and flow rate in terms of linguistic values. A control curve is then plotted to visualize the variation in flow rate given the liquid quantity. The rule base is shown in Table 3 while control curve for flow rate is shown in Fig. 4.

Rule No.	Rule Description
I	IF LQ is SMALL THEN LF is SMALL
II	IF LQ is LARGE THEN LF is FAST

Table 3. Fuzzy Rule Base For Liquid Level Control

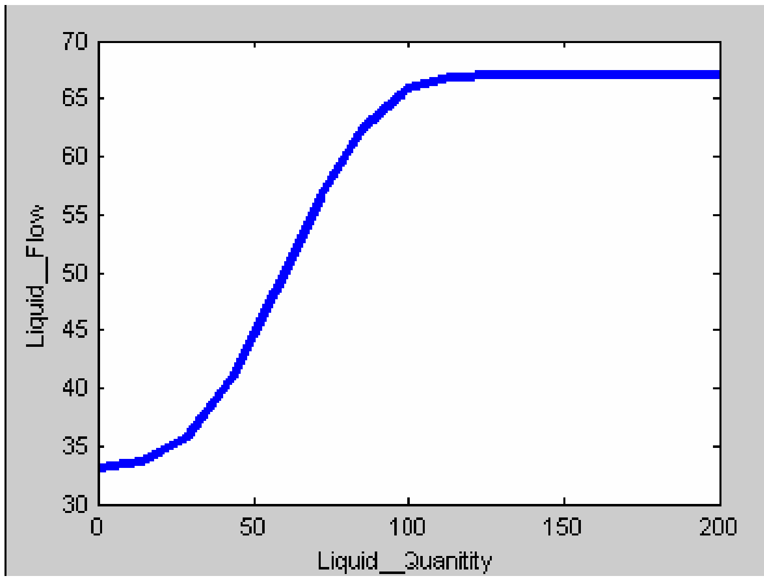


Figure 4. Control Curve for Liquid Flow Rate (LFR)

Rule-I constitutes the sensitive region of fuzzy logic controller. When the liquid level reaches within one liter of final set point, the liquid flow rate starts to decrease, as is visible in control curve, to ensure the smooth and accurate control near the final value. Rule-II describes the situation when the difference in the desired level and current level is large resulting in high flow rate of liquid out of the tank.

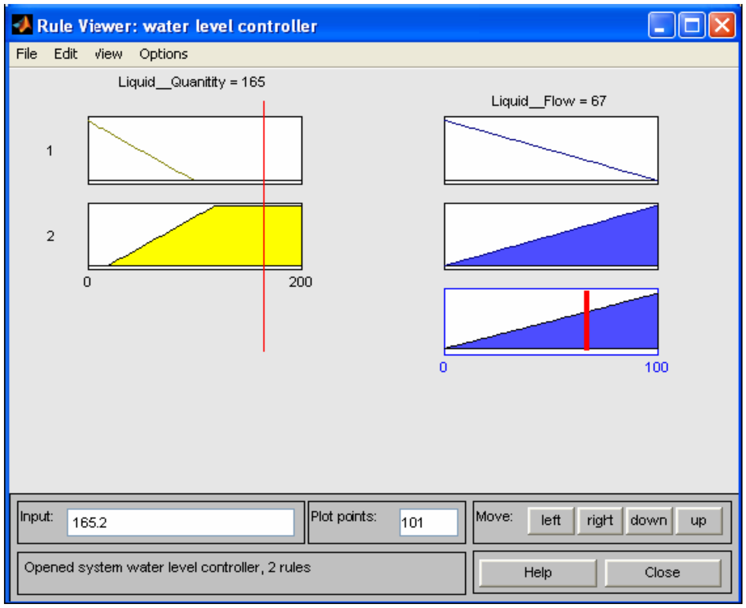
3.3 Fuzzy Implication

Fuzzy implication helps to evaluate the consequent part of each rule. Among the various implication methods available in literature, Mamdani implication method is selected. After the inputs have been fuzzified and FLC know the degree to which each part of the antecedent of a rule has been satisfied, degree of fulfillment of (DOF) of each rule is calculated using AND operator. The output membership function is then truncated at DOF level. All the rules are evaluated in this manner and final output membership functions are aggregated in a cumulative manner using OR operator to yield the final fuzzy output. An example of the implication process is shown in Fig. 5. Figure 5(a) describes the situation when the difference between desired liquid level and current liquid level is large. In this case, only rule-II is fired resulting in a maximum flow rate. However, when the difference enters in the small region, both the rules are fired, as shown in Fig. 5(b), resulting in lesser flow rate and it will continue to decrease until final level is achieved.

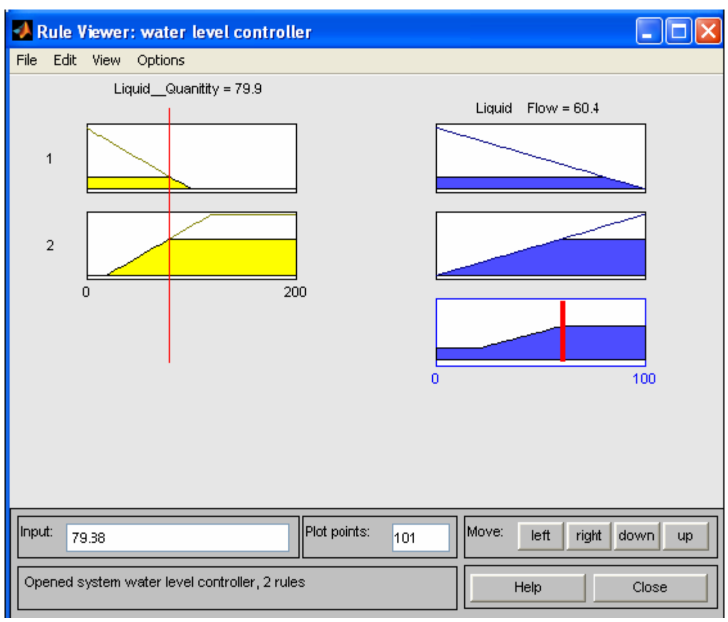
3.4 Defuzzification

The result of the implication and aggregation step is the fuzzy output, which is the union of all the individual rules that are validated or fired. Conversion of this fuzzy output to crisp output is defined as defuzzification. Commonly used defuzzification

$$Z_{\circ} = \frac{\sum_{i=1}^{n} Z_i \mu_{out}(Z_i)}{\sum_{i=1}^{n} \mu_{out}(Z_i)} \qquad (6)$$



(a)



(b)

Figure 5. Fuzzy Implication and Defuzzification Process (a) Δ Level is Large (b) Δ Level is Small

methods are maximum defuzzification and centroid defuzzification. COA method has been used for this purpose and is described as:

where $\mu_{out}(Z_i)$ are the i=1,2,…,n sampled values of the aggregated output membership function and $o\ Z$ is the crisp value which describes the duty cycle of PWM signal for controlling the valve position.

4. System Architecture

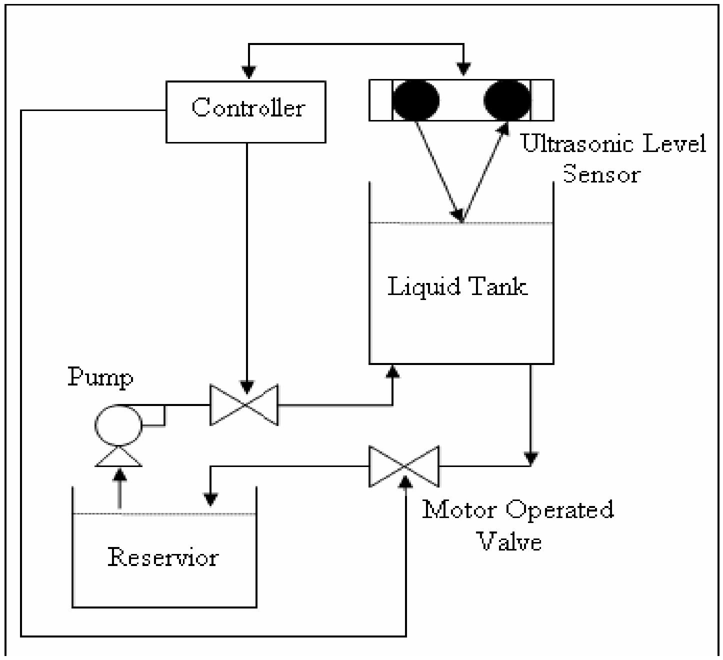


Figure 6. Schematic Diagram of Liquid Level Control System

The schematic diagram of liquid level control system is shown in Fig. 6. The system consists of two cylindrical shaped tanks each having a liquid capacity of ten liters. The liquid level in the tank is sensed with the help of an ultrasonic sensor mounted above the tank while the inward and outward flow rate of liquid in the tank is controlled by using motor operated valve. The controller takes input from level sensor, runs fuzzy algorithm and generates valve control signal to achieve the set point in a smooth fashion. The section provides a brief description of system components.

4.1 Level Sensor

SRF05 ultrasonic sensor has been used for sensing the liquid level in the tank. A short 10uS pulse is applied to the trigger input to start the ranging from controller. The SRF05 sends out an 8 cycle burst of ultrasound at 40 kHz and raise its echo line high (or trigger line). It then listens for an echo, and as soon as it detects one it lowers the echo line again [12]. The echo line is therefore a pulse whose width is proportional to the distance from the liquid surface. As the liquid level in the tank decreases, width of the echo pulse increases.

4.2 Analog Valve

To vary the inward and outward flow rate of liquid in a continuous manner, an analog valve is designed using off-the-shelf components. The valve consists of a dc motor, set of gears to reduce motor speed, a simple water tap and a potentiometer. These components are combined to form a position control system. The flow rate is thus proportional to the valve position. To open the valve to a large extent from its current position, the duty cycle of PWM signal is increased which increases the speed of the dc motor. At the same time, position of water tap is sensed with the help of a potentiometer mounted on it (the potentiometer is used to convert position signal to an analog voltage signal which is then converted to digital form with the help of an ADC0804 analog to digital converter). The error signal between the desired position and current valve position is minimized by further increasing the duty cycle of the PWM signal until error is reduced to zero. In this way, any desired position of the valve can be obtained.

4.3 Data Entering Module

The desired liquid quantity to be transferred from the tank can be entered either through keypad along with LCD, both interfaced to the microcontroller or with the help of mouse from a LabView application running inside the PC. The data from the PC is transferred to the microcontroller through serial port which controls the entire liquid level process by running the fuzzy algorithm. The LabView application is developed to graphically analyze the changing liquid level in the tank. A screen shot of developed program is shown in Fig. 7.

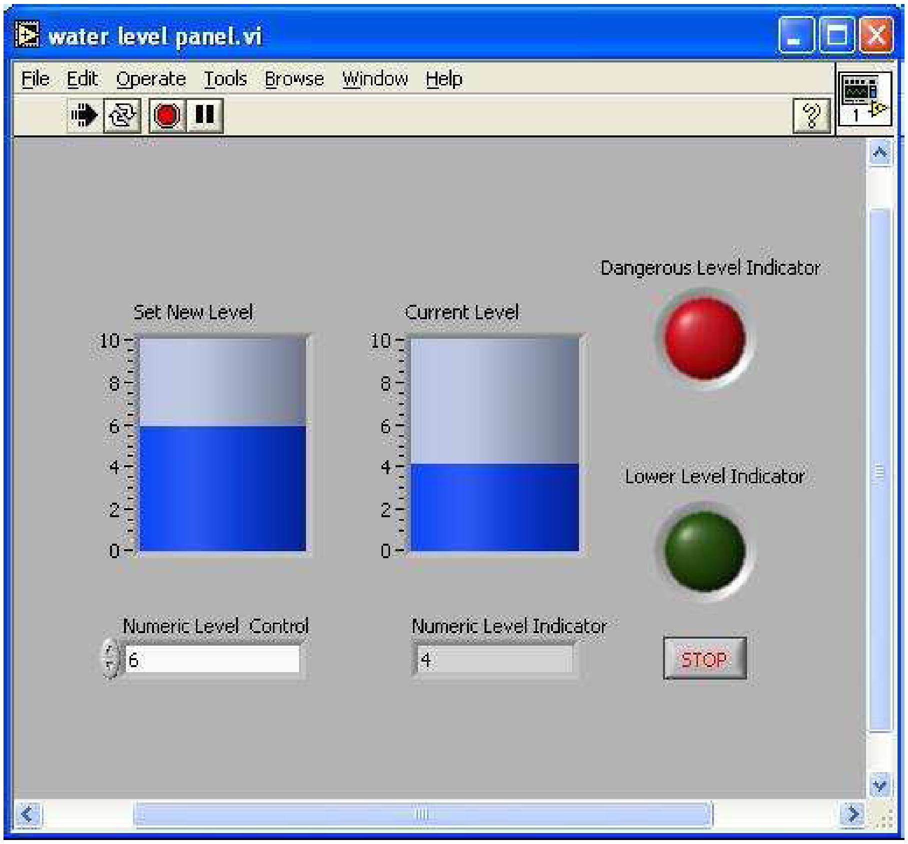


Figure 7. LabView Interface for Visualizing Liquid Level

4.4 Microcontroller

AT89C51 microcontroller is selected because it is a powerful microcomputer which has low power consumption and provides a highly flexible and cost-effective solution to many embedded control applications. It has 4K bytes of in system reprogrammable flash memory, 128 bytes of internal RAM, 32 programmable I/O lines, two 16 bit timers/counters, seven interrupt sources and a programmable serial channel [13]. Microcontroller is responsible for performing various tasks which includes reading data through kepad/computer, measuring liquid level in the tank with the help of ultrasonic sensor, running fuzzy algorithm and generating control signal for valve to transfer the desired amount of liquid. The microcontroller is programmed in C using Keil development platform [14].

5. Controller Implementataion And Results

The fuzzy logic controller for liquid level control system is implemented in real time with AT89C51 microcontroller. The flow chart of program execution is shown in Fig. 8. The proposed scheme with fuzzy logic to transfer a desired amount of liquid is compared to the proportional integral (PI) control. The conventional PI control is prone to errors especially when the liquid level in the tank is low, which actually corresponds to a dead zone nonlinearity. On contrary, fuzzy logic controller has been found to handle these nonlinearities and other sensor noises successfully which proves its validity for liquid level control systems.

6. Conclusion

This paper proposes and implements a simple fuzzy logic controller for liquid level control system. The SISO fuzzy controller takes the desired liquid quantity to be transferred as its input and controls the motor operated valve in proportion to the liquid flow rate calculated after defuzzification. The controller is designed in MATLAB® and is realized in real time using AT89C51 microcontroller. Due to its simplicity, the system can be used in laboratory to demonstrate the difference between conventional and fuzzy logic controllers.

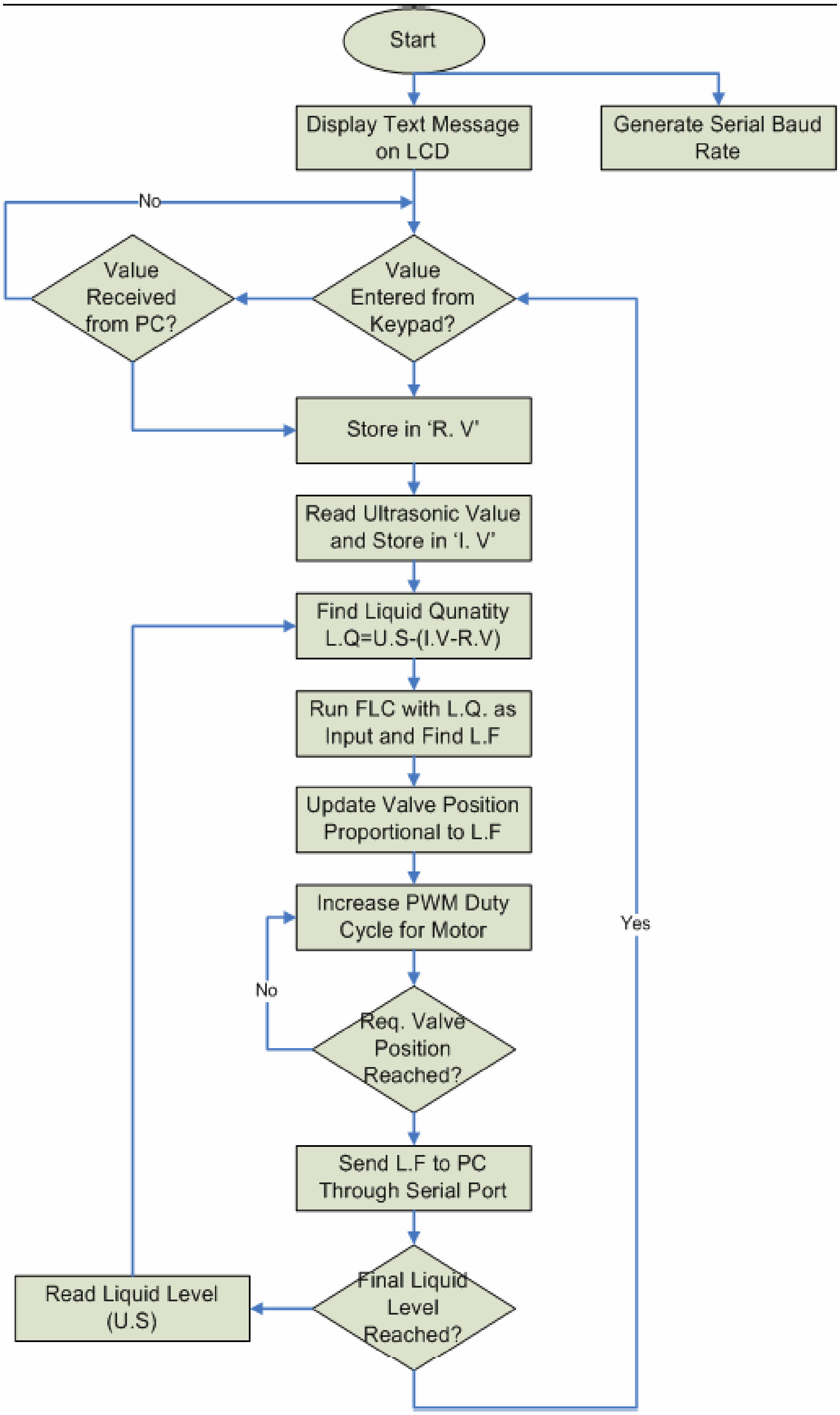


Figure 8. Flow Chart for Microcontroller Program

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