Advances in Engineering Research, volume 198
International Seminar of Science and Applied Technology (ISSAT 2020)

The Implementation of Embedded Fuzzy Logic Controller on Liquid Level Control System

Adnan Rafi Al Tahtawi[1,*] Sofian Yahya[1] Budi Setiadi[1] Chairina Marsya[1]

[1]*Department of Electrical Engineering, Politeknik Negeri Bandung, Bandung 40012, Indonesia*
[*]*Corresponding author. Email: adnan.raf@polban.ac.id*

ABSTRACT
Liquid level control is a system that is often found in the process industry, such as the chemical and petroleum industries. The control method that is usually used to control liquid level is conventional control such as Proportional Integral Derivative (PID) controller. However, conventional control systems are considered more difficult to design because they require a mathematical model of the plant to be controlled. This study aims to design a liquid level control system in a process control module using the Fuzzy Logic Controller (FLC). The liquid level in a process control module will be controlled based on the input variable error value and error change in the form of triangular membership functions. The output value to be achieved is the control signal in the form of pump speed and valve opening. FLC is implemented on a microcontroller with Sugeno type inference. The results showed that the liquid level can reach the setpoint about 25 s without disturbance condition. The liquid level can reach the setpoint about 60 s when the disturbance is activated.

Keywords: *Process control, liquid level, Fuzzy Logic Control, Sugeno*

1. INTRODUCTION

Liquid level control in a tank is often found in several industrial processes such as heating systems, mixing processes, and cooling systems. The liquid level in the tank must be maintained and be at a certain set point to produce good quality products. Several control methods can be used ranging from simple ones such as ON/OFF to those that have high computing. The selection of this method must be adjusted to the needs of the plant itself so that the control process can work effectively. In the process industry itself, usually, the control methods used are conventional controls such as Proportional Integral Derivative (PID). This method is widely used because it has simplicity in terms of design and implementation. However, PID control requires a mathematical model of the plant to be controlled. This has become one of the problems that arise considering that plants in the process industry sometimes have quite high complexity. Therefore, the method of control with an intelligent system approach can be one solution to overcome these problems.

Several previous studies related to liquid level control methods in industrial processes have been conducted either by simulation or hardware experimental. The fuzzy-PID controller was used to control liquid levels using LabView simulations by comparing PID, Fuzzy, and Fuzzy-PID controllers in maintaining liquid levels in a tank [1]. The simulation-based on MATLAB/Simulink has also been studied to maintain liquid level using FLC and PID method [2], [3]. Similar research was also carried out by integrating MATLAB simulation and a hardware microcontroller as the data processor [4], [5].

In the hardware experimental side, the FLC controller was implemented using an Arduino microcontroller to control the liquid level in the tank [6]. The performance comparison of ON/OFF, P, PI, PID, and FLC controllers in the process of controlling liquid level has also been conducted with the result FLC controller has the best control response [7], [8]. The tank system in prototype form has developed by [9], [10] to implement the FLC controller to control liquid levels.

Based on several studies above, it can be concluded that the FLC controller can produce better control performance when compared with other conventional control methods such as PID [1]-[7] and ON/OFF [8]. Thus, in this study, the FLC controller will be designed and implemented to control the liquid level in a tank in a form of a hardware prototype module. As in [9]-[10], this research is focused on designing the system in the form of hardware where the FLC controller will be implemented in a liquid level process control module and unlike [1]-[3], [7] which is focused on simulation

MATLAB. The difference lies in the method of testing the system wherein this study will be tested with disturbance to see the robustness of the FLC controller. This research is a continuation [11] where a liquid level control system has been designed in the process control module with a PID controller using Programmable Logic Control (PLC). The development carried out in this study lies in the control method that uses the FLC intelligent control system.

2. RESEARCH METHOD

2.1. Liquid Level Module Plant

Figure 1 shows a process control module that will be used as a plant for controlling liquid level.

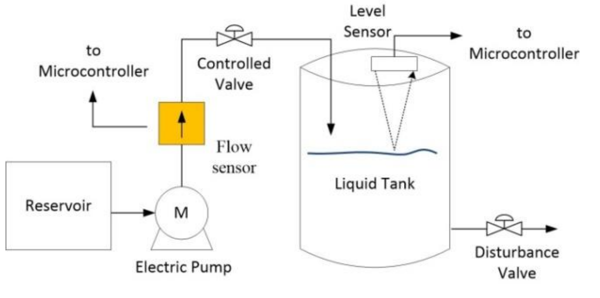

Figure 1 Design of liquid level module

This module consists of two tanks, namely a source tank (reservoir) and a controlled tank. In the module, there is also an electric pump that functions as an actuator for liquid filling, two motorized valves that function as actuators for the regulation of discharge and openings for disturbances, and an ultrasonic sensor for detecting liquid level.

The realization of the process control module can be seen in Figure 2. The module is built on a laboratory scale for research needs with a length of 80 cm and a height of 60 cm. The reservoir capacity used is 12 liters, while the tank capacity is 10 liters.

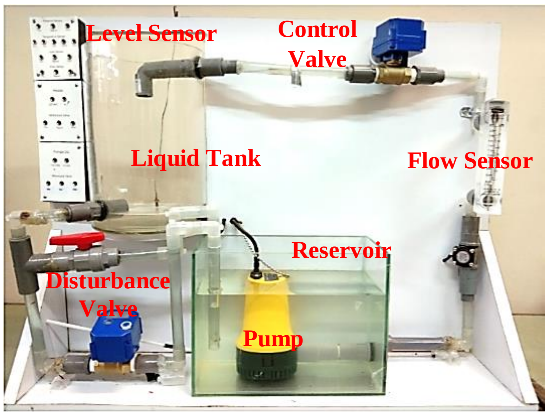

Figure 2 Realization of liquid level module

2.2. Electrical Hardware Design

Figure 3 is an electrical hardware system design for liquid level control. The system consists of a liquid level sensor, a potentiometer for setting the setpoint, a microcontroller used to embed the FLC program, an actuator equipped with a driver, and a power supply.

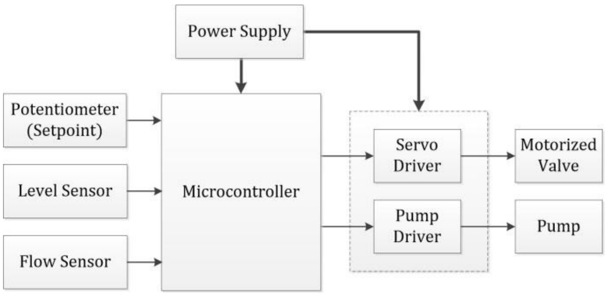

Figure 3 Design of system hardware

Complete specifications of the designed electrical system are shown in Table 1. The components used are selected taking into account the cost and specifications of the module made in the form of a prototype. The components used may differ from those used in the actual process industry.

Table 1. Electrical hardware specification

Specification	Value
Level sensor	
Type	Ultrasonic HC-SR04
Range	2 cm - 400 cm
Switching time	10 us
Working current	15 mA
Resolution	0,3 cm
Flow sensor	
Type	YF-S201
Working voltage	5-18 VDC
Working current	15 mA
Debit	1-30 L/Min
Accuration	± 10%
DC Pump	
Type	YRK-BLK2512
Working voltage	12 VDC
Working current	5,4 A
Maximum debit	70 L/Min
Motorized Valve	
Type	CWX-25S
Working voltage	12 VDC
Working current	60-80 mA
Microcontroller	
Type	Arduino ATMega2560
Clock speed	16 MHz
I/O pin	Digital I/0 54, Analog Input 16
Working voltage	5 VDC

2.3. Software Design

The process control module is designed to be equipped with a microcontroller as a controlling device. The microcontroller used is the ATMega 2560 which has been integrated into the Arduino Mega 2560 module with specifications as shown in Table 1. On the microcontroller, the FLC program is embedded in the C language through the Arduino IDE compiler. The program flowchart designed is shown in Figure 4.

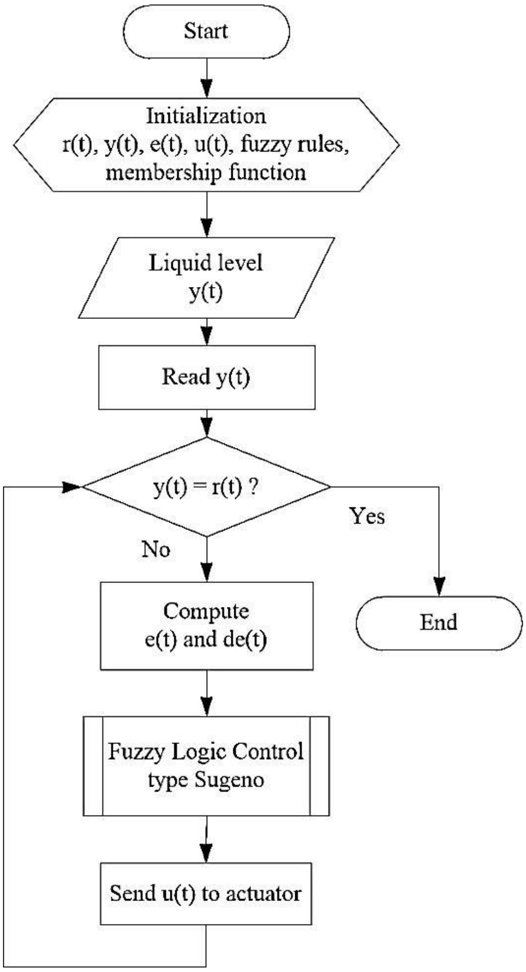

Figure 4 Programming algorithm

The controller will be active if there is an error value. If there is no error value, it means that the liquid level has reached the desired reference value and the controller will not activate.

2.4. Fuzzy Logic Control Design

Figure 5 shows a liquid level control system design with FLC as the controller. The block diagram that is designed consists of a controller, actuator, plant, and sensor.

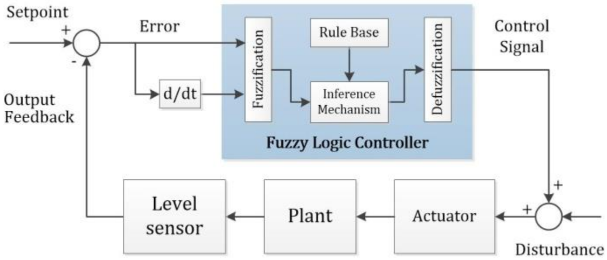

Figure 5 Controller design

The controller block functions to control the liquid level based on errors and changes using FLC. The actuator block consists of two parts, namely the pump and the valve opening. Each actuator is arranged in an FLC mechanism. The plant is designed in the form of a simple module as previously discussed. The sensor used is a height sensor which functions as feedback for controlling the liquid level. In the block diagram, there is also a reference signal as a control set point, an error signal and its changes as input, a control signal that functions to move the pump and valve opening, a fault signal in the form of the degree of leakage valve opening, and a feedback signal from the sensor.

The input data used are the error value (e) and the change (de) obtained from the equation in the following time function.

$$e(t) = r(t) - y(t) \tag{1}$$

$$de(t) = e(t) - e(t-1) \tag{2}$$

where $e(t)$ and $de(t)$ are the error values and its change, $r(t)$ is the reference value, $y(t)$ is the output value, and $e(t-1)$ is the previous error value. The two input values then go through the fuzzification, inference mechanism, and defuzzification stages.

Fuzzification is a stage that functions to change crisp values into fuzzy values through a set of membership functions. Then the resulting fuzzy value enters the inference mechanism stage with the Minimum-Maximum rule using the Sugeno method. After that, the results of the inference mechanism in the form of fuzzy values are converted back into crisp values at the defuzzification stage. The output of the FLC is a control signal that will regulate the pump speed and valve opening for liquid filling in the tank. In the block diagram, there is also a disturbance signal which functions to test the robustness of the FLC system being used. The form of disturbance given is the degree of valve opening which causes liquid leakage in the tank. Grading to allow leakage to the tank is done manually via the disturbance valve provided at the bottom of the tank. When a problem occurs in the form of a leak, the designed controller must be able to maintain the level by returning to fill automatically according to the designed FLC process.

The membership function for error input and its changes can be seen in Figure 6 and Figure 7. Each input has four triangle functions with a value range of 0-

25 for error values and 0-8 for error changes. All inputs are positive which represents an error when the measured level is less than the setpoint. Negative input errors are not considered in this FLC system for simplicity. If a negative input error occurs, then the FLC output does not take any action or has a value of 0.

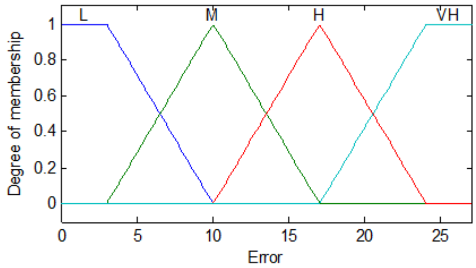

Figure 6 Membership function of input error

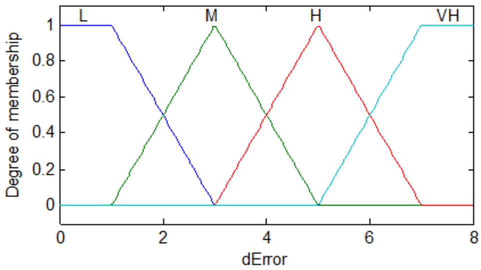

Figure 7 Membership function of input error change

The output membership function is designed to consist of two variables that have crisp values, namely, pump speed (duty cycle) and valve opening (degrees). Pump speed is classified into four crisp functions, namely Very Slow (40%), Slow (50%), Fast (60%), and Very Fast (80%). The valve opening is also classified into four crisp functions, namely Very Small (25°), Small (50°), Large (75°), and Very Large (100°).

Level control based on error and its change using FLC is carried out based on the rules as described in Table 2.

Table 2 Fuzzy rule base for pump output

Pump Valve		dError L	dError M	dError H	dError VH
Error	L	VS VS	VS S	VS L	VS VL
Error	M	S VS	S S	S L	S VL
Error	H	F VS	F S	F L	F VL
Error	VH	VF VS	VF S	VF L	VF VL

The rule base is then used to determine the pump duty cycle and the degree of valve opening by the error data conditions and the measured error changes. The determination of the degree of output membership is based on the Minimum-Maximum function. Furthermore, after obtaining the output data that already has a membership degree, the next step is the defuzzification process. This process aims to convert fuzzy values into crisp values. This study uses the centroid of area method to determine crisp values with the following equation.

$$z = \frac{\sum x_i . \mu(x_i)}{\sum \mu(x_i)} \quad (3)$$

where z is the crisp output, x_i is the crisp value for input to i, and $\mu(x_i)$ is the degree of membership for each x_i.

3. RESULT

At this stage, the designed FLC will be tested. The test aims to determine the dynamic response at the level of liquid in the tank. Testing is carried out using two scenarios, namely testing without disturbance and testing with disturbance.

3.1. System Testing Without Disturbance

The test without disturbance is performed to determine the response to the liquid level in reaching the specified set point. The test was carried out by giving a set point with a level of 11 cm and the initial conditions for a height of 3.3 cm. Then the system is activated and the level response is observed using an ultrasonic sensor. The data is then sent via serial communication to a computer device. The test results without disturbance can be seen in Figure 8.

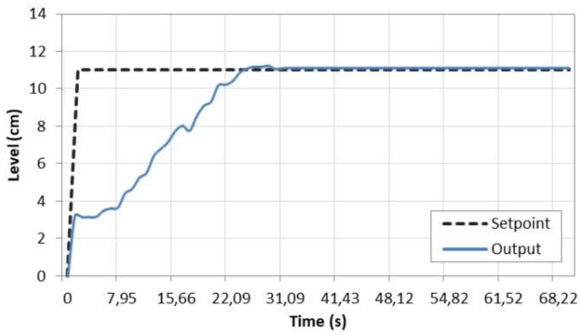

Figure 8 Level responses without disturbance

From the system testing result, it can be seen that the liquid level response has a settling time of 25.95 seconds at a setpoint of 11 cm from the initial level of 3.3 cm.

3.2. System Testing With Disturbance

Testing with disturbance is carried out to determine the response to the liquid level in reaching the desired set point when given the disturbance. As with the without disturbance test, the test is carried out by giving a set point with a liquid level of 11 cm with an initial condition of a level of 3.3 cm. The difference is that the system is disturbed by opening the disturbance valve by

100% so that the liquid leaks in the tank. A 100% valve opening is considered to be a maximum leakage fault to determine the control response when the worst disturbance conditions occur. The test results with interference can be seen in Figure 9.

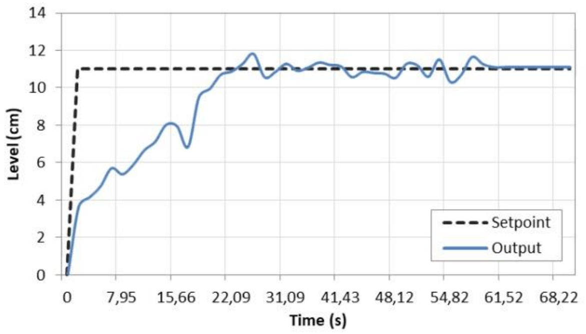

Figure 9 Level responses with disturbance

Based on the testing with disturbance, it can be seen that the system response has a settling time of 62 s. In the results of this test, liquid filling in the tank can be achieved stably although has oscillation previously. The liquid response is more difficult to reach a setpoint because of the amount of discharge that comes out due to disturbance conditions.

3.3. Error Performance Index Analysis

To determine the comparison of the responses without and with disturbance, an analysis of the resulting errors was carried out. The analysis was performed using an error performance index. The parameters used are Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE) which are calculated using the following equation.

$$IAE = \int_0^\infty |r(t) - y(t)|\, dt \tag{4}$$

$$ITAE = \int_0^\infty t\, |r(t) - y(t)|\, dt \tag{5}$$

The response error value is shown in Figure 10 to show the difference between the test without and with interruption. The results of IAE and ITAE calculations are shown in Table 2.

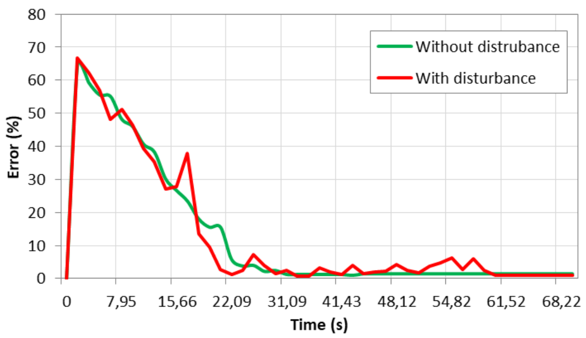

Figure 10 Comparison of error values

Table 2. Integral error-index performance

Scenarios	IAE	ITAE
Without disturbance	887,1	1,05 x 10^4
With disturbance	899,7	1,17 x 10^4

Based on the calculation results, it is found that the system response with disturbance has greater IAE and ITAE parameters when compared to the response of the system with disturbance. The resulting difference for the IAE criteria is 12.6 and the ITAE criteria is 1.2×10^3. Based on these results, it can be concluded that the designed FLC controller can maintain system response when a disturbance occurs even though there are additional errors in the IAE and ITAE criteria. However, these results need to be compared with other control methods such as PID to determine the robustness of the control system when facing disturbances.

4. CONCLUSION

Liquid level control in the process control module using Sugeno FLC has been successfully designed and implemented. The test results show that FLC can maintain the liquid level at the setpoint when given a disturbance in the form of a valve opening. The settling time that is generated in the presence of a disturbance is about 35 seconds longer when compared to the response without disturbance with a difference for the IAE criteria is 12.6 and the ITAE criteria is 1.2×10^3. Further research that can be done is to develop a more robust FLC method to reject disturbance.

ACKNOWLEDGMENT

The authors would like to thank P3M Politeknik Negeri Bandung for research funding through Penelitian Mandiri scheme with decree number B/249.109/PL1.R7/PG.00.03/2020.

REFERENCES

[1] S. B. Prusty, U. C. Pati, and K. Mahapatra, "Implementation of Fuzzy-PID Controller to Liquid Level System using LabVIEW," in Proc. Int. Conf. on Control, Instrumentation, Energy, and Communication (CIEC), 2014, pp. 36-40.

[2] A. S. Thakur, H. Singgih, and S. Wadhwani, "Designing of Fuzzy Logic Controller for Liquid Level Controlling," Int. Journ. of u- and e-Service, Science, and Technology, vol. 8, no. 6, pp. 267-276, 2015.

[3] S. Sindageri and S. V. Halse, "Simulink Model for Liquid Level Control Using Fuzzy Logic Controller, "Int. Journ. of Scientific Research Engineering and Technology (IJSRET), vol. 4, no. 2, pp. 77-81, 2015.

[4] B. Çelik, S. Birtane, E. Dikbıyık and H. Erdal, "Liquid level process control with fuzzy logic based embedded system," in Proc. International Conference on Electrical and Electronics Engineering (ELECO), Bursa, 2015, pp. 874-878.

[5] P. N. Lamkhade, B. J. Parvat, and C. B. Kadu, "Design and Implementation of Fuzzy Logic Controller for Level Control," in Proc. Int. Conf. on Energy System and Application (ICESA), Pune, 2015, pp. 475-479.

[6] F. Chabni, R. Taleb, A. Benbouali, and M. A. Bouthiba, "The Application of Fuzzy Control in Water Tank Level Using Arduino," Int. Journ. of Advance Computer Science and Application, vol. 7, no. 4, pp. 261-265, 2016.

[7] S. Kumar and P. Nagpal, "Comparative Analysis of P, PI, PID, and Fuzzy Logic Controller for Tank Water Level Control System," Int. Journ. of Engineering and Technology (IRJET), vol. 4, no. 4, pp. 1174-1177, 2017.

[8] N. M. N. Sobran, M. M. Salmi, M. B. Bahar, M. N. Othman, and S. H. Johari, "Fuzzy Takagi-Sugeno Method in Microcontroller based Water Tank System," Int. Journ. of Robotics and Automation (IJRA), vol. 7, no. 1, pp. 1-7, 2018.

[9] M. Alotaibi, M. Balabid, W. Albeladi, and F. Alharbi, "Implementation of Liquid Level Control System," in Proc. Int. Conf. on Automatic Control and Intelligent System (I2CACIS), Selangor, 2019, pp. 311-314.

[10] I. Bayram, Z. Zeybek, A. Altinten, and M. Alpbaz, "Application of Fuzzy Control in Wireless Liquid Level Simulator," Wireless Personal Communication, vol. 109, pp. 211-222, 2019.

[11] S. Yahya, S. W. Jadmiko, K. Wijayanto, and A. R Al Tahtawi, "Design and implementation training module for control liquid level on tank using PID method based PLC," in Proc. Int. Conf. on Innovation in Engineering and Vocational Education (ICIEVE), Bandung, 2019.