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Application of Fuzzy Control in a Wireless Liquid Level Simulator

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Abstract
Liquid level control has great proposition in terms of chemical processes. It is important to make the level measurement in the tanks filled with industrial liquids with accurate and reliable equipment and to keep the liquid level at a certain level. In the studies conducted, wireless liquid level control was performed in a process control simulator system. For all computation and data processing procedures, the MATLAB program is used on-line connected to the system where the liquid level system is located. Then, the behavior of the output variable is examined by giving various effects to the liquid level valve opening selected as the setting variable. Fuzzy control of the system was performed by using the most suitable model found in the operating conditions obtained in dynamic studies. Wireless on-line computer control systems are used for this. The best control efficiency was obtained when the values were 4 dm.

Keywords Wireless liquid level control · Fuzzy control · MATLAB/Simulink

1 Introduction

Wireless communication is the transfer of information between two or more points without any cables. In wireless communication, there is no cost such as cable line laying and maintenance repair compared to wired communication. The exchange of

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information takes place with electromagnetic cables radiating in the air. Since there is no cable connection, it can be moved easily, space and time constraints for the users are getting out of the way. The installation of wireless communication systems is faster and simpler. Communication with wireless networks is provided where wired systems cannot be installed and work is dangerous. Wireless communication with radio waves can easily be provided in natural areas such as mountains, hills, rivers, etc., where wired communication is difficult [1].

The fields of application of wireless communication technologies are very broad. Wireless communication is generally used in education, healthcare, transportation, commerce, security, and industry. Common examples; Radios, mobile phones, wireless landline phones, mobile computers, wireless networks and digital suites. With wireless communication, it is expected that most jobs will be carried out from the house in the near future, thus reducing traffic, population density and environmental pollution [2].

Wireless process control has been a popular topic recently in the field of industrial control. Compared to traditional wired process control systems, their wireless counterparts have the potential to save costs and make installation easier. Wireless technologies open up the potential for new automation applications. Wireless measurements include temperature, pressure, flow, pH, conductivity, gas detection, discrete, level, vibration, valve position etc. [3].

The increasing development of the industries comes along with a growing competitive environment, which implies the need of operating costs reduction and process performance improvement for large scale production, in batch or semi-batch for multiple plants. These features usually can be tackled with so-called Wireless Control Systems [4]. Congestion control and avoidance include measures taken for manipulating the traffic within the network in order to combat congestion and avoid congestion collapse. A congestion control model in underwater wireless sensor network with time delay is considered [5]. Wireless is a salient technique for information gathering with a wide range of applications including habitat monitoring, battlefield surveillance, intelligent building [6]. Wireless sensor design presents the architecture of wireless sensor node with the BL-film sensor. The architecture consists of four units: sensing, processing, wireless communication and power supply [7]. A contribution to integrate greenhouse inside climate key's parameters, leading to promote a comfortable micro-climate for the plants growth while saving energy and water resources. A smart fuzzy logic based control system was introduced and improved through specific measure to the temperature and humidity correlation [8]. Non-linear filter applied to the wireless transmitted signals control wind turbines [9]. Also a lab-scale wireless electrocoagulation system based on the concept of bipolar electrochemistry [10]. And a wireless chemical sensor based on a magnetically functionalized hydrogels [11].

In recent years, fuzzy control has successfully been used for controlling a number of physical systems. Fuzzy controllers model the human decision making process with a collection of rules. A fuzzy controller mainly depends on the selection of the membership function that produces maximum performance as a subjective decision. Many fuzzy modeling and control methods have been proposed in the literatüre [12–23].

In this paper, experimental studies in wireless process control simulator have been performed by entering the appropriate parameters in the fuzzy control algorithm according to the dynamic studies performed beforehand. It has been achieved for the first time in the literature that level control simulator using fuzzy algorithm with wireless technology [24].

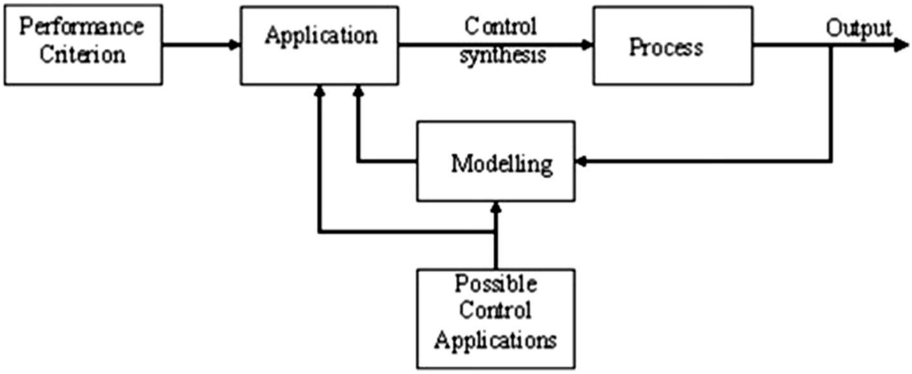

Fig. 1 Fuzzy model based controller

2 Fuzzy Control

Fuzzy control has a wide range of industrial applications. Control rules and membership functions on fuzzy control are generally determined by trial and error method. Contrary to classical controller, fuzzy controllers are more capable of adopting information gained through human experience and they are more significant and convenient in dealing with control problems whose mathematical modeling is really hard and operation is expensive. The difficulties in the application may arise from nonlinear characteristic of processes, time-varying nature of the process to be controlled, unpredicted environmental effects, poor sensitivity of sensors and from the difficulties in making reliable and correct measurements. Technical knowledge of the experienced operator may serve as an alternative to the process model in overcoming such difficulties [25].

2.1 Fuzzy Model Based Control

One of the fundamental problems faced in the design of fuzzy control systems is the determination of control rules and the establishment of relation matrix. In most cases an operator might not determine and practice suitable control rules. Then the fuzzy model based control is the most widely applied one. The most significant part in building a model based control is the establishment of a model. The simplest model, as we all know, is dependent on the experience of the operator [26].

The structure of the fuzzy model based controller is shown in Fig. 1.

2.2 Fuzzy Model Identification

The fuzzy model of a first order system is of the general form [27]:

$$Y_k = Y_{k-1} \circ U_{k-d} \circ R \tag{1}$$

where Y and U are possibility vectors for model output and input, respectively and R is the model relation matrix. In this study, Y_k and U_k were selected as liquid level set point and liquid level valve openness, respectively. Subscribed k represents current time, $k-1$ one sampling time in the past and $k-d$ the dead time of d sampling periods in the past.

Fig. 2 Process control simulator developed with wireless control purpose

Relation matrix could be written as follows,

$$R' = U_{k-d} \times Y_{k-1} \times Y_k \tag{2}$$

R is updated from R′ according to the relation below:

$$R(i^*, j^*, k) = aR'(i^*, j^*, k) + (1 - a)R(i^*, j^*, k) \quad k = 1,\ N \tag{3}$$

$$R(i^*, j^*, k) = \max\left(R'(i^*, j^*, k), R(i^*, j^*, k)\right) \quad \text{for all } i, j, k \text{ expect} \quad i = i^*,\ j = j^* \tag{4}$$

where i* and j* are the positions of the maximum membership values in the possibility vectors U_k and Y_{k-1}, respectively, a is a scalar constant between 0.5 and 1.0.

3 Materials and Methods

Experimental studies were carried out in the Cussons P3005 model Process Control Simulator and a wireless communication system was established to provide data transfer between the system and the computer. A number of modifications have been made to the process control simulator for wireless measurement and control. For this purpose, two antennas are installed to provide data transmission between the system and the inside in order to provide communication between the computer and the system. Also defined as the process variable variables; The liquid level control valve, the heater, the pressure control valve are calibrated and their outputs are connected to the modules. These modules contain the transmitted data between the two antennas. The other part of the process control simulator is the panel where the electronic circuits are located. This pan can control and measure temperature, liquid level control and flow rate. New equipment has been added for wireless control and measurement. Figure 2 shows a process control simulator developed for wireless control.

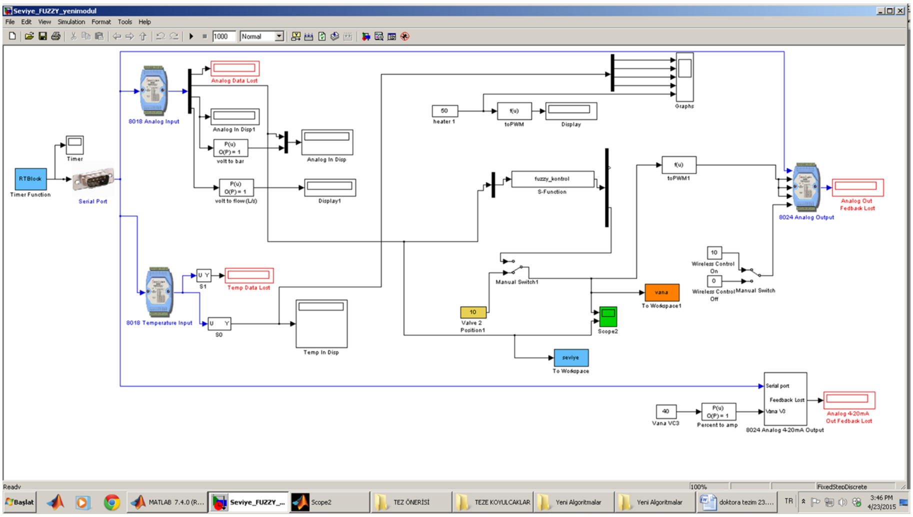

Fig. 3 MATLAB/Simulink block diagram of the fuzzy liquid level control experiment

There is one tank in which the water that is fed to the system is maintained, a pump which is powered by electricity which feeds the system liquid, a jacket cooler which is cooled by network water, two glass tanks which are kept water in the system, one orifice meter for measuring the flow velocity, one transmitter for converting the differential pressure to liquid level, a fuse that automatically closes the pump to prevent overflow of the liquid, pneumatic pressure controller indicator, pneumatic pressure transmitter, pneumatically operated pressure control valve, There are two regulators in the system that deliver air from the compressor to the air at the desired pressure. In addition, there are manually adjusted valves in the system to create four different test setups.

Control experiments were performed using Fuzzy control methods. Once the required parameter values are determined, liquid level control is provided through the algorithm used. In the wireless liquid level control experiments, the liquid level control valve was opened for 100 min at 10% value, and the system was observed.

4 Results

Experiments were performed for different values of parameters in the algorithm used in fuzzy control experiments. The effect of these parameters on the control has been tested for different set values. The MATLAB/Simulink block diagram used in wireless fluid level control experiments is shown in Fig. 3.

Approaches for fuzzy control experiments [25];

- The fuzzy control model has been accepted as the first order.
- Triangular type fuzzy membership functions are used.
- It is accepted that triangular type membership functions are symmetrical.
- The number of membership functions for an input and an output is selected as five.

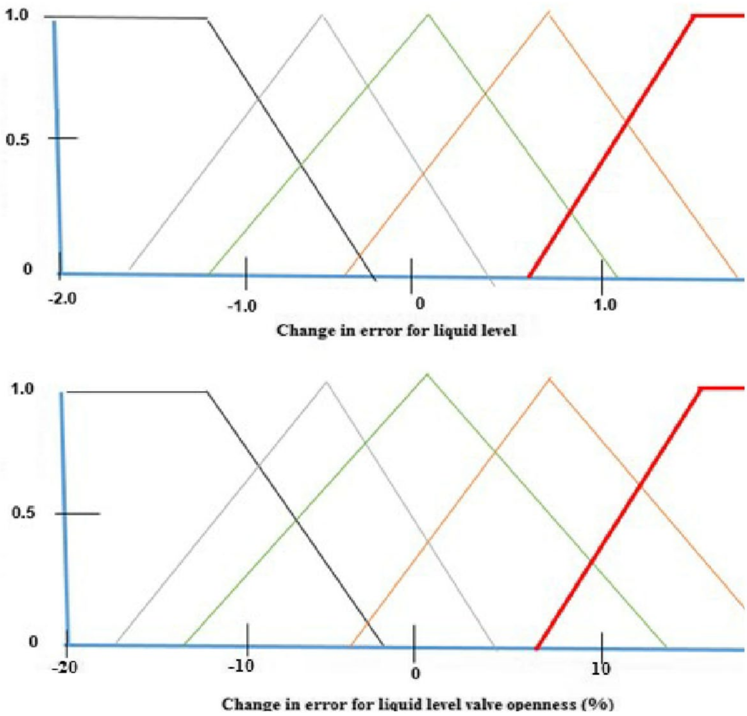

Fig. 4 The fuzzy membership functions for in error for liquid level and liquid level valve openness (%)

Fuzzy membership functions are usually determined by trial-and-error method. In the study, as seen in Fig. 4, the number of fuzzy membership function is determined as five for the input and output variables and the triangular type for the variables. For fuzzy control and level control experiments, the fuzzy membership function sets for the variable and the measured variable are determined and the relation matrix is determined accordingly. Experimental fuzzy control of the system was performed by using these parameters and relationship matrix. When the level profiles obtained at the end of the fuzzy control experiments for different set points were examined, it was observed that the liquid level quickly reached the desired set point. It has been determined that ISE and IAE values calculated according to fuzzy control test results. It has been understood that the results of the fuzzy control results obtained are more reliable and applicable for stable and continuous operation.

Liquid level control experiments were performed at different set points, 3 dm, 4 dm, 5 dm, 6 dm, respectively. Fuzzy control wassuccessful because it responded better to nonlinear condition. As a result of thecontrolexperimentforthe set point 3 dm, as shown in Figs. 5 and 6, theliquidlevel has beenkept at thedesired set valueafter a overshoot. In Figs. 7 and 8, theliquidlevelwasmaintained at thedesired set pointafter a shortperiod of time and a successfulcontrolwasachieved. As shown in Figs. 9 and 10, the fuzzy controller was controlled liquid level at the desired setpoint (5 dm). As seen in Figs. 11 and 12, the control liquid level could be maintained at the desired setpoint after about 700 s.

As seen in Table 1, ISE and IAE values were obtained from the change of the liquid level over time versus the set point values. The best control efficiency was obtained when the values were 4 dm.

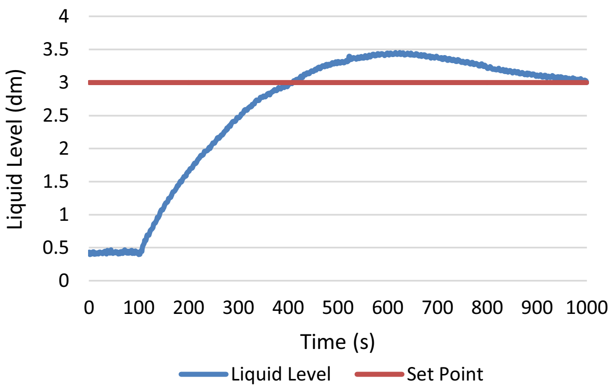

Fig. 5 Controlled liquid level changes for set point 3 dm

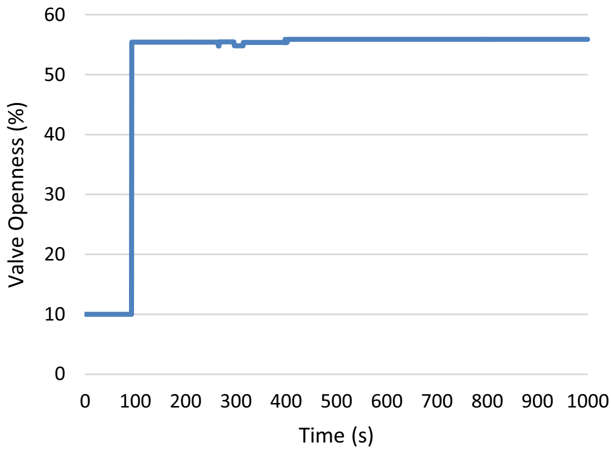

Fig. 6 Liquid level valve position changes for set point 3 dm

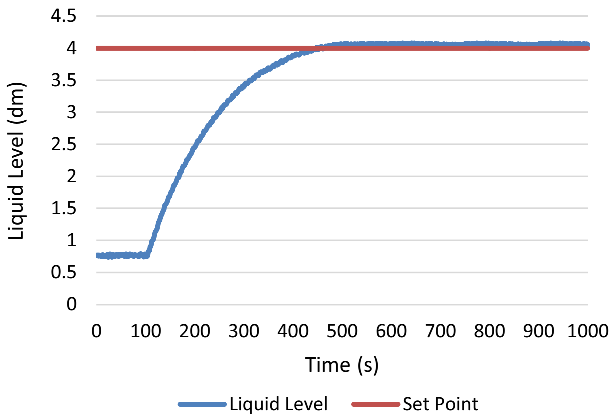

Fig. 7 Controlled liquid level changes for set point 4 dm

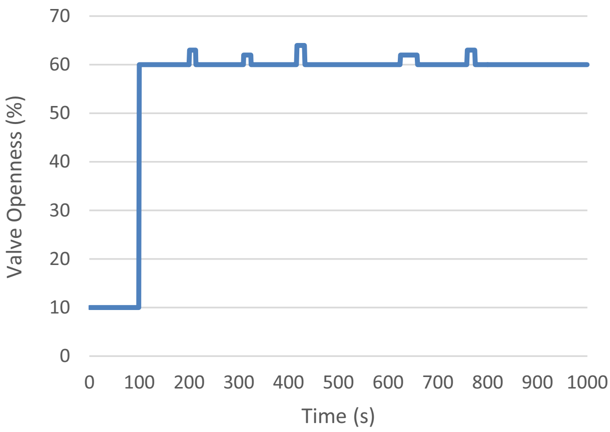

Fig. 8 Liquid level valve position changes for set point 4 dm

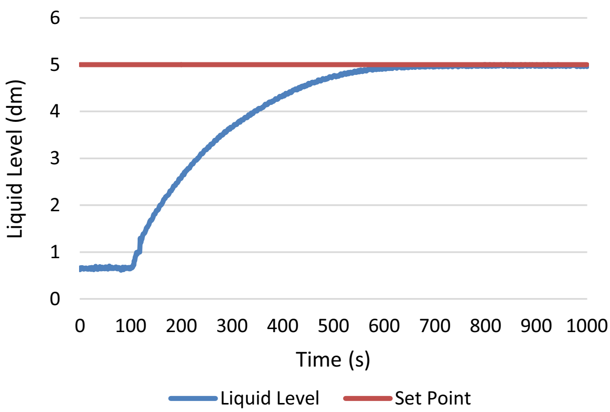

Fig. 9 Controlled liquid level changes for set point 5 dm

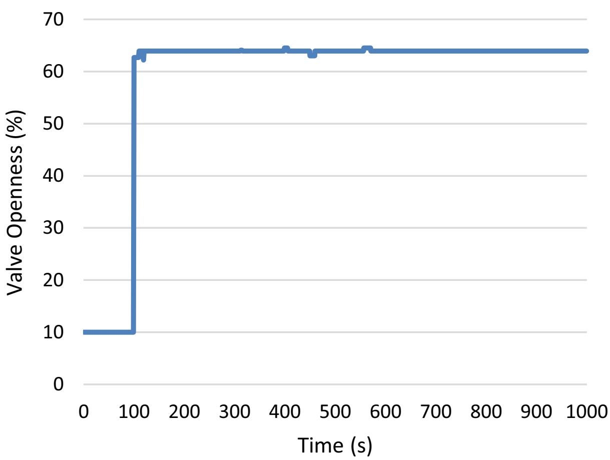

Fig. 10 Liquid level valve position changes for set point 5 dm

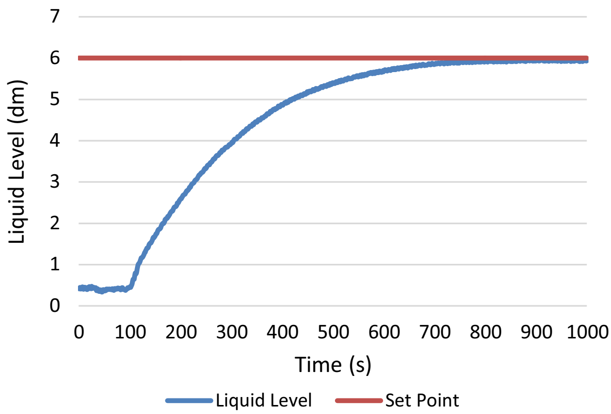

Fig. 11 Controlled liquid level changes for set point 6 dm

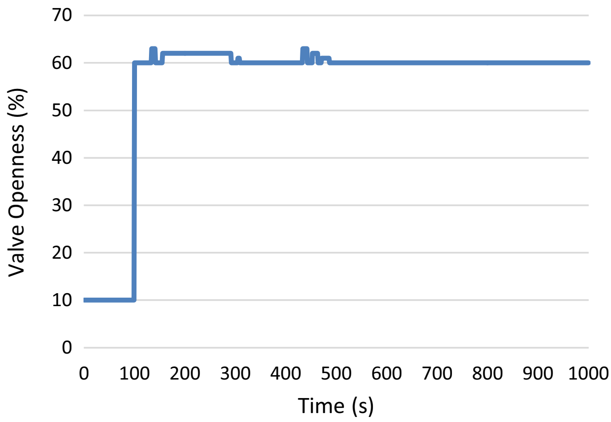

Fig. 12 Liquid level valve position changes for set point 6 dm

Table 1 Control performance values for fuzzy control

Liquid level (dm)	ISE	IAE
3	6182.144	1598.268
4	1194.485	717.421
5	2070.065	847.731
6	3452.25	1112.341

5 Discussion

In wireless liquid level control experiments using fuzzy algorithm, parameter values providing the best fluid level control were determined by conducting experiments on different values of the control parameters in the algorithm under the same conditions. When the level profiles obtained from the fuzzy control experiments for different set points were examined, it was observed that the fluid level rapidly reached the desired set points and the valve opening was stabilized with little oscillation. It has been determined that the ISE and IAE values calculated based on the fuzzy control test results are small. When the experimental results are examined, it is seen that the variable values that can be set in the fuzzy control algorithm are selected from the values recorded in the system, and the control valve increases the control performance by working in the desired openings. It has been understood that the results of the fuzzy control results obtained are more reliable and applicable for stable and continuous operation.

The wireless level measurement and control has been successfully performed in a process control simulator. The block diagram created in the MATLAB/Simulink program was used online for the wireless measurement and control experiments between the process control simulator in the basic operations laboratory and the computer in the process control laboratory. Wireless control has advantages such as easy and quick installation compared to cabling, low installation, maintenance and repair costs, and the ability of wireless communication devices to be portable. The most important result obtained in this study is that wireless communication method is also successful in process measurement and control. According to the obtained experimental results, we propose to improve the wireless control systems and spread them in industrial applications.

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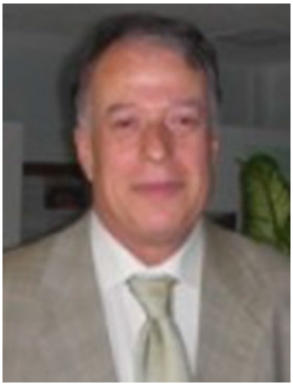

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