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Research Article

Liquid level control with different control methods based on Matlab/Simulink and Arduino for the control systems lesson

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ABSTRACT

Liquid level control is needed in many areas, from simple to complex, from daily life to industry. With the developed system in this study, it was aimed to ensure the students of the control system course to learn the concepts of a closed-loop control system and to observe the effect of changes in the system in real-time. The system consists of two tanks, a pump, a pressure sensor, a power supply, a regulated voltage source, a computer, and an Arduino Due board. By using the Matlab/Simulink and added Arduino blocks, software of the control system was created without code need. It is possible to control the liquid level system via the control board through the computer, as well as to control it without a computer by the embedded software. Liquid level control is carried out with different types of control methods from basic level to advanced level (On-off, PID, ANN-PID, and Fuzzy-PID controller). It is also possible to record the desired parameters in real-time, such as reference level, actual level, error signal, and control signal, in the liquid level control system. In this study, an interface for a PID controller was prepared using Matlab/Gui. It was concluded that with Matlab/Simulink blocks added to the system, different control methods could be applied easily.

1. Introduction

Control of the flow between tanks and fluid level is one of the main problems in industrial processes [1]. Liquid level systems are very complex systems, and traditional control approaches are insufficient to solve this complex structure [2]. In industrial applications, the most commonly used controller for closed-loop control is the proportional–integral–derivative (PID) controller. The best performance in the PID controller is obtained by setting the controller parameters according to the nature of the system [3].

Thakur et al. [2] designed PID and Fuzzy logic controllers in Matlab program to control the water level in a tank. They compared the effects of the controllers by conducting a simulation study. They observed that the Fuzzy logic controller performed better by significantly reducing overshoot and steady-state error. Dinesh et al. [4] discussed the selection of appropriate entry and exit numbers, membership functions, and rules in the Fuzzy logic controller design for non-linear level control of a cone-shaped tank. They compared the results of the classical PID controller with the results of the Fuzzy logic controller. Varghese and Rose [1] simulated the liquid level control of a two-tank system controlled by the first tank in the Matlab program. Ikhlef et al. [5] controlled the tank level with a PID controller over the internet by using a graphical user interface. Artificial neural networks (ANNs), inspired by the human nervous system, have characteristics such as fault tolerance, parallel processing of data, and natural distribution. Kumar et al. [6] modeled an ANN-PID controller in the Matlab/Simulink environment for liquid level control. Since parameters of the PID controller can be set according to the error change by the ANN-PID controller, its properties in the time domain can be improved effectively. Because it is easy to use as open-source and low-cost hardware and software, the Arduino platform is widely preferred.

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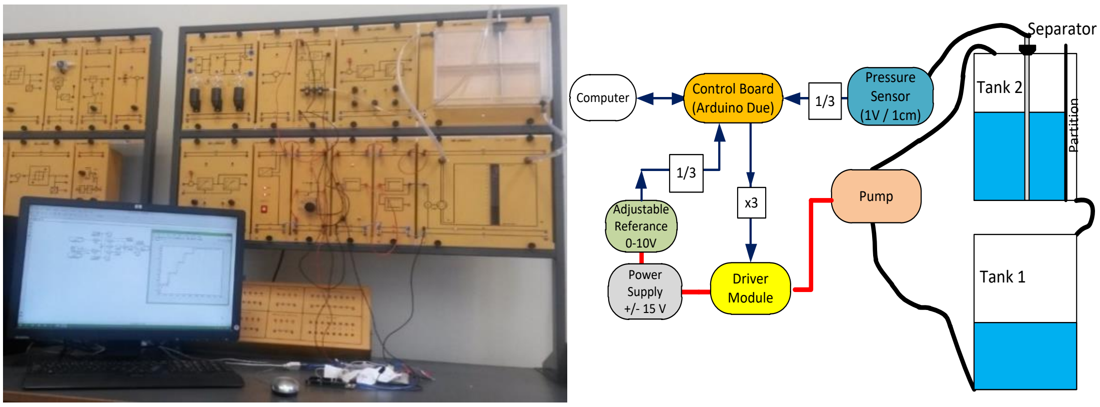

(a) (b)

Figure 1. Liquid level control system (a) and experimental setup block diagram (b)

Sheng [7] set the water level inside the cylindrical tank with a PID controller that he designed using the Arduino microcontroller. Zidane [8] carried out the control of a four-tank system.

In this study, liquid level control was realized with different control methods in real-time by using a two-tank liquid level control system in the Delorenzo control system experimental training set. On-off, PID, ANN-PID, and Fuzzy-PID controllers were applied to the existing system, from basic to advance. It is thought that this study will be useful for students who take the control systems course in different engineering fields in terms of observing a closed-loop control system and having the opportunity to apply different control methods. Users can easily apply different control methods by using Matlab/Simulink blocks. Thanks to the created interface, the system is easier to use, observation of results is fast, and the data of the desired parameters can be recorded.

2. Material and Method

2.1 Experimental Setup

Some of the liquid level control modules in the experimental set of the control systems belonging to the Delorenzo Company were used in this study. The real system is as seen in Figure 1(a). In order to give detailed information about the modules used in the liquid level control system and their connections with each other, the block diagram of the experimental system is given in Figure 1(b). While the tank 1 seen in Figure 1(b) serves as a water tank, the liquid level of the tank 2 is controlled. An adjustable voltage source between 0-10V is used for the reference input of the liquid level system. The pressure sensor works based on the comparison principle. It compares the pressures of inside metal pipe in the tank and ambient. 1V output is taken from the sensor for each 1cm water level in tank 2. The pump operating with 10V empties the tank 1 to tank 2. Since the analog inputs of the Arduino Due board are 3.3V, the potentiometer is used as a voltage divider in two places in order to reduce 10V to this voltage level. Since the board's pulse width modulation (PWM) output will also deliver a maximum of 3.3V, the power required for the pump is ensured by using an amplifier module and then a drive module is used to increase it to 10V. Due to the compartment in tank 2, there is also the possibility of liquid leakage and creating a disturbance effect.

2.2 Control Methods

To control the liquid level, different controllers were designed for a closed-loop control system. On-off and PID controllers were used as the basic level, and ANN-PID and Fuzzy-PID were preferred at the advanced level. Control programs/software were implemented in the Matlab/Simulink environment without using codes. The controller adjusted the power of the pump during operation with the PWM technique. In the block diagrams, reference level, real level, and controller parameters are shown for users in real-time.

2.2.1 On-Off Controller

The pump driven by the on-off controller either runs at full power or does not run at all. If the difference between the desired water level and the actual level in the tank is positive, the pump is active at full power, and if the difference is zero or negative, the pump is disabled. Depending on the error value, the tolerance band is used to prevent the pump from switching on and off continuously. In this way, it is aimed to use both the driver circuit and the pump for a longer period of time. The block diagram designed for the on-off controller is shown in Figure 2.

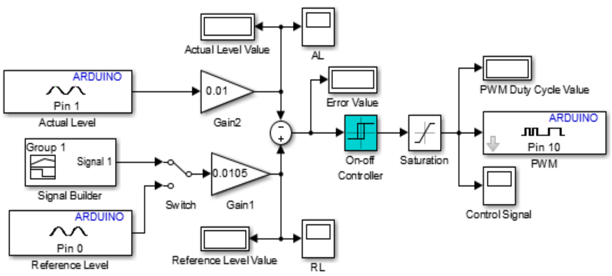

Figure 2. On-off controller block diagram

2.2.2 PID Controller

PID is the most preferred controller in industrial applications. The controller adjusts the power of the pump according to the magnitude of the error value between the reference level and the actual level. If the error is large, the pump is driven at full power, and as the error value gets smaller, the power of the pump is reduced by the controller. The PID controller gives the ideal result for a single reference value with which the parameters are set. The block diagram of the PID controller is given in Figure 3.

2.2.3 ANN- PID Controller

Artificial neural network (ANN) has been created by taking inspiration from the working logic of the human brain. The neural network is of great interest because it has advantages such as good dynamic performance, nonlinear prediction ability, robustness, and error tolerance capability [9]. The network can be trained, and if it encounters different situations, it generates an idea of the new situation. By taking advantage of this situation, it was attempted to solve the case where the PID controller was ideal for a single point. For different reference values, appropriate PID controller gain parameters were determined in the liquid level control system. With these data, the ANN model was created using Matlab/nftool. While the input of the network is the reference value, the output is proportional, integral, and derivative controller gain parameters. In the ANN model, there is one hidden layer with ten neurons. The Levenberg-Marquardt backpropagation algorithm was used in the training of the network. The gain parameters of the PID controller are estimated by the ANN model based on the reference level selected and automatically changed on the controller. This situation can be monitored instantly from the indicators by the user. The ANN-PID controller not only has the advantages of PID, but also has learning, remembering, and nonlinear prediction capabilities. Matlab/Simulink block diagram of the ANN-PID controller is shown in Figure 4.

With the Matlab/nftool, students can easily create a network model that has a different number of hidden layers and a different number of neurons in the layer and try it in the current system.

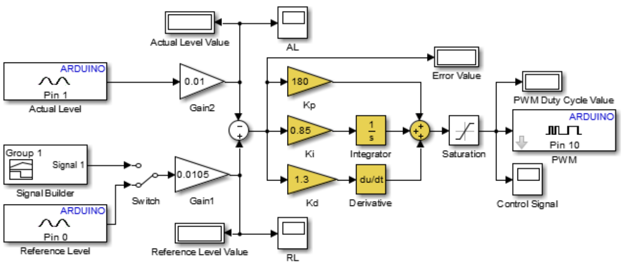

Figure 3. Block diagram of the PID controller

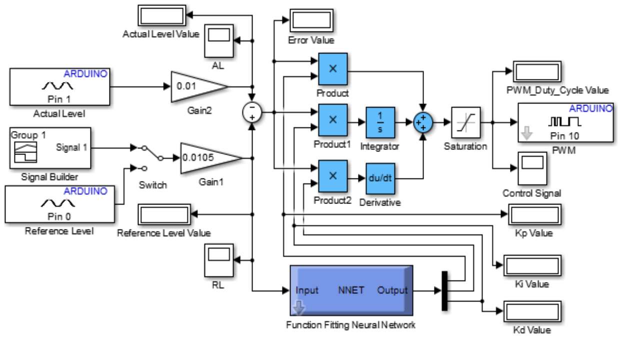

Figure 4. ANN-PID controller block diagram

With the help of Matlab/nntool, they can also use different types of network models in the system.

2.2.4 Fuzzy- PID Controller

Fuzzy logic is a controller that has humanoid thoughts and intermediate values. The controller input is mostly numerical values [10]. It is performed by using linguistic variables instead of numerical values and rules instead of complex mathematical expressions. Linguistic variables are very high, high, medium, low, and very low [1]. The fuzzy logic control method includes fuzzification, rule base, interference, and defuzzification operations [11]. Each of these parts plays an important role in the control process and affects the overall system behavior and controller performance. Fuzzification converts numerical data at the input into linguistic terms. The rule base provides the necessary information for all components of the fuzzy controller. Interference is the brain of the controller. At the end of the interference phase, fuzzy values that are not directly used in the control process are obtained. The numerical value is obtained by the defuzzification stage [12].

While creating the controller, first of all, a Fuzzy inference system (FIS) file is created by using the Matlab/fuzzy interface. The input of the fuzzy controller is the error, and the derivative output of the error is determined as the controller parameter. As seen in Figure 5, a separate Fuzzy logic controller was created for each parameter of the PID controller. Here, Mamdani type fuzzy model was preferred.

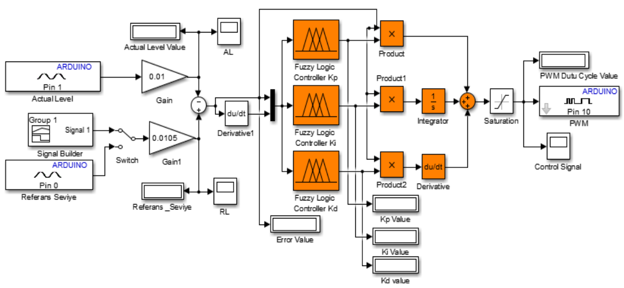

Figure 5. Fuzzy-PID controller block diagram

Seven membership functions for control process precision function were preferred: these were NB (Negative Big), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). NB and PB membership functions were selected in gauss, others in triangular. In Figure 6, membership functions of the fuzzy block of the proportional component of the PID controller are given. Membership functions for the error and derivative of the error are similar, and the boundary ranges are between 0-10 and -1 and +1 respectively, while the membership functions of the output control signal are the same and range between 0-255 (8 bits).

Since seven membership functions are used, the rule table consists of 49 rules (Table 1). Different rule tables are used in other components of the PID controller.

The variation of the output control signal against the inputs of the fuzzy logic controller, which will determine the gain value of the proportional component of the PID controller, is given in Figure 7 as three dimensional. As can be seen in the chart, there is a balanced distribution.

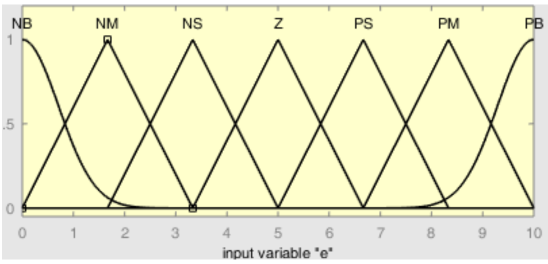

Figure 6. Fuzzy error input membership functions of proportional component of the PID controller

Table 1. The rule table of the fuzzy logic controller, which will determine the proportional parameter of the PID controller [13]

de / e	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PB	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

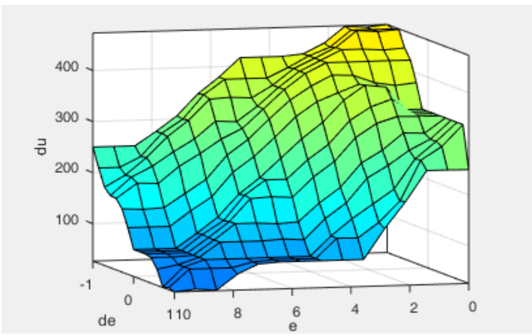

Figure 7. 3D representation of the Fuzzy logic controller

Students can create their own FIS files and use them in the existing system. They can observe their effects by making changes in installed FIS file. They can change the shapes, number, and limits of membership functions and create different rule tables. Our system is able to appeal to users at different levels.

3. Discussion and Results

The adjustable voltage source in the experimental setup or the signaling block in Matlab/Simulink can be used as reference input. Figure 8 shows the level change curves according to different controllers for the time-varying reference input created with the signaling block.

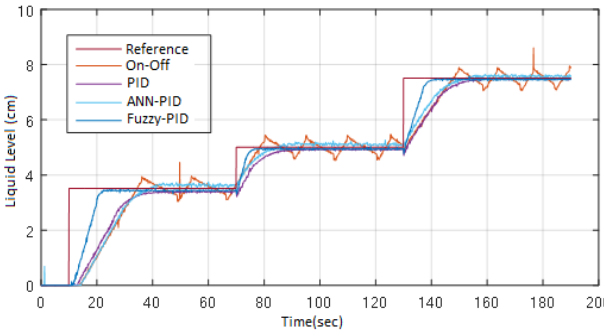

Figure 8. Response curves of controllers for different reference values

In this system, comparison of controllers in terms of parameters such as rise time, overshoot, settling time, permanent status error can be easily made by students. The effects of changes in controller parameters are easily observed in real-time. Any data related to the system can be recorded. As an example, the control signals of the different controllers are shown in Figure 9. The 0-255 range indicates the voltage level of the card the 0-3.3V range. This voltage is raised 3.03 times and applied to the pump. As seen on the on-off controller, the pump is either driven at full power or is disabled. In other controllers, it is observed at intermediate values depending on the error value. It is the Fuzzy-PID controller that gives the fastest response and offers a quick response to the current settings. Our aim is to control the system without the need for codes with different controllers. Thus, it is not the best controller to detect.

With the help of Matlab/Gui, an interface was designed to attract the attention of the students, to learn the concepts about the closed-loop control system in detail, and to observe the parameter changes quickly. From the interface shown in Figure 10, sampling time, simulation time, and PID controller gain parameters are easily determined, and the system is operated. Signals to be plotted in the graphics area can be selected by the user. Here, the set source of voltage on the experiment set is used as a reference input.

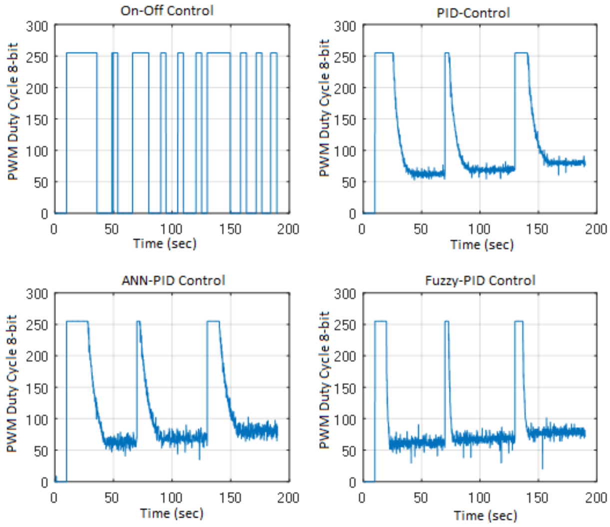

Figure 9. Control signal for different type controllers

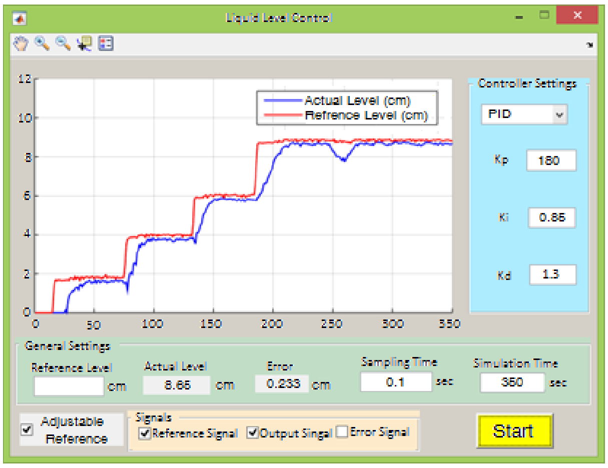

Figure 10. Interface created for PID controller

The system is started by pressing the start button. The graphics drawn with the tools in the menu above the interface can be examined in detail.

4. Conclusions

Liquid level control systems are used widely in the industry and as a result of this, technical personnel with the necessary knowledge and experience are needed. In order to contribute to this need, an experimental setup design and application in which the necessary skills can be gained for liquid level control was realized in this study. Control methods were applied on a two-tank experimental setup, one of which was a water tank and the other was a liquid level control.

The control of the liquid level experimental set was carried out easily by designing basic controllers such as on-off and PID as well as by the advanced controllers such as ANN-PID and Fuzzy-PID. In the application, controllers were designed with Matlab/Simulink and Arduino blocks without the need for codes. Thus, the design was simplified and design time was shortened. The system can be operated in the Matlab/Simulink environment as well as embedded in the Arduino Due board and can be operated independently. Graphics can be drawn and the values of the desired parameters can be recorded. For the PID controller, an interface was created using Matlab/Gui. Since the instant changes of the selected parameters can be observed, the system is started by entering the simulation time, sampling time, and controller parameters. The graphics can be examined in more detail with the tools available in the interface.

Thanks to the system designed in this study, the students can learn the logic of the closed-loop liquid level control system in detail and select the appropriate controller in line with what is expected from the system.

Declaration

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author(s) also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

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