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Digital Control Fuzzy Logic for a Water Tank Level Using Arduino

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Abstract: Fuzzy logic control has been successfully utilized in various industrial applications; it is generally used in complex control systems, such as chemical process control. Today, most of fuzzy logic controls are still implemented on expensive high performance processors. This paper analyzes the effectiveness of a fuzzy logic control using a low cost controller applied to water level control system. The paper also gives a low cost hardware solution and practical procedure for system identification and control. We started, first by identifying the process to obtain its mathematical model. Then we used two methods to control our system (PI and fuzzy control). Simulation and experimental results are presented.

Keywords: Fuzzy control, PI, Water Tank level, System identification, Arduino.

1. INTRODUCTION

The extraordinary development of digital processors (Microprocessors, Microcontrollers) and their wide use in control systems in all fields have led to significant changes in the design of control systems. Their performance and low cost makes them suitable for use in control systems of all kinds that require a lot more capabilities and performance than those provided by the analog controllers.

In certain industry branches, the liquid level control problem is often encountered. The nature of the liquid and friction of control mechanism and other factors makes the system nonlinear [1, 2]. In nowadays, the best-known industrial process controller is the PID controller because of its simplicity, good robustness, high reliability and it can be easily implemented in any processor, but using a PID controller is not fully convenient when it comes to dealing nonlinear systems [3, 4]. But these systems can be successfully controlled using fuzzy logic controllers because of their independency from the mathematical model of the system.

2. SYSTEM DESCRIPTION

Adjusting a liquid level in a tank is the main objective of this work, the structure of the entire system is as shown in Fig. 1. The system consists of a water tank, a liquid level sensor, a pump based on a 12V direct current motor, an electronic circuit (Arduino and a DC/DC step down converter).

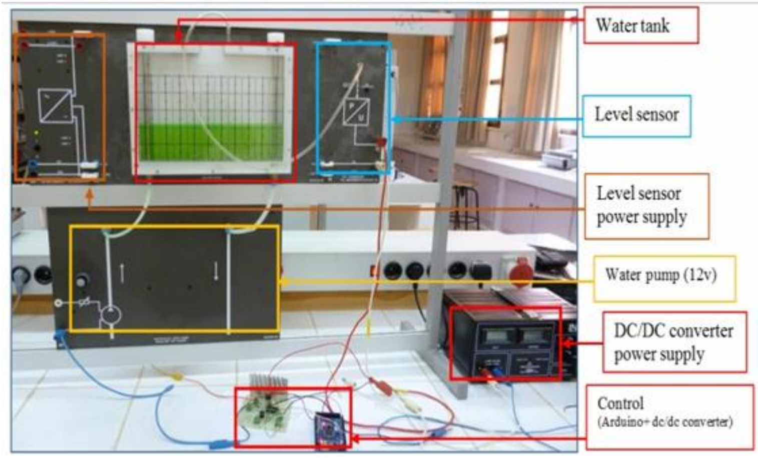

Fig. 1. Structure of water level control

The structure chart of the water tank level system is shown in Fig. 2 which the liquid flows into the top of the tank by a dc motor pump and leaves from the bottom, through a pip equipped with an adjustable valve to adjust manually the flow rate of the liquid leaving the tank and to simulate leaks (disturbances).
The Arduino will act as an acquisition board in identification phase, once we obtain the model of the system the Arduino will play the role of an independent controller, the computer is just used for displaying signals and to impose set points for the controller, it will communicate with the Arduino through RS232 communication.

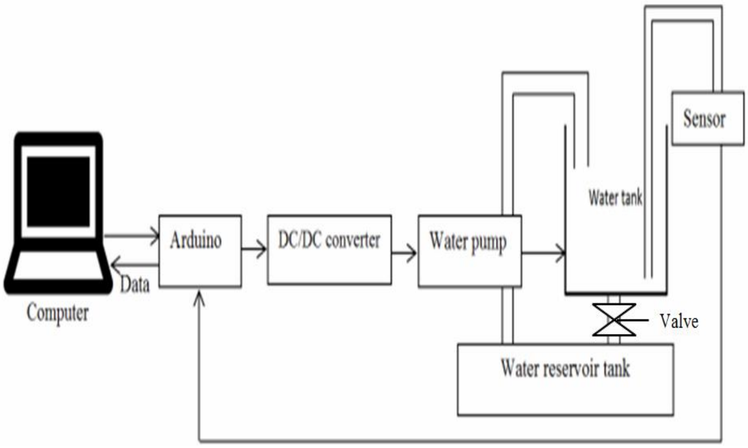

Fig. 2. Structure chart of water tank control system

3. SYSTEM IDENTIFICATION

In order to obtain the mathematical model of the process, we used Arduino as an interface between the computer and the system. The computer is equipped with software that can store incoming samples from Arduino, and then we used “MATLAB identification toolbox” shown in Fig. 3, to process the samples and to obtain the model.

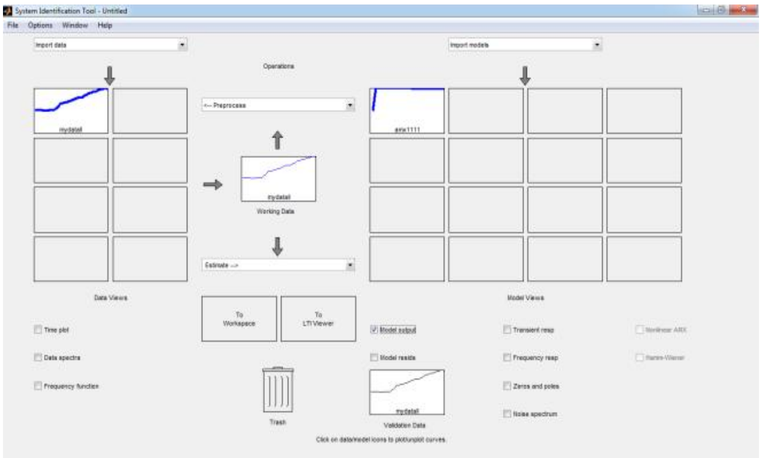

Fig. 3. Graphical user interface of the identification tool box

Fig. 4 shows the open loop response of our system to a constant input *u*(*t*), 15.8cm is the final value of the output *y*(*t*) to a 7.6 input. This corresponds to the steady-state error of 54.6 percent, which is quite large. That is why we have to design a controller that can eliminate the steady-state error. With the help of MATLAB identification toolbox we deduced that the function transfer and it is:

$$G(z) = \frac{0.004483z^{-1}}{1-0.8852z^{-1}}, \textit{sampling time } Ts = 0.2s \tag{1}$$

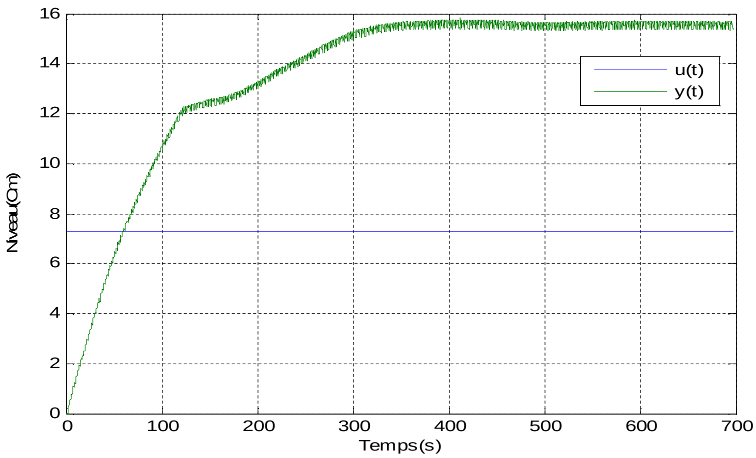

Fig. 4. Response of the system

Fig. 5 represents a comparison between system response and transfer function response to the same input. And we can see that the transfer function response almost matches the reel system response.

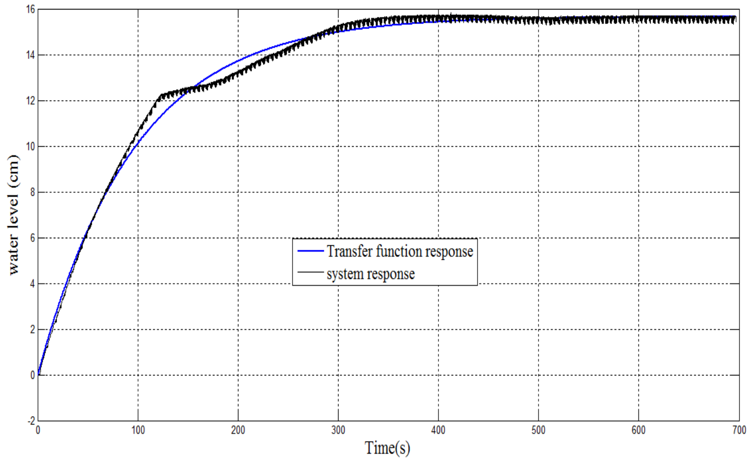

Fig. 5. Comparison between system response and transfer function response to the same input

4. PI CONTROLLER

A Proportional-Integrate-Derivative controller (PID) is a control mechanism, the role of this controller is to minimize the error between a set point and measured data, the control algorithm contains three terms proportional, integrate and derivative term [5, 6]. The most popular controller industrial field is the PI (Proportional-Integrate) controller and it is a special case of a PID controller, it has only two constant parameters K_p and K_i, where K_p is the proportional gain and K_i is the integral gain [7, 8]. The control algorithm $u(t)$ and the controller transfer function $C(p)$ are given by the following relationships:

$$u(t) = K_p(\varepsilon(t) + \frac{1}{\tau_i}\int_0^t \varepsilon(t)dt \qquad (2)$$

$$C(p) = K_p \frac{1+\tau_i p}{\tau_i p} = K_p(1 + K_i \frac{1}{p}) \qquad (3)$$

The design of the PI controller was done using Matlab/Simulink and it was based on the mathematical model obtained from the identification phase. The simulation shown in Fig. 6 was used for testing the performance of our controller, the gains (K_p and K_i) were calculated using pole placement method, (K_p = 1.145 and K_i = 0.015). Fig. 7 shows the results obtained by the simulation.

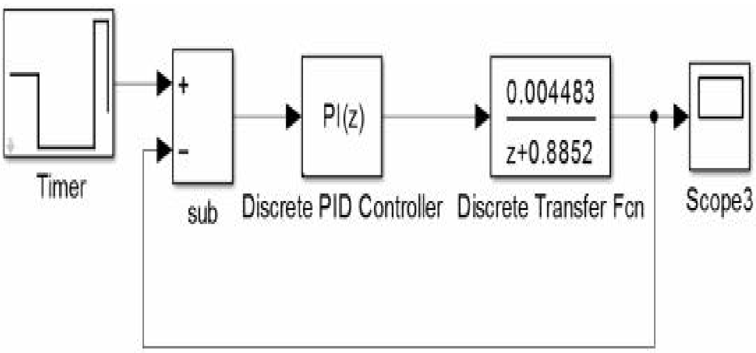

Fig. 6. Simulation of PI controller in simulink

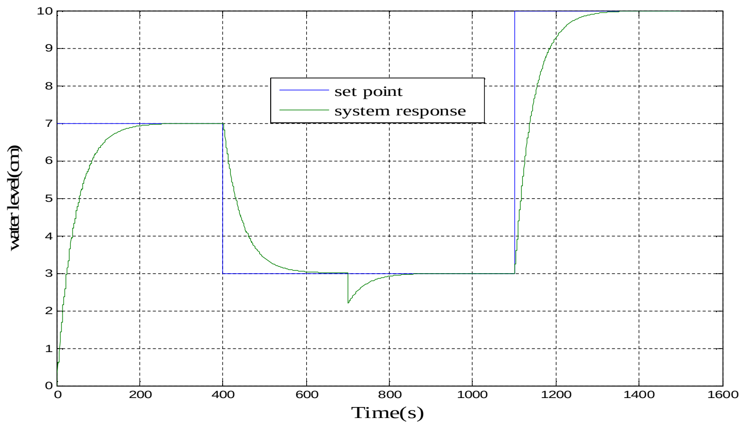

Fig. 7. Behavior of the process with a PI controller (simulation)

After the controller was designed and tested in Matlab/Simulink, the function of the controller mentioned earlier was implemented in Arduino, and then we used it to control our system. Fig 8 presents the behavior of the system with PI controller.

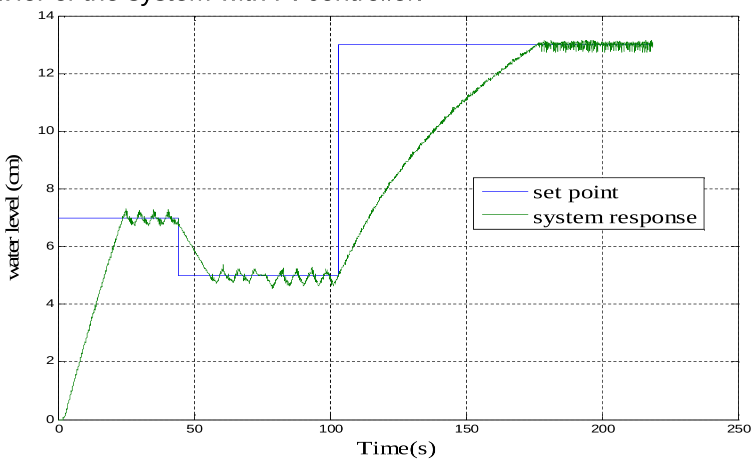

Fig. 8. Behavior of the process with a PI controller (experimental results)

5. FUZZY LOGIC CONTROLLER

The Fuzzy Logic controller consists basically of four parts: fuzzification interface, knowledge base, inference engine, and a defuzzification interface. Fig. 9 shows the basic configuration of a fuzzy logic controller. Each of these parts plays a different role in the control process and affects the performance of the controller and the behavior of the whole system. The fuzzification is the transformation of numerical data from the input to linguistic terms. The knowledge base provides necessary information for all the components of the fuzzy controller [9, 10]. The fuzzy inference engine or the logical decision-making is the core (brain) of the controller. It is capable of simulating the decision-making of human beings. At the end of the inference step, the obtained result is a fuzzy value that we cannot directly use to control our process, so the value should be defuzzified to obtain a crisp value and that is the role of the defuzzification interface.

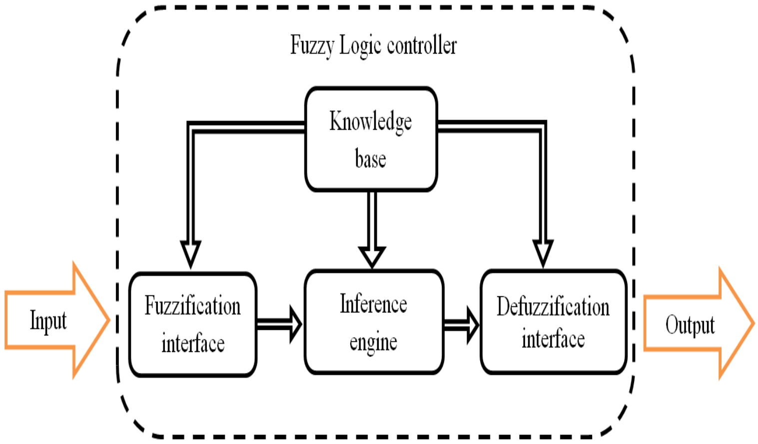

Fig. 9. Basic configuration of a fuzzy logic controller

The fuzzy logic controller usually works with more than two input signals, the system error e and the change rate in the error Δ*e*. The error of the system is defined as the difference between the set point $y_r(k)$ and the plant output $y(k)$ at a moment k:

$$e(k) = y_r(k) - y(k) \tag{4}$$

The variation of the error signal at the moment k is given by the following relationship:

$$\Delta e(k) = e(k) - e(k-1) \tag{5}$$

The configuration of the proposed fuzzy controller is shown in Fig.10. In1 is the system error and In2 is the variation of the error signal.

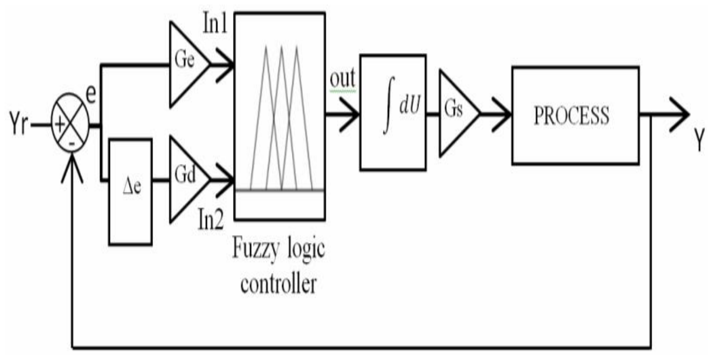

Fig. 10. Fuzzy controller in a closed loop system

The simulation shown in Fig. 11 was used to test the performance of our fuzzy controller and to determine the controller gains.

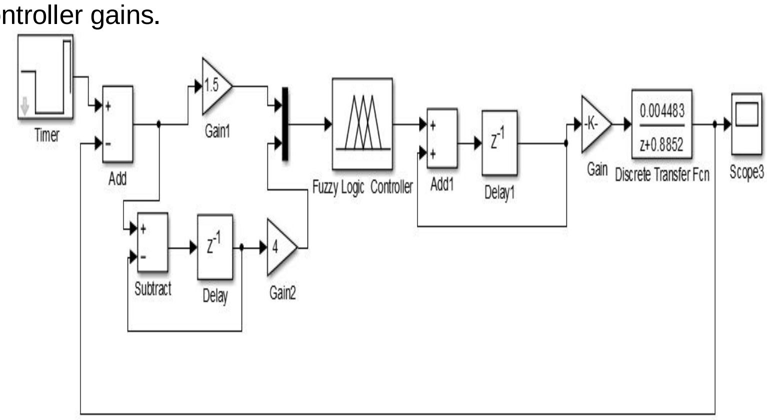

Fig. 11. Simulink model

Using Matlab toolbox "fuzzy logic toolbox", shown in Fig. 12, we designed a fuzzy logic controller with two inputs (error and error derivative) and one output. The proprieties of our controller are given in the Table. 1.

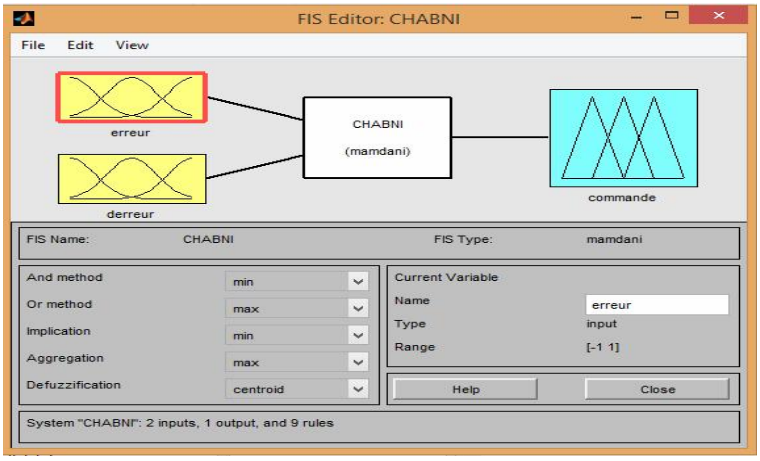

Fig. 12. Graphical user interface of the fuzzy logic toolbox

Table 1. Proprieties of the fuzzy logic controller

Controller type	Mamdani
And method	Min
Or method	Max
Implication	Min
Defuzzification	Centroid

The chosen membership functions of our output and input signals are all similar, they are shown in Fig. 13.

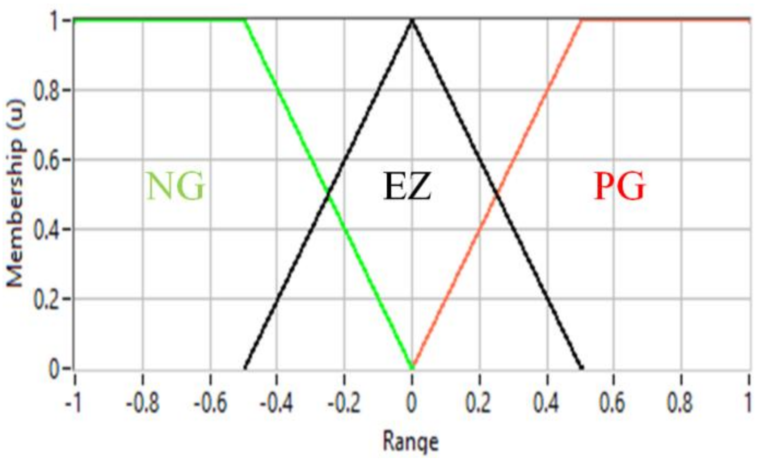

Fig. 13. Membership functions of In1 and In2 and out

The design of the table below (Table .2) was based on the principles of a basic control system which are: If the error is big, and the error rate changes fast, then the controller should eliminate the error quickly and if the error is small, and the error rate change is not fast, then the controller should eliminate the error slowly and if the error is zero, and the error rate doesn't change, then the control command should be zero. The labels inside the table are linguistic variables.

Table 2. Fuzzy rules

In1 / In2	NG	EZ	PG
NG	NG	NG	EZ
EZ	NG	EZ	NG
PG	EZ	PG	PG

The labels in the Table 2 are as follows: NG = very low, EZ = zero and PG = very high.

After many simulations we found the values of constants that satisfy our controller standards. Table 3 shows the values of these constants. The result of the simulation is presented in Fig. 14.

Table 3. Controller gaines

Error gain (Ge)	1.5
Error changing rate gain (Gd)	4
Output gain (Gs)	150

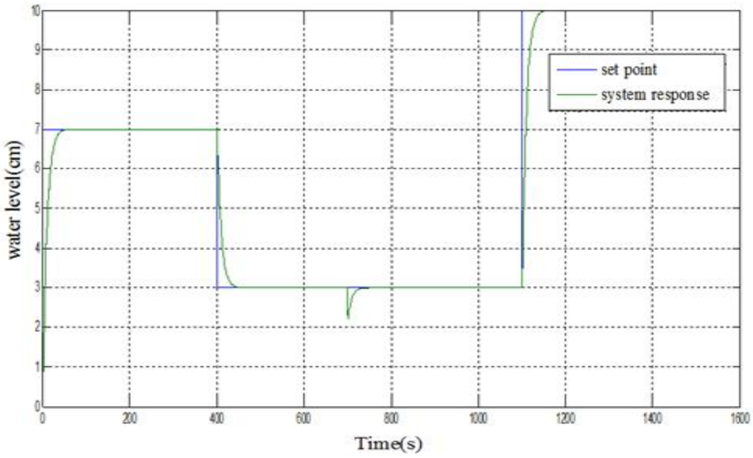

Fig. 14. Behavior of the process with a fuzzy controller (simulation)

After the controller was designed and tested in Matlab/Simulink, the function of the controller mentioned earlier was implemented in Arduino, and then we used it to control our system. Fig. 15 presents the behavior of the system with a fuzzy logic controller.

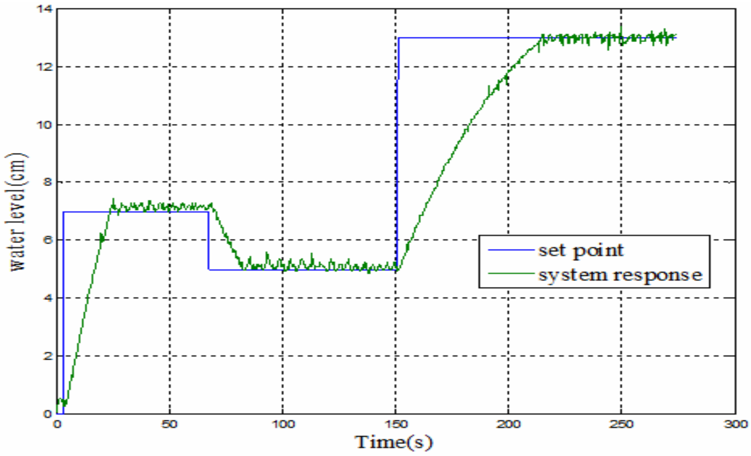

Fig. 15. Behavior of the process with a fuzzy controller (experimental results)

The system was submitted to perturbations (in simulation and experiment). From Figs. 7, 8, 14 and 15 we can see that the fuzzy controller have better performance and stability in every given set point and fast error compensation.

6. CONCLUSION

In this paper we proposed a low cost solution to apply fuzzy logic control for a water tank level control system by using an Arduino, and using it also as a low cost solution for system identification. We reached the main objective of this work which is to test the effectiveness of fuzzy logic control using Arduino, by comparing it to a PI controller. The general structure of both controllers (PI and fuzzy) were presented in this work. The simulations and experimental results showed the superiority of fuzzy control over the conventional control systems.

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