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Determining PID Controller Coefficients for the Moving Motor of a Welder Robot Using Fuzzy Logic[1]

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Abstract—In this paper, a fuzzy algorithm was used for determining the coefficients of a PID controller using an online method. The plant used in this system is a welder robot, which is used for welding oil and gas pipelines. This robot rest on the pipe and weld it by moving around. The speed is adjusted using a motor moving the robot around the pipe. A digital controller also used for implementation. In this research, in order to choose the rules the skills transmit method and that how the PID response is required has been used. In this paper, the type of algorithms that continuously assigns PID coefficients using an online method depending on the characteristics of the system which is based on fuzzy logic was used. First, the rules associated to each output in relation to inputs are depicted in it. Using the mentioned method, simulation results and then implementation results were obtained and discussed.

Keywords: fuzzy algorithm, PID controller, welder robot, speed control

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1. INTRODUCTION

Industrial processes are based on the different parameters, which it leads to need to solving nonlinear optimization problems. One of the most common control strategies is Proportional-Integral-Derivative (PID) control; this method can be used for various process conditions. One of the main and usual difficulties in using PID controllers is how to determine their coefficients [1, 2]. Difficulty in using these controllers is for various applications with different design/requirements. For example, the dynamics of mechanical parts of a welder robot, which was used in this research, are difficult [3–6]. This implies that different responses are expected from different parts of the welder robot [7, 8]. Therefore, in cases where the robot has critical movements, controller coefficients of each product have to be separately determined. In addition, over the time and usage of the robot, the dynamics of mechanical parts would change due to erosion, friction, etc. As a result, the response of the system will change, too [9]. This is the reason why the coefficients of the controller should be reassigned at specific periods of time. To do so, there are algorithms, which automatically readjust the coefficients of PID. There are two types of these algorithms. The first type of these algorithms is the one that is used only once and assigns the coefficients offline [10, 11]. The coefficients assigned in that way will not change over time. This implies that these algorithms can only solve part of above mentioned problem [12]. The other type of these algorithms continuously assigns PID coefficients using an online method depending on the characteristics of the system. In these algorithms the coefficients are calculated comparatively over time. By using these algorithms, both difficulties associated to PID controllers will be solved. In this paper the second algorithm type which is based on fuzzy logic was used [13, 14].

2. PLANT INTRODUCTION

The plant used in this paper is a welder robot, which is used for welding oil and gas pipelines. These robots rest on the pipe and weld it by moving around. Figure 1 show this robot which has been completely constructed in Iran.

[1] The article is published in the original.

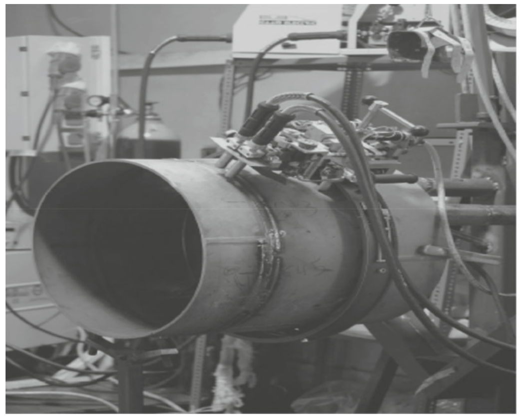

Fig. 1. A welder robot used for welding oil and gas pipes.

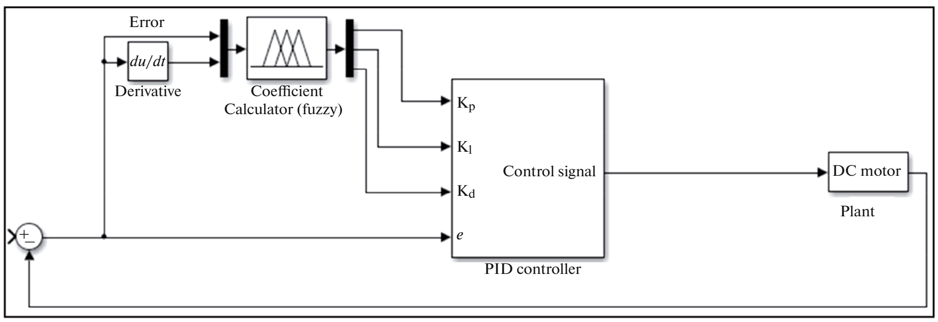

Fig. 2. General Block diagram of the system.

One of the movements of this robot is the moving around the pipeline, which is operated by a DC motor. The velocity of this motor is controlled by a PID controller so that its coefficients are constant and determined via a trial and error system.

In this paper a fuzzy algorithm was used for determining PID coefficients. First, the simulation results of this controller are obtained using a second order model of the robot's system (used coefficients were taken from the motor's catalogue). Then, the results of the controller implementation on a real plant were presented. The block diagram of the whole system is shown in Fig. 2.

3. FUZZY CALCULATOR DESIGN

In this system, there is a fuzzy logic block in which the calculation of coefficients K_P, K_I and K_d is based on the magnitude of error and derivative of error using an online method. This block then feeds the coefficient values to the PID controller block.

There are a number of steps for designing this fuzzy calculator, which should be taken in the following order:

(1) Choosing a Membership Function (MF) and its limits for the inputs 'e' and $\frac{de}{dt}$.

(2) Choosing a Membership Function (MF) and its limits for the outputs K_P, K_I and K_d.

(3) Choosing the type of fuzzy logic (Mamdani or Sugeno).

(4) Choosing fuzzy rules.

(5) Choosing the type of AND, OR, Implication, Aggregation and Defuzzification.

It should be noted that for simplicity in the implementation of this controller, the maximum number of limits for the inputs and outputs has been set to be 3. Increasing the number of limits will obviously enhance the quality of the system response. In that case, the number of rules will also considerably go up. In the following sections, the mentioned steps are explained.

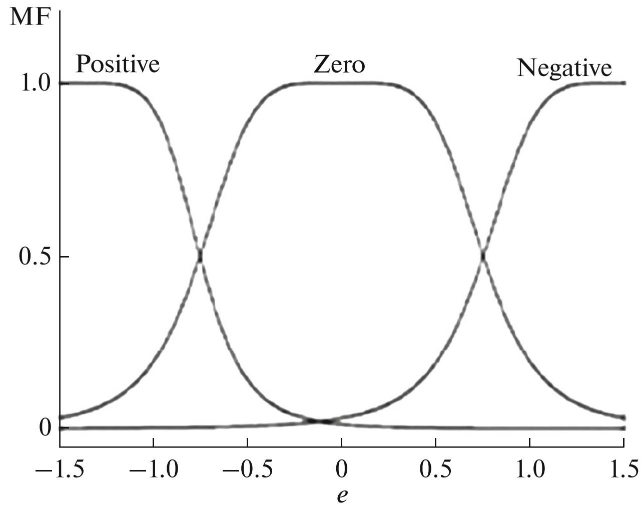

Fig. 3. Membership functions of '*e*'.

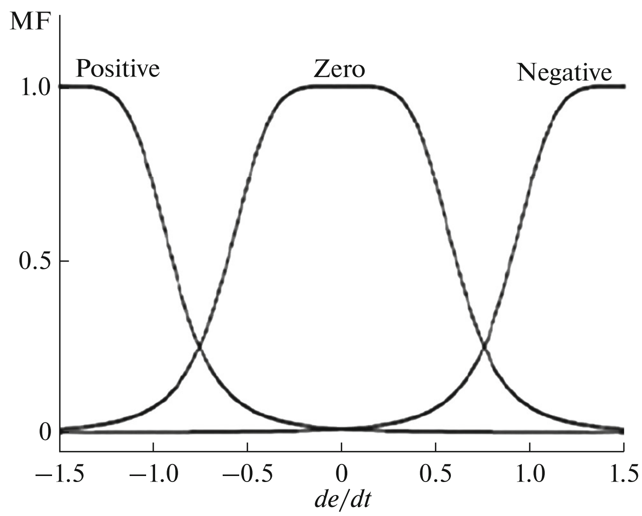

Fig. 4. Membership functions of $\frac{de}{dt}$.

3.1. Choosing a Membership Function for Inputs

For the inputs e and $\frac{de}{dt}$ membership functions of an uncorrelated shape have been chosen as shown in Figs. 3 and 4.

As seen, the inputs have been divided to three sections: positive, zero and negative.

3.2. Choosing a Membership Function for Outputs

The output K_P has been divided to low and high sections so that for each section an uncorrelated shaped function was chosen as shown in Fig. 5.

The outputs K_I and K_d have been divided into three sections: Low, Medium and High and for each of them an approximately singleton-shaped membership function has been chosen (see Figs. 6 and 7).

3.3. Choosing the Fuzzy Logic Type

In this research, the Mamdani method was used.

One of the most important aspects of designing this fuzzy calculator is to choose its rules, which determine how outputs and under which inputs change. In this research, the fuzzy calculator is about to calcu-

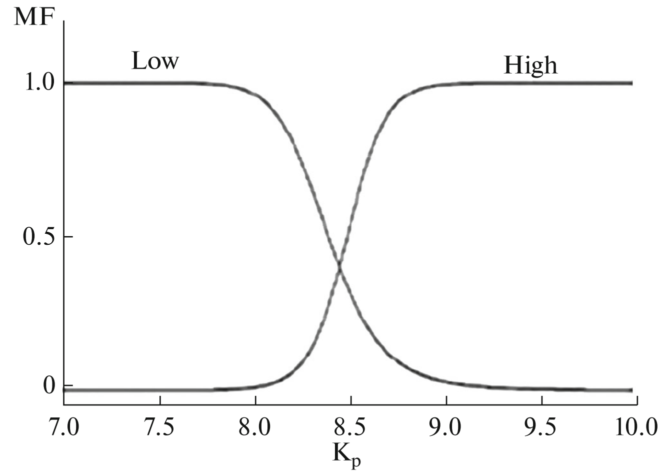

Fig. 5. Membership functions of K_p.

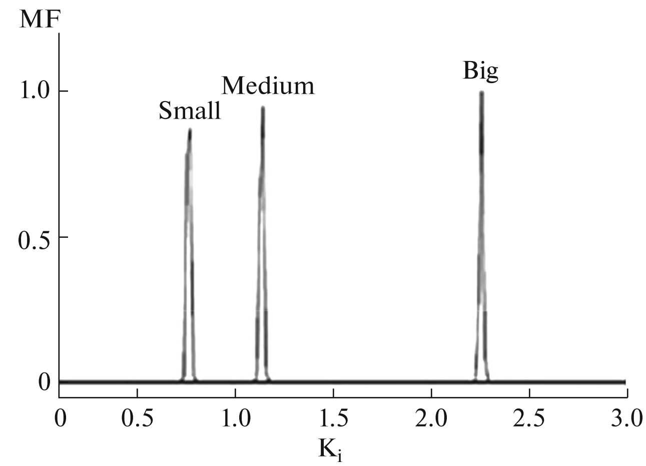

Fig. 6. Membership functions of K_i.

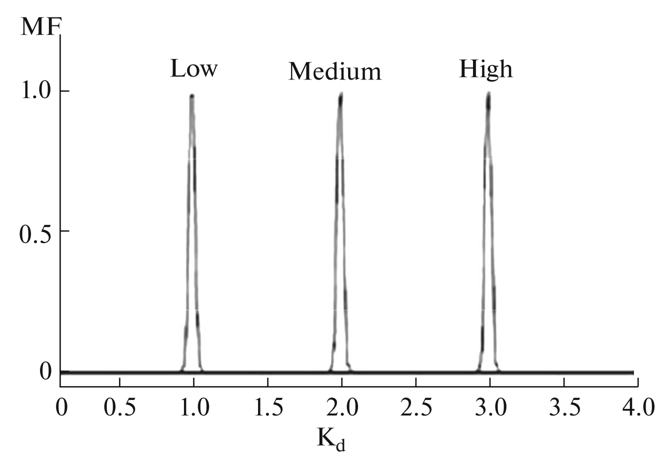

Fig. 7. Membership functions of K_d.

late the coefficients of a PID controller, by choosing he rule type the PID response can be determined. The speed of response, whether it has overshoot or not, the magnitude of overshoot and etc. can be all changed by choosing the rules. In Tables 1, 2, 3 – **H**: High, **M**: Medium, **L**: Low, **S**: Small.

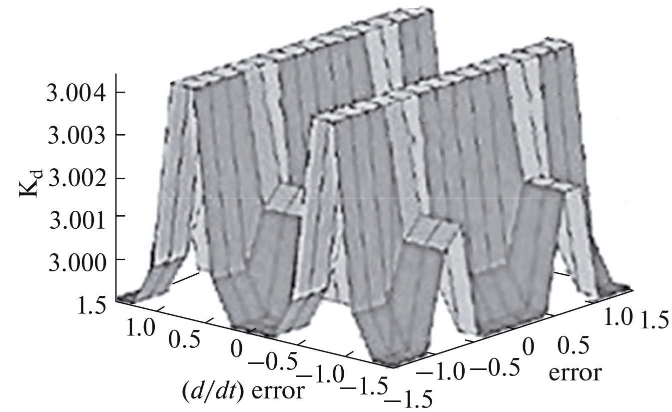

Fig. 8. Surface curve of K_d with respect to inputs.

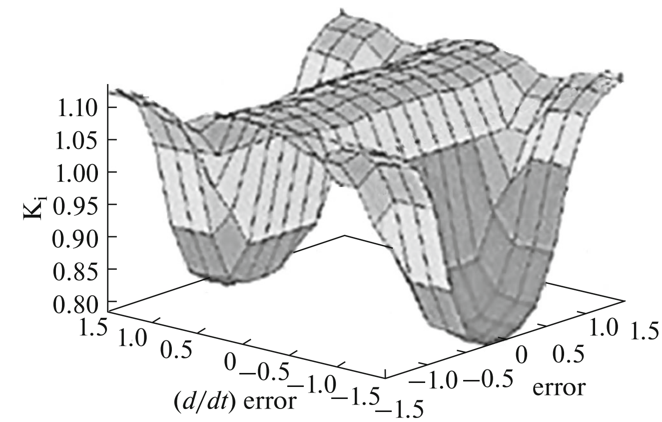

Fig. 9. Surface curve of K_i with respect to inputs.

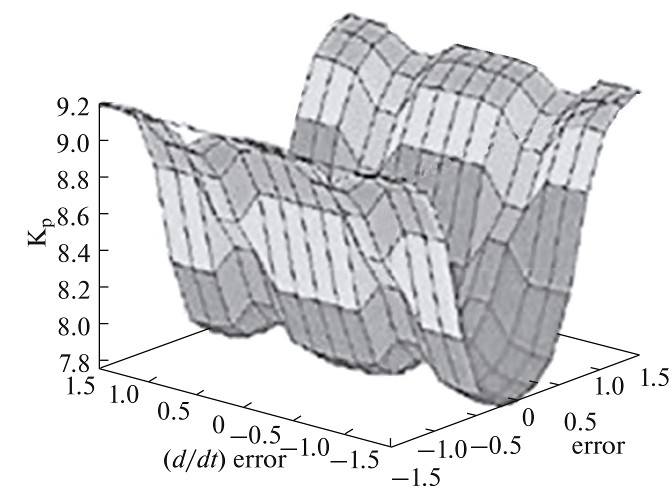

Fig. 10. Surface curve of K_p with respect to inputs.

3.4. Choosing Fuzzy Rules

There are several methods for choosing the rule type of a fuzzy calculator. In this research, in order to choose the rules the skills transmit method and that how the PID response is required has been used. First, the rules associated to each output in relation to inputs are depicted in a table format. Then, the surface curve of each output in respect of inputs is shown in Figs. 8, 9, 10. The output rules are presented in Fig. 8.

Table 1. Fuzzy rules for K_i coefficient

$e \frac{de}{dt}$	Positive	Zero	Negative
Positive	**H**	**M**	**H**
Zero	**L**	**M**	**L**
Negative	**H**	**M**	**H**

Table 2. Fuzzy rules for K_p coefficient

$e \frac{de}{dt}$	Positive	Zero	Negative
Positive	**H**	**M**	**H**
Zero	**L**	**L**	**L**
Negative	**H**	**M**	**H**

Table 3. Fuzzy rules for K_d coefficient

$e \frac{de}{dt}$	Positive	Zero	Negative
Positive	**H**	**M**	**H**
Zero	**M**	**M**	**M**
Negative	**H**	**M**	**H**

4. SIMULATION RESULTS

As seen, the simulation results are presented in the above-mentioned Figs. 8, 9, 10. This is evident that the system response is well formed by the system input and its steady state error is zero. In these Figs. 11, 12, the coefficients of PID controller with respect to time are shown. It should be noted that the type of system response depends on the rule type chosen and the range of output signals. With regards to the robot used in here, a fast response with minimum overshoot was desired. Hence, the rules were chosen in a way that the simulation would yield the same results.

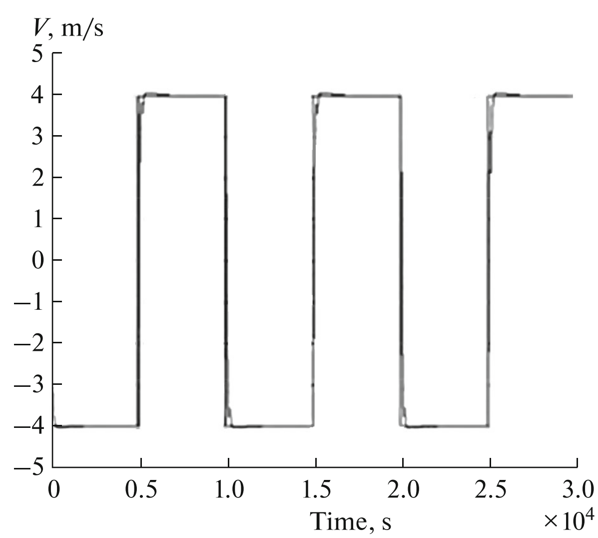

Fig. 11. Response of the output of the system (time, velocity).

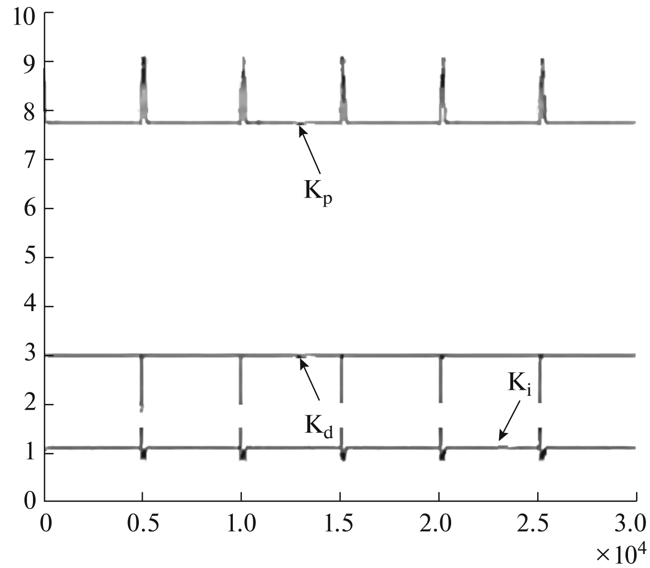

Fig. 12. Coefficients of PID controller through time.

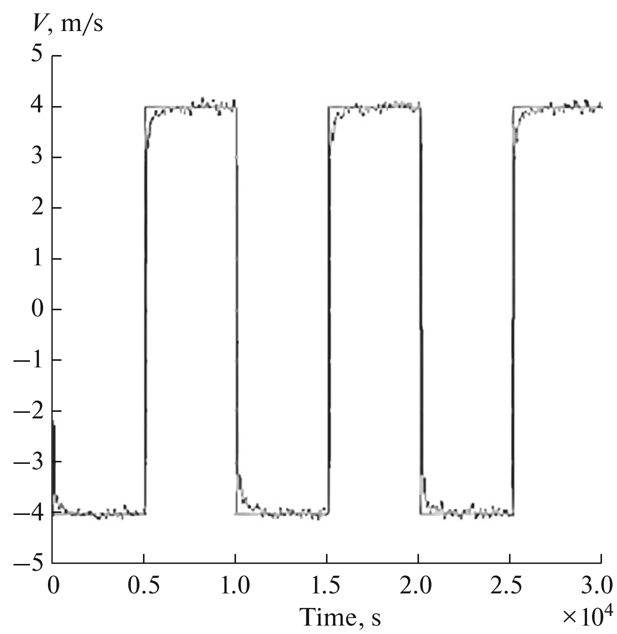

Fig. 13. Response of practical implementation of the system (time, velocity).

5. PRACTICAL RESULTS

The simulated fuzzy algorithm mentioned in the previous section was performed by a microcontroller, which was coded using the C language and implemented on the welding robot. Previously, the coefficients of PID controller were constant but in this mode, they were calculated using the fuzzy algorithm. Moreover, the speed signal was sampled and graphed through the MATLAB software using a PC connector card. The magnitude of coefficients K_p, K_i and K_d with respect to time were stored and graphed via a connection between a microcontroller and PC.

The system speed output and coefficients of PID are shown in following Figs. 13, 14. As seen, the system response is as desired and the steady state error equals to zero response.

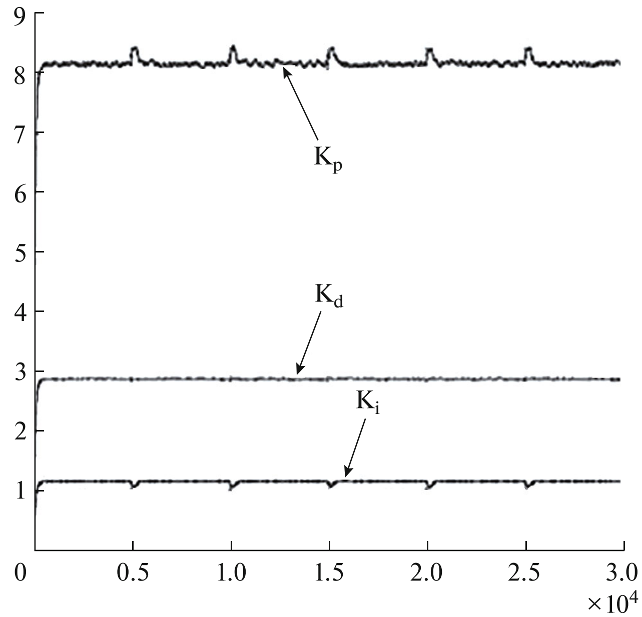

Fig. 14. Coefficients of PID controller in practical implementation.

6. CONCLUSION

As previously mentioned, PID controllers due to their simplicity in implementation are one of the best and most economic controllers. However, the adjustment of their coefficients is a significant problem. One of the conventional methods for automated coefficient adjustment is the application of intelligent or fuzzy methods.

This task is undertaken using the offline and online methods. In this research, the online method has been used; in which the coefficients of the controller are calculated and updated in every period of the sampling process. To do this, the fuzzy logic has been used. Besides membership functions and criteria associated with input-output signals, one of the most important aspects of designing this fuzzy logic is the selection of fuzzy rules.

Due to the simplicity in implementation and limitation in the microcontroller processing time, input/output signals have been divided into up to three states in the current research. To obtain a better response, the number of these states should be increased, implying, but as a consequence, the number of fuzzy rules and processes will increase too. In addition to this, the other type of fuzzy rules can be also tested for enhanced responses, which could be undertaken in further research.

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