

## Sustainable Control System Design Using A Nonlinear Fuzzy Logic Expert System PD Controller Design Approach In Matlab/Simulink

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### Abstract

The Nonlinear Fuzzy Logic (NFL) expert system design is another approach, like the Quantitative feedback theory (QFT), for designing a control system. The Fuzzy logic control is a formal methodology for implementing control system based on human heuristic knowledge. The fuzzy logic expert system tries to mimic an expert operator by converting crisp values into membership functions on a 2 dimensional(2D) array, 2 universes of discourse for the error (e) and the change in error (ce). The Robust design performance for the Oil Rig model-the Lab Servo Rig, in real time (online) using the matlab file (m-files) or the graphical user interface (GUI) in MATLAB is then compared with that of the SIMULINK model as well as the quantitative feedback theory (QFT) approach at the end of our design. For both designs, the same plant, controller and pre-filter models and specifications are used. This paper shows that both QFT and the fuzzy logic methods systematically gave out accurate and identical outputs, suggesting that both methods are highly of practical importance and can be used in the design process of a controller.

**Keywords:** heuristic, Error, MATLAB, SIMULINK, membership functions.

### INTRODUCTION

Many practical systems are characterized by high uncertainty (Patil and Kothawale, n.d; Abbas and Reza, 2008; Abbas and Kothawale, 2011), which makes it difficult to maintain good stability margins and performance properties for closed loop systems (Jadhav, Kadu and Parvat, 2012; Patil and Kothawale, Zhang and Zhang, 2013). There is, therefore, the need for proper control of these systems, in order that their performances do not drift into the region of instability which is highly

undesirable and catastrophic. Hence the need for design of control systems (plant, controller and filter) within specified limits or bounds (boundaries) in order to have desired and optimum performance. This report presents the design of a robust process (laboratory Servo Rig setup as the plant of a control system), having 2 degrees of freedoms feedback structure

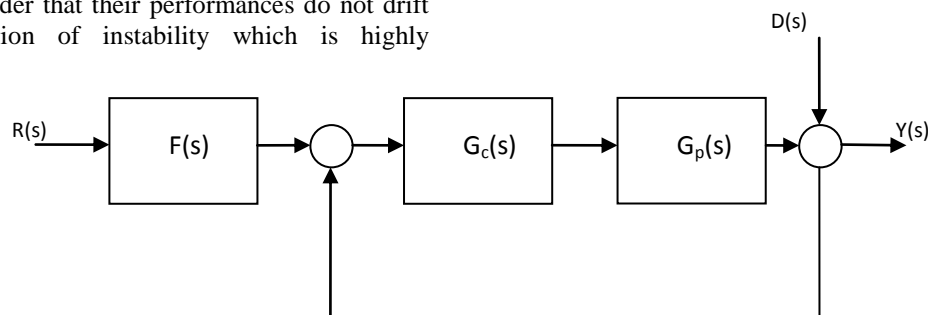


Fig 1. Multiple input single output (MISO) QFT Control Structure, having 2 degrees of freedom

### Significance of the Study

To show that QFT and fuzzy logic methods can be used to design controllers with boundaries in process systems as a means of optimizing productivity in process industries and technology. These methods may be applied in other human endeavor such as energy systems harvesting in renewable system and social sciences. This type of design process is automatic and self-sustaining

### Objectives

- I. To design a nonlinear fuzzy logic expert system PD controller for the laboratory servo Rig.
- II. To illustrate the operation of the fuzzy logic controller on the actual Rig.
- III. To compare and contrast its performance against the QFT controller design method.

### PROCEDURE, RESULT AND COMMENTS

Steps involved:

- ❖ Determination of state variables and control variables

- ❖ Selection of inference method
- ❖ Selection of fuzzification method
- ❖ Determination of knowledge base- discretization and normalization of state variables – partition of variable space – selection of membership functions (MFs) shape – design of rule base
- ❖ Selection of defuzzification strategy
- ❖ Test and tuning(3D surface look-up table)
- ❖ Construction of a lookup table [8]

The step by step procedure and results obtained are outlined below:

### Determination of State Variables and Control Variables

In MATLAB, we open the Sugeno Mandani Fuzzy Logic graphical user interface (GUI). Click on 'file', then on 'new', and then on 'sugeno', to obtain the GUI below:

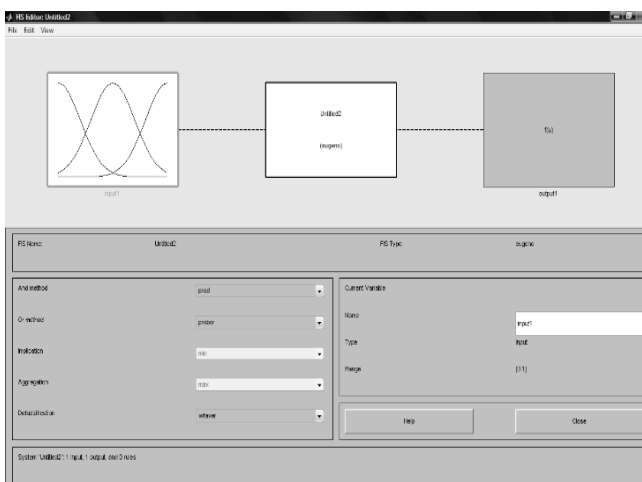


Fig 2. Opening fuzzy file

### Selection of Inference Method

Next is to select the inference method to be used which will depend on the number of inputs to the fuzzy logic controller. On the GUI, click on 'edit', then on 'clear input', then on 'add inputs'(select 2), in order to get 2 inputs.

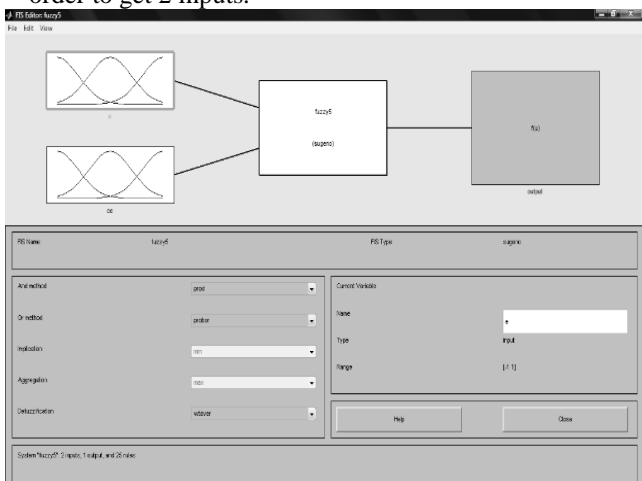
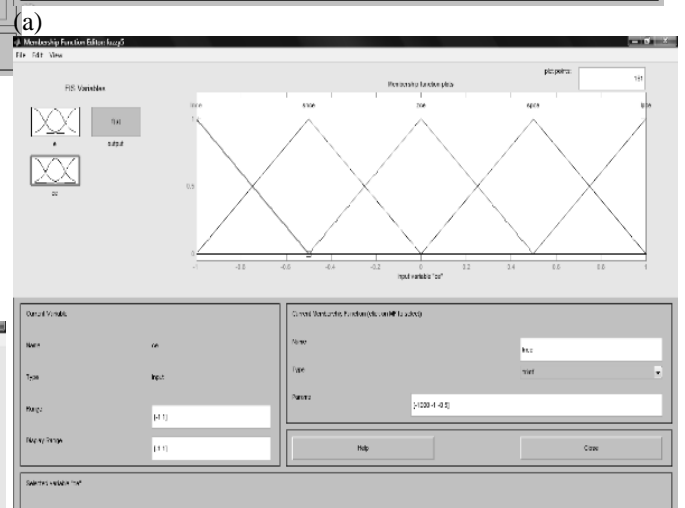
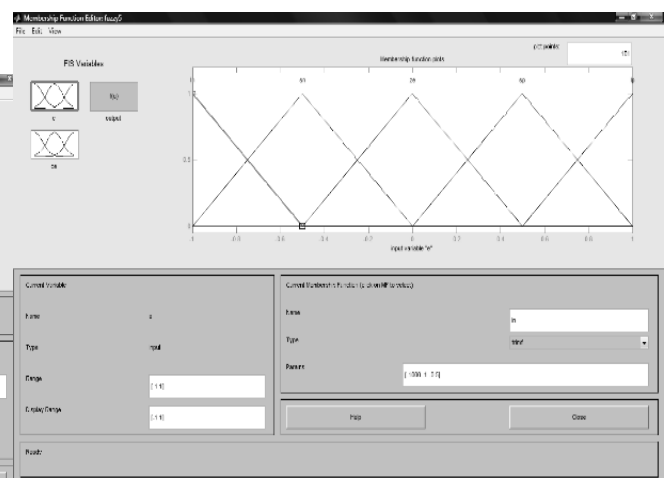


Fig 3. Creating input membership functions

### Selection of Fuzzification Method

The two inputs signals must be fuzzified. This is achieved by:

- (a) Input 1: Click on 'input 1' [the error (e)], to get the display below (fig. 4a) showing the membership functions and giving the input variables names and parameter. We have 5, namely; large negative(ln), small negative(sn), zero(z), small positive(sp) and large positive(lp).The gain parameter range is [-2 2]
- (b) Input 2: Same procedure as input 1 above, but with 'input 2' [the change in error (ce)], we will have:large negative change in error (lnce); small negative change in error (snce); zero change in error (zce); small positive change in error(spce) and large negative change in error(lnce). The gain range is [-14.77 14.77].



(b) Fig 4. Creating range for each membership function in the error (e) and the change in error (ce) inputs respectively.

### Determination of Knowledge Base- Discretization and Normalization of State Variables – Partition of Variable Space – Selection of Membership Functions(MFs) shape – Design of Rule Base

This is achieved by:

Click on 'sugeno' then on 'file', for the membership function rules which are displayed below:

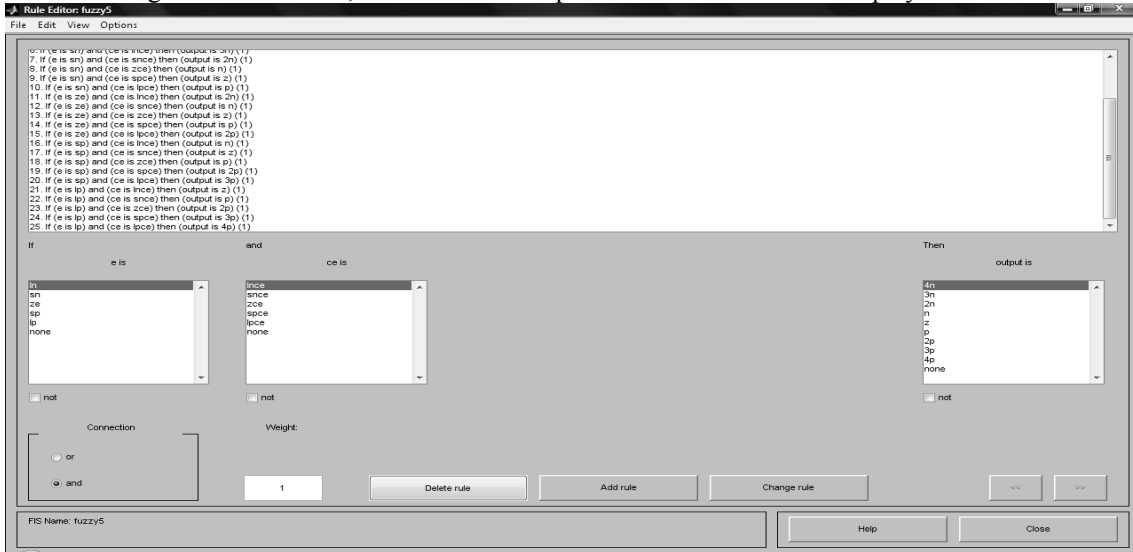


Fig 5. Creating membership functions rules.

**Selection of Defuzzification Strategy**

The two inputs (signals) into the input of the fuzzy logic controller must be fuzzified, which was achieved in step 3 above. At its output therefore, defuzzification must be carried out. The step involve:

Click on 'output' and give names to the variables and ranges from [-14.77 14.77]. Next, click on 'view', then on 'rule viewer' to get 25 rules view (in column form) for the inputs(input1, input2) and the output.[8]



Fig 6. Naming variables

This is realized by Clicking on 'option'and then on'surface', to get the non-linear 3D fuzzy surface

**Test and Tuning(3D Surface Look-up Table)**

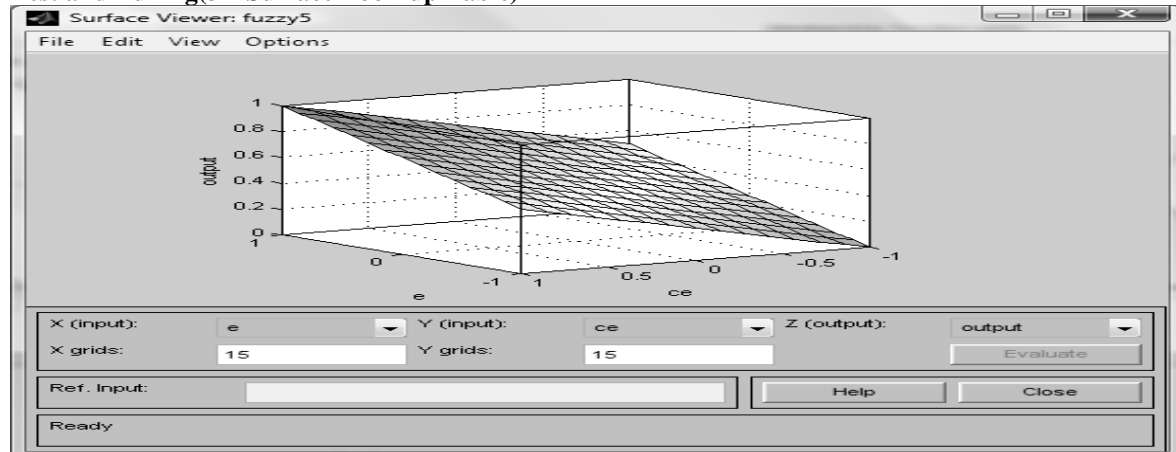
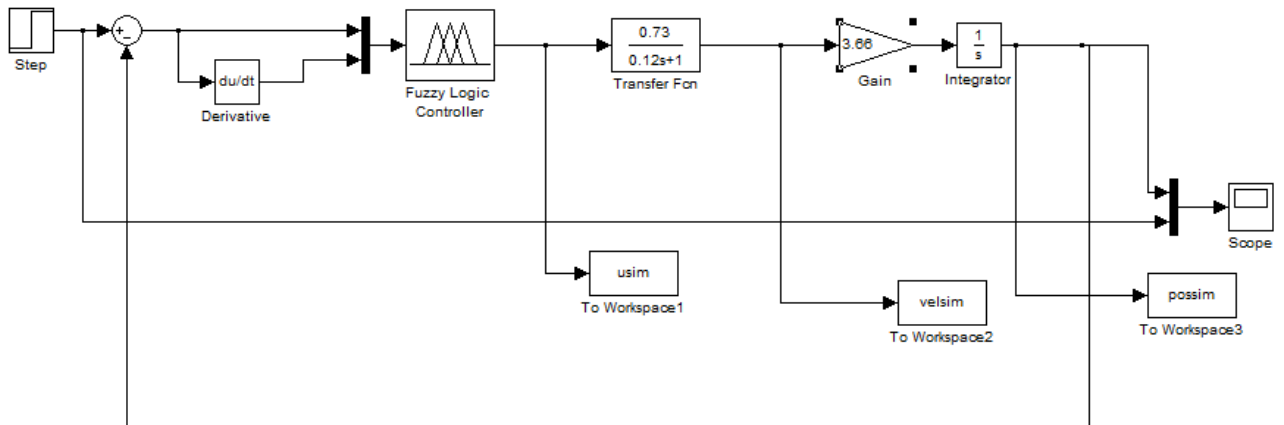


Fig 7. Dimensional fuzzy surface

After tuning/adjusting using the 3D surface look-up table, we then 'File export to workspace' to get the simulation in fuzzy (with  $g_u$  and  $g_l$ , the upper

and lower bounds of the step response.  $g_u = 121/s^2 + 11.66s + 121, g_l = 100/s^2 + 26s + 100$ ).



Next, run or simulate **fuzzy with brake** and **without brake** using the connection of fig. 8a below to get the scope results of the simulation fig. 8 b and c, and the result saved

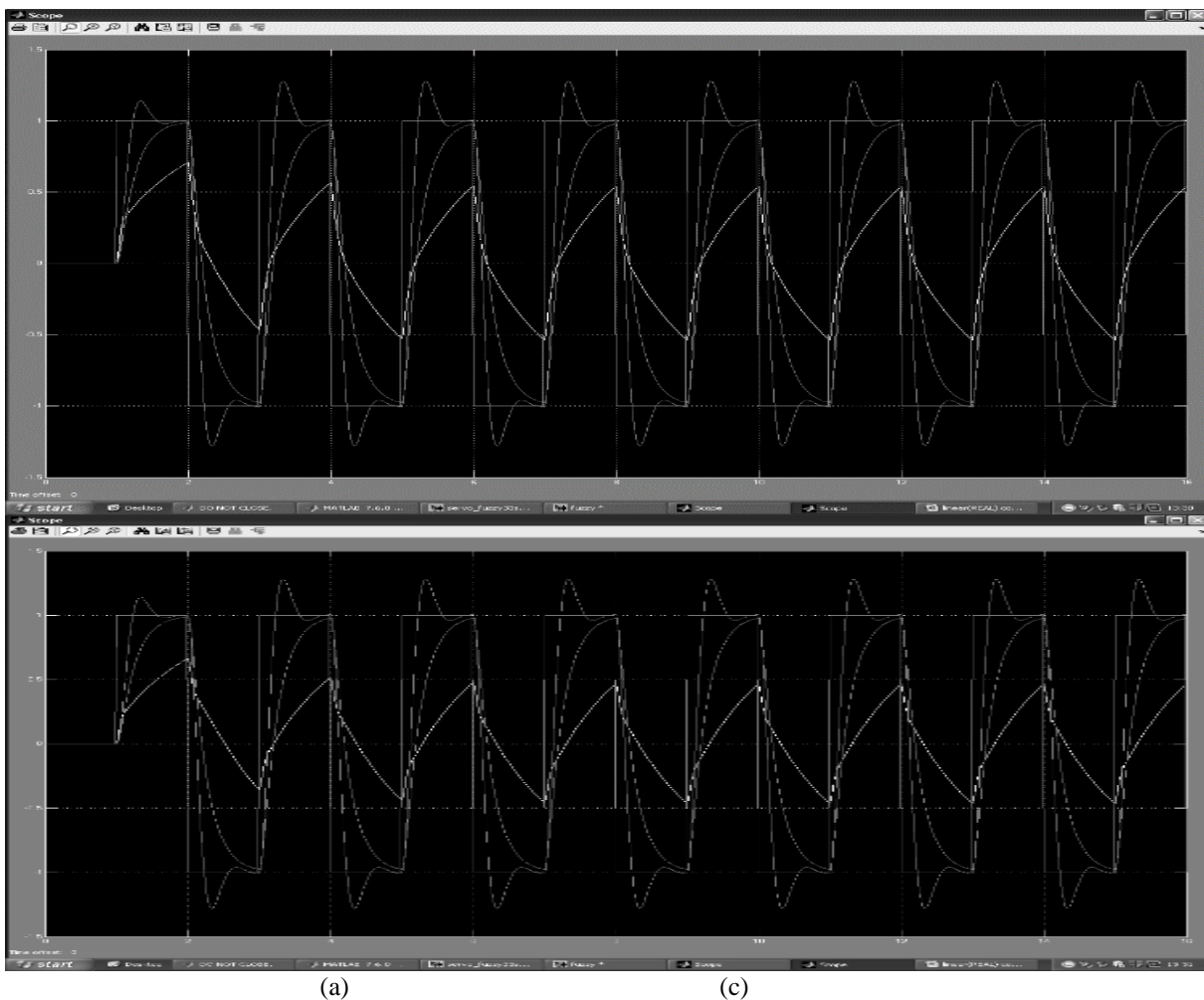


Fig. 7. Fuzzy simulation (a) simulation connection. (b) and (c) are the graphs obtained without brake and with brake

Same export to workspace for the real time fuzzy (with brake and without brake) is done on the servo

Rig by simply moving the arm of the lever to the extremes.

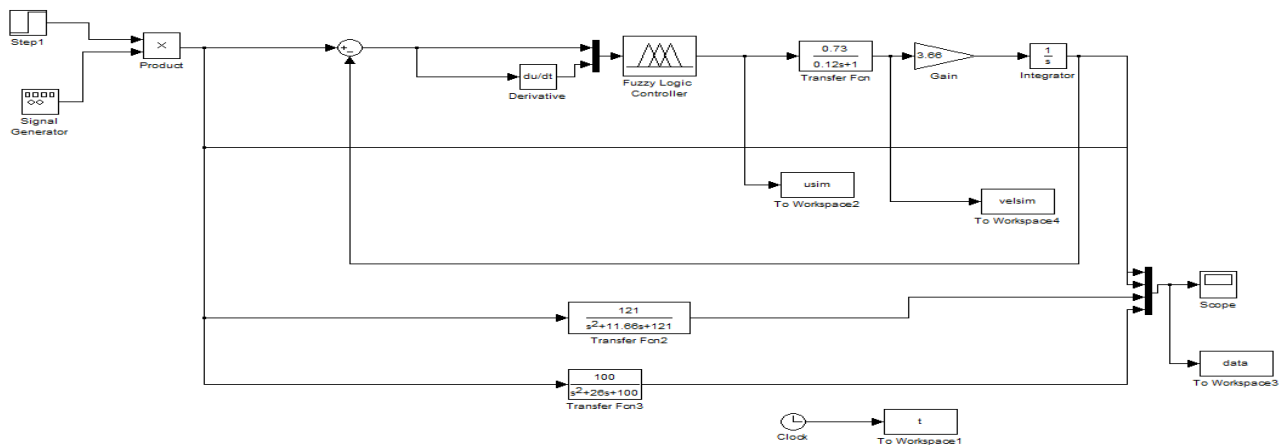
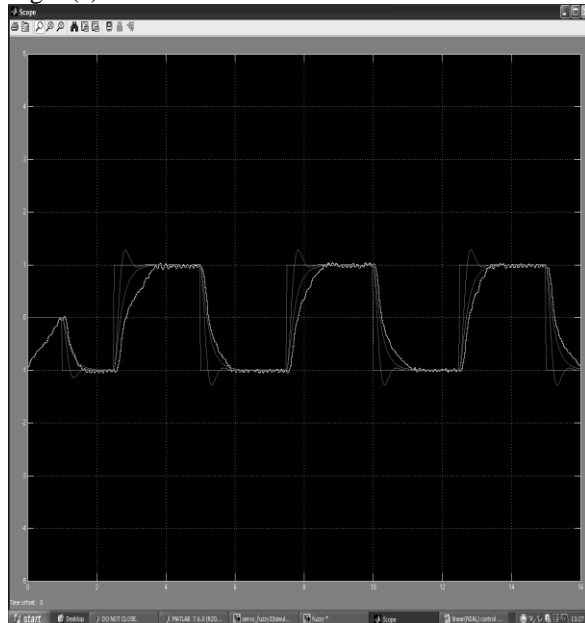


Fig 9 (a)



(b)

Fig 9. (a) The real time simulation of the fuzzy logic and (b), its scope

The final result indicates the real-time (online) simulation and run of the fuzzy logic controller on the Oil Rig model. The same waveforms are obtained in SIMULINK program run/execution.

### Limitation of the Study

The study is limited by test rig and laboratory data used as only a model, however, its application goes beyond the laboratory. It should be noted that the aim is the development of the process of designing the controller

### CONCLUSION

The final waveforms obtained via fuzzy logic can be seen in fig. 9(b). It shows the fuzzy logic controller waveform (the marginally stable wave to the square wave train) lying between **the  $g_u$  and  $g_l$**  (the

upper and lower bounds, shown as the overshoot and undershoot waves/signals respectively).  $g_u$  and  $g_l$  specify the permissible region and boundaries of stable operation of the fuzzy controller. They are given as  $g_u = 121 / (s^2 + 11.66s + 121)$  and  $g_l = 100 / (s^2 + 26s + 100)$ . The transfer function of the controller is  $0.73 / (0.12s + 1)$  with a controller gain of **100 dB**.

At the end of our design and on comparison, it is discovered that both QFT and the fuzzy logic methods systematically gave out accurate and identical outputs (i.e., correctly fitted each other), suggesting that both methods are highly of practical importance and used in the design process of a controller. Both Classical, and fuzzy logic control approaches provide a formal solution to control systems design. (Note that Fuzzy control is a formal methodology for implementing control system based on human heuristic knowledge). The algorithm used for the investigation of the behaviour of the system used in this control laboratory workshop for the two approaches is based entirely on the MATLAB (matrix laboratory)/SIMULINK software program.

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