The Economic Application Approach of Fuzzy Logic Controller Type I and II for Second Order Linear Systems

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Abstract

During the last decades, Fuzzy Logic Controller (FLC) has been studied in many researchers. In this paper, the applications of FLC for second order linear systems are reviewed. However, FLC has a good performance for nonlinear systems as well. The main focus of this research is evaluating the FLC performance for linear case study. Also a comparison between FLC and PI controller has been studied. Moreover, both fuzzy type I and II are applied for evaluating the system performance. All the systems are reviews from the economic perspective. It means that these methods tried to decrease the cost function of the system. All the simulation and results are done in MATLAB environment.

Introduction

FLC is studied in many researches for both linear and nonlinear systems. For instance, fuzzy controller as an adaptive controller for nonlinear systems have been reported [1], [2], and [3]. Also, the theorem of fuzzy logic for linear Functions is defined in [4], [5]. However, fuzzy logic controller are studied for a linear system in this paper. The applications of fuzzy logic controllers are a lot [6]. For instance in electrical engineering, fuzzy logic is applied in the main structure of the DC/DC converter problem in [7]. Also, in [8] and [9], the fuzzy has been considered in many optimization power systems problems. In [10] and [11], fuzzy has been applied to clustering data for wind renewable energies for the first time. On the other hand, fuzzy logic controller type II has been considered in the main structure of the problems as well. In [12] and [17] fuzzy logic type II for the first time is applied to control the switching the high and low voltage power systems. In this study, the Takagi Sugeno fuzzy controller is developed for fuzzy type 1 and type 2 [13].

Mathematical modelling of second order transfer function

A transfer function is a form of mathematical model between input and output of a system. "Transfer functions are commonly used in the analysis of systems such as single-input single-output filters, typically within the fields of signal processing, communication theory, and control theory. The term is often used exclusively to refer to linear, time-invariant systems (LTI), as covered in this article." [14].

The standard equation of a second order transfer function is:

$$G(s) = \frac{wn^2}{S^2+2\xi wnS+wn^2}$$

Where $w_d = w_n\sqrt{1-\xi^2}$. w_d is called the damp natural frequency.

To obtain the poles of system we have:

$$S^2 + 2\xi wnS + wn^2 = o \rightarrow S = \frac{-b \pm \sqrt{b^2-4ac}}{2a} = \frac{-2\xi wn \pm \sqrt{(2\xi wn)^2 - 4(wn^2)}}{2}$$

$$= \xi wn \pm \sqrt{\xi^2 wn^2 - wn^2} = (\xi \pm \sqrt{\xi^2 - 1})\, wn$$

The damping of the second order transfer function can be found in the following table:

If **ξ** > 1	over damped	We have to distinct real root
If **ξ** = 1	Critically damped	We have to equal real roots
If **ξ** < 1	Underdamped	Two complex conjugate roots

Table 1: Characteristics equation of the second order systems

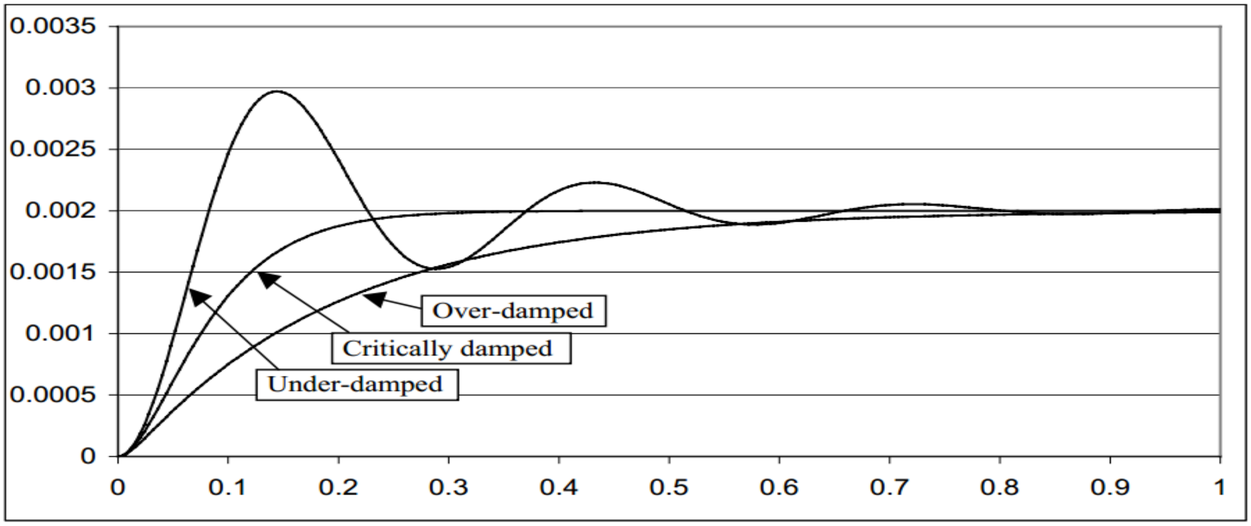

Figure 1: Step response for Under-damped, critically damped and over-damped systems

The final curve of a second order transfer function with a step unit source as an input is:

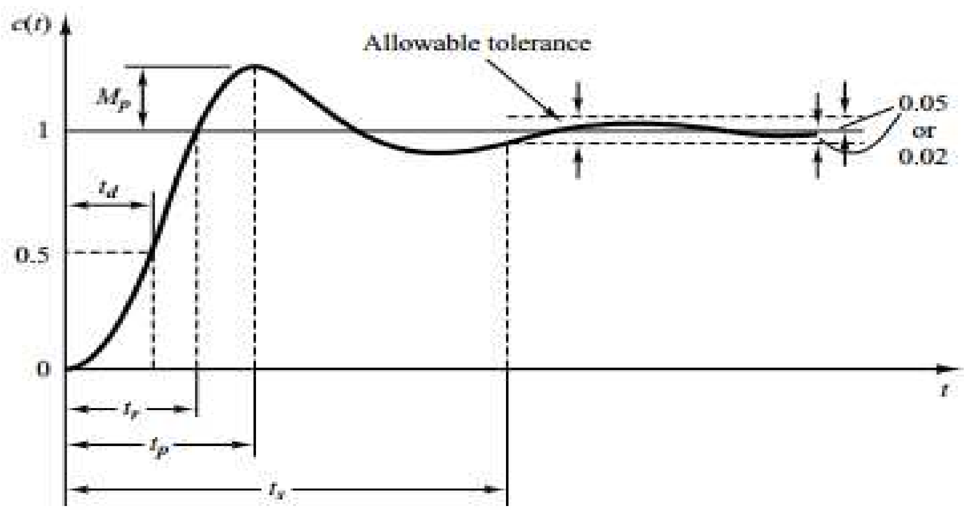

Figure 2: Transient and steady stat analyses

Where

1. Delay time, t_d
2. Rise time, t_r
3. Peak time, t_p
4. Maximum overshoot, M_p
5. Settling time, t_s

According to [15]:

$$M_p = e^{-(\xi/\sqrt{1-\xi^2})\,\pi}$$

$$t_s = \frac{4}{\xi w_n} \qquad \text{(2\% criterion)}$$

$$t_s = \frac{3}{\xi w_n} \qquad \text{(5\% criterion)}$$

$$t_p = \frac{\pi}{w_d}$$

Fuzzy Logic

Fuzzy logic is a type of controller created by Lotfi A.Zadeh in 1956 and continued by Mamadani and Sugeno theory. Todays, it has been applied to other sciences such as artificial intelligence, robotic, and control theory. In practice, fuzzy logic controller has many applications such as:

- Nissan – fuzzy automatic transmission, fuzzy anti-skid braking system
- CSK, Hitachi – Hand-writing Recognition
- Sony - Hand-printed character recognition
- NASA has studied fuzzy control for automated space docking

- Canon developed an auto-focusing camera by fuzzy controller

“Compared to traditional binary sets (where variables may take on true or false values true), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1.

Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false”.[16-22]

There are two types of Fuzzy controller in Matlab Simulink:

1- Mamadani: has a membership function in the output of the controller. No mathematical calculation is needed.
2- Sugeno: has a real number in the output but requires a mathematical model to achieve the output number.

In this project, Sugeno Fuzzy controller had been used.

Results

The final simulation and results of the fuzzy controller for both step and sine wave response are:

Results of (-3 2 3) as the output of fuzzy controller is:

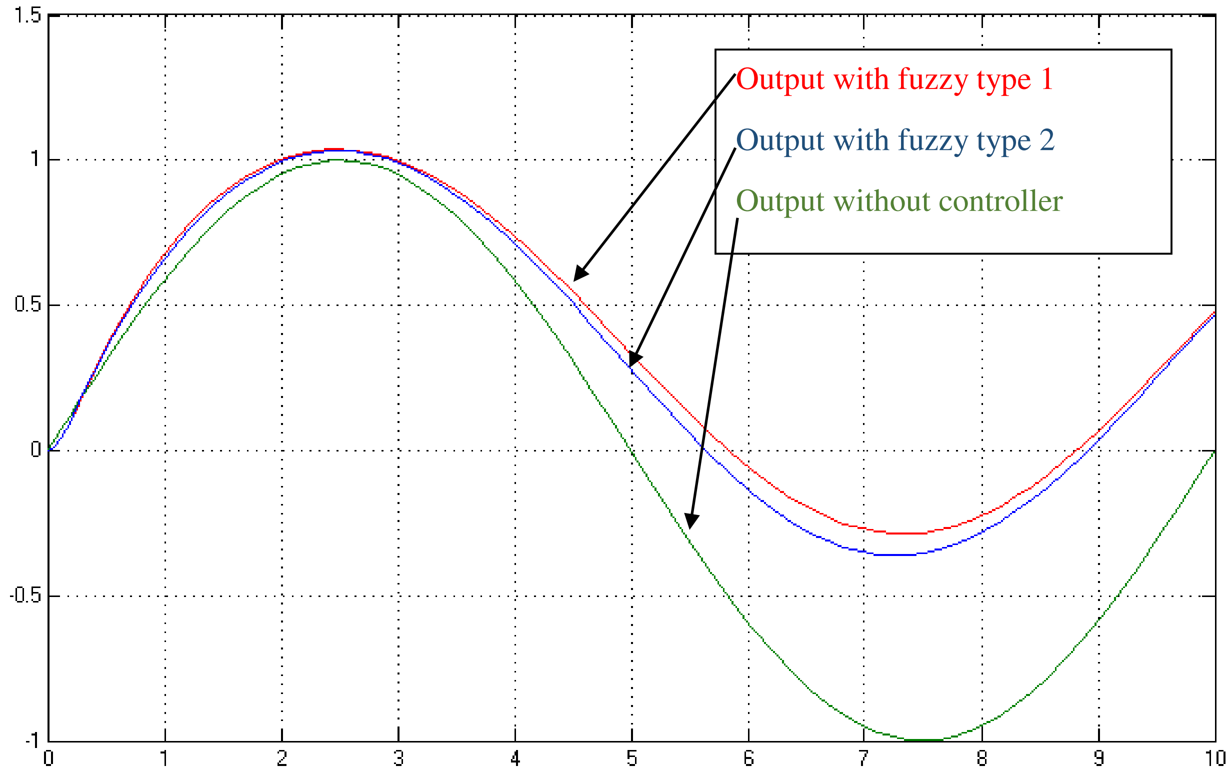

Figure 3: Sine wave frequency is 0.1 (Hz). The output of fuzzy is (-3 2 3)

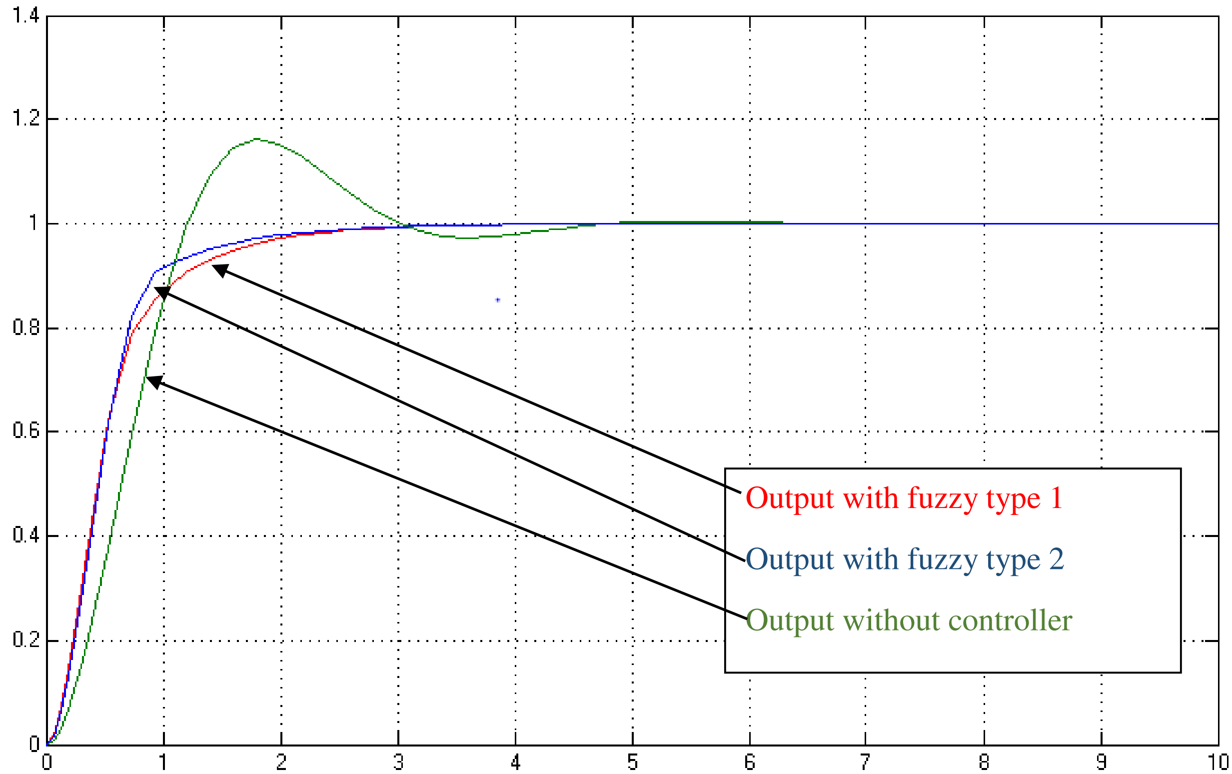

Figure 4: Step response when fuzzy output is (-3, 2, 3)

Results of (-20 2 20) as the output of fuzzy controller is:

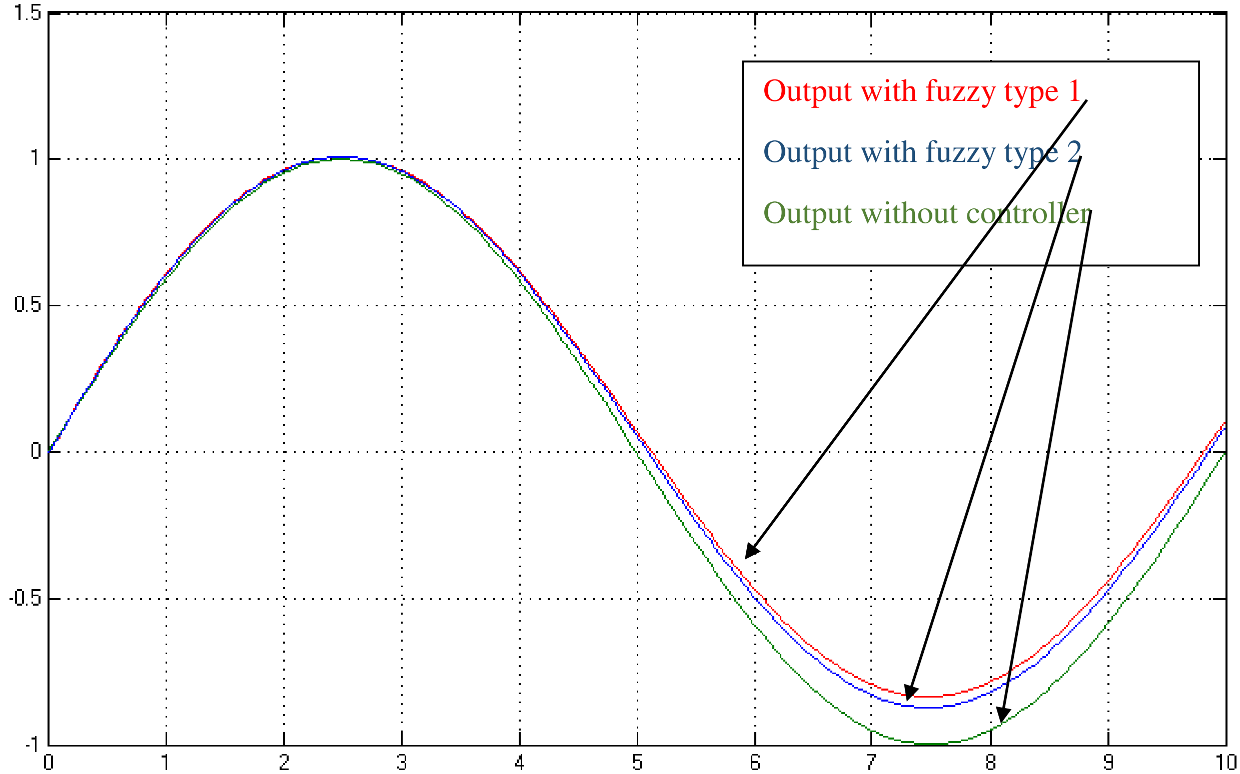

Figure 5:Sine wave frequency is 0.1 (Hz). The output of fuzzy controller is (-20, 2, 20).

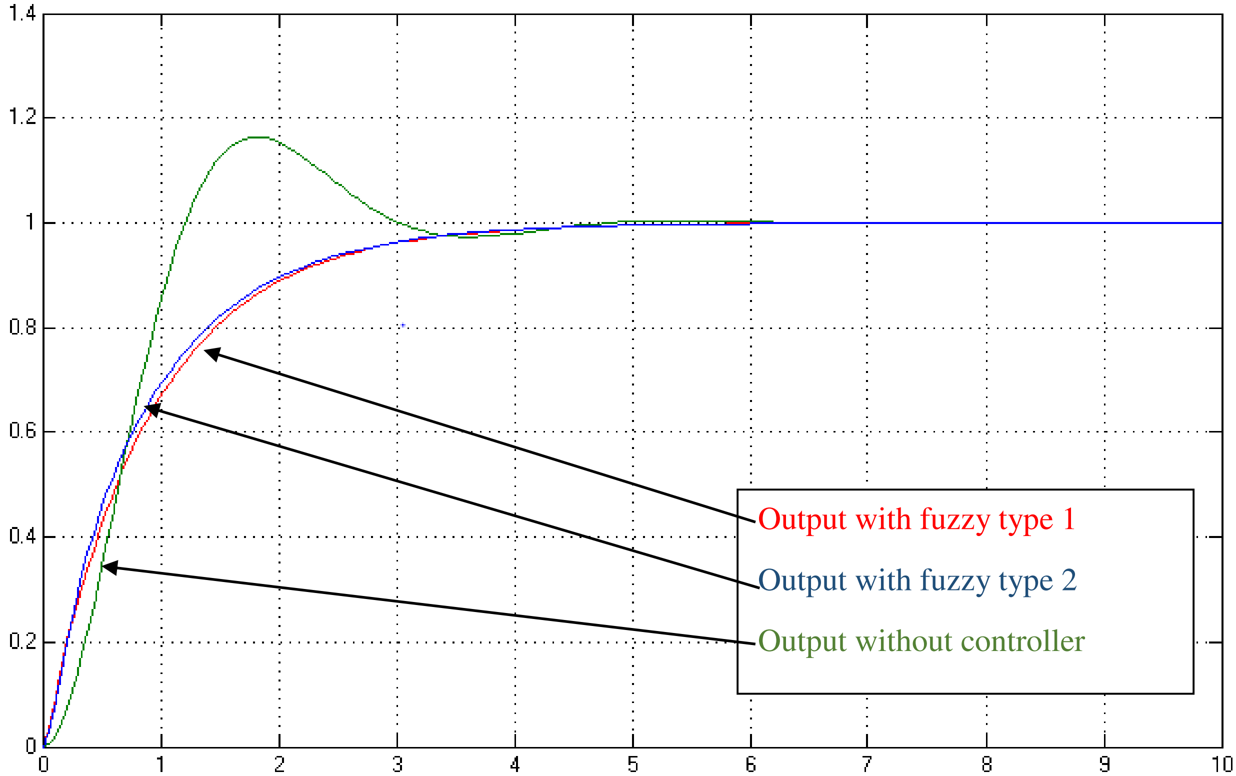

Figure 6: Step response when fuzzy output is (-20, 2, 20)

Conclusion

In this project, analysis of fuzzy controller type 1 and type 2 has been studied for second order linear systems. The performance of the control system has been studied for two different inputs: step response and sine wave response. Base on the finding, the operation of the fuzzy controller type 2 is better than type 1. Root square error and mean square error has been analyzed too. Base on the finding root mean square error and mean square error of fuzzy controller type 2 is lower than fuzzy controller type 1. Also, for the step input, rising time and steady state of the fuzzy type 2 is faster than type 1.

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