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Tuning Method in the Implementation Fuzzy ADRC Controllers for a Mass-Spring-Damper System: An approach

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Abstract. This article presents a new approach that describes a mass-spring-damper system as a second-order system. Thus, the first part implements the Active Disturbance Rejection Control (ADRC) controller, and then the implementation of the fuzzy ADRC controller will be simplified by the tuning technique. The article also presents a simulation of the mass-spring-damper system using the output plant transfer function. The paper implements a controller to control the closed-loop system. Finally, a graphical comparison of the respective controllers is shown in the mass-spring-damper system.

Keywords. Control ADRC, Control Fuzzy ADRC, Mass-Spring-Damper System, Second Order Differential Equation

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1 Introduction

The study of the movement experienced by a mass suspended from the free end of a spring is discussed in most introductory physics courses from theoretical and experimental outlooks. Springs, dampers, and masses are typical components of a mechanical system. In [1], propose a vibration suppression control method for a mass-spring-damper system with one or two dynamic damper(s). The feedback is designed by the interconnection and damping assignment passivity-based control, where the system is transformed into a system having a skyhook damper with an artificial modification of the structure matrix.

Semi-Active Suspension Control Design for Vehicles is described in [4]. In a Semi-active suspension system, the damping coefficient of the shock absorber or spring constant is electronically controlled, without adding external energy to the system, except the device control that changes the damping coefficient or the elastic constant characterizes a semi-active suspension; mostly of the cases, is the damping coefficient of the dissipative element that varies in semi-active suspensions in [4]. The motion equations and state-space model are the same for passive suspension systems, so none of the parameters are changed. In contrast, for semi-active suspension systems, these parameters may vary. The paper [6] presents a new approach to the fuzzy active-disturbance rejection position controller of the bearingless induction machine. In the paper, [5] proposed a control variable for the radial position problem, and the ADRC control is used to improve the closed-loop system dynamic when a changing load occurs on the output system.

The mechanism and Lagrange methods model the mass-spring-damping resonance system and analyze the system stability. The mechanism and Lagrange methods model the mass-spring-damping resonance system, and the system stability is analyzed. The extended state observer (ESO) algorithm analyzes and controls the mass-spring-damping system based on active disturbance rejection control ADRC theory. The ADRC solution, as a generic controller, does not require detailed model information beyond the integral dynamics. Therefore, it is interesting to explore what benefits, if any, can be obtained by incorporating such knowledge into the ADRC solution, perhaps in reducing the load on the estimation of the total disturbance [7]. The ADRC uses the tracking characteristics of the extracted differential signal to formulate the signal transition arrangement between the input and differential signals. When the signal response changes abruptly, the tracking differentiator (TD) can promptly provide the smooth signal as the input signal to the controlled system, thereby ensuring that a large overshoot due to the mutations is not incurred and the system stability is enhanced in [2].

This paper studies implementing a Fuzzy ADRC control in the mass-spring-damper system. The article presents a guide to the introduction section. The section 2 presents the mathematical model and the ADRC controller. The section 3 presents results using Fuzzy ADRC Controller and discussions. In section 4, the conclusions are made.

2 Mathematical model and ADRC Controller

In [3], it is formulated that as a two-degree-of-freedom active disturbance-rejection method, the equivalent-input-disturbance (EID) approach shows its validity for structural control. It uses a state observer to estimate the effect of disturbances on a control input channel. A stability condition of the system with prescribed control performance is derived in the form of a linear matrix inequality (LMI) that is used to design the gain of the state feedback. To simulate the mass-spring-damper system and apply the Proportional-Integral-Derivative (PID) controller and ADRC controllers, it is first necessary to mathematically model the entire system to obtain the plant transfer function. Applying the sum of the forces concerning the mass of the system block, it is possible to obtain equation (1) , where $u(t)$ is the applied external force, m is the block mass

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, k is the spring constant, and f_v is the viscous force of the damper. The motion is in a line which we can take to be the y-axis.

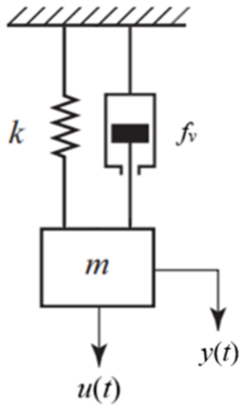

Figure 1: Mass-spring-damper system.

$$u(t) = m\frac{d^2y}{dt^2} + f_v\frac{dy}{dt} + ky \tag{1}$$

Since equation (1) is an ordinary differential equation it is possible to apply the Laplace transform, thus obtaining an external force in the Laplace domain U(s) and also the position Y (equation (2)).

$$U(s) = ms^2 + f_v s + kY \tag{2}$$

The plant transfer function is classified as the ratio of output and input, thus rewriting equation (2) the plant transfer function was obtained the equation (3).

$$P(s) = \frac{Y(s)}{U(s)} = \frac{1}{ms^2 + f_v s + kY} \tag{3}$$
$$P(s) = \frac{1/m}{s^2 + \frac{f_v}{m}s + \frac{k}{m}Y}$$

For the transfer function in terms of natural frequency (ω_n) and damping coefficient (ϵ) we have:

$$H(s) = \frac{\omega_n^2}{s^2 + 2\epsilon\omega_n s + \omega_n^2} \tag{4}$$

where $\omega_n = \sqrt{\frac{k}{m}}$ and $\epsilon = \frac{f_v}{2m\omega_n}$

The mass-spring-damper system is characterized as a second-order system, thus the ADRC controller for a second-order system is given as:

$$\ddot{y} = f(y, \dot{y}, d, t) + bu \tag{5}$$

Where y is the position, u is the input parameter, b is a constant, d is an unknown parameter (external perturbation) and $f(y, \dot{y}, d, t)$ is known as the generalized perturbation of the system and its knowledge not required for controller design and implementation. The only information needed is its real-time estimated value. Let $\tilde{f}$ be the estimate $f(y, \dot{y}, d, t)$ at a time t, then the control law proposed by the ADRC method is as follows:

$$u = \frac{-\tilde{f} + u_0}{b} \tag{6}$$

3 Results using Fuzzy ADRC Controller and discussions

ADRC adopts a nonlinear state error feedback strategy, which can significantly improve the efficiency of feedback control. Non-linear state error feedback is based on the principle of "small error, large gain, large error, small gain", appropriate selection of parameters and linear interval for segmentation, and the use of different gain control in different intervals can obtain the effect of rapid adjustment. Fuzzy-Self-adapted ADRC structure, its structure is shown in Figure (2) and Fuzzy-Self-adapted ADRC structure with rotational transformation, its structure with rotational transformation is shown in Figure (3).

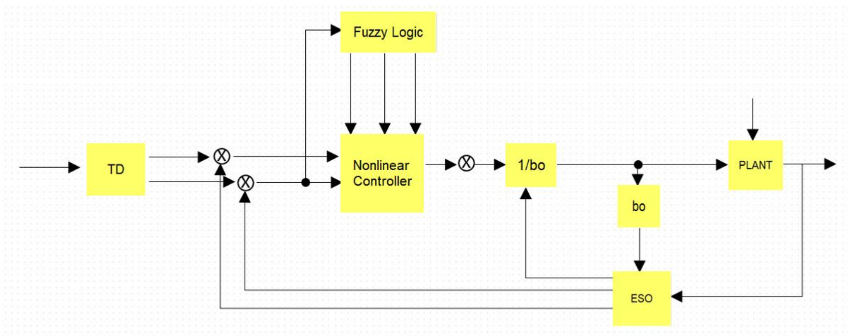

Figure 2: Fuzzy-Self-adapted ADRC structure.

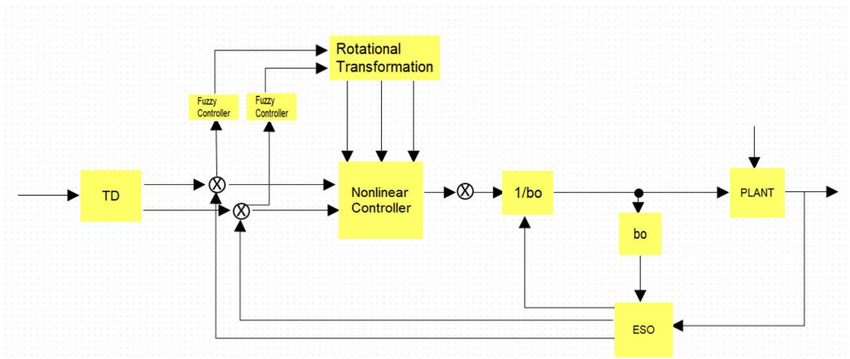

Figure 3: Fuzzy-Self-adapted ADRC structure with rotational transformation.

The following results were based on the articles [5], [6]. So the notations, inputs, outputs, error and other parameters can be seen in detail in [5], [6]. This article introduces the fuzzy logic controller, according to the input of , e_1, Δe_1, e_2, Δe_2 and using fuzzy control rules to change the ADRC parameters $\{\Delta i_x, \Delta i_y\}$, with rotational transformation is obtained approaching the optimal

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parameters $\{\beta_0, \beta_1, \beta_2\}$. To meet the requirements of the $\{e_1,\ \Delta e_1,\ e_2,\ \Delta e_2\}$ parameters of the Fuzzy ADRC, in the controller, the fuzzy variables are e_1, e_2, $\{\Delta i_x, \Delta i_y,$, in your domain, seven language sets defined such as { (NB), (NM), (NS), (QZ), (PS), (PM), (PB) }. For $\{\Delta i_x, \Delta i_y\}$ parameter configuration, fuzzy control table is formed, as demonstrated in Tables (2) and (3). The adjustments gave rise to the error and the change in the error pertinence functions illustrated in Figures (4), (5) and the output pertinence functions represented in Figure (6) and the rules summarized in Table (2).

Table 1: Linguistic labels adopted to describe fuzzy sets.

Label	Signification
NB	Negative Big
NH	Negative Huge
NM	Negative Medium
NS	Negative Small
QZ	Quasi- Zero
PH	Positive Huge
PS	Positive Small
PM	Positive Medium
PB	Positive Big

Table 2: Rules for x-axis fuzzy controller.

d \ f	NB	NM	NS	QZ	PS	PM	PB
NB	NH	NH	NH	NB	NM	NS	QZ
NM	NH	NH	NB	NM	NS	QZ	PS
NS	NH	NB	NM	NS	QZ	PS	PM
QZ	NB	NM	NS	QZ	PS	PM	PB
PS	NM	NS	QZ	PS	PM	PB	PH
PM	NS	QZ	PS	PM	PB	PH	PH
PB	QZ	PS	PM	PB	PH	PH	PH

Table 3: Rules for y-axis fuzzy controller.

g \ h	NB	NM	NS	QZ	PS	PM	PB
NB	NH	NH	NB	NB	NM	NS	QZ
NM	NH	NB	NB	NM	NS	QZ	PS
NS	NB	NB	NM	NS	QZ	PS	PS
QZ	NB	NM	NS	QZ	PS	PS	PM
PS	NM	NS	QZ	PS	PS	PM	PB
PM	NS	QZ	PS	PS	PM	PB	PH
PB	QZ	PS	PS	PM	PB	PH	PH

It is said to see that, each piece of the position Fuzzy-ADRC controller is construed, Its entire control frame is demonstrate in Figure (2). The x_1 is the monitoring signal of θ^* , x_2 is the differential signal of θ^* , z_1 is the monitoring signal of θ , z_2 is differential signal for z_1, z_3 is system observation of the incertitude piece of the perturbance that is $w(t)$ as the observation for

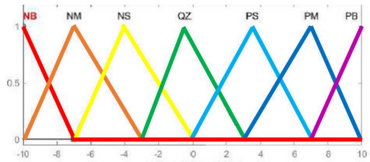

Figure 4: Membership functions of input variables.

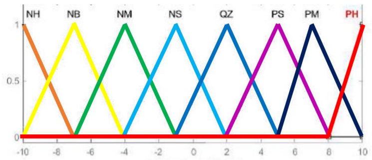

Figure 5: Membership functions of input variables.

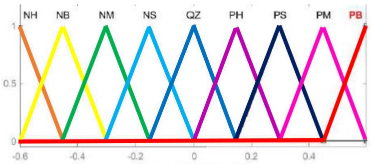

Figure 6: Membership functions of output variables.

the certain part, where the differential is different from the differential signal in a controller, its effect is not amplified, but disincentive to the noise signal. According to the table of allocation of members of fuzzy set Tables (2) and (3) and the fuzzy control model of parameters, and with diffuse synthetic reasoning to project diffuse matrix, then defuzzification and correction parameters found $\{\Delta i_x, \Delta i_y\}$, with rotational transformation is obtaneid $\{\Delta\beta_0, \Delta\beta_1, \Delta\beta_2\}$ and replaced it in the equation:

$$\beta_0 = \beta_0^{'} + \Delta\beta_0 \tag{7}$$

$$\beta_1 = \beta_1^{'} + \Delta\beta_1 \tag{8}$$

$$\beta_2 = \beta_2^{'} + \Delta\beta_2 \tag{9}$$

Where variables $\beta_0, \beta_1, \beta_2$ is the nonlinear controller initial value. According to rotational transformation is obtaining parameters $\beta_0, \beta_1, \beta_2$. Finally, with the principles of Fuzzy ADRC parameters tuning, we can obtain Fuzzy-ADRC. In the Figure (7) presents a comparison between the simulations. With $\beta_0^{'} = 0$, $\beta_1^{'} = 0$, $\beta_2^{'} = 0$, $\{\Delta\beta_0\}$ $\{\Delta\beta_1\}$,$\{\Delta\beta_2\}$ domains are $[-6, +6]$, $[-6, +6]$, $[-0.6, +0.6]$. Thus $\beta_0 = \Delta\beta_0$, $\beta_1 = \Delta\beta_1$ and $\beta_2 = \Delta\beta_2$. The fuzzy adrc controller is well optimized because there is a good tuning of the fuzzy adrc controller.

4 Conclusions

The article presents a new approach that describes a mass-spring-damper system as a second-order system. Thus, when implementing the Fuzzy ADRC controller in the mass-spring-damper system. The implementation of the Fuzzy ADRC controller was simplified by the technique used.

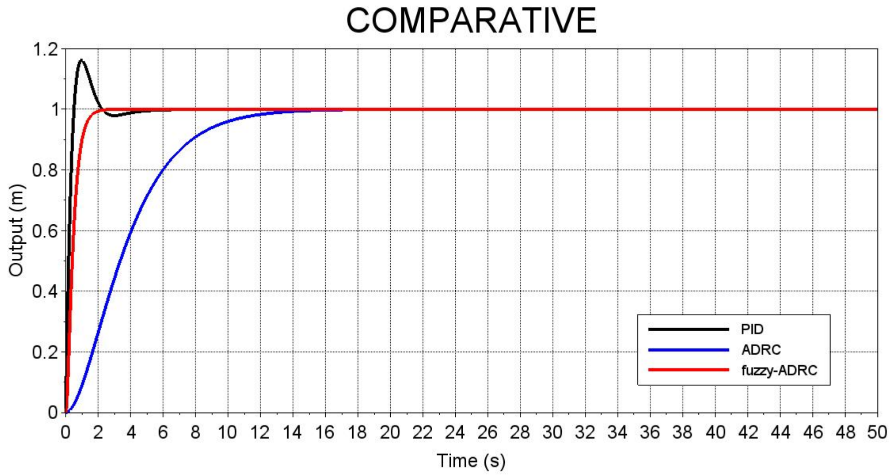

Figure 7: Comparison between simulations.

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