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Fuzzy Control of a Scale Prototype Overhead Crane

Martín Gutiérrez
VI Technology, Inc.
5114 Balcones Woods Dr. Ste. 307-462
Austin, TX 78759, USA.
martin.gutierrez@vi-tech.com

Rogelio Soto, *Member, IEEE*
Centro de Inteligencia Artificial
ITESM, Campus Monterrey
Sucursal de Correos "J"
Monterrey, N.L. 64849, Mexico.
r.soto@ieee.org

Abstract

A fuzzy logic controller was designed for a scale prototype overhead crane. The set of fuzzy rules that describe the controller behavior was derived in such a way to resemble the behavior of a precalculated trolley acceleration profile. Results from simulations and experimental tests show that the load angular displacement overshoot does not depend on trolley travel distance. Besides, any remaining oscillation is damped by the controller when the trolley gets to the desired position.

1 Introduction

Crane operation automation is very important for almost any industry. Due to its nonlinear nature, it's very difficult to propose a complete and satisfactory solution for a generic overhead crane. Fuzzy logic controllers have shown that can handle very well this kind of nonlinear systems. The developed fuzzy control algorithms were tested in a scale prototype overhead crane (SPOC). The prototype was built using a direct current motor, a belt, a rail, a trolley, a steel rope and a spherical load [1]. A model of the SPOC is shown in Figure 1.

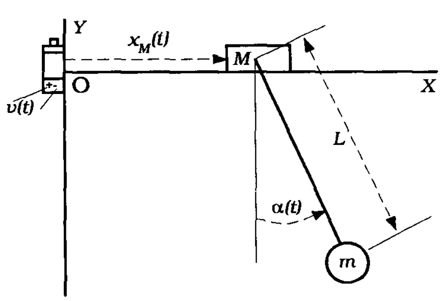

Figure 1: Model of the crane.

In order to simulate the fuzzy controller before testing the prototype, we developed a mathematical model including dynamic and static frictions. The constants of the model were identified using several experiments including Pseudo Random Binary Sequence (PRBS) and optimization tools. Fuzzy logic controller design is shown in Section 2, where the controller structure as parameter selection is described. Then the simulated and experimental results are shown in Section 3.

2 Fuzzy controller design

The fuzzy logic controller was implemented using the controller structure shown in Figure 2.

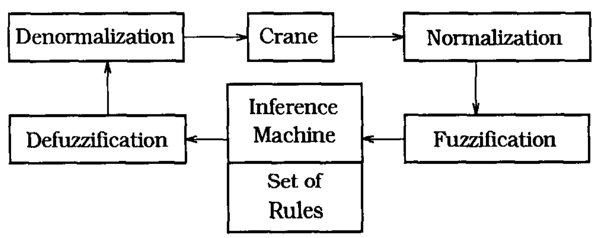

Figure 2: Controller architecture.

2.1 Normalization and Denormalization

In fully linear controllers for overhead cranes the trolley maximum travel speed depends on the travel distance. This is a non-desired behavior for most of real industrial cranes. In order to avoid this problem, crane outputs ($x_M(t)$ and $\alpha(t)$) were normalized. Denormalization is used to adjust the result from the defuzzification process to the motor voltage range.

2.2 Fuzzification

Fuzzification is the process where controller-input crisp values are converted to fuzzy ones. Figures 3 and 4 show the fuzzy set distribution assigned to the controller inputs ($x_M(t)$ and $\alpha(t)$). Numerical values were obtained based on trial and error, observing the controller performance during simulations and real tests using the SPOC. Nonetheless, there is an explanation for the number of sets and their distribution. For in-

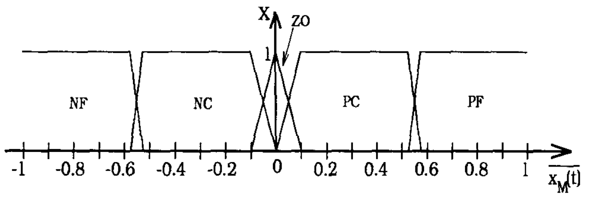

Figure 3: Linguistic representation for $\overline{x_M(t)}$

stance, in Figure 3 NF and PF represent the travel zone for the trolley, NC and PC the break zone and ZO makes sure the trolley gets the desired position.

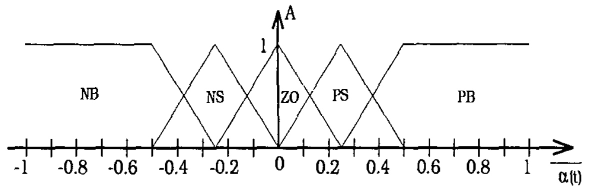

Figure 4: Linguistic representation for $\overline{\alpha(t)}$

In Figure 4, NB and PB are the zones where the load angle is very big and therefore unacceptable. In this case the controller tries first to damp the angular displacement and then to move the trolley to the desired position. NS and PS are the zones where the angular displacement is acceptable and ZO describes the desired equilibrium zone.

2.3 Derivation of fuzzy rules

The voltage applied to the D.C. motor ($v(t)$) was represented as a linguistic variable using the fuzzy sets shown in Figure 5. This definition gives enough flexibility in choosing the consequent of the fuzzy rules.

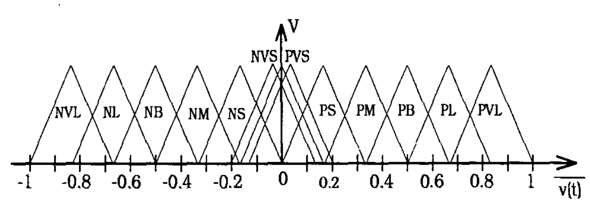

Figure 5: $v(t)$ as a linguistic variable

The set of fuzzy rules is the core of the controller. Choosing these rules is the most difficult part in designing a fuzzy controller. In order to come up with this set of rules we tried first to resemble the behavior of a linear controller like the controllers presented in [2] and [3]. Unfortunately the controller became very complex using four inputs ($x_M(t)$, $\dot{x}_M(t)$, $\alpha(t)$ and $\dot{\alpha}(t)$), ten linguistic values for each variable and more than 100 rules. Besides the controller performance was very poor. Then, we decided to start over using only two process outputs ($x_M(t)$ and $\alpha(t)$) for two reasons. First to simplify the controller and second, because these outputs carry enough information to control the crane.

The next step was to look for a method to move the trolley to the desired position while minimizing oscillations in the load. This method could come from a real crane operator's experience, using the prototype or any other source. The most interesting method that we found was the physics approach. In this method a profile for the trolley acceleration is precalculated. The basic idea of the profile is to accelerate the trolley until the load gets the minimum allowed angular displacement. Then continue moving at a constant speed until the load gets the maximum allowed angular displacement. Next accelerate again the trolley in order to get the point where the trolley and the load are traveling at the same speed so the angular displacement must be zero. Finally the profile suggest applying the reverse maneuver in order to stop the trolley and the load.

Usually this kind of controller works very well in simulations and very bad in practice. The problem is that they are using open loop controllers based on the assumption that there are no frictions and that they know accurately all the parameters of the model. Therefore when the trolley stops moving the load always have remaining oscillations [4].

Then we derived the set of fuzzy rules based on the precalculated profile proposed by [4]. This profile is shown in Figure 6.

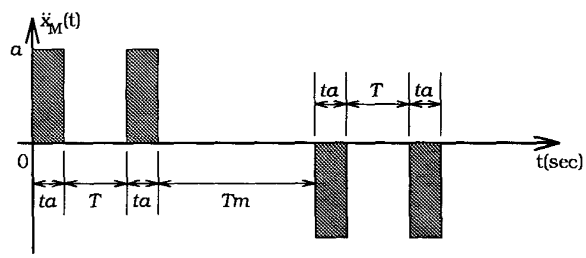

Figure 6: Trolley acceleration profile.

The controller's set of fuzzy rules is shown in Table 1. The first column has the linguistic values for the angular displacement and the last row the linguist values assigned to the trolley position.

The controller will try to damp any angular displacement first and then it will move the trolley to the desired position avoiding oscillations. This behavior is possible due to the nonlinear capabilities of fuzzy logic control. The fuzzy rules were evaluated using Larsen method [5].

Table 1: Controller's set of fuzzy rules.

PB	PVL	PL	PB	PB	PB
PS	PL	PB	PM	PM	PVS
ZO	PB	PVS	ZO	NVS	NB
NS	NVS	NM	NM	NB	NL
NB	NB	NB	NB	NL	NVL
α/X	NF	NC	ZO	PC	PF

2.4 Defuzzification

The objective of this process is to get a crisp value using the result of the inference process. To convert the scaled fuzzy sets to crisp values we used the center of area method. Then we aggregate these values using the arithmetic method.

3 Simulated and Experimental Results

Figure 7 shows the result of 45 simulations plotted in the phase plane using a grid of initial conditions for the state variables. Here, we can observe that the controller will try to reduce the load angular displacement first and then move the trolley to the desired position. Besides, we can observe that all the trajectories lead to the origin. This plot does not pretend to be a stability proof. Nonetheless, according to [5] using the phase plane approach, we can predict the stability of the system from a qualitative point of view.

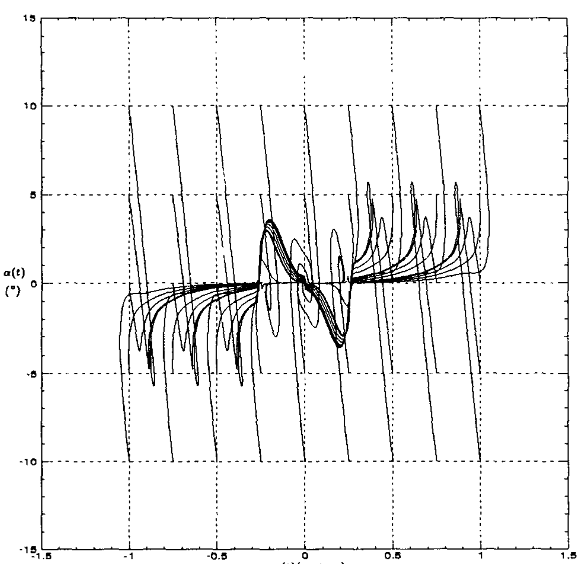

Figure 7: Phase plane.

3.1 Experimental Response

Finally, the response to a step input of 1 m. (trolley travel distance) is shown in Figure 8. $x_M(t)$ and $\alpha(t)$ are plotted for 8 sec. of time.

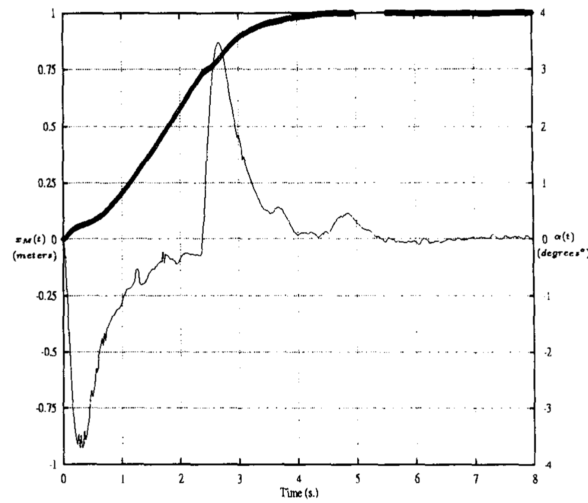

Figure 8: Experimental response.

Here we can observe that the remaining oscillations in the load when the trolley gets the desired position are damped by the controller doing slight movements in the trolley. And second, the load angular displacement overshoot does not depend on the trolley travel distance. If we increased the trolley travel distance, the controller would apply the same maneuver to start and to stop moving the trolley.

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