INVESTIGATION OF REAL TIME CONTROL IN DYNAMIC SYSTEM USING FUZZY LOGIC CONTROLLER

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Abstract— *The main objective of this paper is to investigate the performance of inverted pendulum using pole on cart system. Inverted pendulum system is unstable without control, that is, the pendulum wills simply fall over if the cart isn't moved to balance it and naturally falls downward because of gravity. Thus, the inverted pendulum system is inherently unstable. In order to keep it upright, or stabilize this system, one needs to manipulate it, either vertically or horizontally and it requires a continuous correction mechanism to stay upright since the system is unstable, non-linear and non-minimum phase behavior. To overcome this problem, the fuzzy logic controller will be designed. The Fuzzy Logic Controller has been chosen to stabilize the pendulum rod and keeping the cart in a desired position. Fuzzy logic has provided a simple way without going through the mathematical approach as conventional controller in order to arrive at a definite conclusion based upon nonlinear and an unstable of inverted pendulum system. Besides that, Fuzzy logic control system (FLC) was chosen as the control technique because of its ability to deal with nonlinear systems, as well as its intuitive nature. One special feature of fuzzy logic control is that it utilizes the expertise of humans to control the physical system, so that complex system can be controlled without extensive modeling of the relationship between the input and output of the system.*

1. INTRODUCTION

Traditional control theory has perfect control ability for explicitly controlled system, however, which is a little weak to describe too complex or difficult system accurately. Therefore, many researchers seek ways to resolve this problem; those researchers have also focused on fuzzy mathematics and applied it to control problems. Zadeh [1] created fuzzy mathematic son an uncertainty system of control which is great contribution. Since the 70s, some practical controllers appear in succession, so that we have a big step forward in the control field. A number of control design approaches using adaptive control [2–4], sliding mode control [5, 6],*H*∞ [7–9], optimal control [10–12], control based data driven [10, 13–15], and fuzzy control [16, 17]. The inverted pendulum system is controlled by the method of fuzzy control and realizes steady control. The inverted pendulum is a typical automatic control in the field of controlled object [18], which is multivariable and nonlinear and strong coupling characteristics, and soon. The inverted pendulum system reveals a natural unstable object, which can accomplish the stability and good performance by the control methods.

2. SYSTEM DESCRIPTION

The dynamic behavior of inverted pendulum can be simplified into a 2-DOF dynamic model as Fig. 1. The cart of mass M=.5 kg is considered as a prismatic joint which makes linear motion along horizontal direction. The friction force acting on prismatic joint is 0.1N/m/s and moment of inertia I=0.006kgm2. The rotating components of this inverted pendulum consist of a pole of length L= .3m and mass m =.2 kg. The function of the inverted pendulum is to maintain the position of pole in upright position by changing the position of cart. The actuating force F is generated by an actuator. The variables x and θ represent the Horizontal displacements of cart and angle of rotation of pole, respectively

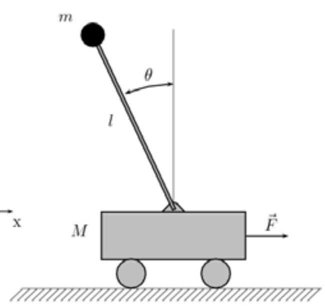

Figure 1 Pole on Cart System

3. MATHEMATICAL MODEL

The mathematical model for the inverted pendulum is taken from [18] and is briefly described as follows. Consider pole on cart system shown in Fig. 1. The pole and cart are connected together through revolute joint. The dynamics for cart on pole system, excluding the actuator is described by the linear equation (1) and (2).

$$(M+m)\ddot{x}+b\dot{x}-ml\ddot{\theta}=F \tag{1}$$

$$\left(I+ml^2\right)\ddot{\theta}-mgl\theta=ml\ddot{x} \tag{2}$$

To transform the motion equations of the inverted pendulum into a space state model, the following state variables are considered:

$$x=[x,\ \dot{x},\ \theta,\dot{\theta}]^T$$

Where indicate cart displacement; refers cart velocity; refers pole displacement; refers pole velocity. The motion equations of the pole on cart system for the inverted pendulum can be written in state space form as follows:

$$\begin{pmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{pmatrix} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & \dfrac{-(I+ml^2)b}{I(M+m)+Mml^2} & \dfrac{m^2gl^2}{I(M+m)+Mml^2} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \dfrac{-mlb}{I(M+m)+Mml^2} & \dfrac{Mgl(M+m)}{I(M+m)+Mml^2} & 0 \end{pmatrix} \begin{pmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{pmatrix} + \begin{pmatrix} 0 \\ \dfrac{(I+ml^2)}{I(M+m)+Mml^2} \\ 0 \\ \dfrac{ml}{I(M+m)+Mml^2} \end{pmatrix} F$$

The output of the system in state space represented as

$$[y] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \phi \\ \dot{\phi} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} F$$

4. INTELLIGENT CONTROLLER DESIGN

The whole premise behind intelligent control is that the system to be controlled does not have to be rigidly modeled. This is the biggest distinction between intelligent control and classical control. Here the designer only has to input the appropriate stimuli to the intelligent control and evaluate it on its output. The intelligent control itself develops a model of the system to be controlled. Fuzzy logic, like most of the IC techniques attempts to model the way of reasoning that goes on in the human brain. It is based on the idea that the human reasoning is approximate, non-quantitative, and non-binary. In many cases, there is no black and white answer, but shades of grey.

A. Control Problem

An inverted pendulum system is unstable without control, that is, the pendulum wills simply fall over if the cart isn't moved to balance it and naturally falls downward because of gravity. Thus, the inverted pendulum system is an inherently unstable. In order to keep it upright, or stabilize the system, one needs to manipulate it, either vertically or horizontally and it requires a continuous correction mechanism to stay upright since the system is unstable, non-linear and non-minimum phase behavior. To overcome this problem, the fuzzy logic controller will be designed.

B. Fuzzy controller

The Fuzzy Logic Controller [10-12]used in the active suspension has two inputs that are body error e, change in error ce of suspension travel and one output which is desired actuator force F. The control system itself consists of three stages: fuzzification, fuzzy inference machine and defuzzification.The fuzzification stage converts real-number (crisp) input values into fuzzy values, while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage.

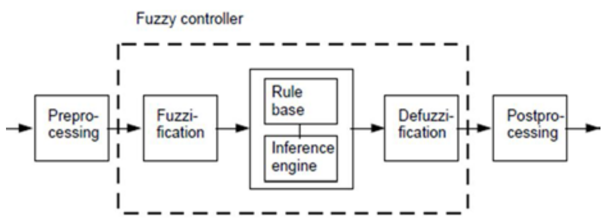

Figure 2 layout of fuzzy logic control

The schematic of fuzzy controller for active suspension is shown in Fig. The process of converting a numerical variable into a linguistic variable (fuzzy number) is called Fuzzification. Under Fuzzy inference, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Mostly MIN or PRODUCT is used as inference rules. In MIN inference, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth (fuzzy logic AND).

A possible choice of the membership functions for the mentioned variables of theactive suspension system represented by a fuzzy set is as shown in Figure. 3 to 5.

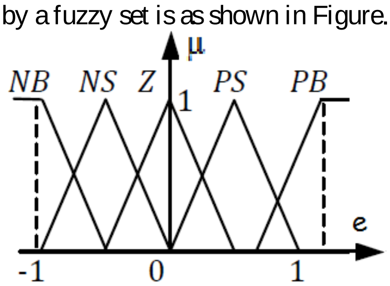

Figure 3 Membership function for error

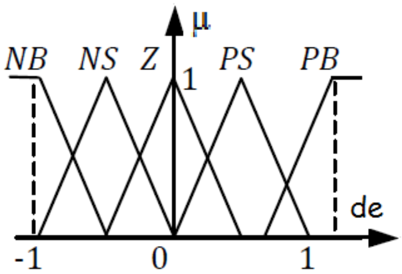

Figure 4 Membership function for change in error

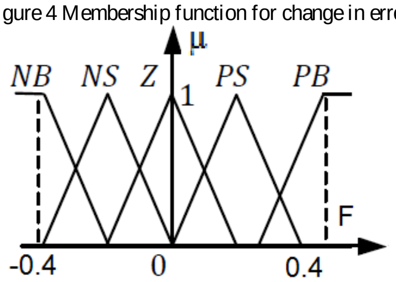

Figure 5 Membership function for actuator force

For the rule bases a classic interpretation of Mandani was used. Under rule base, rules are constructed for outputs. The rules are in "If Then" format and formally the If side is called the conditions and the Then side is called the conclusion. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques. The rules table for fuzzy logic control is shown in table.

The rule base used in the active suspension system can be represented by the following table with fuzzy terms derived by modeling the designer's knowledge and experience.

TABLE 1 FUZZY RULES TABLE

e/de	NB	NM	ZE	PM	PB
NB	NB	NB	NM	NM	Z
NM	NB	NM	NM	ZE	PM
ZE	NM	NM	Z	PM	PM
PM	NM	ZR	PM	PM	PB
PB	ZR	PM	PM	PB	PB

The abbreviations used correspond to:

- NB … Negative Big
- NM … Negative Medium
- ZE … Zero
- PM … Positive Medium
- PB … Positive Big
- e …. Error
- de …. Change in error
- F … control force

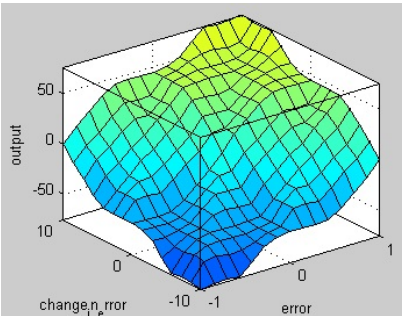

Fig 6 Mapping of Fuzzy variables

The linguistic control rules of the FLC obtained from the Table used in such a case are as follows:

- R1: IF (e =NB) AND (de =NB) THEN (F=NB)
- R2: IF (e =NM) AND (ce=NM) THEN (F=NB)
- .
- .
- .
- R25: IF (e =NM) AND (ce=NM) THEN (F=PS)

Defuzzification is a process in which crisp output is obtained by the fuzzy output. In other words, process of converting fuzzy output to crisp number. There is more Defuzzification

Methods in which two of the more common techniques are the CENTROID and MAXIMUM methods.

5. SIMULATION

In this section, the controller was tested to compare the results of the designed fuzzy logic controller with a traditional PID Controller of inverted pendulum. Simulation results are carried out using an MATLAB/SIMULINK and SIMMECHANICS toolbox, including time-varying parameters in order to demonstrate the efficiency of the proposed method. For comparison purposes, the numerical results of the inverted pendulum with fuzzy controller are also presented.

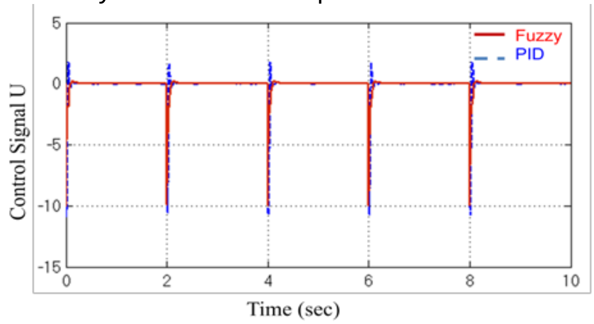

Figure 7Generated Control Signal from PID & Fuzzy controller

It shows that the inverted pendulum system is unstable without the controller. Put the controller gain to design the simulation program in the Simulink environment. The results of the control signal for PID & Fuzzy controller for inverted pendulum system are shown in Figure 7.

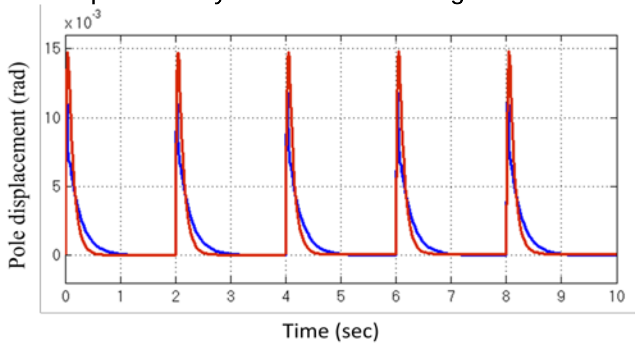

Fig.8Displacement of pole for PID & Fuzzy controller

Initially, input disturbance force of square-wave signal is applied to cart. In Figures 8& 9, the initial angle of the pendulum is 0.015 rad and the other initial values are all zeros. It takes 1 sec for fuzzy controller to be stabilize pole on cart, whereas PID controller takes 1.3 sec.The pendulum system is managed to be stabilized in upright position, even though the disturbance is applied to the cart position alternately.

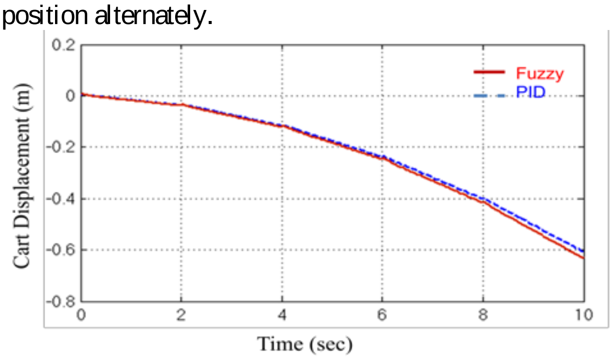

Figure 9 Displacement of Cart for PID & Fuzzy controller

In this case, Fuzzy Logic controller takes less setting time than PID Controller. Simulation results show that the system responses converge to the equilibrium point,which indicates that the design of the fuzzy controller is stable.

6. CONCLUSION

Fuzzy Logic based inverted pendulum were proposed and simulated. The Fuzzy Logic Controller has been chosen to stabilize the pendulum rod and keeping the cart in a desired position. Fuzzy logic has provided a simple way without going through the mathematical approach as conventional controller in order to arrive at a definite conclusion based upon nonlinear and an unstable of inverted pendulum system.

The results shows that the Fuzzy Logic controller takes less setting time and better stability as like PID Controller.We have demonstrated that pole displacement and velocity of inverted pendulum is controlled by using fuzzy logic control. We would like point out that improving antecedent and consequent membership values, and scaling factors may further enhance the performance of the system. Hence to determine these values, neural network parameter optimization techniques may be used.

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