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SELF-RULED FUZZY LOGIC BASED CONTROLLER

K. Oytun Yapıcı

Istanbul Technical University
Faculty of Mechanical Engineering
System Dynamics and Control Laboratory
Inonu Cad.No.87 Gumussuyu 34437
Istanbul TURKIYE
yapici@itu.edu.tr

Abstract: In this paper a different kind of fuzzy logic controller structure is proposed with a different viewpoint where the controller has no rulebase and no membership functions. However composing the structure of the controller is based on the concept of fuzzy logic and human decision making. The controller is applied to a nonlinear system successfully and the results are shown. Control surfaces obtained from this controller is similar to the surfaces obtained from conventional fuzzy logic controllers. The controller is suitable to apply easily in case of more than two inputs in the controller structure and computation of the output from the controller is computationally efficient. *Copyright © 2007 IFAC*

Keywords: Fuzzy control, fuzzy logic, PD controllers, linguistic variables, intelligent control, nonlinear control systems.

1. INTRODUCTION

Although it has a long history, fuzzy logic control applications in the literature have increased in the last decade. Fuzzy logic controllers simulate the decision making process of the human beings. There were debates over the use of fuzzy logic controllers where it is stated that humans are not good controllers (Abramovitch and Bushnell, 1999). These debates are over now as it is understood that the decision making process of the humans is combined with the accurate computing power of the computers.

Designing fuzzy logic controllers for a system may not be very easy. There are many parameters which have to be determined to setup a fuzzy logic controller. Especially we need to determine the rules which are in the form of if-then statements that simulate the decision making process. These rules also consist of linguistic variables used by humans hence these linguistic variables must be modeled using membership functions. In this paper, a fuzzy logic based controller which does not have a rule base and membership functions has been proposed. Instead, there is a mapping curve which assigns a logical value to the input and output variables and the rules are inherently consisted in the structure of the controller.

2. STRUCTURE OF THE CONTROLLER

As it is well known, there are curves named membership functions representing linguistic variables in the structure of Mamdani type fuzzy logic controller (Mamdani, 1974) where inputs and outputs are represented with linguistic variables with these membership functions as shown in Figure I. Takagi-Sugeno type fuzzy logic controller (Takagi and Sugeno, 1985) has different structure where outputs are not represented with membership functions but represented by various functions instead, most often polynomials.

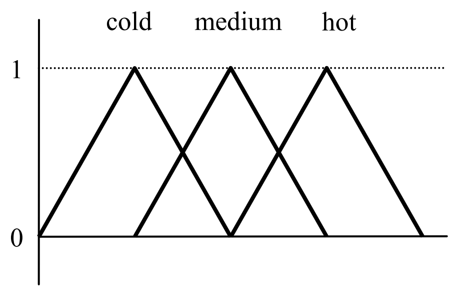

Fig. I. Mapping of concept heat to the interval [0 1] with membership functions.

The structure of the controller proposed in this paper models the concepts as a whole and maps them to the interval [0 1] with one curve as shown in Figure II.

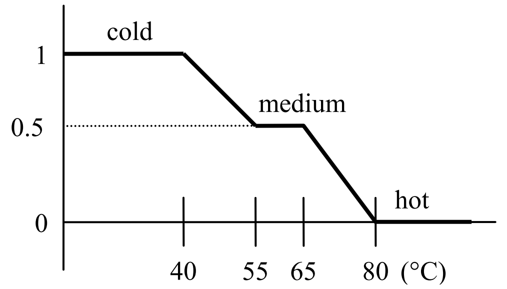

Fig. II. Mapping of concept heat to the interval [0 1] with one curve.

1.1 Mapping inputs to the interval [0 1]

Mapping of the inputs to the interval [0 1] is done as shown in Figure II. If we assign 0 to the one end of the concept heat then we must assign 1 to the other end. Here 1 is assigned for cold and 0 is assigned for hot. Linguistic variables between these two will take the values between 0 and 1.

The flat regions at this curve represent our decision is clear in that region. Here linguistic variables cold, medium and hot are the regions where our decision is clear. There may also be more flat regions than these at this curve however there will be at least two specific flat regions at the ends of the curve if the input space is infinite. The curves which are not flat represent the regions where our decision is not clear or fuzzy and connect the flat regions.

The numbers assigned to the inputs here are meaningless but will gain a meaning at the output. For instance, consider an IF-THEN statement in the form:

IF the water is hot THEN I will make tea

The IF part of the statement is meaningless if THEN part of the statement is not known hence one cannot conclude if the water is hot or not.

1.2 Mapping of the output to the interval [0 1]

Mapping of the output to the interval [0 1] is somewhat different as shown in Figure III.

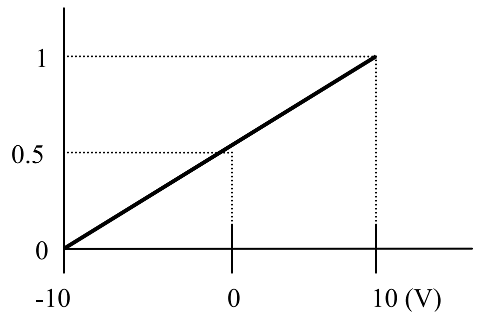

Fig. III. Mapping of voltage to the interval [0 1].

It seems like the mapping is linear but the mapping of the output can be nonlinear as seen on Figure IV.

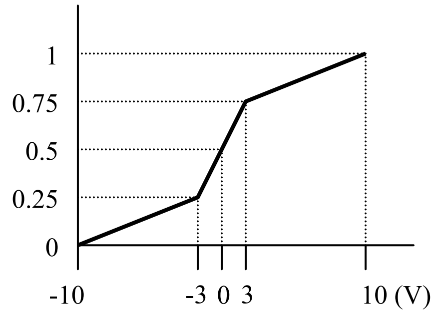

Fig. IV. Nonlinear mapping of voltage to the interval [0 1].

Moving a point in the output space arbitrary to the left or right without moving the number assigned to it in the interval [0 1] will make some regions in 1-D output space to tighten and some regions to widen.

There are not any flat regions at the output curve thus this makes the output from the controller to be unique for any inputs.

1.2 Relationship between the inputs and output

The relationship between the inputs and output is shown in Figure V. Every input can be considered separately. Input 1 is intersected with the curve assigned to it and mapped to the interval [0 1]. Input 2 is also intersected with the curve assigned to it. Corresponding output value for input 1 can be found by intersecting with the output curve from the value assigned to it in the interval [0 1] which is shown as in Figure V. The procedure is same for the input 2. Here corresponding output value for input 1 is U1 and corresponding output value for input 2 is U2. The meaning of this is input 1 decides what should the output to be for its current state and input 2 decides what should the output to be for its current state. Thus there will be two different output values. While we cannot apply two different outputs to the system at the same time we must conciliate these two outputs. This procedure is done with the calculation of the arithmetic average of the logical numbers assigned to the inputs which are a and b, and intersecting obtained value with the output curve as shown in Figure V. While the output curve is nonlinear final output value could not be obtained by taking the arithmetic average of U1 and U2. This procedure is same for the application to multi input controllers. For example; if there are four inputs then we will have four logical values separately to be conciliated. Thus we have to divide the sum of these logical values to the number of the inputs. If there is a weighting filter in the controller structure which is explained in section 1.4 we have to use these weights while dividing the sum of the logical values. For instance; in case of two inputs and if one of them is weighted then the control input will be calculated by dividing the sum of logical values to (1+w) where w corresponds to the weight of the related input.

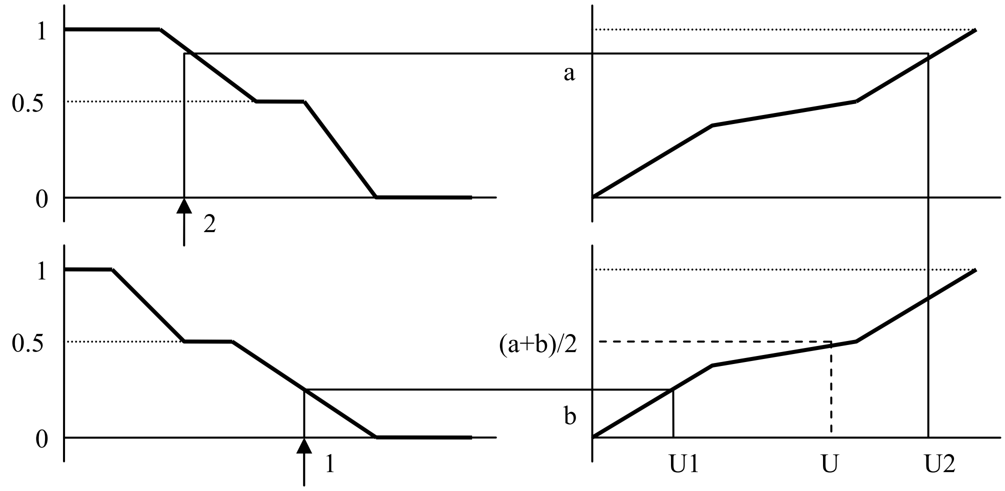

Fig. V. Relationship between inputs and outputs.

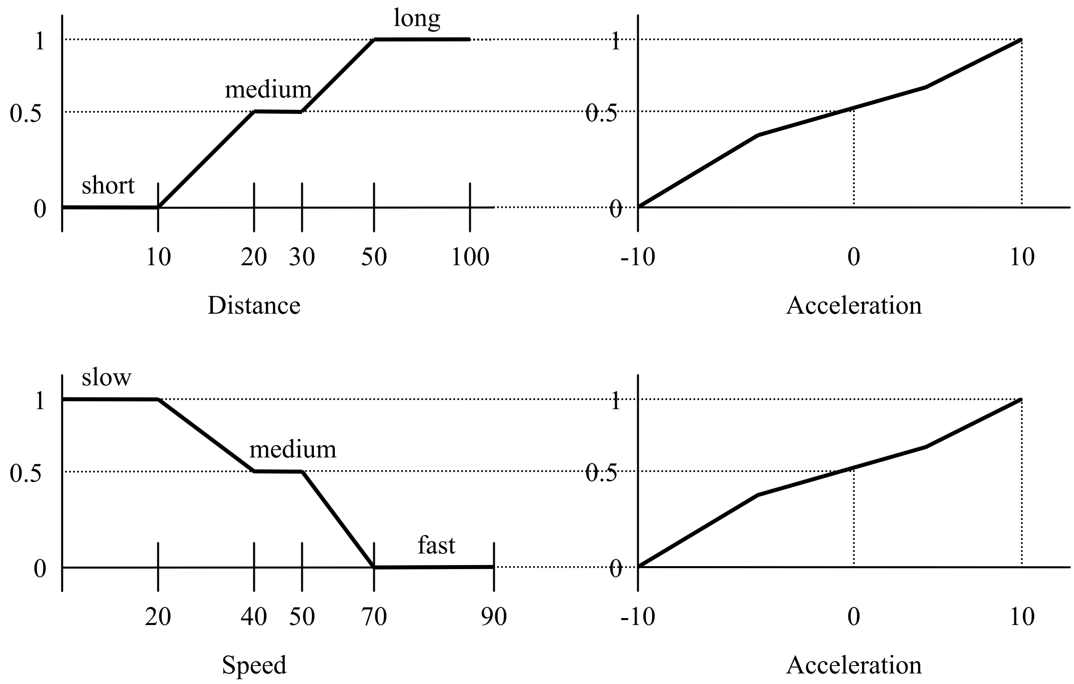

Fig. VI. Distance controller structure for a car.

1.3 The rules consisted inherently in the controller structure

There are rules important for decision making process in the structure of fuzzy logic controllers. The controller proposed here also has rules but these are not explicitly introduced to the controller. These rules can be found inherently in the structure of the controller. Let's consider a simple example from (Tanaka, 1996) as shown in Figure VI. Here the controller is controlling the distance between two cars. The inputs to the controller are distance and speed and the output is acceleration. Some of the rules which are needed for control will be as follows:

Rule 1: IF the distance is short
AND the speed is slow
THEN maintain the speed

Rule 2: IF the distance is short
AND the speed is fast
THEN decrease the speed

Rule 3: IF the distance is long
AND speed is slow
THEN increase the speed

Rule 4: IF the distance is long
AND speed is fast
THEN maintain the speed

Applying the procedures mentioned in section 1.2 it can be seen that these rules are obtained with this structure. It can also be seen that we can obtain other rules such as:

Rule 5: IF the distance is medium
AND speed is medium
THEN maintain the speed

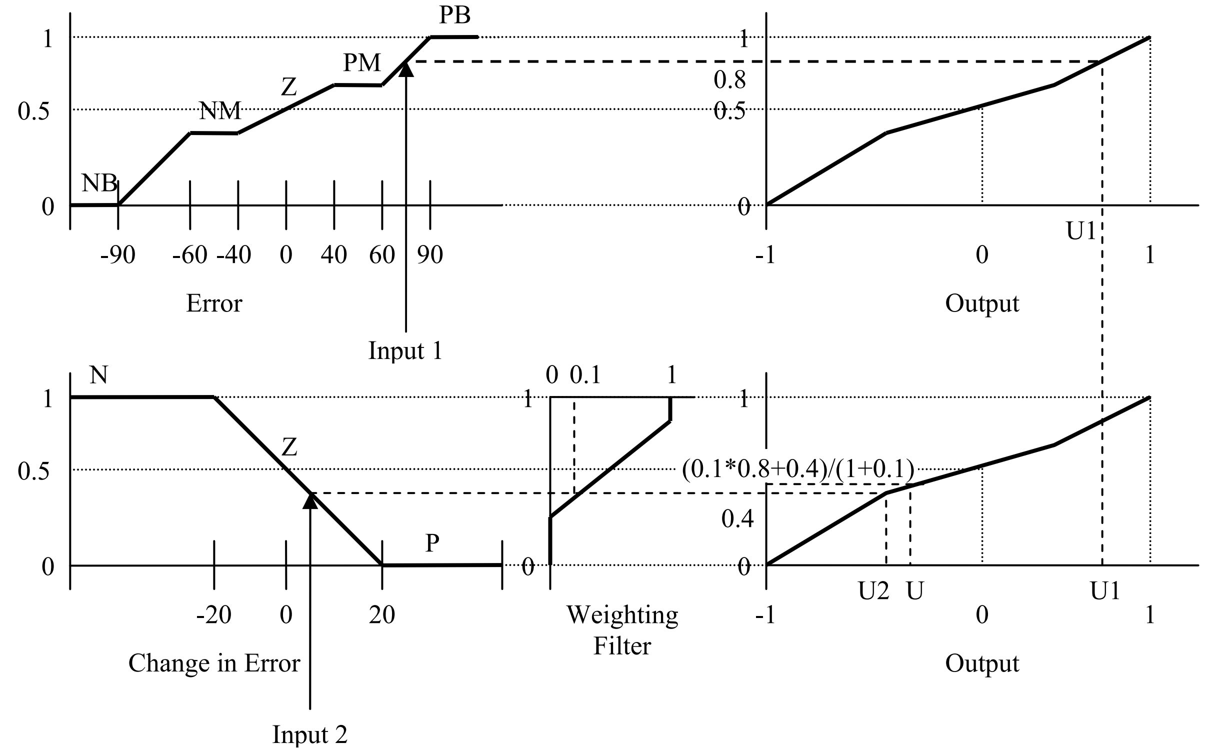

Fig. VII. Structure of the controller with weighting filter.

If we use conventional linguistic variables which are used with fuzzy logic controllers such as P, PM, Z, NM, N for the outputs we can obtain the general structure of the rule base obtained with this controller as shown below:

		Distance		
		S	**M**	**L**
Speed	**F**	N	NM	Z
	M	NM	Z	PM
	S	Z	PM	P

This rule base is similar to the rule bases mostly used with the fuzzy logic controllers.

Even though there is not any rule base for this controller there is no need to assign linguistic variables either for the inputs or for the outputs but it is shown that they are inherently consisted in the structure of the controller.

1.4 Weighting filter

There may be a need to weight the inputs in some circumstances. In this case a weighting filter can be used which weights one input by looking at the state of another input. For instance; linguistically we can express this as follows:

If the change in error is positive reduce the importance of the error.

Thus the controller will pay more attention to the decision made by looking at the change in error. This is in fact corresponds to the changing the composition of the rule base. If we reduce the weight of the error to 0 just in case the change in error is positive the general structure of the rule base obtained from the controller will be as shown below:

		Error		
		PB	**Z**	**NB**
Change in Error	**N**	P	PM	Z
	Z	PM	Z	NM
	P	N	N	N

If the change in error is positive, the controller will calculate the output just by looking at the decision made by the state of input change in error, while the weight of the error will be 0 when the change in error is positive. With the addition of weighting filter the structure of the controller will be as shown in Figure VII. From the figure it can be easily seen that weighting filter is a one to one mapping curve from the logical space in the interval [0 1] to the weighting space in the interval [0 1].

3. APPLICATION EXAMPLE

This controller is applied to the well known inverted pendulum which is used as a benchmark system for control applications. Although the controller has four inputs and one output, the application of the proposed controller to the inverted pendulum was very easy and successful. To be able to show the control surfaces another nonlinear system is selected which is a four rotor unmanned air vehicle called quadrotor. Block diagram of the controlled system is as shown in Figure VIII. There are six fuzzy-PD type controllers controlling the system and four of them are different in structure. Controllers are coded in embedded MATLAB function block in Simulink. The structure of the fuzzy-PD controllers are shown in Table 1. To be able to show small changes at the curves, these curves are not plotted.

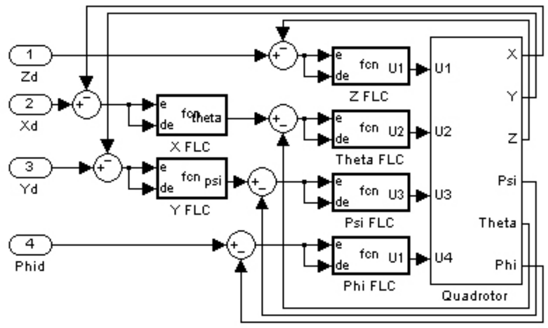

Fig. VIII. Block diagram of the controlled system.

Dynamic model of the quadrotor is as shown below with the assumption of $I_{xx} = I_{yy}$ (Bouabdallah, *et al.,* 2006):

$$
\begin{aligned}
m\ddot{X} &= u_1(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi) \\
m\ddot{Y} &= u_1(\sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi) \\
m\ddot{Z} &= u_1(\cos\theta\cos\psi) - mg \\
I_{yy}\ddot{\theta} &= \dot{\psi}\,\dot{\phi}\left(I_{zz} - I_{xx}\right) + J_R\dot{\psi}\,\Omega + u_2 l \\
I_{xx}\ddot{\psi} &= \dot{\theta}\dot{\phi}\left(I_{yy} - I_{zz}\right) - J_R\,\dot{\theta}\,\Omega + u_3 l \\
I_{zz}\ddot{\phi} &= u_4
\end{aligned}
$$

From the dynamic model we see that the system is nonlinear, unstable, underactuated and coupled.

Table 1. Structure of the controllers

Z controller structure

e	0 0 0.49 0.5 0.51 1 1 -1 -0.5 -0.001 0 0.001 0.5 1
de	0 0 0.4 0.5 0.6 1 1 -3 -2 -0.2 0 0.2 2 3
output	0 0.4 0.5 0.6 1 -51.809 -50.38 9.81 70 71.429

X and Y controller structure

e	0 0 0.45 0.5 0.55 1 1 -1 -0.5 -0.1 0 0.1 0.5 1
de	0 0 0.4 0.5 0.6 1 1 -2 -1 -0.1 0 0.1 1 2
output	0 0.4 0.5 0.6 1 -1 -0.6 0 0.6 1

θ and ψ controller structure

e	0 0 0.4 0.5 0.6 1 1 -3 -0.8 -0.05 0 0.05 0.8 3
de	0 0 0.5 1 1 -3 -2.5 0 2.5 3
output	0 0.4 0.5 0.6 1 -704.23 -600 0 600 704.23

φ controller structure

e	0 0 0.5 1 1 -1 -0.5 0 0.5 1
de	0 0 0.5 1 1 -3 -2 0 2 3
output	0 0.5 1 -3662 0 3662

In Table 1 first row corresponds to the logical values assigned to the values shown in second row, which are the values from the input or output spaces. Controller Z is controlling the altitude by looking at the error and change in error and deciding what the input U1 should be. Controllers which are controlling X and Y motion decide what the angles θ and ψ should be and their structures are same. Controllers controlling θ and ψ angles decide what the control inputs U2 and U3 should be and their structures are same as well. Finally controller which is controlling the φ angle decides what the control input U4 should be. Controlling X and Y motions through the states θ and ψ will reduce the degrees of freedom of the system to 4. Control surfaces obtained from these controllers are calculated with Mathematica and shown in Fig. XI, X, XI and XII. From the control surfaces it can be seen that these surfaces are similar to the surfaces obtained with conventional fuzzy-PD type controllers (Passino and Yurkovich, 1998). System responses to the desired references X_d=4m, Y_d=3m, Z_d=4m, φ_d=pi/6 are shown in Figure XIII, XIV, XV, XVI, XVII and XVIII.

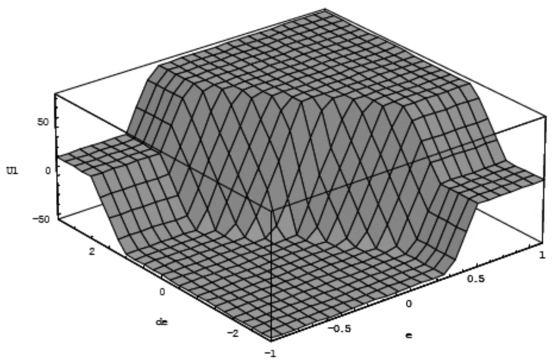

Fig. IX. Control surface of Z controller.

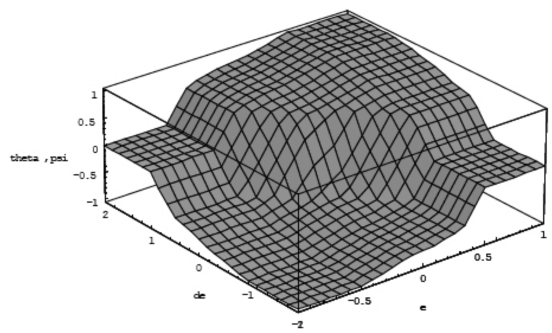

Fig. X. Control surface of X and Y controller.

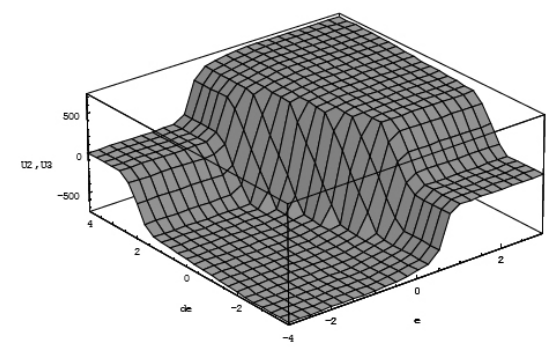

Fig. XI. Control surface of θ and ψ controller.

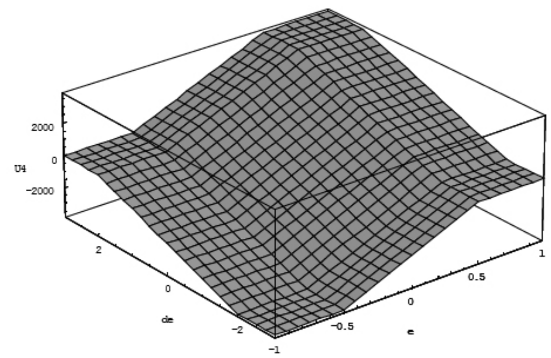

Fig. XII. Control surface of φ controller.

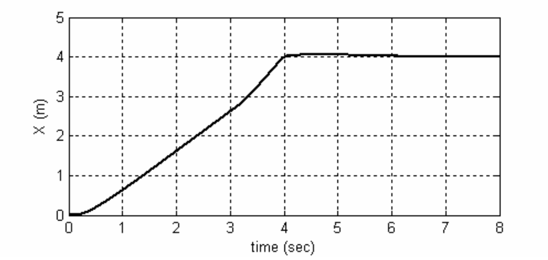

Fig. XIII. X versus time.

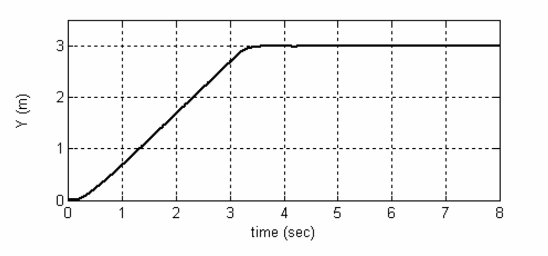

Fig. XIV. Y versus time.

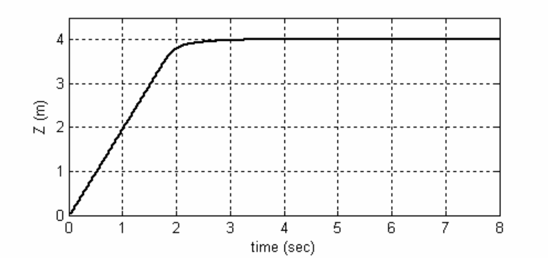

Fig. XV. Z versus time.

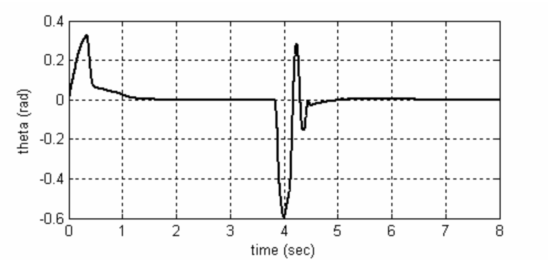

Fig. XVI. θ versus time.

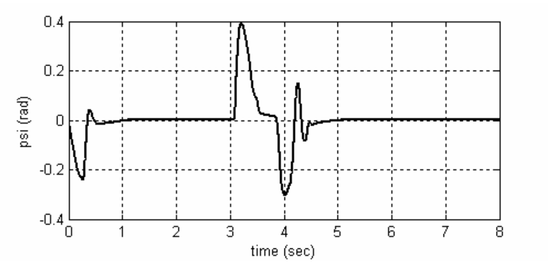

Fig. XVII. ψ versus time.

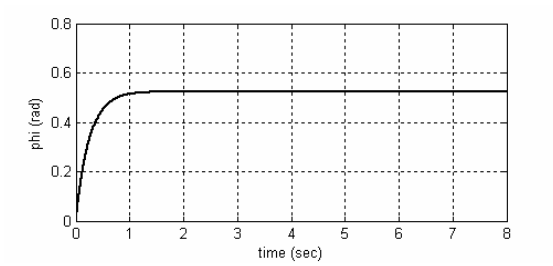

Fig. XVIII. φ versus time.

4. CONCLUSION AND FUTURE WORK

A different kind of fuzzy logic controller is proposed with a different viewpoint. Although it seems complex, the structure of the controller is simpler than the conventional fuzzy logic controllers as there aren't any rules and membership functions. Hence control applications with multi-input controllers will be very easy. Controller has guaranteed continuity at the output as it is with T-S type fuzzy logic controllers. Control surfaces of fuzzy-PD type controllers used in the application example are similar with the surfaces obtained with conventional fuzzy-PD type controllers. The fuzzy controller proposed here may not be as flexible as the conventional fuzzy logic controllers but it is anticipated that it can be used with most of the linear and nonlinear systems. Tuning of the controller is very easy with a trial and error method however there is a need to make the controller adaptive with a learning algorithm so it can optimize itself as it controls the system.

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