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BEAM AND BALL PLANT SYSTEM CONTROLLING USING INTUITIONISTIC FUZZY CONTROL

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ABSTRACT

In this study, simplified “beam and ball (BNB) system” is controlled using “intuitionistic fuzzy control (IFC)” method. It is aimed to keep the ball on it in balance by applying DC voltage in different magnitudes to the DC motor of the system called "ball and beam plant", which has a beam on which a DC motor is attached to the middle point and a ball moving without friction. In order to better observe the effect of this new generation controller applied to the system, parameters such as the torque of the motor, the mass of the beam and the ball, internal and external disturbance, friction etc. were ignored and the system is simplified. The position and velocity of the ball on the beam is taken as input for the controller, while the controller output is chosen as a DC voltage. After I-Fuzzification, I-Inference and I-Defuzzification process are performed in controller block, performance and efficiency of the system are discussed in terms of steady state error, setting time, maximum overshoot, chattering.

Keywords: *Beam and Ball (BNB) System, Controller Design, Intuitionistic Fuzzy Control (IFC)*

1. INTRODUCTION

The under actuated mechanical systems represent a challenge for the control. An active field of research exists, due to the applications of these systems such as aircrafts, spacecraft, flexible and legged robots [1]. BNB system is one of the most used subsystems among these nonlinear systems. As shown in Figure1, a simple BNB system consists of a beam, ball, and an activator connected to the balance point of beam [2]. Here, by means of the DC motor, the beam is rotated clockwise and counterclockwise to keep the ball in the middle of the beam. Thus, according to the position and speed information of the ball, voltage control signal is applied to the DC motor and the control of the system is completed in this way. For

this, various control methods have been applied for the same or more developed BNB systems.

Olfati-Saber and Megretski developed a new version of back stepping procedure for systems that do not have a triangular structure [1]. Yu and Ortiz proposed an asymptotically stabilizing PD controller that ensures that, for a well-defined set of initial conditions, the ball remains on any point of the bar [3]. Keshmiri et al. are designed Linear Quadratic Regulator (LQR) considering two Degrees-of-Freedom and coupling Dynamics [4]. Almutairi and Zribi are designed a static and a dynamic sliding-mode controllers using a simplified model of the system [5]. Modelling and control of ball and beam system using PID controller is developed by Maalini et.al [6]. Particle swarm optimization algorithm is presented as a robust and highly useful optimization technique to tune the gains of the PID controllers in the two feedback loops of the classic Ball and Beam Control System by Rana et.al [7].

In recent years, fuzzy logic control method in Beam ball system control has also been examined by many researchers and various studies have been performed. For example Amjad et.al presented the design and analysis of a FLC for the outer loop and a PD controller for the inner loop of a ball and beam system. Additionally, a classical PID controller based on ITAE equations for the beam position has been also designed to compare the performance of both types of controllers [8]. Based on the T-S fuzzy modeling, the dynamic model of the ball and beam system has been formulated as a strict feedback form with modeling errors by Chang et.al. Then, an adaptive dynamic surface control (DSC) has been utilized to achieve the goal of ball positioning subject to parameter uncertainties. The robust stability of the closed-loop system has been preserved by using the Lyapunov theorem. In addition to simulation results, the proposed T-S fuzzy model-based adaptive dynamic surface controller has been applied to a real ball and beam system for practical evaluations [9]. Oh et.al, introduced a design methodology for an optimized fuzzy cascade controller for ball and beam system by exploiting the use of hierarchical fair competition-based genetic algorithm (HFCGA) [10]. Castillo et al. described the design of a fuzzy logic controller for the ball and beam system using a modified Ant Colony Optimization (ACO) method for optimizing the type of membership functions, the parameters of the membership functions and the fuzzy rules [11]. Combined with the conventional dynamic surface control, an adaptive fuzzy scheme is proposed for the equilibrium balance of the ball for beam and ball system by Chang et.al [12].

In the above mentioned studies, it can be seen that many modern control methods, including fuzzy control, are presented to control the beam and ball system. However, in this

study, an intuitionistic fuzzy controller was designed and simulated for a sampled beam and ball system for the first time in the literature.

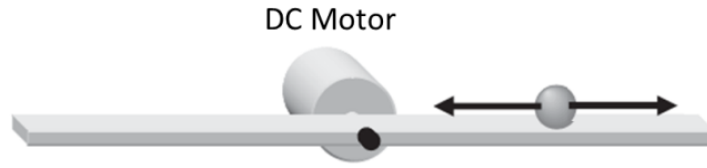


Fig.1 Sampled Beam and Ball System

2. Preliminaries

After Zadeh's [13] impressive description of fuzzy set theory, many studies have been conducted by many researchers. Then this theory was developed over the years and several Fuzzy Logic Controllers (FLCs) were designed for various linear or nonlinear systems. With the definition of the intuitionistic fuzzy logic concept, which is a more generalized version of the fuzzy logic concept, by Atanassov[14], IFLCs that are more applicable and functional to many systems in real life began to be developed. Because it has become easier to design a controller for systems that involve uncertainties such as disturbance.

An intuitionistic fuzzy set A on a non-empty set X named as universe of discourse given by a set of ordered triples $A = \{(x, \mu_A(x), \eta_A(x)) : x \in X\}$ where $\mu_A(x) : X \rightarrow I$, and $\eta_A(x) : X \rightarrow I$ are functions defined such that $0 \leq \mu(x) + \eta(x) \leq 1$ for all $x \in X$, $\mu(x)$ and $\eta(x)$ represent the degree of membership and degree of non-membership of x in A respectively. For each $x \in X$, the intuitionistic fuzzy index of x in A can be defined as follows: $\pi_A(x) = 1 - \mu_A(x) - \eta_A(x)$. π_A is called the degree of hesitation or indeterminacy [15].

3. Ball and Beam Mathematical Model

As shown Figure 2, the right and left directions in the sense of movement of the ball are respectively (-) and (+) and the middle of the bar, that is the point where the DC motor is connected, is taken as balance or the stability point. It is also assumed that the dc motor will rotate clockwise when induced with (+) voltage and counterclockwise when induced with (-) voltage ideally and without friction.

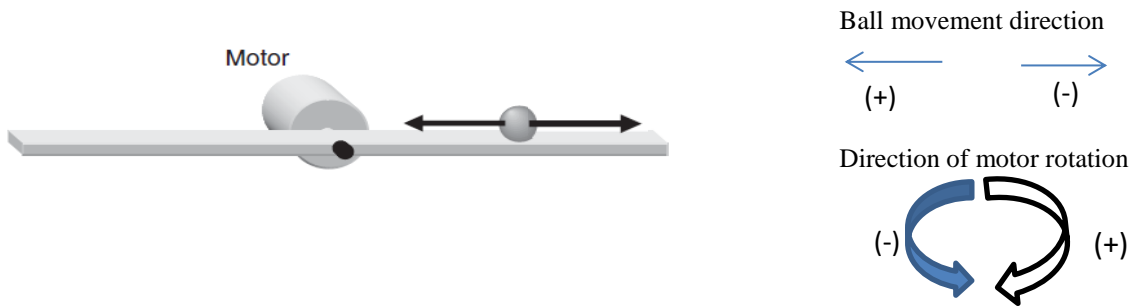


Fig.2 Directions for BNB Systems

Here, the distance of ball to the stability (balance) point and the velocity of ball are assumed as the error (e) and the derivative of error (\dot{e}), respectively. Thanks to the voltage to be obtained according to the e and \dot{e} controller inputs, it is aimed that the motor rotates the beam and the ball remain stable in the stability point. The simplified BNB system is depicted in Figure 2 and modeled (for simulation purposes) by [16]:

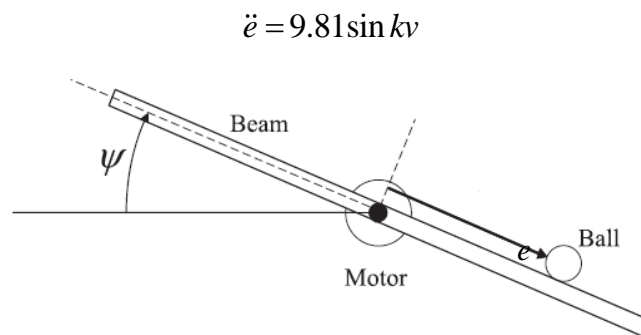


Fig.3 Beam and Ball System

In Figure 3, e is the position of the ball along the beam (with $e = 0$ defined as the center of the beam), and ψ is the beam angle commanded by the motor (with $\psi = 0$ defined as horizontal). The input to the ball and beam system is the voltage v supplied to the motor. The beam angle ψ is proportional to v (i.e. $\psi = kv$) [2].

4. Controller Design

I-Fuzzification, I-Inference ve I-Defuzzification processes are required respectively for an IFC (Intuitionistic Fuzzy Controller) design.

As seen in Figure 4, while e and \dot{e} crisp values are sent to the controller input, crisp v value is taken from the controller output.

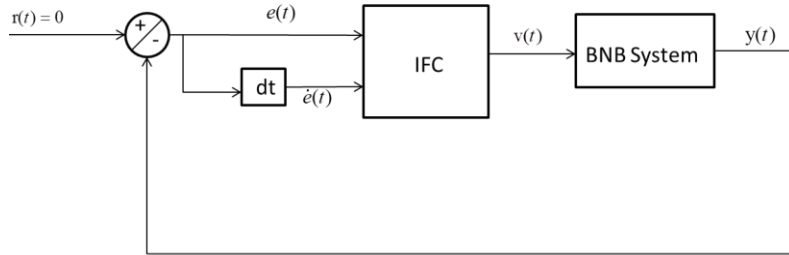
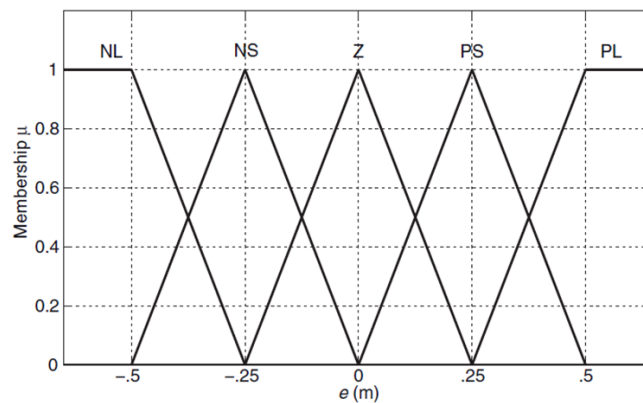


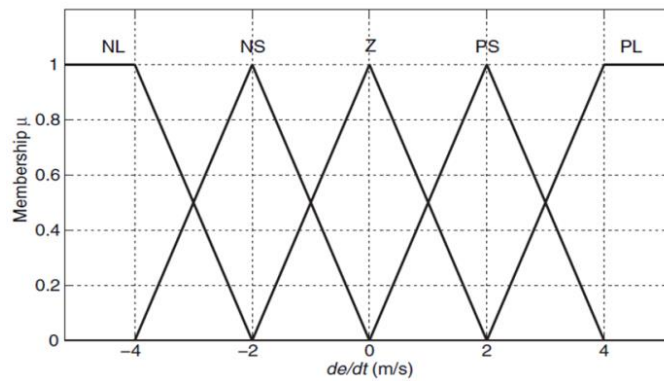
Fig.4 BNB System with Controller

a. I-Fuzzification:

First of all, IFC crisp inputs e and \dot{e} need to fuzzification. For this, using the triangular membership functions in figure 5, membership degrees for both inputs are obtained. (with NL: Negative Large, NS: Negative Small, Z:Zero, PS: Positive Small, PL: Positive Large). Also, using the singleton membership functions as in Figure 6, the output (v) is fuzzification [2].



a.



b.

Fig.5 a. Triangular fuzzy sets for ball position b. Triangular Fuzzy Sets for ball velocity

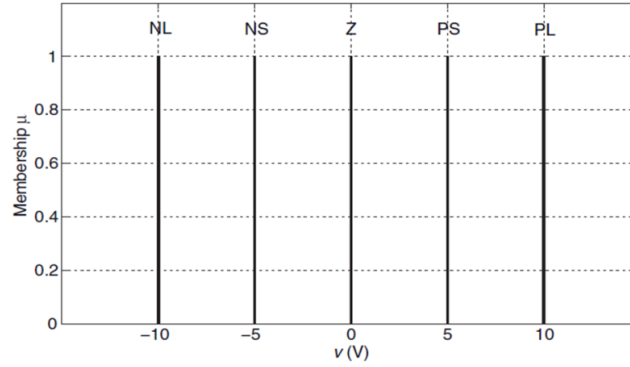


Fig.6 Singleton Fuzzy Sets for v

After the membership degrees of inputs are obtained, the degrees of non-membership degrees of inputs are found by using a sugeno type generator [17]. Thus, IFPs (Intuitionistic fuzzy pairs) consisting of membership and non-membership degrees $\langle \mu_A, \nu_A \rangle$ are obtained.

b. I-Inference:

After obtaining the intuitionistic fuzzy input and output sets, the rule base is created. Since there are 5 intuitionistic fuzzy sets for each input, a total of $5 \times 5 = 25$ rule bases are obtained as shown Table 1. [2]

v		\dot{e}				
		NL	NS	Z	PS	PL
e	NL	NL	NL	NL	NS	Z
	NL	NL	NL	NS	Z	PS
	Z	NL	NS	Z	PS	PL
	PS	NS	Z	PS	PL	PL
	PL	Z	PS	PL	PL	PL

Table.1 Rule Base

In IFC, although the same rule base is defined in the inference part of the system as in the FC design, the inference process is performed by using IFPs, not just degrees of membership. In this study intersection and implication methods are chosen as “min T-norm” and “Mamdani implication” respectively [18].

c. I-Defuzzification:

Finally the IFC design is completed by converting the new intuitionistic fuzzy pairs obtained from inference process to the v crisp output using the “a novel center of area (COA)” type intuitionistic defuzzification method [19]

5. Numerical Solution

The controllers designed above are simulated using Matlab/Simulink. In the simulation, 4th Runga-Kutta method is used with the step size of 0.001s. Also initial conditions are chosen as $[e, \dot{e}] = [0.3m, -2.5m/s]$. Additionally $k = 0.2$ and sugeno constant $\lambda = 1$ are chosen. Simulation results are obtained as in Fig 7,8,9.

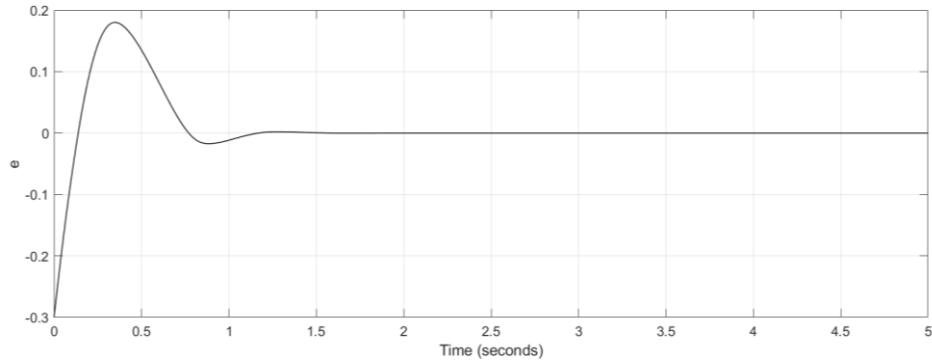


Fig.7 Ball Position (e)

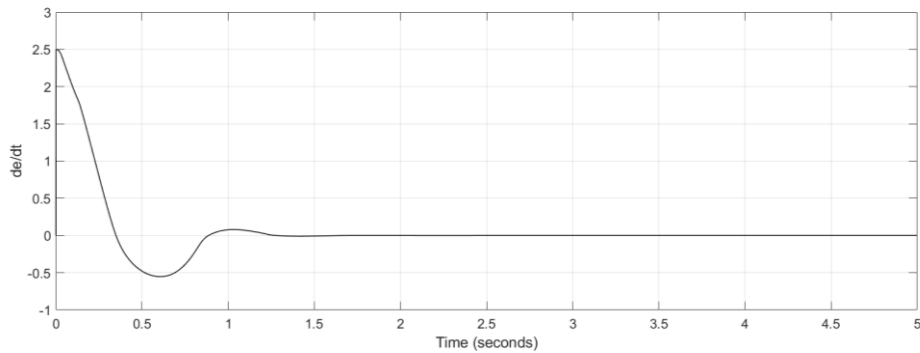


Fig.8 Ball Velocity (de/dt)

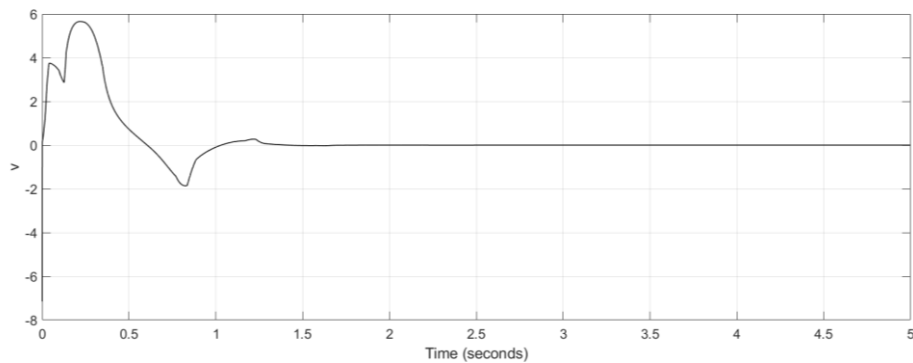


Fig.9 Applied Voltage (Control Output) (v)

Considering the simulation results, it is observed that the system reached stability in approximately 1.86s, the steady state error is approximately 1.068×10^{-5} m and the maximum overshoot is 0.18m. Additionally, no chattering is observed.

6. CONCLUSION

In this paper a novel IFC has been designed for a simplified BNB system for the first time in literature. The performance of this proposed control method discussed in terms of steady state error, setting time, maximum overshoot, chattering. It has been seen that the steady state error and maximum overshoot were low and no chattering occurred. In future studies, it is planned to apply the designed IFC to more complex BNB systems. Also, using Intuitionistic fuzzy logic, it is aimed to design more complex controllers such as IFSMC and IFSAMC and to apply them to complex BNB systems.

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