Neural Fuzzy Control of Ball and Beam System

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ABSTRACT

This paper presents an offline control of ball and beam system using fuzzy logic. The objective is to control ball position and beam orientation using fuzzy controllers. A Matlab/Simulink model of the proposed system has been designed using Newton’s equations of motion. The fuzzy controllers were built using seven gbell membership functions. The performance of proposed controllers was compared in terms of settling time, steady state error and overshoot. The simulation results are shown with the help of graphs and tables which illustrates the effectiveness and robustness of proposed technique.

KEYWORDS

Ball and beam, Fuzzy logic, Neural network, MSE, Matlab, Simulink, Membership function

INTRODUCTION

Ball and Beam systems are underactuated systems and are widely used for control applications due to their inherent non-linearity and instability (Chang et al., 2011; Frank et al., 2015). It is common control engineering problem and consists of a ball mounted on beam, servo motor and various sensors (Keshmiri et al., 2012; Cheng and Tsai, 2016). The objective is to control the ball position by changing angle of the beam (Li & Wu, 2010; Shirke & Kulkarni, 2015). The information from sensors can be taken and their difference can be fed back into the controller in order to gain the desired position of the ball. These systems are widely used for verifying control performances of various nonlinear systems (Yang et al., 2014). It mimics the dynamics of aircraft during flight, landing and turbulence (Kocaoglu & Kuscu, 2013). Many classical and modern methods have been successfully applied for control of these systems (Colon et al., 2015). In a study by Chang et al. (2011) control of ball and beam system using an adaptive fuzzy scheme has been investigated. The authors optimised parameters of fuzzy controllers using proposed approach. The Lyapunov theorem was further used to analyse the close loop stability of the system. Song & Smith (2002) applied incremental best estimate directed search (IBEDS) to fuzzy logic controller for optimisation of ball and beam system. The study showed that it was much easier to control a 4-dimensional ball and beam system than a 4-dimensional inverted pendulum system.
Recently, Lin et al. (2014) proposed a fuzzy neural network (FNN) for position control of a ball and beam system. A cascaded inner-outer loop scheme was constructed and parameters of inner loop FNN were tuned using gradient descent method. In another study by Bhushan et al. (2013) an adaptive control of ball and beam and cart pole system using Lyapunov function with fuzzy approach has been proposed. The adaptive control comprises of an ideal control and a sliding mode control. The sliding mode control was used for ensuring the stability of Lyapunov function. Oh et al. (2009) introduced an optimised fuzzy cascade controller for ball and beam system using hierarchical fair-competition based genetic algorithm (HFCGA). The proposed scheme consists of outer and inner controller in a cascaded architecture. The parameters of fuzzy controller were auto tuned using HFCGA. In a work by Almutairi & Zribi (2010) a sliding mode control of ball on a beam system has been proposed. The authors developed a static and dynamic sliding mode controller using both simplified and complete model. The results showed better performance of controllers designed using complete model of the system. Naredo & Castillo (2011) used ant colony optimisation (ACO) for tuning fuzzy controller of ball and beam system. The study considers four inputs with two membership functions. The results showed that ACO with three parameter coding provides an optimal set of parameters for fuzzy control.

In a research by Chang et al. (2012) a pair of decoupled fuzzy sliding mode controllers (DFSMCs) has been applied for control of ball and beam system. The performance of the proposed control was further improved using ACO which optimised the controller parameters. In a study by Lin et al. (2011) a balancing model for cart-see saw system using fuzzy logic and fuzzy coordinator compensation techniques has been developed. The objective of the study was to drive the sliding cart and keep the see saw angle close to zero in equilibrium. The experimental results indicate that the proposed methodology significantly enhances the performance of the system. Recently Yuanyuan & Yongxin (2015) designed a fuzzy PID controller for ball and beam system. The transfer function and object model of the proposed system has also been obtained. The results showed the effectiveness of the proposed algorithm compared to traditional PID control. Lv et al. (2011) studied a ball and beam system combined with CCD camera which collects the images of system and a ruler. The authors designed a fuzzy self-tuned PID controller and a Back propagation neural network PID controller. The balance control of ball and beam system was successfully obtained using both the controllers.

In a recent research by Gao et al. (2015) a ball balancing system using a microcontroller and control algorithm with a real-time sensory feedback has been developed. The proposed system can be successfully used by students for understanding PID control in Matlab environment. In another study by Sathiyavathi & Krishnamurthy (2013) stabilisation of ball and beam system using simple internal model control (SIMC) based PID control and H infinity controller has been successfully achieved. The simulation and experimental results demonstrated the dynamic behaviour of ball and beam system. In this study authors designed and compared fuzzy logic and neural network controllers for stabilisation of ball and beam system. Fuzzy controllers are non-conventional controllers which mimics the behaviour of human experts by encoding their knowledge in form of if-then fuzzy rules (Johnson & Smartt, 1995). It finds wide applications in the field of control, power systems, energy sector etc (Sadeghi, 2013; Arya et al., 2012). The fuzzy set theory can handle uncertainties more easily compared to other traditional tools and theories (Cavallaro, 2013). The fuzzy controllers were designed using seven gbell shape membership function. The mathematical equations for the system were derived using Newton’s law which were further used to build Matlab simulink model of the proposed system. The results obtained from previous simulations were collected and further used for the training of neural controller. The study compares both the controllers in terms of settling time, overshoot and steady state error. The mean square error (MSE) and regression (R) values obtained for neural controller highlighted its effective learning capability. The simulations are performed in Matlab-Simulink environment which proves the validity of proposed approaches.
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