Simulation Studies for Stabilization Control of Furuta Pendulum System Using Cascade Fuzzy PD Controller

Mukhtar Fatihu Hamza1,2, Hwa Jen Yap1, Imtiaz Ahmed Choudhury1, Abdulbasid I Isa3 and Aminu Y Zimit1,2

1Department of Mechanical Engineering, University of Malaya, Kuala Lumpur, 50603, Malaysia.
2Department of Mechatronics Engineering, Bayero University, Kano, 3011, Nigeria.
3Department of Electrical and Electronics Engineering, Sokoto State polytechnic, Sokoto, 8519, Nigeria

Abstract- A fuzzy PD controller in cascade form is proposed in the present study to deal with stability issue of Furuta pendulum. The Furuta pendulum which is widely known as Rotary inverted pendulum (RIP) is under-actuated mechanical system. This paper, described a development of nonlinear dynamical equations of the RIP system using Kane's method. The Simulink model of RIP is developed based on the derived equations. The open loop simulation studies are carried out and the results indicated that, the RIP system is inherently nonlinear and unstable. The fuzzy PD controller is designed for stability control of RIP. The simulation result found show that the proposed controller is effective based on the four performance indexes (i.e. settling time, overshoot, undershoot and steady state error). The proposed fuzzy PD controller can be used to solve the stabilization control for other systems with unstable and nonlinear behavior.

Keywords - Rotary inverted pendulum (RIP); Fuzzy logic control; Kane's method; Dynamic modelling; Newton-Euler; Lagrange methods

I. INTRODUCTION

The Rotary inverted pendulum (RIP) was proposed in 1992 [1]. RIP is in the class of under-actuated mechanical systems with two degree-of-freedom (DOF). The RIP exhibits some challenging and interesting properties, such as nonlinearities and instability[1-3]. These features make RIP attract high attention from researchers and it is known widely as experimental setup for testing both linear and nonlinear control algorithms. The RIP system consists of pendulum, rotational arm and a servomotor system which drives the output gear. RIP has many important real applications like robotics, aerospace vehicles, pointing control, and marine vehicles[4]. In addition, when the pendulum of RIP is at hanging position, it represents real model of the simplified industry crane application. The picture of classical experimental set-up for RIP is shown in Figure 1 (a). It consists of two optical encoders for measuring the pendulum’s and arm’s angles respectively. It also comprised of the data acquisition device for collecting the information from the encoders and give it to the computer. The data acquisition device also received the control signal from the computer and give it to the power amplifier for the amplification of the signal before feeding to the motor as illustrated in Figure 1 (b).

The control objectives of the RIP can be categorized into four: 1. Controlling the pendulum from downward stable position to upward unstable position known as Swing-up control. 2. Regulating the pendulum to remain at the unstable position known as stabilization control. 3. The switching between swing-up control and stabilization control known as switching control. 4. Controlling the RIP in such a way that the arm tracks a desired time varying trajectory while the pendulum remains at unstable position known as trajectory tracking control. The present study focus on the stabilization control only.

The modelling of RIP focuses on the kinematic and/or dynamic. Many types of RIP have been developed together with their mathematical model [5-7]. Newton-Euler, Lagrange-Eular and Lagrange methods were used to develop the nonlinear mathematical model of RIP [5]. Lagrange multiplier was used in the derivation using Lagrange method, while the calculation of redundant forces was involved in Newton method. As a result, Newton-Euler, Lagrange-Eular and Lagrange methods requisite complicated and tedious formulation for a large multi-body system [8, 9]. Consequently, they likely led to an inefficient computation. Kane's method can be regarded as an alternative method of modelling. This method does not require the calculation of multipliers or redundant forces. Kane method is based on the partial velocities of the constituents of the system[10]. Hence, Kane's method is more efficient than Lagrange and Newton-Euler methods in terms of computation.

Many types of control algorithms have been proposed for stabilization of RIP. For example, some linear controllers were proposed in literature. Pole placement (PP), was used for stabilization control in [11, 12], also PP with integrator was employed for stabilization control in [13]. Linear quadratic regulator (LQR): was proposed to solve The stabilization problem of RIP in [14, 15]. Mixed H2/H∞ was shown to be more robust than LQR and full state feedback controllers for stabilization of RIP with less oscillations in

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