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August 12-14, 2011, Kuala Lumpur, Malaysia

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Paper ID : S028

Paper Title : Modeling and Simulation for Inverted Pendulum on Rotating Disc

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MODELING AND SIMULATION FOR INVERTED PENDULUM ON ROTATING DISC

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ABSTRACT
The point of view expressed in this paper will be focused on modeling and simulation for inverted pendulum on rotating disc. This inverted pendulum has been model separately into three parts of sub-model as well as DC motor, rotating disc and pendulum models. The stable and unstable system depends on an effect of a torque which is proportional to speed and opposed to motion and force applied to the plant. It shall be argued in this paper that inverted pendulum is one of the unstable systems. The output response will be based on simulation results.
KEY WORDS
modeling, simulation, inverted pendulum, stability

1. INTRODUCTION

From previous research work, the inverted pendulum has been modeled on the cart, arm-driven and others pendulum forms. These pendulum forms following its dynamics[1] that are basic to behaviors at which involving the maintenance of balance. This paper is looking forward on modeling inverted pendulum on rotating disc form which consist three sub-models such as DC motor, rotating disc and pendulum. The relationships of these sub-models depend on speed, position and motion designed.

Based on speed, position and motion designed, the main issue to be considered in the development of the parameter estimation algorithm is the overall stability of the closed-loop control system. The stability of the closed-loop system requires guarantees of the convergence of the system state and of (at least) the boundedness of the error in the approximator parameter vector [2]. This error might impact the performance given by simulation results. Therefore, in control system stability, studies on unstable and non-linear system of rotational disk or so called the Furuta Inverted Pendulum is an interesting and challenging topic.

This paper aims to model the inverted pendulum on rotating disc. It also aims to stabilize it using Real-Time MATLAB software with one or more advanced control systems. In order to realize the stability control of rotational inverted pendulum, the proposed system should be properly set up which include the plant, electronic components, mechanical hardware and controller.

The rotational inverted pendulum can be realized by mounting the pendulum on a motor shaft. By controlling on energy feedback, the system automatically stops inputting excess energy and allows the system to coast to a balanced position. When the remaining potential energy required is equal to the kinetic energy, the feedback will become very small and the pendulum will coast to vertical position. The velocity term causes the input to change directions when the pendulum stops and begins to swing in the opposite directions [3].

In this project, a similar system as applied on arm-driven inverted pendulum which is an inverted pendulum on rotating disc will be set up [4]. Fig.1 shows the mechanical design of the inverted pendulum as proposed in the project. The hardware set up for the overall system consists of a DC servomotor and other electronic components, and mechanical part will be implemented to build the inverted pendulum plant.

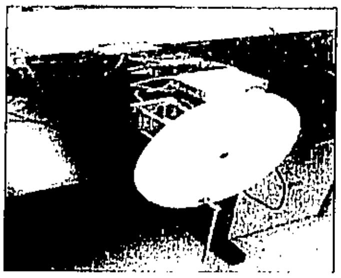

Fig.1: Inverted pendulum on a rotating disc

2. MODELING SYSTEM

According to Meriam and Kraige [5], when the earth rotates, the acceleration of a freely falling body as measured from a position attached to the surface of the earth is slightly less than the absolute value. The lab experimental tests might prove the acceleration of a freely falling body gives impact to the disc rotating and rod pendulum. This impact could be improved for better with modeling system. Modeling system applied rotational disc and dc servomotor, and inverted pendulum development at which helpful and useful to get the best response of stability. DC servomotor circuit with load of rotational disc [6] is illustrated in Fig.2 and the parameter is identified in Tab.1.

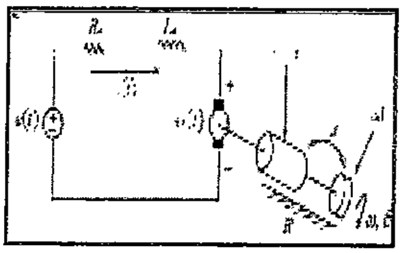

Fig.2: DC servomotor circuit with load of rotational disc

Tab.1: Parameters of DC servomotor and load

Physical quantity	Symbol (SI unit)	Measurement Values
armature inductance	L_a (H)	0.20×10^{-3}
armature resistance	R_a (Ω)	1.11
back-emf constant	K_b (Vs/rad)	36.4×10^{-3}
torque constant	K_t (Nm/A)	36.4×10^{-3}
viscous-friction coefficient	B or D_1(Nms/rad)	5.469×10^{-3}
rotor inertia	J_1 (kgm^2)	6.77×10^{-6}
load inertia	J_2 (kgm^2)	2.132×10^{-3}
total inertia	J (kgm^2)	2.139×10^{-3}

Based on this model, transfer function of disc and DC servomotor is created as following:

$$\frac{\theta(s)}{E(s)} = \frac{K_t}{s\,[(L_a s + R_a)(Js + B) + K_b K_t]} \qquad (1)$$

where θ(s) referring to the position angle from disc and E(s) referring to voltage gives to DC servomotor.

Besides, this modeling system applied for inverted pendulum in human leg and the model is summarized on Fig.3 and Fig.4 where its assumes an applied torque (T_m), pendulum angle (θ_3) viscous damping, D_3 at the hip joint (encoder 1) and inertia J_3 around the hip joint (encoder 2) [7].Tab.2 identified applicable pendulum parameters.

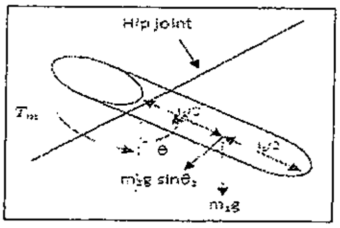

Fig.3: Inverted pendulum model

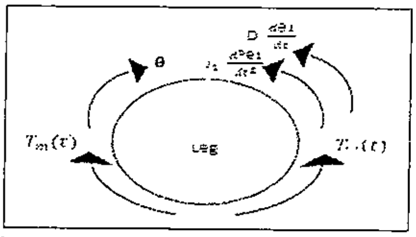

Fig.4: Free-body diagram of inverted pendulum model

Tab.2: Pendulums parameters

Physical quantity	Symbol (SI unit)	Measurement Values
mass of short pendulum	m_3 (kg)	2.44×10^{-1}
length of short pendulum	l_3 (m)	1.85×10^{-1}
inertia of short pendulum	J_3 (kg m^2)	6.959×10^{-4}

From this inverted pendulum model, transfer function is created as shown in the equation below:

$$\frac{\delta\theta_3(s)}{T_m(s)} = \frac{1/J_3}{s^2 + (D_3/J_3)\,s + [m_3 g l_3/(2J_3)]} \qquad (2)$$

3. SIMULATION RESULTS

Fig.6 and Fig.7 show the inverted pendulum plant and harmonic characteristics for the control system with fuzzy controller design each. Fuzzy controller design is more convenient rather than PID controller. This fuzzy controller based on rule added. The rule added to this couple fuzzy controller refers to acceleration of disc and pendulum, and disc and pendulum theta position. Kevin and Stephen [8] claims that coupled fuzzy controller could reduce the vibration at the endpoint as much as possible while still achieving adequate slew rates.

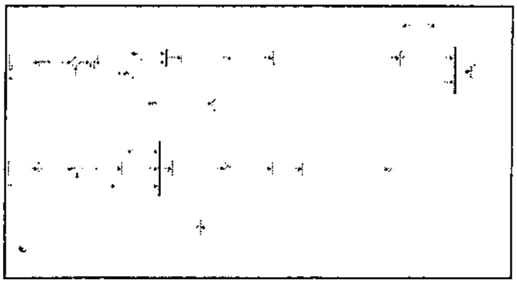

Fig.6: Coupled fuzzy controller for inverted pendulum plant by simulation

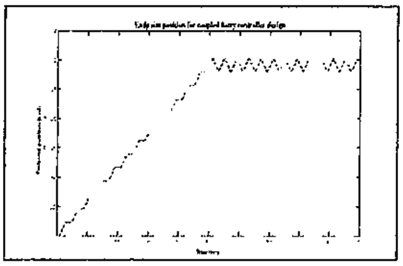

Fig.7: Simulation of the endpoint position for coupled fuzzy controller design

4. SUMMARIES

This project spends more time on modeling the inverted pendulum at which the complete model plant includes a rod pendulum, a flat disc and dc motor. Through this plant, two encoders are connected to the dc motor and flat disc. Both encoders measured speed and position for the disc and pendulum. The main objective for this project is maintaining the rod pendulum on rotating disc to remain vertical with development of advanced control system. Thus, due to its design model, a bit harder to remain this pendulum because of the non-linear behavior. This paper proposed fuzzy controller for inverted pendulum model development. From theoretical understanding, a few experimental tests have break out for comparison stability of control system. As there is an error with the result, this complete plant needed some revision from previous and future study.

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