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Rotary Inverted Pendulum Control using Fuzzy Logic Controller

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Abstract: ***In Modern world the technology is developing faster. The system uses different control theories and various technologies are updated faster. Now here control analysis of various pendulums especially cart pendulum, rotary (Futura) inverted pendulum in various techniques like fuzzy controller Using some soft computing techniques like fuzzy logic controller because now the machine learning will be going to overrule all the fields. The analysis of various sources and simulated it in MATLAB.***

Keywords: fuzzy logic, rotary inverted pendulum, NI ELVIS.

I. INTRODUCTION

In the control field, Inverted pendulum control is a basic and important with a lot of challenging problems. The system consists of encoder pendulum arm, output pendulum gear, encoder and dc servo motor. The hardware system we are going to use are QNET 2.0 Rotary Inverted Pendulum Board for NI ELVIS. NI ELVIS will integrate the twelve commonly used instruments like digital multimeter, oscilloscope, dynamic signal analyzer, function generator etc. for accurate measurement. A very good example for describing an inverted pendulum is rockets at a take-off position because it is unstable in open-loop designs. Another example we can say the gantry crane. Here, we are assuming the trolley as the pendulum's arm and the load is at the pendulum tip. The rotary inverted pendulum at inverted positioned is going to be controlled using fuzzy logic controller. The platform of programming used here is MATLAB. Here, there are two control parts they are 1. Swing Up Controller and 2. Balancing Position Controller.

1.1 Swing-up Controller is the system used in controlling the rotary inverted pendulum will be rotated to upright position. Here the fuzzy swing-up controller is used for controlling the pendulum to be swing up to the upright position

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1.2 Balancing Controller is system to balance the pendulum in the upright position. A fuzzy controller will be designed for pendulum balancing. The input variables are the pendulum angular velocity and pendulum angle α. The output is the proportional gain for the pendulum angle K p, α.

II. HARDWARE DESCRIPTION

The hardware systems we are going to use are "The Quanser QNET 2.0 Rotary Inverted Pendulum Board for NI ELVISII". The brief description about the kit is given below. The Quanser QNET 2.0 Rotary Inverted Pendulum various servo system was built to teach and show a various form of inverted pendulum-based experiments.

A direct-drive of 18V brushed DC motor is covered during a solid aluminum frame is used to drive the system. The angular position of the DC motor and pendulum is measured by Single-ended rotary encoders.

The complete rotary servo system of NI ELVIS II+ consist of a 18V brushless DC motor, Encoders near the DC motor and pendulum. a built-in PWN amplifier and the PCI connecter which is inbuilt for NI ELVIS II+.

2.1 DC Motor: The QNET Rotary Pendulum includes a direct-drive brushed DC Motor of 18V covered with a solid aluminum frame.

2.2 Encoder: The single-ended optical shaft encoders are used to measure the angular position of the DC motor and the pendulum. They provide a output of 2048 counts per revolution in quadrature mode.

2.3 Power Amplifier: The QNET Rotary Pendulum circuit card integrated with a PWM voltage-controlled power amplifier that provides 2A current at peak and 0.5 endless current on the basis of thermal current rating of motor. The output to the load range between ±10 V.

2.4 Status LED: The system also provided with a variety of safety measures that uses the Status LED for feedback particularly two digital enable lines (one high, one low) are used to ensure proper system configuration.

III. MODELLING OF THE SYSTEM

3.1 Open Loop Modelling

The mathematical modelling of the system is needed to be designed before the controller designing. Using the system in define the state variables of the system.

$$\varkappa_1 = \theta, \varkappa_2 = \propto, \varkappa_3 = \dot{\theta}, \varkappa_4$$

The state equations are

$$\breve{\theta} = -\frac{\mathrm{M}p^2 glp^2 r\cos\big(\theta(t)\alpha(t)\big)}{(\mathrm{M}_P r^2\ \sin(\theta(t)\,)^2 - J_{eq-}\mathrm{M}_P\ r^2)J_p\ -\ \mathrm{M}_P l_p^2\, J_{eq}} - \frac{J_p \mathrm{M}_P r^2 r\cos\big(\theta(t)\big)\sin(\theta(t)\,))\dot{\theta}^2}{(\mathrm{M}_P r^2\ \sin(\theta(t)\,)^2 - J_{eq-}\mathrm{M}_P\ r^2)J_p\ -\mathrm{M}_P l_p^2\, J_{eq}} - \frac{J_p\,\tau_0\ + \mathrm{M}_P l_p^2\tau_0}{(\mathrm{M}_P r^2\ \sin(\theta(t)\,)^2 - J_{eq-}\mathrm{M}_P\ r^2)J_p\ -\ \mathrm{M}_P l_p^2\, J_{eq}}$$

$$\ddot{\alpha} = -\frac{lp\mathrm{M}p((-gJ_{eq} + \mathrm{M}_P r^2\ \sin(\theta(t)\,)^2\, g_{-}\mathrm{M}_P\ r^2 g))\alpha(t)}{(\mathrm{M}_P r^2\ \sin(\theta(t)\,)^2 - J_{eq-}\mathrm{M}_P\ r^2)J_p\ -\ \mathrm{M}_P l_p^2\, J_{eq}} - \frac{l_p\mathrm{M}_P\sin(\theta(t)\,)J_{eq}\dot{\theta}^2}{(\mathrm{M}_P r^2\ \sin(\theta(t)\,)^2 - J_{eq-}\mathrm{M}_P\ r^2)J_p\ -\mathrm{M}_P l_p^2\, J_{eq}} - \frac{l_p\mathrm{M}_P r\,\tau_0\cos\,(\theta(t))}{(\mathrm{M}_P r^2\ \sin(\theta(t)\,)^2 - J_{eq-}\mathrm{M}_P\ r^2)J_p\ -\ \mathrm{M}_P l_p^2\, J_{eq}}$$

T_0= the torque at pivot arm by motor voltage is

$$\tau_o = \frac{\mathrm{K}_t(V_m - K_m\dot{\theta})}{R_m}$$

The formulation of linear state-space representation of the inverted pendulum is given as

$$\dot{x}(t) = Ax(t) + Bu(x)$$
$$y(t) = Cx(t) + Du(x)$$

The Linearization of nonlinear equations $u(x) = \mathcal{V}_m$ and $\alpha = \pi$ results:

The center of mass of the pendulum

$$\varkappa_{cm} = \frac{\int \wp x dx}{\int \wp\, dx}$$

The link's density is

$$p_a = \frac{M_{pa}}{L_{pa}}$$

The weight's density is

$$p_b = \frac{M_{pb}}{L_{pb}}$$

The center of mass of composite object of multiple bodies is,

$$\varkappa_{cm} = \frac{\sum_i x_i\, m_i}{\sum_i m_i}$$

Symbols	Description
M_p	Mass of the rotary inverted pendulum
L_p	Length of the rotary inverted pendulum
l_p	Length of pendulum center of mass from the pivot
J_p	Pendulum moment of inertia
r	Length of arm pivot to pendulum pivot
g	Gravitational acceleration constant
J_m	Motor shaft moment of inertia
J_{eq}	Equivalent moment of inertia for the motor shaft pivot axis
R_m	Motor armature resistance
K_t	Motor torque constant
K_m	Motor back-electromotive force constant
p	Density of pendulum body

3.2 System Models with values:

The following equations are the mathematical modelling of the system,

$$\dot{x}(t) = Ax(t) + Bu(x)$$
$$y(t) = Cx(t) + Du(x)$$

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 22.324 & -0.289 & 0 \\ 0 & 36.20 & -0.076 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 8.95 \\ 2.28 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

3.4 Controller design

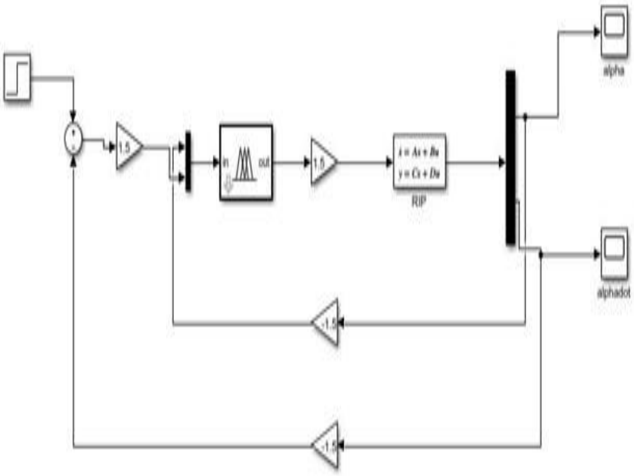
The discrete state model of the system is as under**:** X (k + l)

= AX(k) + Bu(k)

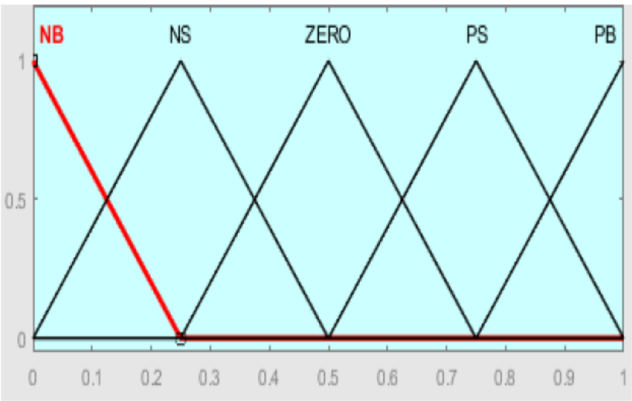
$$A = \begin{bmatrix} 1.007 & 0.02 & 0 & 0 \\ 0.089 & 1.008 & 0 & 0 \\ -0.0001261 & -7.720e-07 & 1 & 0.02 \\ -0.011126 & -0.0001261 & 0 & 1 \end{bmatrix}$$

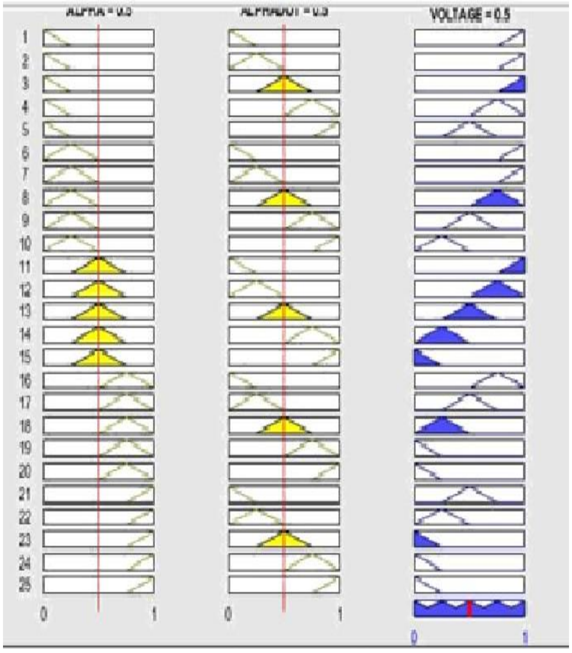
$$B = \begin{bmatrix} -7.892e-005 \\ -0.0078553 \\ 0.00018577 \\ 0.018577 \end{bmatrix}$$

IV.CIRCUIT DIAGRAM:



4.1 Membership Function

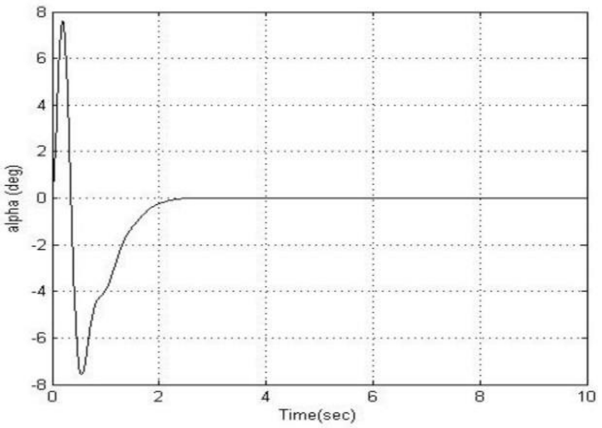




4.2 Rule Viewer:

V.RESULT:

The Stabilization of the fuzzy logic controller of the Rotary Inverted Pendulum was within 0.5sec. The peak overshoot was 0.09(% MP). The rise time was $T_r = 0.05$.



VI.CONCLUSION:

Under certain condition, the system is stable for a conventional controller. But in the actual system, the control process becomes difficult because of the uncertainties of parameters and the determination of the efficiency, accuracy of fuzzy logic controller and reliability shows the robust control with fuzzy logic simulation studies. The structure of fuzzy controller is simple, and hence the system is analyzed and implemented in fuzzy logic system.

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