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Analysis of Fuzzy Controller System for Rotary Inverter System

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Abstract
At this time various types of controllers used in industry, including fuzzy controllers. Fuzzy control is a control that implements the human capacity. Rotary inverter pendulum system is also known as a test plant in the control system because it is non-linear and very unstable. This paper presents analysis of Fuzzy controller for rotary inverter pendulum.. The simulation results by initial angle of 0.1 radians on a pendulum, the Fuzzy controller able to get balancing of pendulum at time settling is 3.543 sec, time rise is 1.58 sec, time delay is 0.488 sec and error steady state is 0.000088.

Keywords: Fuzzy, stability, rotary inverter pendulum

INTRODUCTION

At this time various types of controllers used in industry, including fuzzy controllers. Fuzzy control is a control that implements the human capacity to exercise control by using rule if - than. Fuzzy control has the advantage of not requiring mathematical modeling in designing controls making it easier to perform high-order control system [1].

Rotary inverter pendulum is one of the non-linear system that describes the problem of stability [2]. Rotary inverter system pendulum is very unstable so to control the system techniques is not easy be compared with a control technique in which linear and stable system [3]. Rotary inverter pendulum had some control problems including swing-up that change the position of the pendulum from the bottom position to the top position, then a stabilization which balances the pendulum remains in top position and, tracking is put the position of the pendulum arm to the reference point given in conjunction with the balance of the pendulum. But in this study which will be the discussion is to balance the pendulum remains at the top position [4].

Rotary inverter pendulum system is also known as a test plant in the control system because it is non-linear and very unstable [5]. Rotary inverter pendulum system consist of rotating arm that is driven by a motor and a pendulum rod mounted on the edge of the rotating arm [6].

RESEARCH METHODOLOGY

The methodology research begins with literature review related to this study. Then conduct mathematical modelling for rotary inverter pendulum. Solution of mathematical modelling obtained using matrix. The next step is designing the controller with Fuzzy logic control (FLC). Simulation is done using MATLAB Simulink.

Fig. 1 shows the free diagram of rotary inverter pendulum [7]. After the Lagrangian of the system is found and various derivatives are calculated to find and then [7]:

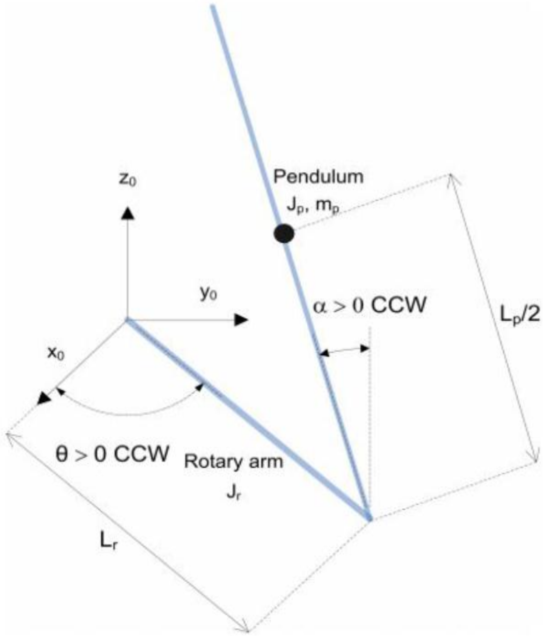

Figure 1. Free diagram of rotary inverter pendulum [7]

$$\left(m_pL_r^{\,2}+\frac{1}{4}m_pL_p^{\,2}\cos(\alpha)^2+J_r\right)\ddot{\theta}-\left(\frac{1}{2}m_pL_pL_r\cos r(\alpha)\right)\ddot{\alpha}+ \left(\frac{1}{2}m_pL_p^{\,2}\sin(\alpha)\cos(\alpha)\right)\dot{\theta}\dot{\alpha}+\left(\frac{1}{2}m_pL_pL_r\sin(\alpha)\right)\dot{\alpha}^{2}=\tau-B_t(\dot{\theta}) \quad (1)$$

$$\frac{1}{2}m_pL_pL_r\cos(\alpha)\ddot{\theta}+\left(J_p+\frac{1}{4}m_pL_p^2\right)\ddot{\alpha}-\frac{1}{4}m_pL_p^2\cos(\alpha)\sin(\alpha)\theta^2 -\frac{1}{2}m_pL_pg\sin(\alpha)=-B_p\dot{\alpha} \quad (2)$$

The torque applied at the base of the rotary arm is generated by a servo motor which is described by the equation 3:

$$\tau=\frac{\eta_gK_g\eta_mK_t(V_m-K_gK_m-m\dot{\theta})}{R_m} \quad (3)$$

The linearized model is needed then assume when the inverted pendulum is near its equilibrium point: $\theta=0^\circ,\alpha=0^\circ,\dot{\theta}=0,\dot{\alpha}=0$ and we get:

$$A=\frac{1}{J_T}\begin{bmatrix}0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & \frac{1}{4}m_p^2L_p^2L_rg & -(J_p+\frac{1}{4}m_pL_p^2)B_r & -\frac{1}{2}m_pL_pL_rB_p\\ 0 & \frac{1}{2}m_pL_pg(J_r+m_pL_r^2) & -\frac{1}{2}m_pL_pL_rB_r & -(J_r+m_pL_r)B_p\end{bmatrix} \quad (4)$$

$$B = \frac{1}{J_T}\begin{bmatrix} 0 \\ 0 \\ J_p + \frac{1}{4} m_p L_p^2 \\ \frac{1}{2} m_p L_p L_r \end{bmatrix} \quad (5)$$

$$C = \begin{bmatrix} 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \quad (6)$$

$$D = 0 \quad (7)$$

Putting the values of from Table 1. we get the exact values of state space matrices:

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 80.3 & -45.8 & -0.930 \\ 0 & 122 & -44.1 & -1.40 \end{bmatrix} \quad (8)$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 83.4 \\ 80.3 \end{bmatrix} \quad (9)$$

$$C = \begin{bmatrix} 0 & 1 & 0 & 0 \end{bmatrix} \quad (10)$$

$$D = 0 \quad (11)$$

Table 1 Rotary Inverted pendulum specification [7]

Parameter	Simbol	Value
Mass of rotary arm (kg)	m_r	0.257
Length of rotary arm (m)	L_r	0.2159
Rotary arm moment of inertia (kg.m^2)	J_r	9.98×10^{-4}
Arm viscous damping coefficien (N.m.s/rad)	B_r	0.11
Mass of the pendulum (kg)	m_p	0.127
Length of the pendulum (m)	L_p	0.337
Pendulum viscous damping coefficient (N.m.s/rad)	B_p	0.0024
Pendulum moment of inertia (kg.m^2)	J_p	0.0012
Motor armature resistance (Ω)	R_m	2.6

Back-emf constant (V.s/rad)	K_m	0.0077
Torque constant (N.m/A)	K_t	0.0077
High gear total gear ratio	K_g	70
Gravity (kg.m/s^2)	g	9.8
Gearbox efficiency	η_g	0.9
Motor efficiency	η_m	0.69

Fuzzy Logic Control (FLC):

Fuzzy logic is a way to map an input into an output. The fuzzy logic is very usefull for complex system to solve the problem in the system [8]. Conventional controller has shortcoming to solve the problem in complex system, because the conventional system has crisp value output in accordance with a predetermined input [9]. That is not like fuzzy logic is flexible to disturbance in system input.

The fuzzy logic has some process that are fuzzyfication, inference fuzzy system, and defuzzyfication [10].

Design Fuzzy Controller:

The design of fuzzy logic control in this study using mamdani fuzzy method. In this research, input of fuzzy logic controller is error and derror. The value of error obtained from equation below:

$$Error = SP - PV \qquad (12)$$

Where:
SP (setpoint) = final value
PV (Present value) = actual value

And to get the error value system follows the equation:

$$Derror = Error(n) - Error(n\text{-}1) \qquad (13)$$

Where :
Error(n) = present error
Error(n-1) = previous error

In this study, the composition rules used method max and fuzzy rules for rotary inverter system pendulum in Table 2.

Table 2 Rule base for rotary inverter pendulum

Error / *Derror*	N	Z	P
N	NE	NE	ZE
Z	NE	ZE	PO
P	ZE	PO	PO

The next process is the process of mapping defuzzyfication fuzzy sets to crisp. This process is the opposite of fuzzyfication. There are many defuzzyfication method in mamdani fuzzy, but in this study is used method the midpoint (Centroid Method) commonly used in the process defuzzyfication

RESULTS AND DISCUSSION

The result of open-loop simulation for rotary inverted pendulum angle response as shown in Fig.2. It can be got that the system is unstable and pendulum can not achieve balance in top position.

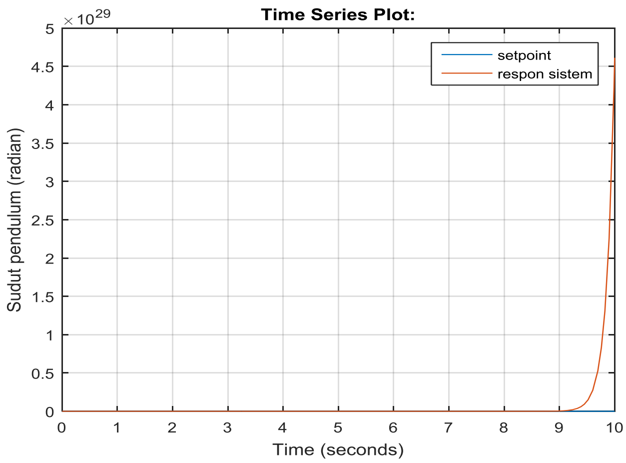

Figure 2. Response step graph of rotary inverted pendulum system without a controller

After Fuzzy is simulated and its plant is rotary inverter pendulum system without by using the initial angle of 0.1 rad and it will produce a graph as in Fig. 3. Seen from Fig. 3 that the settling time required pendulum with initial angle of 0.1 radians to be stable around 0 radian is at 3.543 second. The transient response obtained for analysis of Fuzzy controller contained in Table 3:

Table 3. Analysis transient responses

Fuzzy Controller		
time (sec)		stable
t_d	0.488	
t_r	1.58	
t_s	3.543	
Ess		0.000088

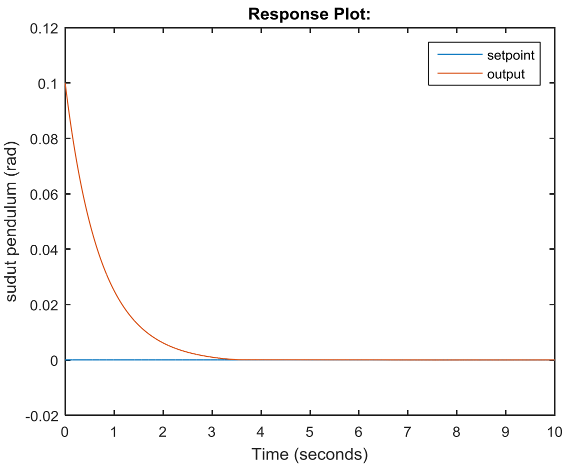

Figure 3. Response step graph of rotary inverted pendulum system with Fuzzy controller

Based on the results of the simulation and analysis of system response, Fuzzy controller has good performance in achieving a stable condition because the Fuzzy controller has a fast settling time is 0.7 seconds. As for the maximum undershoot characteristics, fuzzy controller has no undershoot.

CONCLUSIONS

Based on results of simulation and analysis of the fuzzy control the balance of the pendulum on a rotary system inverter pendulum, it can be concluded that Fuzzy controller capable of generating good response, as is evident from the results of the system by giving the initial angle of 0.1 radians, Fuzzy controller can maintain the balance of the pendulum to remain in the top position which produces time settling is 3.543 sec, time rise is 1.58 sec, time delay is 0.488 sec and error steady state is 0.000088.

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