International Journal of Mechanical Engineering
ISSN : 2277-7059 Volume 1 Issue 1
http://www.ijmejournal.com/ https://sites.google.com/site/journalijme/

Anti-Swing Control Strategy for Automatic 3 D.O.F Crane System Using FLC

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Abstract. This paper presents a control strategy to overcome positioning control and anti-swing control for a 3 Degree-of-Freedom (D.O.F) crane system. It is well known that the 3 D.O.F crane system is a type of machine, generally equipped with a hoist, wire ropes or chains, and sheaves. It can be used to lift and lower materials and to move them horizontally. However, controlling the 3 D.O.F crane systems requires a good control method to achieve a high positioning control and in particular to suppress swing that produced during operation. Hence, choosing an appropriate control to resolve positioning control and swing angle is not a trivial task in particular to transfer payloads quickly, effectively and safely. Presently, the existing of 3 DOF systems used a conventional PID controller to control position and swing angle. The controllers were designed based on the model and parameter of the crane system. In general, modelling and parameter identifications are troublesome and time consuming. Therefore, we propose a Fuzzy Logic Control (FLC) which has simpler and practical design approach. Effectively, it is anticipated that the FLC can be used to avoid a complex mathematical calculation which is always time consuming. In addition, the model derivation is often inaccurate due to the presence of nonlinearities and uncertainties. Throughout this paper, the FLC performances are compared with PID controller through experiment. The results showed that FLC has produced good result for positioning and anti-swing control for 3 D.O.F. crane system.

Keywords: Fuzzy Logic Control, 3 D.O.F Crane system, PID Control.

1. Introduction

The 3-DOF crane represents one of the most widely deployed real-world platforms in the world today that uses levers and/or pulleys for gripping, lifting and moving loads horizontally, as well as lowering and release the gripper back. The task of the 3-DOF crane is to move the payload from one point to another point. Until recently, cranes are manually operated by professional person. But when cranes became larger and they are being moved at high speeds, their manual operation becomes difficult. Undesired oscillation can always be found during the moving process especially at the end location of the transport [1]. In factories, cranes speed up the production processes by moving heavy materials to and from the factory as well as moving the products along production or assembly lines. In building construction, cranes facilitate the transport of building materials to high and critical spots. Similarly on ships and in harbors, cranes save time and consequently money in making the process of loading and unloading ships fast and efficient.

Hence the system produces swing angle which need to be controlled so that the payload will be transferred quickly, effectively and safely. Many researchers have proposed different controllers by using specified prototype crane. For example, Fang *et al.* [2] have proposed nonlinear coupling controllers to improve transient response for 3-DOF overhead crane. Jalani *et al.* [3] have proposed FLC for swing angle and NCTF for linear movement of gantry crane. Al-Mousa [4] proposed two types of controllers consist of Fuzzy Logic and time delayed position feedback controllers in control rotary crane. Sutakorn *et al.* [5] focusing on investigating adaption control technique based on Fuzzy Sugeno approach use in overhead travelling crane and Othman [6] have proposed rough controller to compared with FLC method.

In this research a 3-DOF crane which is different in terms of size, parameters and etc [7] is used for the FLC investigation. However, the ultimate design is still to ensure that the load swing angle and positioning produced by the crane systems are successfully controlled and FLC can be implemented with minimum mathematical model [8].

The 3-DOF crane used for this study consists of 3 subsystems namely payload, jib and tower. However, the focus of the study is only concentrating on jib controller in which the jib itself consists of swing and trolley position control.

2. Modelling (JIB)

The model of JIB system is developed for the control purpose. The jib is modeled as a two-dimensional linear gantry by assuming the payload is at a fixed height and is also fixed about the α gimble angle, which is the motion perpendicular to the jib length. In other words, it is assumed the payload only rotates about γ gimble angle. The trolley is suspended on a linear guide and is fastened to a motorized belt-pulley device. When the current in the dc motor, I_{mj}, is positive the trolley moves away from the tower and towards the end of the jib. This is defined as positive velocity. Thus the position of the trolley x_j, increases positively as it goes towards the right of the free-body diagram shown in the Fig. 1.

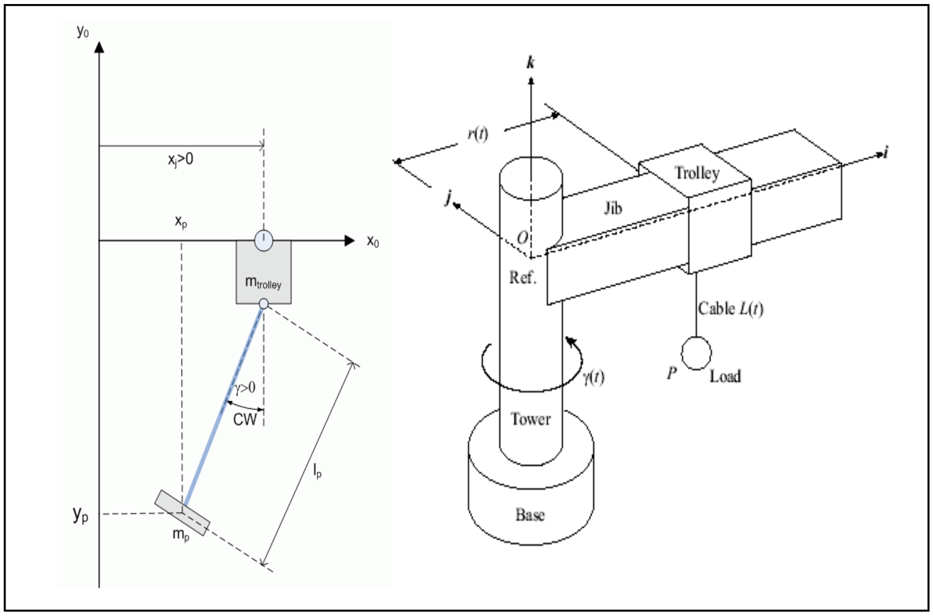


Fig. 1. Free body diagram of jib system and model of 3DOF Crane

Using Fig. 1, the position of the payload's center of mass with respect to the Cartesian coordinate system is

$$x_p = x_j(t) \quad l\sin(\gamma(t)) \tag{1}$$

and

$$y_p = \quad l\cos(\gamma(t)) \tag{2}$$

The nonlinear system of equations are also linearized and represented in state-space format. When ignoring the rotational kinetic energy from the pendulum, the linear state-space system of the 3 DOF Crane in Jib system is

$$\frac{\partial}{\partial t}x = Ax + Bu \tag{3}$$

$$y = Cx + Du \tag{4}$$

where

$$x^T = [x_j(t), \gamma(t), \frac{d}{dt}x_j(t), \frac{d}{dt}\gamma(t) \tag{5}$$

and the matrices are

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & -\dfrac{m_p r_{j,pulley}{}^2 g}{m_{trolley} r_{j,pulley}{}^2 + J_\Psi K_{g,j}{}^2} & 0 & 0 \\ 0 & -\dfrac{g(m_{trolley} r_{j,pulley}{}^2 + m_p r_{j,pulley}{}^2 + J_\Psi K_{g,j}{}^2)}{(m_{trolley} r_{j,pulley}{}^2 + J_\Psi K_{g,j}{}^2) l_p} & 0 & 0 \end{bmatrix} \tag{6}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \dfrac{r_{j,pulley}\eta_{g,j} K_{g,j} \eta_{m,j} K_{t,j}}{m_{trolley} r_{j,pulley}{}^2 + J_\Psi K_{g,j}{}^2} \\ \dfrac{r_{j,pulley}\eta_{g,j} K_{g,j} \eta_{m,j} K_{t,j}}{(m_{trolley} r_{j,pulley}{}^2 + J_\Psi K_{g,j}{}^2) l_p} \end{bmatrix} \tag{7}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \tag{8}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{9}$$

3. Fuzzy Logic Control Design

Fuzzy logic controller used for suppressing the vibration of the payload is one of the recent developing methods in control that earned its popularities. The idea behind the fuzzy logic controller is to write the rules that operating the controller in heuristic manner, mainly in If A Then B format. In general, as shown in Fig. 2, fuzzy logic controller is constructed by the following elements [9]:

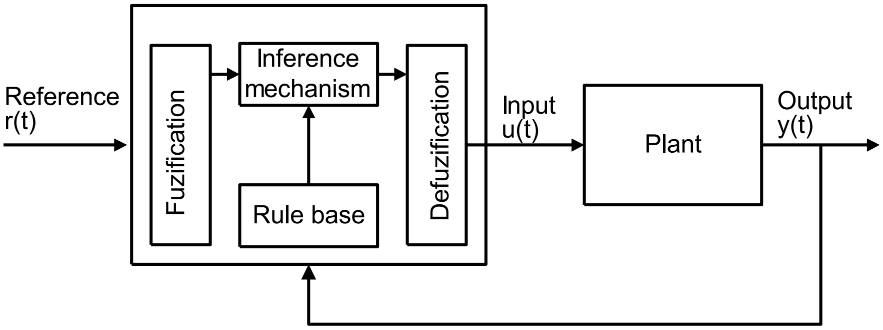
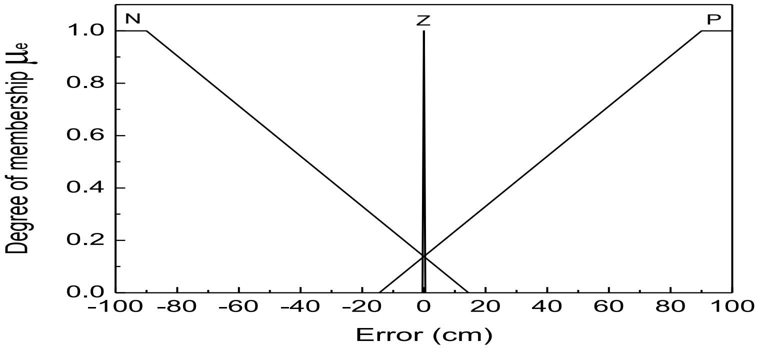


Fig. 2: Fuzzy controller structure

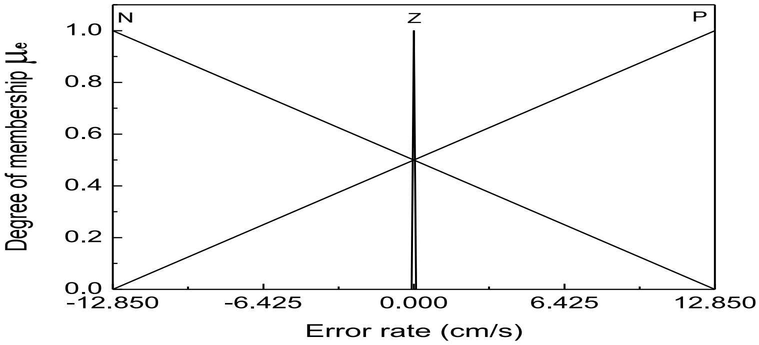
- *A rule base* (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve good control**.**
- *An inference mechanism* (also called an "inference engine" or "fuzzy inference" module), which emulates the expert's decision making in interpreting and applying knowledge about how best to control the plant.
- *A fuzzification interface*, which converts controller input into information that the inference mechanism can easily being used to activate and apply rules.
- *A defuzzification interface,* which converts the conclusions of the inference mechanism into actual inputs for the process.

3.1 Membership Functions

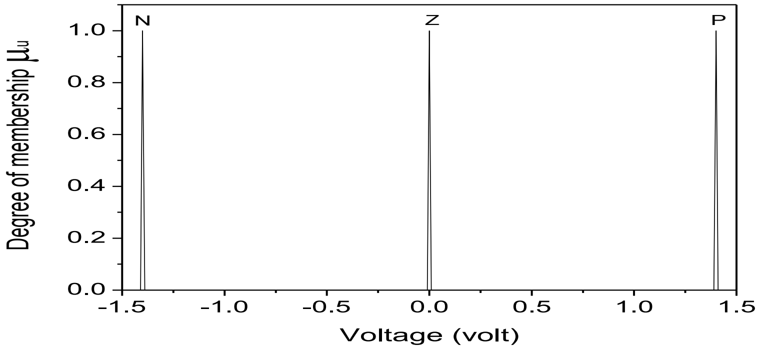
The membership functions for error, error rate and voltage of the position control consist of Negative (N), Zero (Z) and Positive (P) as shown in Fig. 3(a), Fig. 3(b) and Fig. 3(c) respectively. The universe of discourse is from -100 to 100 cm for error, -12.85 to 12.85 cm/s for error rate and -1.4 to 1.4 for voltage. Meanwhile, membership functions for error, error rate and voltage of anti-swing control consist of Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB) as shown in Fig. 4(a), Fig. 4(b) and Fig. 4(c) respectively. The universes of discourses of error, error rate and input voltage are from -1 to 1 rad, -2.5 to 2.5 cm/s and -1.4V to1.4 V respectively.



(a) Input membership function of error e

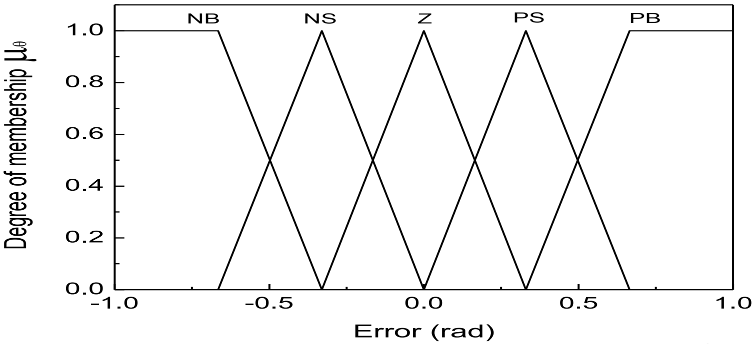


(b) Input membership function of error rate $\dot{e}$

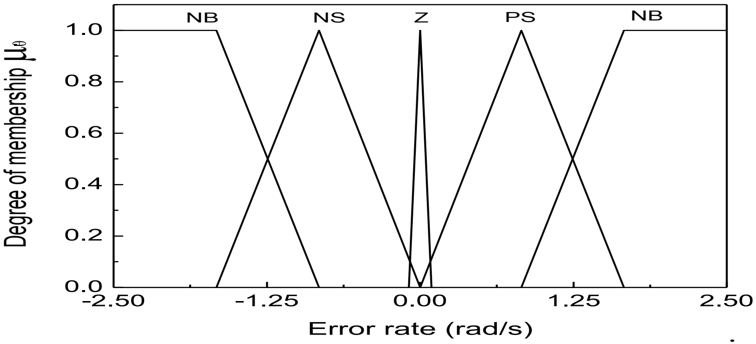


(c) Output membership function of voltage u

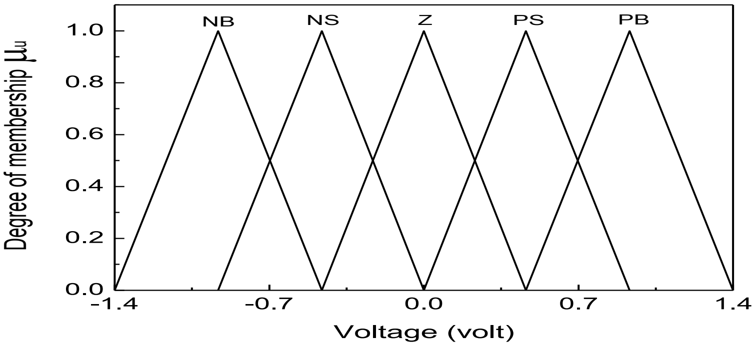
Fig. 3. Membership function of position control



(a) Input membership function of swing angle θ



(b) Input membership function of swing angle velocity $\dot{\theta}$



(c) Output membershipfunction of voltage u

Fig. 4. Membership function of anti-swing control

3.2 Fuzzy Rule Base

Fuzzy control rules for constant height of the payload are shown in the Table 1 and Table 2 which consist of five membership functions of output voltage. The control rules have been designed based on operator's knowledge and experienced, for example when the swing angle is NS and the swing angle change is Z, then NS of voltage is needed to control the load swing.

Table 1. "Position" matrix

$x/\Delta x$	P	Z	N
P	PB	PB	PS
Z	NB	Z	PB
N	NS	NB	NB

Table2. "Angle" matrix

$\gamma/\Delta\gamma$	PB	PS	Z	NS	NB
PB	PB	PB	PB	PB	PB
PS	PB	PS	PS	PS	PS
Z	PB	PS	Z	NS	NB
NS	NS	NS	NS	NS	NB
NB	NB	NB	NB	NB	NB

3.3 Fuzzy Inference and Defuzzification

The Fuzzy inference for position (10) and anti-swing control (11) has adopted the Mamdani's Min-Max method and computed as

$$\mu_u = \vee\left\lfloor \mu_x \wedge \mu_{\bar{x}} \right\rfloor \tag{10}$$

and

$$\mu_u = \vee\left\lfloor \mu_\gamma \wedge \mu_{\bar{\gamma}} \right\rfloor \tag{11}$$

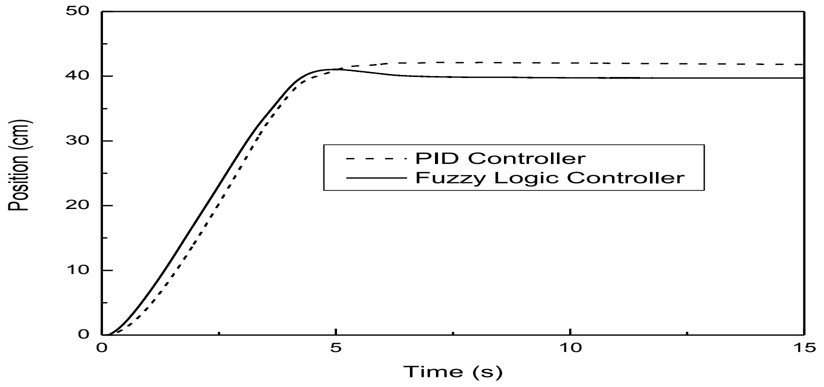
where $\wedge$ and $\vee$ denote the minimum and maximum operators respectively while μ_x, $\mu_{\bar{x}}$ and μ_u denote degree of memberships of the error, error rate and output voltage for position control. Meanwhile, μ_γ, $\mu_{\bar{\gamma}}$ and μ_u represent error, error rate and output voltage for anti swing control respectively. Moreover, in order to convert the fuzzy value to the crisp value of fuzzy position and anti- Swing control, the centre of area (COA) of defuzzification method is used as follow:

$$u_o = \frac{\int_u \mu_u(u)u\,du}{\int_u \mu_u(u)\,du} \tag{12}$$

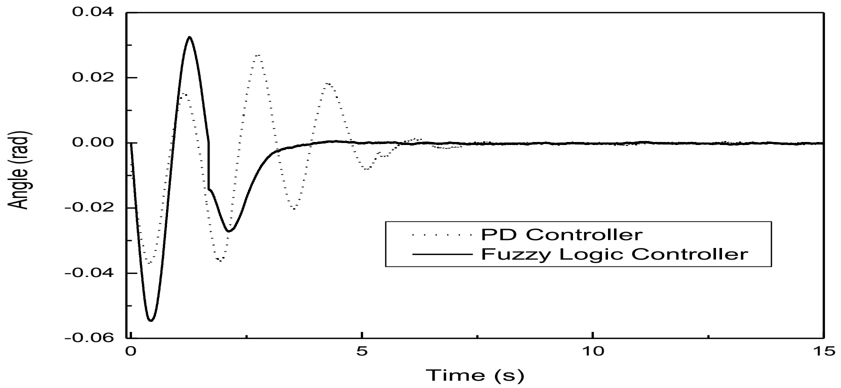
Where u_o is a control input voltage obtained by using COA defuzzification method.

4. Performance

The performance of the proposed FLC is compared with PID controller in experiment. Here, the performance of position control system is evaluated based on overshoot, rise time, settling time and steady state error. On the other hand, anti-swing control is evaluated based maximum amplitude and settling time.



(a) Position response



(b) Anti-swing response

Fig. 4. Responses to a step input (a) Experimental results for trolley position (b) Experimental results for swing angle

Table 3. Performance of Position Control

Controller	Overshoot (%)	Rise time (sec)	Settling time (sec)	Steady State Error
PID	5.3	2.9	>50	4.65x 10^{-1}
Fuzzy Logic	2.6	2.8	5.4	-8.03 x 10^{-1}

Table 4. Performance of Anti-Swing Control

Controller	Maximum Amplitude (rad)	Settling time (s)
PD	0.04	11
Fuzzy Logic	0.06	5

Fig. 4(a) and Table 3 show the response and performance of positioning control respectively through experiment. The results showed that the FLC for position control gave smaller overshoot, shorter settling time, faster rise time and lower steady state error.

Moreover, Fig. 4(b) and Table 4 show that the experiment response and performance of anti-swing control respectively. The results showed that the FLC for anti-swing control gave slightly bigger overshoot (i.e. different of 0.02 rad). However the settling time for the FLC is faster than the PID controller (2 times faster).

5. Conclusion

In this paper, Fuzzy Logic Control is chosen and designed to control the position and load swing angle for 3 DOF crane systems. The experimental results showed that the proposed of FLC have better performance in comparison to the conventional PID controller. In addition, the FLC has a simpler design method, algorithm and less mathematical computation.

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