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APPLICATION OF FUZZY AND PID ALGORITHM IN GANTRY CRANE CONTROL

ỨNG DỤNG GIẢI THUẬT MỜ VÀ PID TRONG ĐIỀU KHIỂN CẦN TRỤC

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ABSTRACT

Gantry crane (2D crane) system had been applied popularly in practice, especially in goods transportation. Fuzzy and PID algorithm are widely used in industry and had been applied successful for controlling 2D crane. This paper verifies again both Fuzzy and PID algorithms in controlling a 2D crane system. This article also proposes a fuzzy controller with four inputs and one output used to control 2D crane system. In this paper, both algorithms are proved to work well with crane model in simulation and real experiment.

***Keywords**: fuzzy; PID; gantry crane; goods transportation; intelligent control; linear control.*

TÓM TẮT

Cần trục (loại 2D) được ứng dụng rộng rãi trong thực tế, đặc biệt là trong vận chuyển hàng hóa. Giải thuật mờ và vi tích phân tỉ lệ (PID) được sử dụng nhiều trong công nghiệp, và cũng đã được sử dụng thành công trong điều khiển hệ cần trục 2D. Trong khuôn khổ bài báo, cả hai giải thuật được chứng minh đã hoàn thành tốt với cùng hệ thống trên mô phỏng và thí nghiệm.

Keywords: *mờ; vi tích phân tỉ lệ; cần trục; vận chuyển hàng hóa; điều khiển thông minh; điều khiển tuyến tính.*

1. INTRODUCTION

Crane is a popular model in both industry [5] and laboratory [6]. Crane can be divided into two types: 2D-crane and 3D-crane. In this paper, authors focus on 2D-crane due to its simplicity in mechanical structure. With 2D-crane, which has the other name as "Gantry Crane", the aim of vibration termination is an important subject in control engineering [7-9]. But it is still a new subject in Vietnam.

PID algorithm was tested successful for controlling gantry crane in [2], [3], and the results were just shown in simulation. Fuzzy algorithm had been used to control successfully this system in simulation and reality [4], but the structure of controller is two separate MISO fuzzy logic controllers, each controller has two inputs and one output. This structure was used to reduce the number of rule for fuzzy controller. But with this arrangement, the accuracy of fuzzy controller which formed to apply the experiment of the expert for MIMO – SIMO system was decreased. This paper verifies again PID and Fuzzy algorithm for controlling gantry crane in simulation and reality. The structure of the controller is different to the one in [2], [3] and [4], it is a MISO fuzzy controller with four inputs and one output.

The paper concludes five sections. Section 1 introduced the content of the paper. Then, section 2 described the mathematical model control basis of algorithm for model. Simulation in section 3 described the response of system under PID and fuzzy controllers. In section 4, a real model is constructed and tested under different types of controllers. Finally, section 5 ends the paper.

2. THEORETICAL BASIS

2.1. Gantry crane model

In [1], mathematical equations described 2D crane system can be expressed as follow:

$$\ddot{\alpha} = \frac{-\left(M_c + M_p\right)M_p g l_p \sin\alpha - \left(M_c + M_p\right)B_p\alpha - M_p^2 l_p^2\dot{\alpha}^2 \sin\alpha\cos\alpha + M_p l_p \cos\alpha B_{eq}\dot{x} - F_c M_p l_p \cos\alpha}{\left(M_c + M_p\right)I_p + M_c M_p l_p^2 + M_p^2 l_p^2 \sin^2\alpha}$$

$$\ddot{x} = \frac{-(I_p + M_p l_p^2)B_{eq}\dot{x} + (M_p^2 l_p^3 + I_p M_p l_p)\dot{\alpha}^2 \sin\alpha + M_p l_p \cos\alpha B_p\dot{\alpha} + (I_p + M_p l_p^2)F_c + M_p^2 l_p^2 g \cos\alpha\sin\alpha}{(M_c + M_p)I_p + M_c M_p l_p^2 + M_p^2 l_p^2 \sin^2\alpha}$$

The mathematical model of Gantry Crane can be described in Fig. 1 below

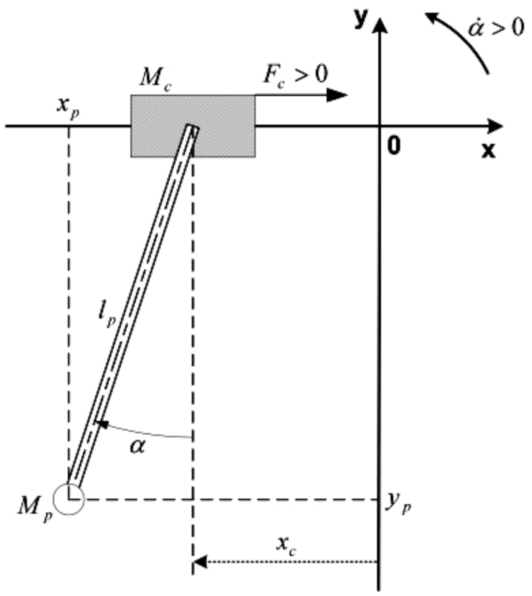

Fig. 1. *2D crane scheme*

2.2. PID algorithm

PID controller includes two PID controller: PID1 controlled x positon (with setpoint 1) and PID2 controlled alpha angle. The scheme of PID controller is shown in Fig.2.

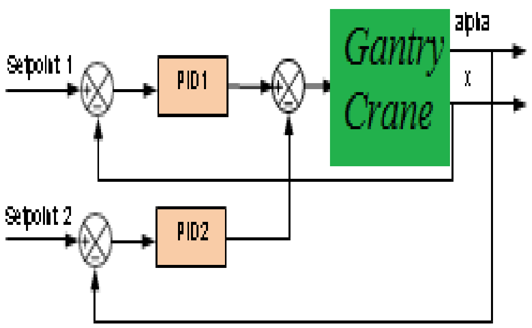

Fig. 2. *The PID control scheme of 2D crane*

PID1 and PID2 control parameters are: Kp1, Ki1, Kd1 và Kp2, Ki2, Kd2.

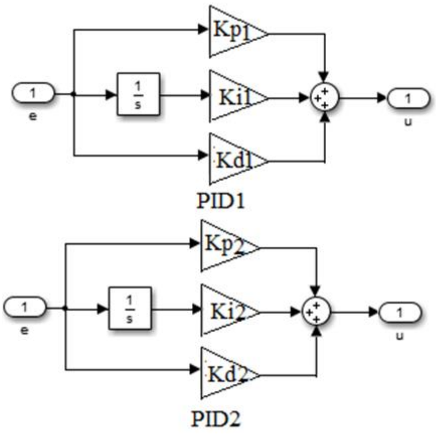

Fig. 3. *The scheme of each PID controller*

2.3. Fuzzy algorithm

The selected fuzzy controller includes four inputs: the angle and its velocity , the position x and its velocity . The output is voltage supplied to motor or motor's moment.

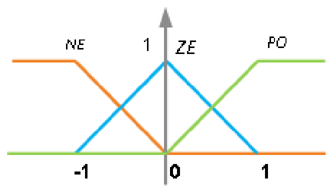

Fig. 4. *Membership functions of four standardized input*

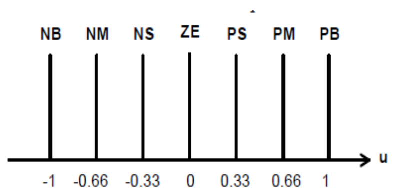

Fig. 5. *Membership functions of standardized output*

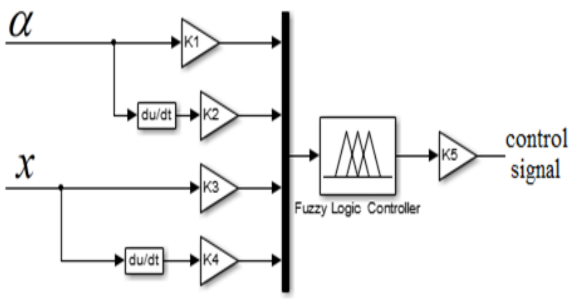

Fig. 6. *The fuzzy control scheme of 2D crane*

The number of rule using in fuzzy controller is 81 as listed in APPENDIX. Some of used rules are listed below:

If α is ZE and $\frac{d\alpha}{dt}$ is ZE and x is ZE and $\frac{dx}{dt}$ is ZE then u is ZE.

If α is NE and $\frac{d\alpha}{dt}$ is ZE and x is ZE and $\frac{dx}{dt}$ is ZE then u is NS.

If α is PO and $\frac{d\alpha}{dt}$ is ZE and x is ZE and is ZE then u is PS.

……………………………………………

3. SIMULATION RESULTS

The PID controller parameters are selected as follow: *Kp1=21.43; Ki1=8.35; Kd1=15.06; Kp2=9.64; Kì=51.92; Kd2=33.16* and Fuzzy controller parameters are: *K1=0.112; K2=1.974; K3=4.318; K4=2.621; K5=3.46.*

The initial values of $\begin{bmatrix} x & \dot{x} & \alpha & \dot{\alpha} \end{bmatrix}$ are:

$$x_{init} = 0.1(m);\ \dot{x}_{init} = -0.07(m);$$
$$\alpha_{init} = 0.04(rad);\quad \dot{\alpha}_{init} = -0.01(rad)$$

The simulation of system is shown as follow:

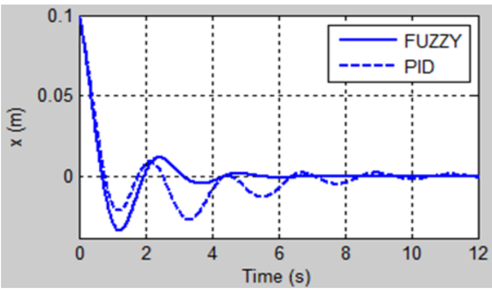

Fig. 7*. The cart position*

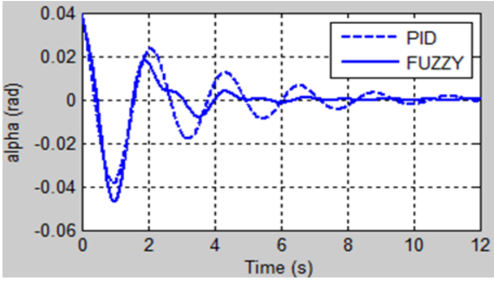

Fig. 8. *The alpha angle*

From the Fig. 7, 8, simulation shows that settling time is improved much if fuzzy controller is used instead of PID controller. But, PID controller makes response less overwhelm than Fuzzy controller. So, each controller has advantages and disadvantages, depending on quality requirement.

If the set-point of are 0.5m, then the output of system is as in Fig. 9, 10. It is obvious that each controller is good in settling time and bad in overwhelm (fuzzy control) or vice versa (PID control)

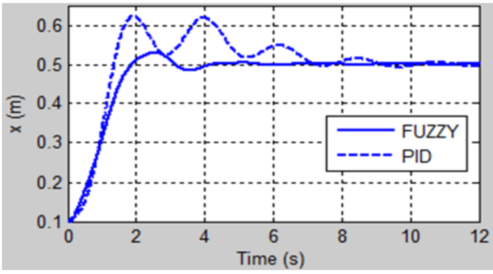

Fig. 9. *The cart position with x_setpoint is 0.5m*

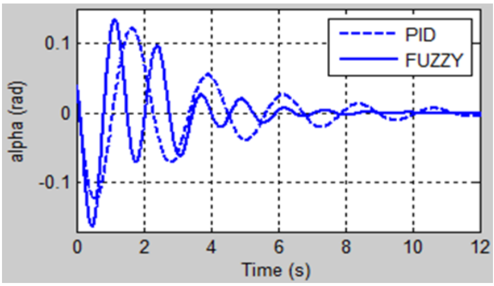

Fig. 10. *The alpha angle with x_setpoint is 0.5m*

In simulation, it is obvious that the fuzzy controller make system stable faster than PID controller (the settling time in comparison in Fig, 7, 8, 9, 10). But in some case of fuzzy control (Fig. 8, 10), the system fluctuate more in the first seconds of the operation time. But through these figures, the fuzzy algorithm was shown to be suitable for gantry crane.

4. EXPERIMENTAL RESULTS

The PID controller parameters are: *Kp1=0.8; Ki1=0.001; Kd1=0.5; Kp2=1.2; Ki2=0.001; Kd2=0.005* and Fuzzy controller parameters are: K1=1/2; K2=1/6; K3=1/10; K4=1/4; K5=90.

Experimental 2D Crane model is shown in Fig. 11.

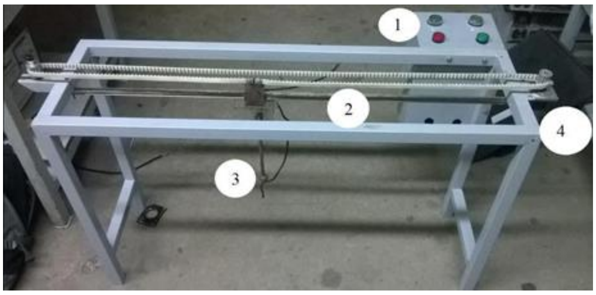

***Fig. 11.** 2D crane model in practice*

1: Control panel.

2: Rail for the movement of crane in x axis.

3: Pendulum presented for cargo.

4: 24VDC motor.

At the 2s moment, forced a constant force to pendulum, the fluctuation of the pendulum and the cart is shown in Figure. 12. After more than one minute, the pendulum stops vibrating. So, it is necessary to decrease this settling time by control algorithm like PID and fuzzy

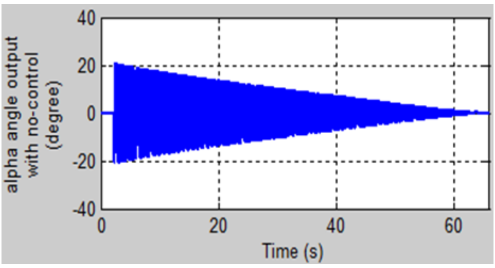

***Fig. 12.** The alpha angle without control*

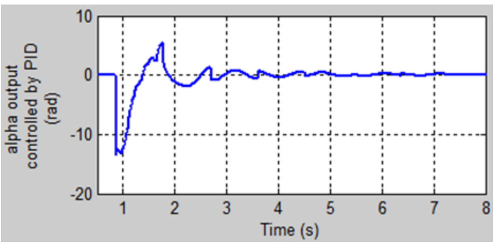

***Fig. 13**. The alpha angle with PID controller*

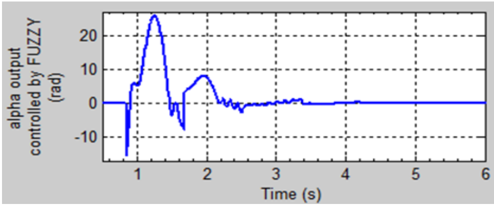

***Fig. 14.** The alpha angle with Fuzzy controller*

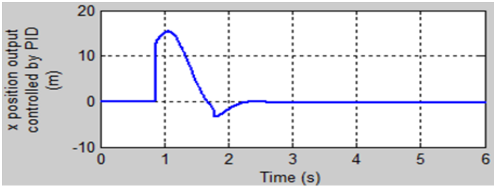

***Fig. 15.** The cart position with PID controller*

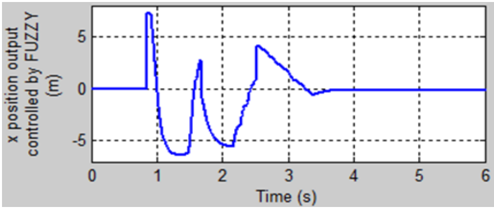

***Fig. 16.** The cart position with Fuzzy controller*

The experimental results show that both algorithms are proved to work well with crane model in reality. In experiment, from Fig. 13, 14, 15, 16, the settling time from fuzzy controller is shorter than that from PID controller. And the system under the controller respond better than under no control when being compared to the Fig. 12. Comparing to Fig. 12, settling time of system under both controllers was decrease remarkably, from one minute to only three seconds.

5. CONCLUSION

PID controller and Fuzzy controller can control 2D crane well in simulation and reality. But, with PID controller, the system is less fluctuant and more stable than with fuzzy controller. Fuzzy controller makes the system respond faster but fluctuate easier.

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APPENDIX

STT	θ	$\Delta\theta$	**X**	Δx	**U**	**STT**	θ	$\Delta\theta$	**x**	Δx	**U**
1	NE	NE	NE	NE	NB	42	ZE	ZE	ZE	PO	PS
2	NE	NE	NE	ZE	NB	43	ZE	ZE	PO	NE	ZE
3	NE	NE	NE	PO	NM	44	ZE	ZE	PO	ZE	PS
4	NE	NE	ZE	NE	NB	45	ZE	ZE	PO	PO	PS
5	NE	NE	ZE	ZE	NM	46	ZE	PO	NE	NE	PM
6	NE	NE	ZE	PO	NS	47	ZE	PO	NE	ZE	NS
7	NE	NE	PO	NE	NM	48	ZE	PO	NE	PO	PS
8	NE	NE	PO	ZE	NS	49	ZE	PO	ZE	NE	ZE
9	NE	NE	PO	PO	ZE	50	ZE	PO	ZE	ZE	PS
10	NE	ZE	NE	NE	NB	51	ZE	PO	ZE	PO	PM
11	NE	ZE	NE	ZE	NM	52	ZE	PO	PO	NE	PS
12	NE	ZE	NE	PO	NS	53	ZE	PO	PO	ZE	PM
13	NE	ZE	ZE	NE	NM	54	ZE	PO	PO	PO	PB

STT	θ	$\Delta\theta$	X	Δx	U	STT	θ	$\Delta\theta$	x	Δx	U
14	NE	ZE	ZE	ZE	NS	55	PO	NE	NE	NE	NM
15	NE	ZE	ZE	PO	ZE	56	PO	NE	NE	ZE	NS
16	NE	ZE	PO	NE	NS	57	PO	NE	NE	PO	ZE
17	NE	ZE	PO	ZE	ZE	58	PO	NE	ZE	NE	NS
18	NE	ZE	PO	PO	PS	59	PO	NE	ZE	ZE	ZE
19	NE	PO	NE	NE	NM	60	PO	NE	ZE	PO	PS
20	NE	PO	NE	ZE	NS	61	PO	NE	PO	NE	ZE
21	NE	PO	NE	PO	ZE	62	PO	NE	PO	ZE	PS
22	NE	PO	ZE	NE	NS	63	PO	NE	PO	PO	PM
23	NE	PO	ZE	ZE	ZE	64	PO	ZE	NE	NE	NS
24	NE	PO	ZE	PO	PS	65	PO	ZE	NE	ZE	ZE
25	NE	PO	PO	NE	ZE	66	PO	ZE	NE	PO	PS
26	NE	PO	PO	ZE	PS	67	PO	ZE	ZE	NE	ZE
27	NE	PO	PO	PO	PM	68	PO	ZE	ZE	ZE	PS
28	ZE	NE	NE	NE	NB	69	PO	ZE	ZE	PO	PM
29	ZE	NE	NE	ZE	NM	70	PO	ZE	PO	NE	PS
30	ZE	NE	NE	PO	NS	71	PO	ZE	PO	ZE	PM
31	ZE	NE	ZE	NE	NM	72	PO	ZE	PO	PO	PB
32	ZE	NE	ZE	ZE	NS	73	PO	PO	NE	NE	ZE
33	ZE	NE	ZE	PO	ZE	74	PO	PO	NE	ZE	PS
34	ZE	NE	PO	NE	NS	75	PO	PO	NE	PO	PM
35	ZE	NE	PO	ZE	ZE	76	PO	PO	ZE	NE	PS
36	ZE	NE	PO	PO	PS	77	PO	PO	ZE	ZE	PM
37	ZE	ZE	NE	NE	NM	78	PO	PO	ZE	PO	PB
38	ZE	ZE	NE	ZE	NS	79	PO	PO	PO	NE	PM
39	ZE	ZE	NE	PO	ZE	80	PO	PO	PO	ZE	PB
40	ZE	ZE	ZE	NE	NS	81	PO	PO	PO	PO	PB
41	ZE	ZE	ZE	ZE	ZE						

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