An Adaptive Fuzzy Controller for Overhead Crane

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***Abstract*- An adaptive Fuzzy PD controller (AFPDC) is proposed in this paper. Output scaling factor (SF) of the proposed fuzzy controller is updated according to the process trend by a fuzzy gain modifier, which is determined by error and change of error of the system. Effectiveness of the proposed AFPDC is demonstrated on a laboratory scale overhead crane. Moving a suspended load along a pre-specified path is not an easy task when strict specifications on the swing angle and transfer time need to be satisfied. In this study, twin adaptive fuzzy controllers are designed to control the trolley position of the crane and swing angle of the load. The proposed adaptive scheme guarantees a fast and precise load transfer and the swing suppression during load movement, despite of model uncertainties.**

Keywords- Fuzzy rules, Crane position control, Swing angle, Self-tuning.

I. INTRODUCTION

The overhead crane system is widely used in industry and port for moving heavy cargos [1]. In such applications, anti-sway and position control have become the requirements as a core technology for automated crane system. The purpose of crane control is to reduce the swing of the load while moving the trolley to the desired position as fast as possible. Crane operators, often aided with automatic anti-sway systems, are always involved, and the resulting performance, in terms of swiftness and safety, heavily depends on their experience and capability. Thus, the need for faster cargo handling requires the precise control of crane motion so that its dynamic performance is improved [2].

Various attempts have been made to solve the problem of swing of load [3- 5]. Most of them focus the control on suppression of load swing without considering the position error in crane motion [6]. Besides, several authors have considered optimization techniques to control the cranes. They have used minimal time control technique to minimize the load swing. Since the swing of load depends on the motion and acceleration of the trolley, minimizing the cycle time and minimizing the load swing are partially conflicting requirements.

The aim of fuzzy techniques is to get ahead of the limits of conventional techniques, and to improve existing tools by optimizing the closed-loop dynamical performances. A number of approaches have been proposed to implement hybrid control structures that combine conventional controllers with fuzzy logic techniques to control the nonlinear systems [7]. Among the various types of hybrid controllers, just like the widely used conventional PI controllers [8] in process control systems, PI-type fuzzy logic controllers (FLC's) are most common and practical followed by the PD-type FLC's. But like conventional PI-controllers [9], performance of PI-type FLC's for higher order systems, systems with integrating elements or large dead time, and also for nonlinear systems may be very poor due to large overshoot and excessive oscillation. PD-type FLC's are suitable for a limited class of systems [10], like integrating, non-minimum and few non-linear systems. PID-type FLC's are rarely used due to the difficulties in the generation of a complicated three-dimension rule base.

It is well known that most industrial control systems in practice are usually non-linear and higher order systems with considerable dead time, and their parameters may be changed with changes in ambient conditions or with time. In a conventional fuzzy logic controller, this non-linearity is tried to be eliminated by a limited number of *if-then* rules, but it may not produce desired control surface with fixed valued scaling factors (SFs) and uniform membership functions (MFs). In spite of a number of merits, there are many limitations while designing a fuzzy controller, since there is no standard methodology for its various design steps, and no well-established criterion for selecting suitable values of its large number of design parameters. Different attempts have been made to tune the control rules to achieve the desired control objectives. But, the tuning of a large number of FLC parameters can be a time-consuming, expensive and difficult task. Such problems may be eliminated by adopting self-tuning or adaptive schemes [11-16]. In our proposed controller, a simple self-tuning scheme is used to continuously update the controller gain with the help of process error and change of error.

In this study, we attempt to provide a practical solution for the anti-swing and precise position control of an overhead crane. The position of trolley, swing angle of load and their differentiations are applied to derive the proper control input of the trolley crane. Two PD-type fuzzy logic controllers are used to deal separately with the feedback signals, swing angle and trolley position, and their differentiations [17-19]. The fuzzy rules can be designed according to the experience of crane workers. The main advantage of this separated approach is to greatly reduce the computational complexity of the crane control system. The total number of fuzzy rules for the complete control system is therefore less than the number of rules used by conventional fuzzy system. Besides, when designing the proposed fuzzy controllers, no mathematical model of the crane system is required in advance. Thus, the proposed algorithm is very easy to implement.

ISBN No. 978-1-4673-2048-1/12/$31.00©2012 IEEE

The rest of the paper is organized as follows. Section II describes the crane set-up. The proposed self-tuning scheme is presented in section III, and in Section IV its effectiveness is tested on an overhead crane. The paper concludes in section V.

II. THE OVERHEAD CRANE SET-UP

A laboratory scale crane setup (FEEDBACK, UK) shown in Fig.1 consists of a cart moving along the 1m length track and a load is attached with the cart through shaft. The cart can move back and forth causing the load to swing. The movement of the cart is caused by pulling the belt in two directions by the DC motor attached at the end of the rail. By applying a voltage to the motor we control the force with which the cart is pulled. The value of the force depends on the value of the control voltage. Two variables that are read using optical encoders, installed on the cart, as shown in Fig. 2 are the load angle and the cart position on the rail. The controller's task will be to change the DC motor voltage depending on these two variables, in such a way that the desired crane control task is fulfilled. Initially the control signal is set to -2.5v to 2.5v and the generated force is of around -20N to +20N. The cart position is physically bounded by the rail length and is equal to -0.5m to +0.5m.

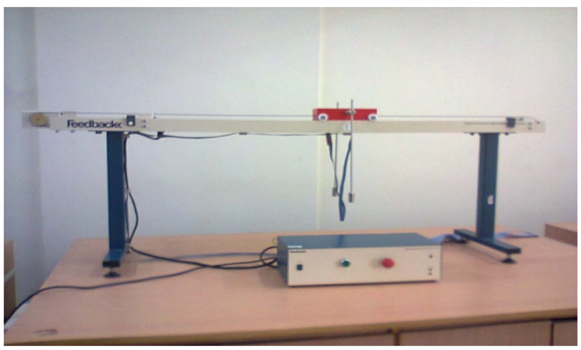

Fig. 1 Overhead crane set-up

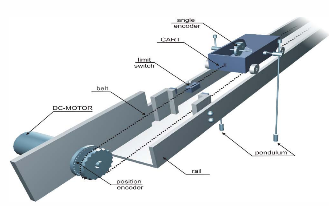

Fig. 2 Mechanical unit of the overhead crane

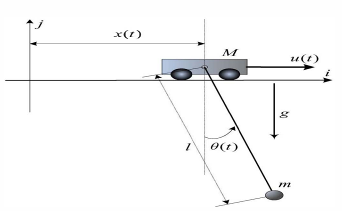

Fig. 3 Model of the overhead crane system.

Fig.3 shows the schematic of overhead crane traveling on a rail, where *x(t), θ (t)* and *u(t)* are the cart position, load swing angle and cart driving force respectively. The cart mass, load mass, load arm length, and gravity are represented by *M, m, l* and, *g* respectively. In this paper, the stiffness and mass of the rope are neglected and the load is considered as a point mass. The proposed scheme is focused on anti sway tracking control of an indoor overhead crane; therefore, the hoisting motion and the effects of wind disturbance are not considered. Then, the equations of motion of the overhead crane system without uncertainty [4] are obtained through the following equations:

$$(M+m)x''+(ml\cos\theta)\theta''-(ml\sin\theta)\theta'^2 = u \quad \text{---------(1)}$$

$$ml^2\theta''+(ml\cos\theta)\, x''-mgl\sin\theta=0 \quad \text{----------(2)}$$

The main difficulty in controlling the overhead crane system basically lies in the handling of the coupled nature between the sway angle and cart movement. The dynamic model obtained is nonlinear in nature, that means the cart position and its derivative or swing angle and its derivative is a nonlinear function.

III. PROPOSED CONTROLLER DESIGN

A skilled operator always tries to eliminate the error by changing controller output within the shortest possible time. Like the human operator, the output scaling factor should be considered a very important parameter of the FLC since its function is similar to that of the controller gain. Moreover, it is directly related to the stability of the control system. So the output SF should be determined very carefully for the successful implementation of a FLC. Depending on the input error (*e*) and change of error (*Δe*) of a process, an expert operator always tries to modify the controller gain, i.e., output SF, to enhance the system performance and to improve the stability robustness [11-17]. Following such an operator's policy, here, we suggest a simple self-tuning scheme of Fuzzy PD Controller (FPDC), where an online gain modifier (*β*) is determined from the relation, β=3(1+α). The parameter α is obtained from the multiplication of *e* and *Δe*.

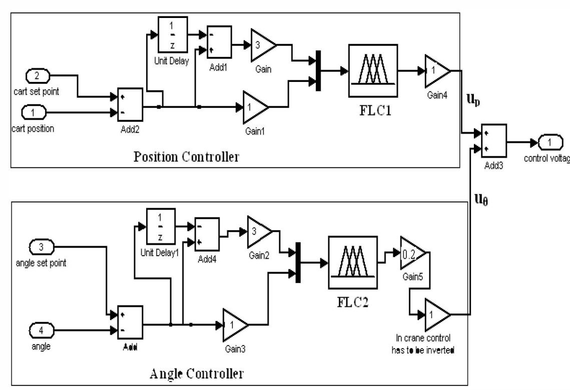

Fig. 4 Diagram of FPDC for overhead crane control

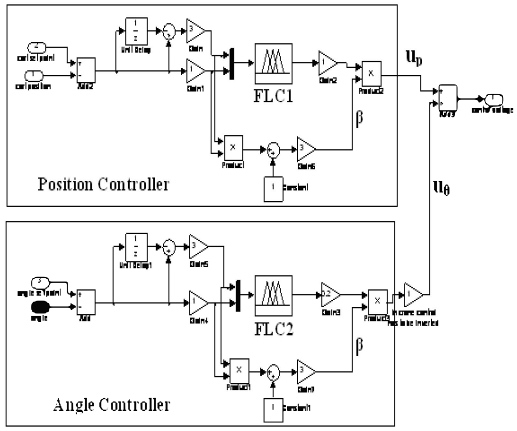

Fig. 5 Diagram of AFPDC for overhead crane control

The feedback signals from the overhead crane act as the input variables of FPDC and AFPDC as shown in the Figs. 4 and 5. There are two similar fuzzy logic controllers, which deal separately with cart position and sway angle as shown in Fig.4 and Fig.5 respectively. The position controller and angle controller, which deal separately with the cart position and swing angle, drive the overhead crane. In this design, the position error (e) and change of position error (Δe) are selected as the input linguistic variables of fuzzy position controller. The input linguistic variables of fuzzy angle controller are selected as the swing angle error (e_θ) and its derivative Δe_θ.

In our design, the left swing of the load is defined as positive swing, while the right swing of the load is negative swing. The output of the FPDC for position and swing angle control are u_P and u_θ respectively as indicated in Fig.4. Thus, the actual control action to drive the cart is defined as: $u=u_P+u_\theta$. For the overhead crane control using AFPDC, we incorporate a gain adaptive scheme through an online gain modifier β determined by the relation $\beta=3(1+\alpha)$, where α is obtained from the multiplication of the controller inputs as shown in Fig.5. The controller output u of FPDC and AFPDC is used to drive the DC motor of the overhead crane system. Fig.6 shows the MFs of e, Δe and u_P, whereas the MFs of e_θ, Δe_θ and u_θ are represented by Fig.7. Error (e) due to position and error (e_θ) due to angle are obtained respectively from the cart position encoder and swing angle encoder. The ranges of input-output variables for position controller are [-1, +1] and [-20°, $+20^\circ$] for angle controller.

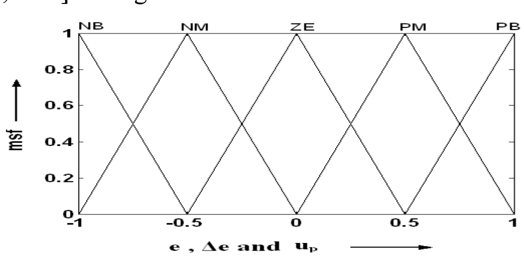

Fig. 6. MFs of e, Δe and u_P

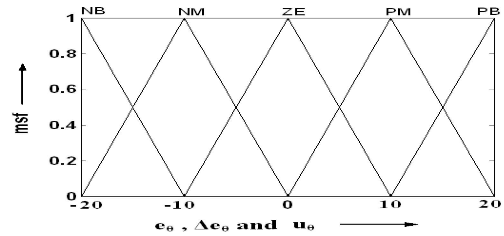

Fig. 7. MFs of e_θ, Δe_θ and u_θ

TABLE I. FUZZY CONTROL RULES FOR COMPUTATION OF POSITION CONTROLLER OUTPUT

Δe \ e	NB	NM	ZE	PM	PB
NB	NB	NB	NB	NM	ZE
NM	NB	NB	NM	ZE	PM
ZE	NB	NM	ZE	PM	PB
PM	NM	ZE	PM	PB	PB
PB	ZE	PM	PB	PB	PB

TABLE II. FUZZY CONTROL RULES FOR COMPUTATION OF ANGLE CONTROLLER OUTPUT

Δe_θ / e_θ	NB	NM	ZE	PM	PB
NB	PB	PB	PB	PM	ZE
NM	PB	PB	PM	ZE	NM
ZE	PB	PM	ZE	NM	NB
PM	PM	ZE	NM	NB	NB
PB	ZE	NM	NB	NB	NB

Each of the position and angle controllers consists of 25 fuzzy rules as shown in Table1 and Table2 respectively. The proposed dual controller structure for crane control divides the input antecedents of fuzzy rules into two parts. Hence, both position controller and angle controller have only $i/2$ fuzzy antecedents, where 'i' is the number of input linguistic variables, here $i=4$. If each input variable has 'n' linguistic terms, here $n=5$, then the possible control rules required for our scheme is $2*n^{i/2}=50$. Thus the total number of rules for FPDC and AFPDC in the crane control scheme are greatly reduced compared to traditional fuzzy control schemes, which may need n^i, *i.e.*, $5^4=625$ rules. Therefore, the present control scheme is easier to understand.

IV. RESULTS

The proposed gain adaptive or self-tuning scheme is tested on an overhead crane (Fig.1) with sinusoidal input and step input with amplitude 0.3m. The controller output u of FPDC and AFPDC separately applied to the overhead crane to control the crane position as well as swing angle of the load attached. The AFPDC outperforms the FPDC for different types of input applied as shown in Fig.8 to Fig.15. Real-time experiments on the overhead crane illustrate the advantages of proposed self-tuning scheme for sine input as well as step input. From Table3, we find that different performance parameters such as

IAE, ITAE, and ISE are reduced by a large percentage when controlled by AFPDC compared to FPDC. In case of AFPDC, rise time is decreased to 1 sec. for step response. Figs. 10, 11, 14, and 15 show that the load swing is minimum and specially in case of step input the swing angle approaches to almost zero for our proposed scheme. We also study the system with conventional controller and found that the load sway is not smooth for different inputs, which is one of the most desirable parameters for overhead crane control in industry. The study reveals that the proposed gain adaptive scheme for fuzzy controller can fix the over-head crane in its desired position with negligible sway angle.

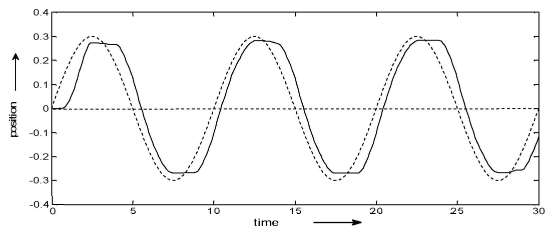

Fig. 8 Overhead crane position control for sine input using FPDC (dotted lines – reference crane position and solid lines – actual crane position)

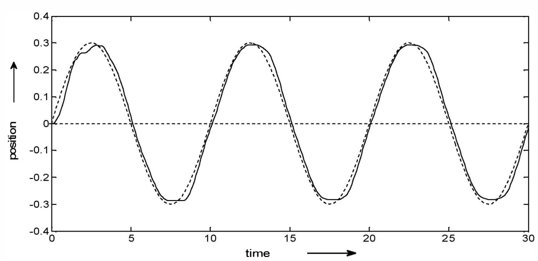

Fig. 9 Overhead crane position control for sine input using AFPDC (dotted lines – reference crane position and solid lines – actual crane position)

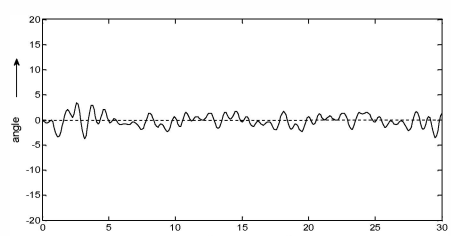

Fig. 10 Overhead crane swing angle control for sine input using FPDC

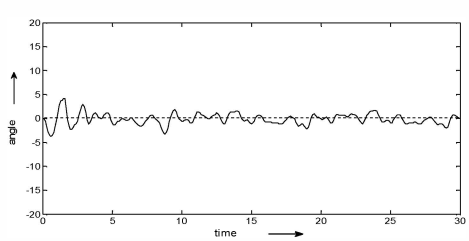

Fig. 11 Overhead crane swing angle control for sine input using AFPDC

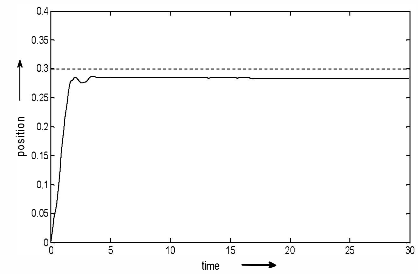

Fig. 12: Overhead crane position control for step input using FPDC (dotted lines – reference crane position and solid lines – actual crane position)

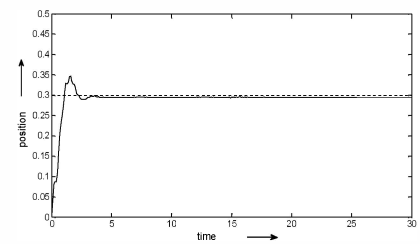

Fig. 13 Overhead crane position control for step input using AFPDC (dotted lines – reference crane position and solid lines – actual crane position)

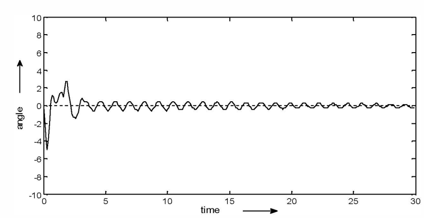

Fig. 14 Overhead crane swing angle control for step input using FPDC

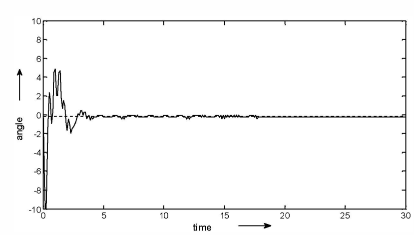

Fig.15: Overhead crane swing angle control for step input using AFPDC

TABLE III: PERFORMANCE ANALYSIS OF THE PROPOSED CONTROLLERS IN OVERHEAD CRANE CONTROL

Reference Input	FLC	t_r(sec.)	IAE	ITAE	ISE
Sine (amplitude 0.3)	FPDC		32.6416	799.2207	2.8917
	AFPDC		10.4266	253.3936	0.2815
Step (amplitude 0.3)	FPDC	1.6	7.5129	75.5667	0.6952
	AFPDC	1.0	3.6658	26.6158	0.3926

V. CONCLUSION

In this study, we proposed a simple self-tuning scheme for FLC's. Here, the controller gain (output SF) has been updated on-line through a gain modifying parameter β defined on error (e) and change of error (Δe). Even with significant reduction of rule-base, proposed AFPDC exhibited effective and improved performance compared to its conventional fuzzy counterpart. The proposed twin control scheme for overhead crane reduces the computational complexity and is very easy to understand. By applying the proposed self-tuning method and dual control scheme the load swing angle of the crane comes to a minimum. Experimental results verified that the proposed AFPDC not only positioned the trolley in the desired location, it also significantly reduced the load swing during movement.

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