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A practical fuzzy controllers scheme of overhead crane

Chengyuan CHANG, Shihwei HSU, Kuohung CHIANG
(Department of Electronic Engineering, Ching Yun University, Jhongli, Taoyuan 320, Taiwan, China)

Abstract: This paper presents fuzzy-based design for the control of overhead crane. Instead of analyzing the complex nonlinear crane system, the proposed approach uses simple but effective way to control the crane. There are twin fuzzy controllers which deal with the feedback information, the position of trolley crane and the swing angle of load, to suppress the sway and accelerate the speed when the crane transports the heavy load. This approach simplifies the designing procedure of crane controller; besides, the twin controller method reduces the rule number when fulfilling the fuzzy system. Finally, experimental results through the crane model demonstrate the effectiveness of the scheme.

Keywords: Overhead Crane; Fuzzy Control

1 Introduction

The overhead crane system is widely used in industry for moving heavy cargos. Thus anti-sway and position control have become the requirements as a core technology for automated crane system that are capable of flexible spatial automatic conveyance.

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. However, the overhead crane has serious problems: the crane acceleration, required for motion, always induces undesirable load swing. Such swing of load usually degrades work efficiency and sometimes causes load damages and even safety accidents. Thus, the need for faster cargo handling requires the precise control of crane motion so that its dynamic performance is improved [1 ~ 3].

Traditionally, the crane operator drives the trolley with the· steps of accelerated motion, uniform motion, decelerated motion, creeped motion and breaking. Fig. 1 shows the distance-speed reference curve of conventional operation of overhead crane [4,5]. The experienced crane workers drive the trolley carefully to keep the load from severe swing. However, the conservative control method is ineffective in modern industry. This study proposed the fuzzy twin controllers to control the trolley crane.

Various attempts have been made to solve the problem of swing of load. 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 [7 ~ 9]. 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. Besides, there are many papers investigating the stability problem of controller design [10 ~ 12], but those researches lack experiments to illustrate the effectiveness.

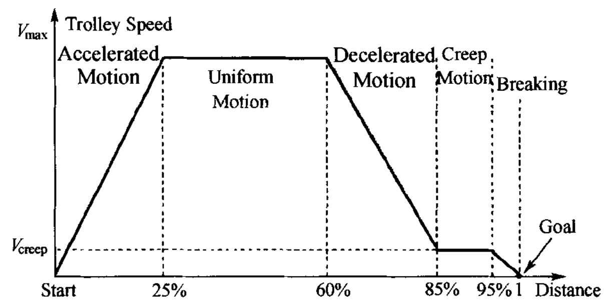

Fig. 1 Distance-speed reference curve for conventional operation of overhead crane.

This study presents a practical solution for the anti-swing and precise position control for the cranes. The position of trolley, swing angle of load and their differentiations are applied to derive the proper control input of the trolley crane. Two fuzzy logic controllers (FLC) are used to deal separately with the feedback signals, swing angle and trolley position and their differentiations. The fuzzy rules are designed according to the experience of crane workers. The main advantage of this separated approach is to greatly reduce

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the computational complexity of the crane control system. The total fuzzy rule number for fulfilling the control system is therefore less than the rule number of 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 be implemented.

This paper is organized as follows. Section 2 reviews the proposed fuzzy twin controller structure for crane control system. In section 3, experimental results of crane control system are presented in comparison with the conventional crane control method to illustrate the advantage of proposed fuzzy approach. This paper concludes with a summary in section 4.

2 Fuzzy logic controllers for crane

The physical apparatus of the overhead crane system is pictured in Fig. 2. The length of overhead crane model is five meters, and the height is two meters. The block diagram, which is represented in Fig. 3, illustrates the proposed fuzzy logic crane control system. In this diagram, two encoders with the resolution 2000 PPR (pulses per round) are installed on the trolley of crane to detect the motion position and swing angle. The feedback signals from overhead crane act as the input variables of fuzzy controllers.

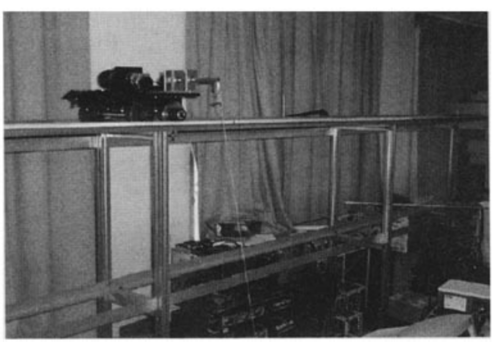


Fig. 2 Physical apparatus of the overhead crane system.

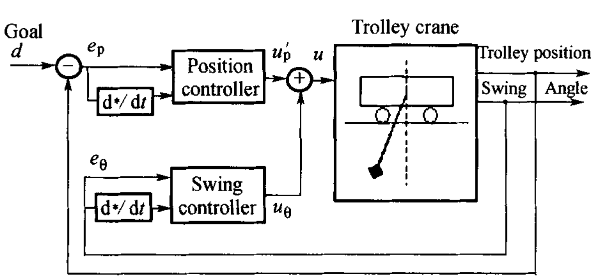


Fig. 3 Block diagram of fuzzy logic crane control system.

There are two similar fuzzy logic controllers, position controller and swing controller, which deal separately with the motion position and swing angle information to drive the trolley crane. The twin fuzzy controllers work as like the conventional PD-type controllers. In the design, the error e_p and its derivative error $\dot{e}_p$ are selected as the input linguistic variables of fuzzy position controller, where

$$e_p = \text{Goal d-present position}, \quad (1)$$

$$\dot{e}_p = e_p(k+1) - e_p(k). \quad (2)$$

The initial trolley position is set to zero in this paper. The index k means the kth sample time. Besides, the input linguistic variables of fuzzy swing controller are selected as the swing angle e_θ and its derivative $\dot{e}_\theta$, where

$$e_\theta = \text{swing angle of load}, \quad (3)$$

$$\dot{e}_\theta = e_\theta(k+1) - e_\theta(k). \quad (4)$$

The left swing of load is defined as positive swing, while the right swing of load is negative swing. After the procedures of fuzzy fuzzification, inference process and defuzzification, one denotes the output linguistic variables of the respective position controller and swing controllers as u'_p and u'_θ. The actual power to drive the trolley is defined as u.

$$u = u'_p + u'_\theta. \quad (5)$$

The designing procedures for both the fuzzy-based position controller and swing controller, are described in the following steps [13].

Step 1 This step fuzzifies the input signals into fuzzy variables. The input and output space are partitioned into five fuzzy regions overlapping each other. In general, each fuzzy region is labeled by a linguistic term. These linguistic terms for the input variables of the twin controllers are given as NL, NS, AZ, PS, and PL. One uses the triangular and trapezoidal membership functions to fuzzify the input linguistic variables. Figs. 4(a) ~ (d) show the respective membership functions of $e_p, \dot{e}_p, e_\theta$ and $\dot{e}_\theta$, which were obtained respectively from the trolley position encoder and swing angle encoder. The ranges of input variables e_p and $\dot{e}_p$ are $[-d/6, d/6]$ and $[-200, 200]$, e_θ and $\dot{e}_\theta$ are $[-40, 40]$ and $[-40, 40]$, respectively, and the ranges of the output variable u_p and u_θ are $[-5, 5]$. The linguistic terms of output variables u_p and u_θ are defined as five fuzzy singletons, which are represented in Fig. 4(e), controlling the servo driver of DC-motor to drive the trolley crane.

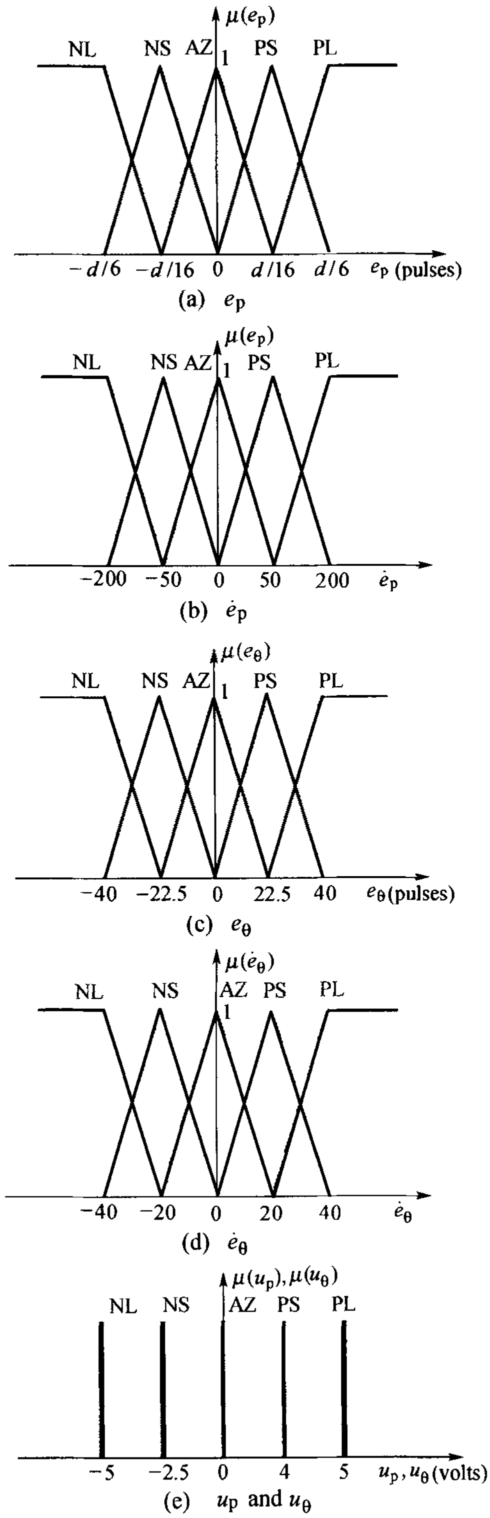


Fig.4 Membership functions.

Step 2 This step introduces the fuzzification function for each input variable to express the associated measurement uncertainty. Generally speaking, the purpose of the fuzzification function f is to interpret measurement of input variables, each is expressed by a real number, as more realistic fuzzy approximations of the respective number. The proposed paper applies fuzzy singleton function in the fuzzification process. It means that the measurements for input variables are employed in fuzzy inference engine directly.

Step 3 In order to fulfill the fuzzy logic control system, Both the position controller and the swing controller consist of twenty-five IF-THEN rules with the following form

$$\text{If } e_* = A \text{ and } \dot{e}_* = B \text{ then } u_* = C, \qquad (6)$$

where A, B and C are fuzzy numbers chosen from the set of fuzzy numbers that represent the linguistic states NL, NS, AZ, PS and PL, the notation " * " in (6) means p or θ. The IF part of the fuzzy rules are formed by the error and its derivative, and the consequences are decided according to the crane workers' experience and judgment. Since each input variable has five linguistic variables, the total number of possible nonconflicting fuzzy rules for both position controller and swing controller is $2 \times 5^2 = 50$. The rule bases are shown in Table 1 and Table 2. These fuzzy rules can be understood very easily.

Table 1 Rule map of fuzzy position controller.

e_p	$\dot{e}_p$				
	NL	NS	AZ	PS	PL
PL	PL	PL	PL	PS	PS
PS	PL	PL	PS	PS	AZ
AZ	PS	AZ	AZ	NS	NL
NS	AZ	AZ	NS	NL	NL
NL	NS	NS	NL	NL	NL

Table 2 Rule map of fuzzy swing controller.

e_θ	$\dot{e}_\theta$				
	NL	NS	AZ	PS	PL
PL	NS	NS	NL	NL	NL
PS	AZ	AZ	NS	NL	NL
AZ	PS	AZ	AZ	NS	NL
NS	PL	PS	PS	AZ	NS
NL	PL	PL	PS	PS	AZ

Step 4 The designer has to select suitable inference and defuzzification methods for designing fuzzy controllers. The inference and defuzzification procedures convert the conclusions obtained from fuzzy rules to a single real number. The resulting real number, in some sense, summarizes the elastic constraint imposed on possible values of the output variable by the fuzzy set.

For each input singleton pair (e_* and $e*$), one calculates the degree of their compatibility $\beta_j(e_*, e*)$

with the antecedent of each inference rule j. When $\beta_j(e_*, e^*) > 0$, the jth rule is fired. At least one rule is fired for all possible input pair in the fuzzy controller design. The min-min-max inference method is used to conclude all the fired rules in this paper.

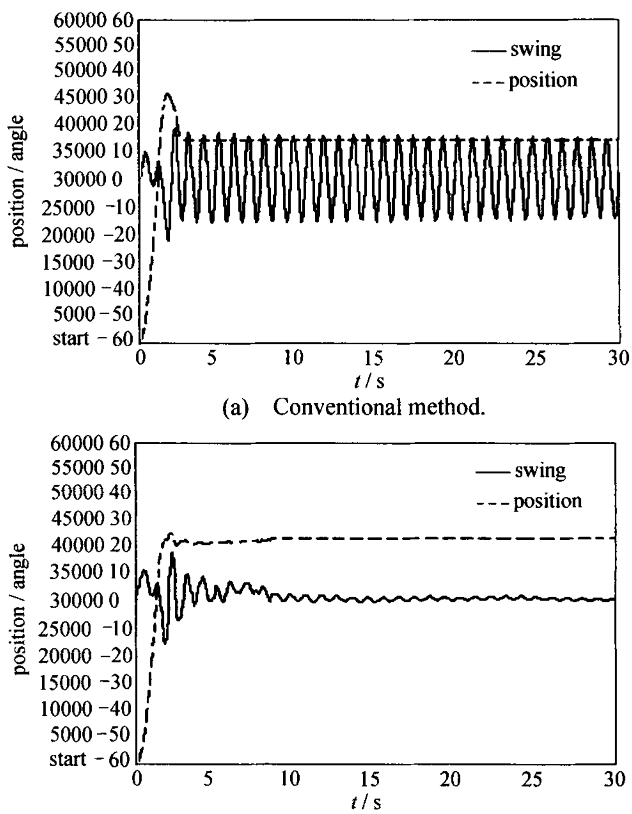
In order to obtain the defuzzified real value, one utilizes the most frequently used centroid method to defuzzify the inference results. The outputs of the fuzzy position and swing controllers are u'_p and u'_θ, respectively.

The proposed twin controller structure provides an easy but effective way to control the fuzzy system well. The twin controllers in this paper separate the input antecedents of fuzzy rules into two parts, position and swing angle parts. Hence, both position controller and swing controller have only $M/2$ fuzzy antecedents, each containing N linguistic terms, then the necessary rule number to fulfill the system is $2 * N^{M/2}$. The rule number is greatly reduced. For example, both the position controller and swing controller have two input linguistic variables. The four input linguistic variables are partitioned into five parts each; hence the necessary rule number to control the crane is reduced to 50. When compared with traditional fuzzy schemes, the separated twin controllers method helps to make fuzzy control easier than usual. Besides, the proposed twin controllers structure is suitable for any use of fuzzy control applications.

3 Experimental results

There are several experimental results illustrating the advantages of fuzzy based crane control system. Encoders' data make us know the real position of trolley and swing angle of load at any time. After the procedures of fuzzification, fuzzy inference and defuzzification, each fuzzy controller gets a control value. The authors use the summation of the control values, u'_p and u'_θ, to drive the trolley. The fuzzy controllers will control the trolley until the existing distance to goal is less than $0.01 * d$, meanwhile, the swing angle of load is less than 10 units. The notation d is the initial distance to the goal. For using 2000 PPR encoders, a unit of swing equals to 360/2000 degrees.

Experiment illustrates the advantages of fuzzy scheme. We uses the conventional method to control the crane for the purpose of comparison. When operating the crane according to the speed reference curve such as shown in Fig. 1, the friction and limitation of mechanism will make the trolley precisely stop at the fixed position become impossible, hence additional braking the trolley to the goal is necessary. We employed a flexible wire with 120cm long in the experiment. The load for transportation is 3kg. The distance to goal is 39500 normalized units, i.e. $d = 39500$. Suppose that position of trolley is 0 normalized unit at the start, Fig. 5(a) shows the position of trolley and swing angle of load when transporting the heavy load by conventional control method. One can easily find that the swing is too severe to damage the load. Fig. 5(b) shows the result of fuzzy based approach. It is obvious that the trolley stops at the correct position and the swing is negligible, and meanwhile the transporting time of load is shortened. The steady state error is caused by some airstreams. When transporting the load towards the destination, it is more difficult to restrain the sway especially by conventional approach. However, Fig. 5(b) shows that the load sway by fuzzy approach is also very smooth. The performances for fixing the crane on fixed position and restraining the sway of load are better than conventional scheme.



(a) Conventional method.

(b) Fuzzy based twin controllers method.

Fig. 5 Transporting the 3kg load with 120 cm flexible wire.

4 Conclusion

This paper provides fuzzy based twin controllers to control the overhead crane. By applying the proposed method, not only the transporting speed is increased but also the swing of load is very smooth. Moreover, the proposed method separates the input linguistic variables into two parts, position variables and swing variables. Hence, only fifty rules are necessary to fulfill the system. The proposed separated algorithm helps to reduce the computational complexity of the fuzzy controller. Experimental results prove that the proposed method enhances the performance of fuzzy control system for overhead crane. The work efficiency is therefore improved.

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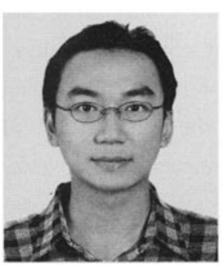
Chengyuan CHANG was born in Taiwan, R.O.C., in 1968. He received the B.S. and M.S. degrees in electrical and control engineering from National Chiao-Tung University, Hsin-Chu, Taiwan, R.O.C., in 1990 and 1994, and the Ph.D. degree in electrical engineering from National Central University in 2000. He is currently an Associate Professor in the Department of Electronic Engineering, Ching Yun University, Jhongli, Taiwan, R.O.C. His current research interests are in the area of fuzzy controller, neural networks and control theory applications. E-mail: cychang@cyu.edu.tw.

Shihwei HSU received the B.S degree in electronic engineering from Ching Yun University, Tao-Yuan, Taiwan, R.O.C., in 2005. He is currently working towards the M.S. degree in automation technology at National Taipei University of Technology, Taipei, Taiwan, R.O.C. His research interests are in the areas of fuzzy, neural networks and control theory applications.



Kuohung CHIANG was born in Hsinchu, Taiwan, R.O.C., in 1980. He received the B.S. degree in electronic engineering from Ching Yun University, Tao-yuan, Taiwan, in 2005. He is currently pursuing the M.S. degree with Fu-Jen Catholic University, Taipei, Taiwan. His current research focuses are fuzzy logic control and sliding mode control for three-dimensional overhead crane system.