Control Strategy for Automatic Gantry Crane Systems: A Practical and Intelligent Approach

Wahyudi[1]; Jamaludin Jalani[2], Riza Muhida[1] and Momoh Jimoh Emiyoka Salami[1]
[1]Faculty of Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia
[2]Kolej Universiti Teknologi Tun Hussein On, Johor, Malaysia
wahyudi@iiu.edu.my

Abstract: *The use of gantry crane systems for transporting payload is very common in building constructions. However, moving the payload using the crane is not an easy task especially when strict specifications on the swing angle and on the transfer time need to be satisfied. Various attempts in controlling gantry cranes system based on open- loop and closed-loop control systems were proposed. However, most of the proposed controllers were designed based on the model and parameter of the crane system. In general, modeling and parameter identifications are troublesome and time consuming task. To overcome this problem, in this paper, a practical and intelligent control method for automatic gantry crane is introduced and evaluated experimentally. The results show that the proposed method is not only effective for controlling the crane but also robust to parameter variation.*

Keywords: *Crane, controller, nominal characteristic trajectory following, fuzzy logic and robust*

1. Introduction

Gantry cranes are widely used for transporting heavy loads and hazardous materials in building constructions. The crane should move the load as fast as possible without having any excessive payload motion at the final position. However, most of the common gantry cranes result in a swing motion when payload is suddenly stopped after a fast motion (Omar, 2003). The swing motion can be reduced however, it is often time consuming process which eventually affect the productivity (operational efficiency) in building constructions. Moreover, the gantry crane needs a skilful operator to manually control it using his/her experience to immediately stop the swing at the right position. Furthermore to unload, the operator has to wait until the load stops swinging. The failure in controlling crane might also cause accident and harm people.
Various attempts in controlling gantry cranes system based on open loop and closed-loop control system have been proposed. For example, open-loop time optimal strategies were applied to the crane by many researchers (Manson, 1992 and Auernig et.al, 1981). Poor results were obtained in these studies because open-loop strategy is sensitive to the system parameters (e.g. rope length) and could not compensate for the effect of wind disturbance. Another similar approach is termed the input shaping (Teo et.al, 1998 and Singhose et.al, 1997). However the input shaping method is still an open-loop approach.
Feedback control which is well known to be less sensitive to disturbances and parameter variations (Bellanger, 1995) has also been adopted for controlling the gantry crane system. Omar has proposed PD controllers for both position and anti-swing controls (Omar, 2003). However, it is well known that controlling the position by using PD controller is not very effective in eliminating the steady state error. The PID controller has also been proposed for controlling the gantry crane system (Wahyudi et.al, 2005). However the performance of the controller degrades when the actuator saturates (Wahyudi and Jalani, 2005). In adition, an adaptive control strategy has also been proposed by Yang and Yang (Yang et.al, 2006). However, in controller design, the proposed controller requires a nonlinear control theory which needs a complicated mathematical analysis.
Fuzzy logic controller has also been proposed for controlling the gantry crane by several researchers (Omar, 2003 and Lee and Cho, 2001). However, the fuzzy logic is still designed based on the model of the gantry crane. The fuzzy logic controller uses mapping method which needs delayed feedback controller before fuzzy logic can be designed and implemented (Omar, 2003). This method is not practically applicable and time consuming because the fuzzy logic controller could not be implemented directly as it relies on other controller to fulfill the design specifications. Another researcher has also used fuzzy logic controller for suppressing the payload swing (Lee and Cho, 2001), however this

approach still requires a PID controller for position control of the payload.

In general, the above-mentioned control strategies would result in good performance when the exact model and its parameters are used in the design of the controller, which only can be done by an expert control engineer. It is well known that modeling process is a complex and time consuming process. In addition, parameter identification is required when the parameters of the crane model are not available. The parameter identification is also another complex and time consuming process. Furthermore, advanced controllers tend to be complex and complicated for real time implementation which is required for crane system. However, in practical application, engineers who are not expert in control system often need to design controller. Hence simplified controller design and structure are very important in practical applications.

In order to overcome the above-mentioned shortcomings, a practical and intelligent control method for automatic gantry crane is introduced and examined in this paper. The design of proposed method is based on a simple open-loop experiment and without the need either to model crane or perform system identification. The effectiveness of the proposed method as well as the robustness to parameter variations are evaluated experimentally in a lab-scale gantry crane system. Its performance is also compared with that of classical PID and fuzzy logic controllers. The experimental result shows that the proposed control method has better performance compared with the automatic gantry crane system controlled by the other controllers. It is also shown that the proposed system is more robust to parameter variation than the others.

The rest of this paper is structured in the following manner. The next section provides an overview of the proposed controllers whilst Section 3 describes the design of the NCTF controller based on a simple open-loop experiment. The fuzzy logic controller for anti-swing control is discussed in Section 4. The design of the proposed controllers based on the lab-scale gantry crane system is described and then the experimental results are elaborated in Section 5. Next, the robustness to parameter variation is reported in Section 6. Finally, concluding remarks are offered in the last section.

2. Proposed Control Structure

The structure of the proposed practical controller for the gantry crane system is shown in Fig. 1. The proposed controller consists of nominal characteristic trajectory following (NCTF) controller and fuzzy logic controller. The NCTF controller is used to control the position of the trolley while the fuzzy logic controller is used to suppress the swing vibration such that there is no an excessive swing vibration especially when the payload reaches the desired position.

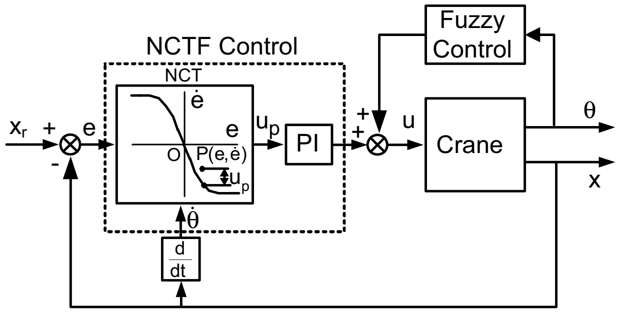


Fig. 1. Proposed practical control structure

Originally, the NCTF controller is proposed as a practical controller for point-to-point (PTP) precision positioning system driven by an electric motor (Wahyudi, 2002). As the objective of the controlling gantry crane system is to transfer a load from one location to another location, control of gantry crane, therefore is identical to a PTP control system. Hence, it is justified to use the NCTF controller for the automatic gantry crane system.

The NCTF controller consists of NCT and PI compensator. The objective of NCTF controller is to make the plant motion follow the NCT and ends at the origin of the phase plane. Fig. 2 shows an example of plant motion controlled with the NCTF controller. The motion comprises two phases. First one is the reaching phase and the other one is the following phase. In the reaching phase, the compensator forces the plant motion to reach the NCT as fast as possible. Then, in the following phase, the compensator controls the plant motion to follow the NCT and end at the origin. The plant motion stops at the origin, which represents the end of the positioning motion. Thus in the NCTF control system, the NCT governs the positioning response performance. The parameter of u_p represents the difference between the actual error rate and NCT. If the parameter of u_p is zero, the plant motion perfectly follows the NCT. Consequently, it causes a good performance of the NCTF controller. In order to get the parameter of u_p is zero, the PI compensator is used to control the plant.

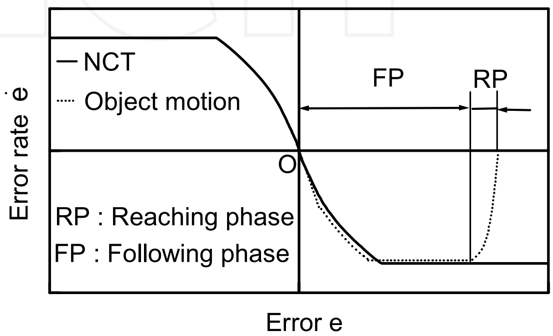


Fig. 2. NCTF and plant motion

The NCTF controller is designed based on a simple open-loop experiment. Hence mathematical model and parameters of the plant are not required. It has been shown that, the NCTF control system has a good positioning performance and robustness (Wahyudi et.al, 2001 and Wahyudi et.al, 2003). The NCTF controller is also effective to compensate for the effect of the friction which is the source of positioning inaccuracy (Wahyudi et.al, 2005).

3. NCTF Controller

The crane discussed in this paper is an electric driven crane system such as a DC or an AC servomotor. By neglecting the effect of the payload swing to the trolley motion, the dynamic model of the trolley motion can be expressed as:

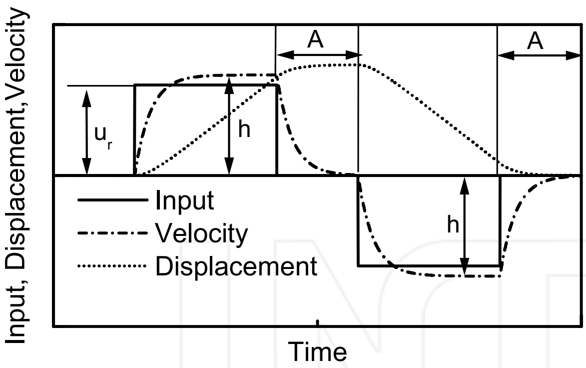
$$\frac{X(s)}{U(s)} = \frac{K\alpha}{s(s+\alpha)} \tag{1}$$

where $X(s)$ is the trolley displacement, $U(s)$ an input to the plant, and K and α are the positive constants, which relate to the motor dynamics and mechanical system, respectively.

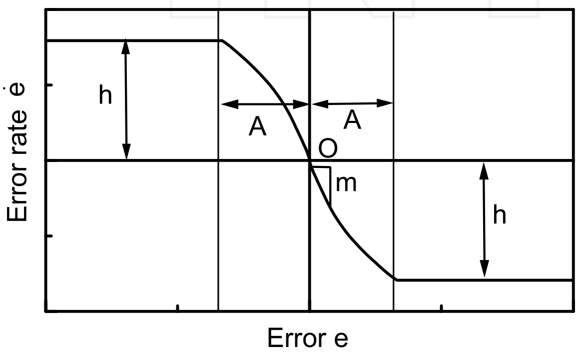
The NCTF controller design is based on a simple open-loop experiment of the plant as follows:

1. Open-loop-drive of the plant with stepwise inputs and measurement of the displacement and velocity responses of the plant.

   Fig. 3(a) shows the stepwise inputs, and the velocity and displacement responses due to the stepwise inputs. In this paper, the rated input to the actuator u_r is used as height of the stepwise inputs.



(a) Stepwise inputs and responses



(b) Nominal characteristics trajectory (NCT)

Fig. 3. NCT determination

2. Construction of the NCT by using the plant responses.

   The velocity and displacement responses are used to determine the NCT. Since the main objective of PTP positioning system is to stop a plant at certain position, a deceleration process (curve in area A of Fig. 3(a)) is used. Variable h in Fig. 3 is the maximum motion velocity. From the curve in the area A and h in Fig. 3(a), the NCT in Fig. 3(b) is determined [12,15]. Since the NCT is constructed based on the actual responses of the plant, the NCT includes nonlinearity effects such as friction and saturation. The important NCT characteristics, which would be used to design the compensator, are NCT inclination m near the origin and maximum error rate h. In this case, from the relationship between plant dynamics of Eq. (1) and Fig. 3(b), it is clear that the inclination near origin m and the maximum error rate h relate with parameters of the plant as follows (Wahyudi et.al, 2003 , Wahyudi et.al, 2005):

$$K = \left|\frac{h}{u_r}\right| \tag{2}$$

$$\alpha = -m \tag{3}$$

3. Design of the compensator based on the NCT information.

   Here, the following PI compensator is adopted due to its simplicity:

$$u = K_p u_p + K_i \int u_p dt \tag{4}$$

where K_p and K_i are proportional and integral gains respectively. Using the PI compensator parameters K_p and K_i, and the NCT characteristic near the origin (see Fig. 3(b)), the transfer function of the closed-loop positioning system controlled by the NCTF controller can be expressed as follows (Wahyudi et.al, 2003 , Wahyudi et.al, 2005):

$$\frac{X(s)}{X_r(s)} = G(s) = G_1(s)G_2(s) \tag{5}$$

where

$$G_1(s) = \frac{\alpha}{s+\alpha} \tag{6.a}$$

$$G_2(s) = \frac{2\zeta\omega_n + \omega_n^2}{s^2 + 2\zeta\omega_n + \omega_n^2} \tag{6.b}$$

$$K_p = \frac{2\zeta\omega_n}{K\alpha} \tag{6.c}$$

$$K_i = \frac{\omega_n^2}{K\alpha} \tag{6.d}$$

When ζ and ω_n are large enough, $G(s)$ becomes nearly equal to $G_1(s)$, which represents the condition when the plant motion follows the NCT in line with the objective of the NCTF control system. Moreover, large values of ζ and ω_n also make the closed-loop system robust to friction or inertia variation of the plant in continuous systems (Wahyudi et.all, 2003). Finally, by using ζ and ω_n as design parameters and considering Eqs. (2) and (3), the PI compensator parameters are selected as follows:

$$K_p = \frac{2\zeta\omega_n u_r}{mh} \tag{7}$$

$$K_i = \frac{\omega_n^2 u_r}{mh} \tag{8}$$

Here, ω_n and ζ are design parameters which should be decided by the designer. In general, large values of ω_n and ζ are preferable in the design of PI compensator. However digital implementation of the NCTF controller limits the design parameters to maintain the closed-loop stability. Detailed discussion on the theoretical background of the NCTF control system has been reported (Wahyudi et.al, 2003 , Wahyudi et.al, 2005).

Due to the fact that the NCT and the compensator are constructed from a simple open-loop experiment of the plant, the exact model, including the friction characteristic and time consuming identification task of the system parameters are not required to design the NCTF controller. Consequently, this controller design is very simple to design and easy to implement in practical situations.

4. Fuzzy Logic Controller

The use of fuzzy logic controller for anti-swing control of the payload has gained popularity recently. 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. A Mamdani-based fuzzy control shown in Fig. 4 is adopted due to its simplicity. In general fuzzy logic controller is constructed by the following elements (Passino and Yurkovich, 1998):

1. *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.
2. *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.
3. *A fuzzification interface*, which converts controller input into information that the inference mechanism can easily be used to activate and apply rules.
4. *A defuzzification interface,* which converts the inference mechanism results into actual inputs for the process.

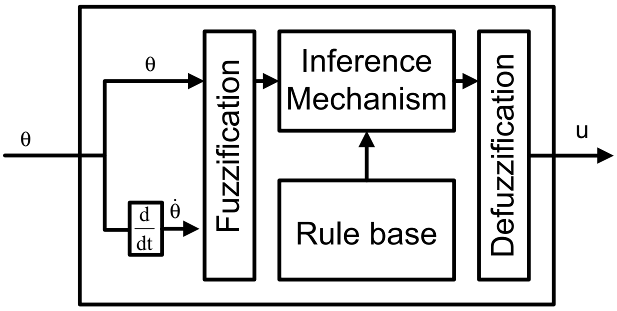


Fig. 4. Fuzzy logic for anti-swing control

There are two inputs to the fuzzy logic controller namely swing angle and swing angle rate. The relation between the inputs and output is expressed by using a rule designed based on a heuristic approach. Here, the design of fuzzy logic control is based on a heuristic approach. For example the expert knowledge of skillful operator during the manipulation of gantry crane system is adopted in fuzzy logic controller design. It shows that fuzzy logic controller is a controller that may realize the skill of human operators and the design rules describe the subjective fuzziness of operators' experiences instead of the use of mathematical model of the plant.

5. Experimental Results

5.1. Experimental setup

The performance of the proposed controller is evaluated by using it to control a lab-scale gantry crane system shown in Fig. 5. The lab-scale gantry crane system is driven by a DC motor with its DC servo motor amplifier. The rated input voltage to the motor amplifier is 1.4 V. Two potentiometers are used as sensors to measure the position and swing angle of the payload. The lab-scale gantry crane only considers the planar movement of trolley with fixed load and the hoisting mechanism used for lifting/unloading is also not considered during its operation.

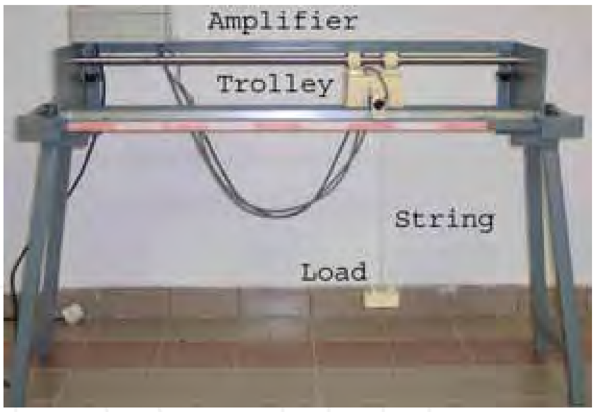


Fig. 5. Lab-scale gantry crane system

The experimental setup is shown in Fig. 6. As shown in Fig. 6, two computers are used namely Host PC and Target PC. The lab-scale gantry crane is connected to the controller in Target PC through analog-to-digital and digital-to-analog (AD/DA) board. Another PC called as the Host PC is needed for generating the controller algorithms of both the NCTF and fuzzy controllers digitally with 1 ms sampling time. The MathWork's *MATLAB/Simulink* is used for real-time controller implementation through RTW and xPC Target.

By using *RTW* and *xPC Target* in *MATLAB/Simulink* environment, there is no need to write a low level programming language for realizing a controller and/or accessing other components such as AD/DA board. The controllers are developed in Simulink using its blocks, and then it is built so that C code is generated, compiled and finally a real-time executable code is generated and downloaded to the Target PC. In particular, the *xPC Target toolbox* supports and provides built-in drivers for many industry standard AD/DA boards including the PCI-6024E DAQ card by National Instrument which is used in this experiment. This combination provides a unique and complete solution for rapid control prototyping and testing of automatic gantry crane system.

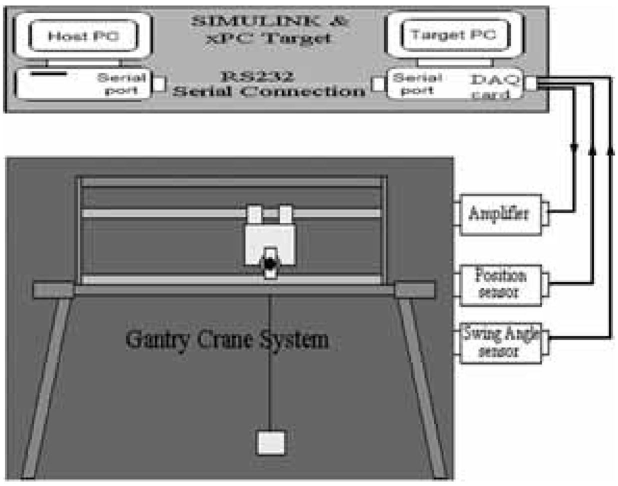


Fig. 6. Experimental setup

5.2. Design of proposed control method

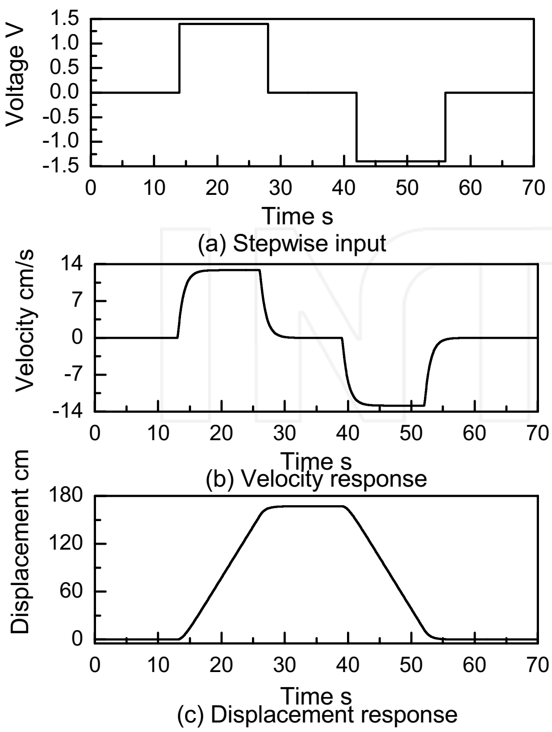


Fig. 7. Step wise input and plant responses

The stepwise input shown in Fig. 7(a) is applied to the plant. The height of the stepwise input, which is 1.4 V, is decided based on the rated input to the motor driver. The velocity and displacement responses due to the stepwise input are shown in Figs. 7(b and c), respectively. Then, Fig. 8 illustrates the determined NCT based on Fig. 7. The NCT has a $-1.10\ s^{-1}$ inclination near the origin and a 12.8 cm/s maximum error rate h. The compensator parameters are designed by using h and m of the NCT. By referring to the digital implementation of the PI compensator as discussed in Wahyudi et al. [9], design parameters $\zeta = 0.1$ and $\omega_n = 1000$ are selected. Table 1 shows the value of the compensator parameters calculated from Eqs. (8) and (9).

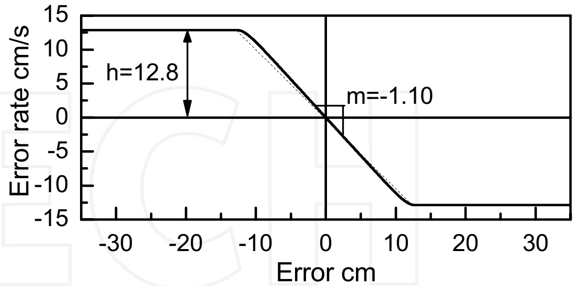


Fig. 8. The nominal characteristic trajectory

Next, fuzzy logic for anti-swing control is designed. The main design process of the fuzzy logic controller consists of the development of input and output of the membership functions, fuzzy rule base and defuzzification method. Since there is no specific form to be used when designing fuzzy logic control, thus, the basic triangle and trapezoidal forms are chosen for input and output membership functions. In most cases, the performance of fuzzy control is minimally influenced by the shapes of memberships, but mainly by the characteristics of control rules (Lee and Cho, 2001).

Controllers	Parameter		
	K_p	K_i	K_d
NCTF controller	14.1	$2.47\text{x}10^{-4}$	-
PID controller (position control)	2.54	$7.80\text{x}10^{-4}$	0.88
PD controller (anti-swing)	63	-	4.2

Table 1. NCTF and PID parameters

Fig. 9 shows the membership functions of the fuzzy logic controller for anti-swing control. It consists of Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB) as shown in the diagram. The universes of discourses of error, error rate and input voltage are from -1 to 1 rad, -2.5 to 2.5 rad/s and -1.4 to1.4 V respectively.

Table 2 lists the generated linguistic rules for anti-swing control. The rules are designed based on the condition of the swing angle and the swing angle rate as illustrated in Fig. 10. Consider the trolley of the crane moves to positive direction and the payload sway on clockwise direction. As illustrated in Fig. 10(a), at this condition intuitively the force should be applied to negative direction in order to compensate the swing. Meanwhile, if the trolley moves to negative direction as shown in Fig. 10(b) and the payload sway to anti clockwise direction, the forced should be imposed to positive direction to suppress the swing motion. In the case there is no swing, no force should be applied. Furthermore, the proposed fuzzy logic control adopts well-known Mamdani min-max inference and centre of area (COA) methods.

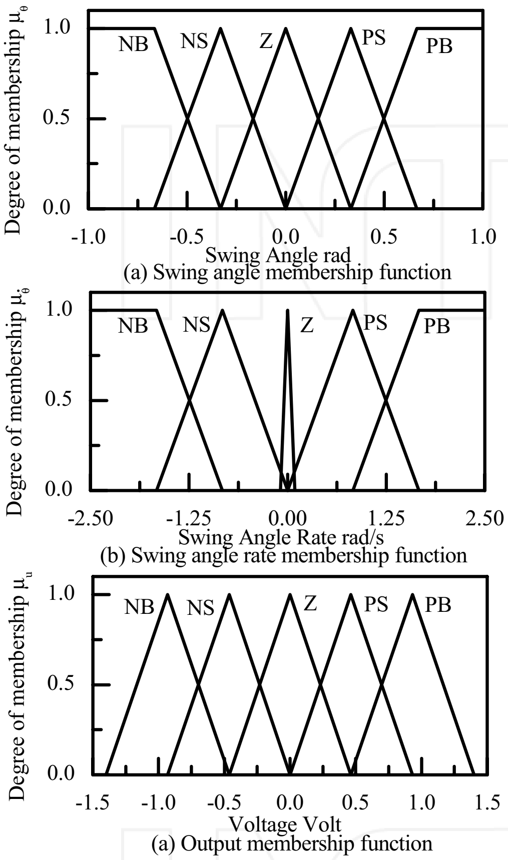


Fig. 9. Membership function of inputs and output signals

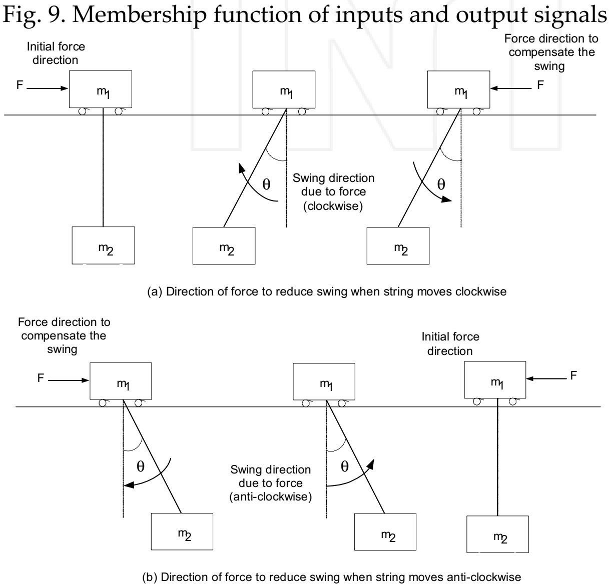


Fig. 10. Rule generation based the motion condition

Swing angle rate / Swing angle		$\dot\theta$ PB	PS	Z	NS	NB
θ	PB	PB	PB	PB	NB	NB
	PS	PB	PS	PS	NS	NB
	Z	PB	PS	Z	NS	NB
	NS	PB	PS	NS	NS	NB
	NB	PB	PB	NB	NB	NB

Table 2. Fuzzy rules for anti-swing control

5.2. Controller benchmark

The proposed control method is evaluated and compared with two other popular methods namely classical PID and fully fuzzy logic controllers. These controllers are chosen as benchmark due to fact that the PID controller represents a well-known model-based controller while fuzzy logic is non-model based controller. The structure of the PID control for crane system is shown in Fig. 11. The PID controllers are designed and optimized by using the *NCD blockset* of MATLAB. In order to realize fast motion with small overshoot, the PID controller is optimized by considering the following desired specifications (Wahyudi and Jalani, 2005):

- Overshoot ≤ 2 %
- Settling time ≤ 1 sec
- Rise time ≤ 1 sec
- Steady-state error ≤ ±0.001

Moreover, in order to suppress the swing angle quickly, the PD controller is optimized based on the following desired specifications (Wahyudi and Jalani, 2005):

- Settling time ≤ 5 sec
- Swing Amplitude ≤ 1 rad

Fig. 12 shows the time response constraint for optimization of the PID and PD controllers in *NCD blockset*.

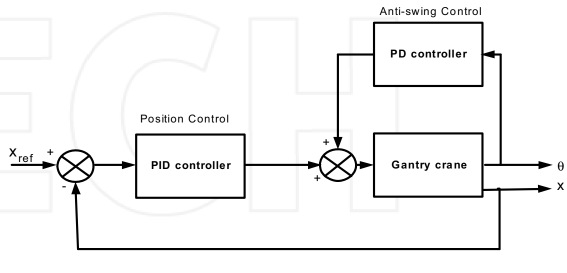
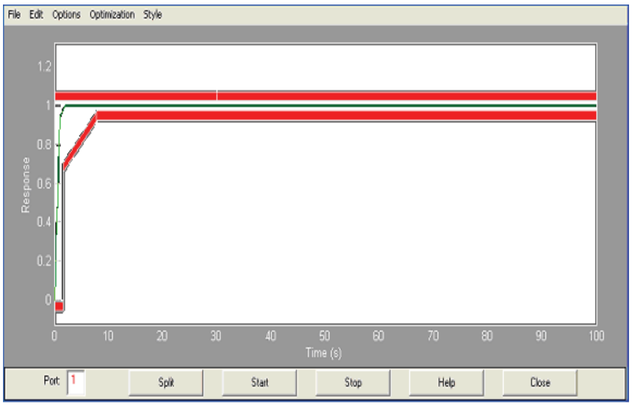
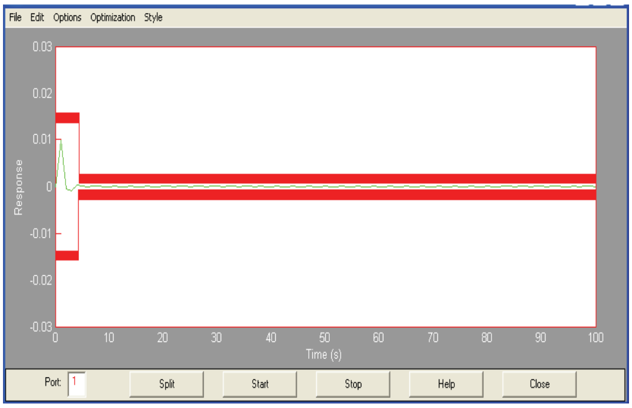


Fig. 11. PID controller based automatic crane system

The initial parameters for PID and PD controllers must be specified before the *NCD blockset* executes the tuning and optimizing process. The initial controller parameters can be obtained either by trial and error or given as default by the *NCD blockset*. Finally, the optimized PID and PD controller parameters obtained using NCD blockset are shown in Table 1.



(a) Time response constraint of position controller



(b) Time response constraint of anti-swing controller
Fig. 12. PID controller optimization using *NCD blockset*

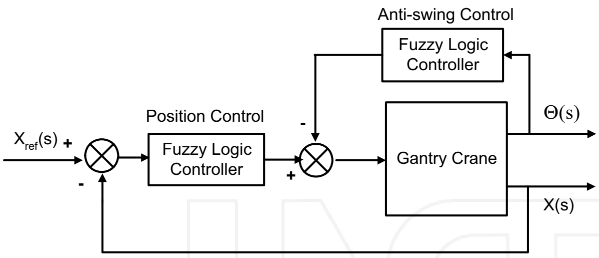
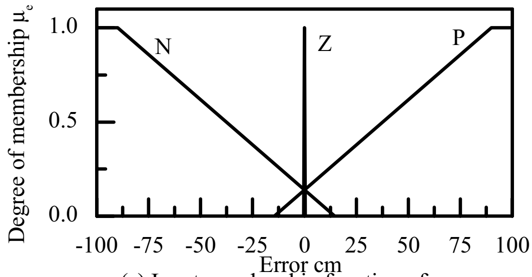
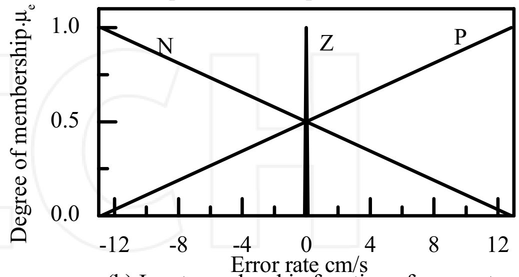


Fig. 13. Fuzzy controller based automatic crane system

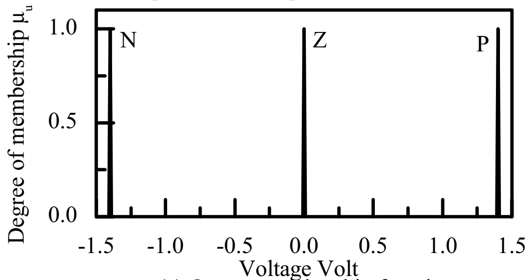
Another controller which is used as a benchmark is fuzzy logic controller as shown in Fig. 13. Here both the position and anti-swing control use fuzzy logic control approach. The fuzzy control for anti-swing control is exactly the same with the proposed control method. On the other hand, fuzzy logic controller for position controller uses two inputs namely error and error rate. The membership function of the inputs and output are shown in Fig. 14. The membership functions of the inputs and output consist of Negative (N), Zero (Z) and Positive (P) as shown in Fig. 14. 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 to1.4 for voltage. Furthermore, the design of rule for the fuzzy control for position controller is also based on the same approach as that for anti-swing control. The full list of the rule is shown in Table 3. Detail discussion on the fuzzy-based automatic gantry crane can be found in Wahyudi and Jalani (2006).



(a) Input membership function of error e



(b) Input membership function of error rate



(a) Output membership function

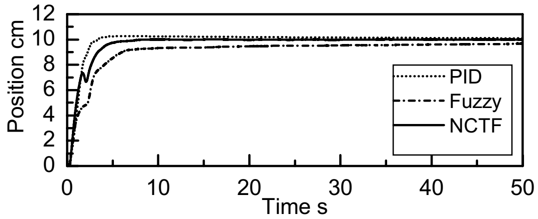
Fig. 14. Membership function of inputs and output

Error \ Error rate		ė		
		P	Z	N
e	P	P	P	P
	Z	N	Z	P
	N	N	N	N

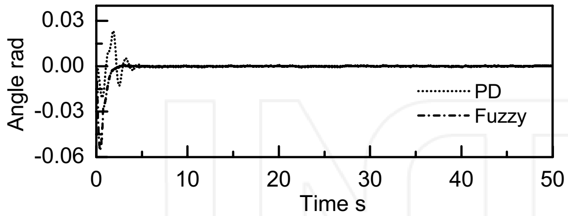
Table 3. Fuzzy rules for position control

5.3. Performance evaluation

The performance of the proposed control method for automatic gantry crane system is compared with the benchmark controllers namely the PID and fuzzy logic controllers. Three different desired positions of the payload are chosen to evaluate the proposed controller performance namely 10, 40 and 70 cm step inputs. These reference inputs (desired outputs) represent short, medium and long range movements of the payload respectively. The performance of the position control is evaluated based upon the maximum overshoot (M_P), settling time (T_s) and positioning accuracy (E_{ss}). On the other hand, performance of the anti-swing controller is evaluated based upon maximum amplitude (A_{max}) and settling time (T_s).



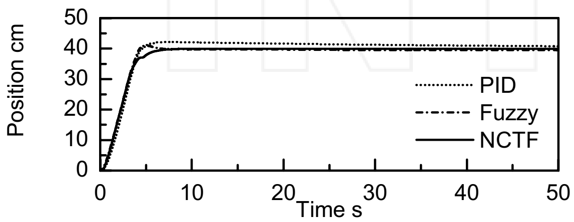
(a) Position response



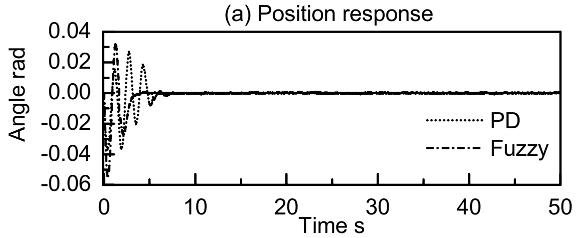
(b) Anti-swing response

Fig. 15. Responses to a 10 cm step input

Figs. 15-17 show the responses of the crane system to 10, 40 and 70 cm step inputs and their performances are listed in Tables 4 and 5. Figs. 15-17 and Table 4 show that the positioning performance of the proposed method is better than that of PID controller for the selected different reference inputs. On the other hand, in comparison with fuzzy control, the proposed control is better in terms of overshoot and accuracy. Although the proposed controller gives a faster settling time than that of fuzzy control for 10 cm reference input, the settling time of the proposed method is slightly slower that of fuzzy for 40 and 70 cm reference inputs. In general it can be concluded that the NCTF controller used in the proposed method has been able to successfully control the position of the payload better than the other controllers and it produces more consistent performance at different desired positions.



(a) Position response



(b) Anti-swing response

Fig. 16. Responses to a 40 cm step input

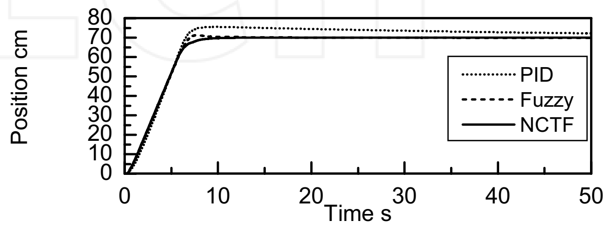
Figs. 15-17 and Table 5 show that the proposed method suppresses the swing motion better than the PD controller for the selected different reference inputs since it gives a shorter settling time. Since both the proposed and fuzzy controllers use the same fuzzy logic controller in the anti-swing control, they produce the same performance as expected. The maximum swing amplitude due to the proposed method is higher as compared with the PD controller, however, it is still acceptable. By considering both position and swing angle suppression performances previously discussed, it is clear that the proposed method which is designed without mathematical model of the crane is the best controller for the crane system.

Reference	Controller	M_p (%)	T_s (sec)	E_{ss} (cm)
10 cm	Proposed	0.22	5.36	-0.0080
	PID	2.79	6.15	-0.0997
	Fuzzy	0	>50	-0.3270
40 cm	Proposed	0	6.07	0.0930
	PID	5.33	>50	-0.8030
	Fuzzy	2.62	5.44	0.4650
70 cm	Proposed	0	7.87	0.0657
	PID	7.92	>50	-2.19
	Fuzzy	1.71	6.73	0.158

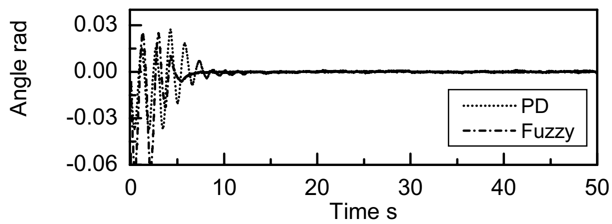
Table 4. Positioning performance comparison

Reference	Controller	A_{max} (rad)	T_s (sec)
10 cm	Proposed	0.06	3.8
	PID	0.02	6.1
	Fuzzy	0.06	3.8
40 cm	Proposed	0.06	5.4
	PID	0.04	10.90
	Fuzzy	0.06	5.4
70 cm	Proposed	0.06	6.7
	PID	0.04	12.7
	Fuzzy	0.06	6.7

Table 5. Anti-swing performance comparison



(a) Position response

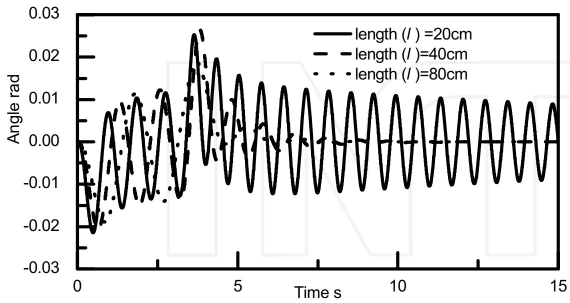


(b) Anti-swing response

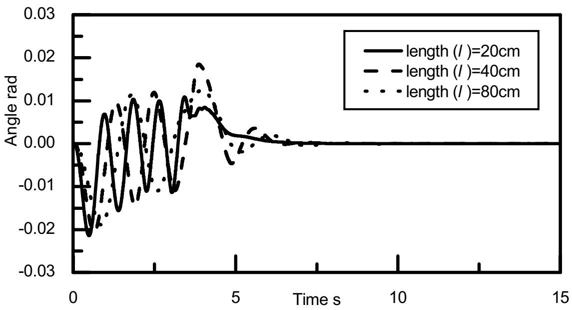
Fig. 17. Responses to a 70 cm step input

6. Robustness Evaluation

In the gantry crane system, one of the major contributing factors to the uncertainty is the variation of the string length. Hence robustness of the controller is an important requirement to retain performance of the gantry crane system. Here, the robustness of the proposed and PD controllers are examined by testing the effect of string length (ℓ) on the performance of the gantry crane system. Three different lengths, ℓ =20, 40, and 80 cm, have been tested and the results are shown in Fig. 18.



(a) PD controller



(a) Fuzzy logic ontroller

Fig. 18. Robustness evaluation

Fig. 18(a) shows that the PD controller has small effect on the settling time and amplitude if a longer length of the string is used. However, the response becomes worse as soon as the shorter length of the string is used. The settling time due to the shorter length became longer even though there is small effect on the amplitude. On the other hand, Fig. 18(b) shows that for varied string length the fuzzy logic controller has smaller effect on the settling time and amplitude changes as compared with the PID controller. Therefore, it shows that the fuzzy logic controller is more robust to the length variations than the PD controller.

7. Discussions

The proposed controller was not implemented on the full scale crane systems due to economical and safety constraints. Instead it was implemented on the lab-scale crane system. Although the proposed controller was implemented on the lab-scale gantry crane system, it is expected the proposed controller would work well in term of performance and robustness in the real crane system used in construction. This is due to fact that both lab-scale and real gantry cranes have similar dynamics characteristic. The performance and robustness to cable length variation of the proposed controller would be good enough for real crane system.

The wind disturbance which usually exists in the real environment of the building construction is not examined in this paper. However in general, feedback control, which is also adopted in this paper, is well-known to be less sensitive to both disturbances and parameter variations (Bellanger, 1995). As it has been shown that the proposed controller is robust (insensitive) to parameter variation, it is reasonable to expect that the proposed controller would also suppress the wind disturbance. In addition, the NCTF controller has been proved theoretically that it is robust to disturbance rejection (Wahyudi et.al,2003). Nevertheless, a further experiment has to be done to confirm the system robustness to disturbance including wind disturbance.

Finally, this paper only discussed the control aspect of the crane system. In the real environment of, safety features should be incorporated in the system to minimize accidents and damage to humans and machines in the building site.

8. Conclusions

The practical control method has been proposed for controlling the automatic gantry crane system. The proposed method consists of the NCFT and fuzzy logic controller for position and anti-swing control respectively. The proposed control method is practically applicable without the need to have the exact model of the plant during controller design process. The design of NCTF controller is based on a simple open-loop experiment while the fuzzy logic controller is based on human experience. The performance of the proposed system is evaluated experimentally on a lab-scale gantry crane system. It is also compared with model-based PID and non-model based fuzzy logic control methods. The result shows that the proposed method is more effective for controlling both position and swing vibration of the crane than the other controllers. Further evaluation shows that the proposed control system is also robust to parameter variations.

9. Acknowledgments

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