An Experimental of 3D Gantry Crane System in Motion Control by PID and PD Controller via PFPSO Optimization

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***Abstract*—Gantry crane system is widely used for material transportation. In this system, uncontrolled oscillation always be found during the moving process. This problem may extend the carrying time and causes safety problem. This paper presents a method for controlling a Gantry Crane System based on Proportional-Integral-Derivative (PID) controller strategy. A combination of the Priority Fitness Scheme and Particle Swarm Optimization (PFPSO) is used to optimize five parameters of PID and PD controller (K_P, K_I, K_D, K_{Ps} and K_{Ds}). The proposed method is examined in an experimental platform of 3D INTECO gantry crane system. Then the performance is compared with two other tuning methods which are Zeigler-Nichols (ZN) and Standard Particle Swarm Optimization (PSO). The performances of the system are assessed in terms of trolley position and payload oscillation. The results shown that the optimal parameters obtain from the PFPSO is the smallest and the trolley was able to reach at the desired position without creating an overshoot with low payload oscillation compared to ZN and PSO.**

***Index Terms*—3D Gantry Crane System; PID Controller; PSO Optimization.**

I. INTRODUCTION

The crane system is an electromechanical system, which is used to lift and lower some materials and move them from one place to another. There are two main problems which occurred in the gantry crane system which are the travel of the trolley to the desired position with minimize payload oscillation during the movement [1]–[3]. Previously, the skillful operators manually control the sway of the gantry crane by combine their intuition, experience and skill in order to manipulate a load hanging on a hoisting cable by stopping the trolley near to the desired position and then letting the payload to stop oscillating gradually by a further gentle movement of the trolley. However due to human fatigue may affect significantly the performance and operation of gantry crane [4]. Besides, the actual systems are influenced by noise and external disturbance incusing gantry such as wind and unstable mounting may degrade the performance of the gantry crane system.

Intelligent control algorithms such as fuzzy, sliding mode, neural network, and genetic algorithm have a lot of advantages related to the interpolative reasoning approach, but also have some restrictions due to its complexity. Input shaping technique has been proposed for the vibration control [5]–[7]. However, this method is focused on the payload oscillation compared to the positioning of the trolley. In [8]–[10], a Fuzzy Logic Controller (FLC) is implemented in the 3D crane system to reduce oscillations during the positioning of a 3D crane system. The research is then been improved by designing a controller design by using bond graph model of 3D crane system [11]. However, the fuzzy logic designed still need to struggle in finding satisfactory rules, membership function, fuzzification and defuzzification parameter heuristically [12]. On the other hand, feedback controls which are well known to be less sensitive to parameter variations and disturbances have also been proposed. From the previous research, it clearly seen that Proportional-Integral-Derivative (PID) controller is able to control the movement of the trolley to reached the desired position and minimize the payload oscillation [13]–[15]. PID controller is considered as a good prospect and widely used in industries and nonindustrial applications to control the system for achieving the desired output. However, difficulties occurred in tuning of PID parameters. The easiest way to tune the parameter is by traditional tuning methods such as trial and error but it is not significant and satisfactory performances is not guaranteed. Other than that, Ziegler-Nichols (ZN) is one of the tuning methods that is widely used due to their simplicity [16]. Through this tuning method, it is found that it is very aggressive and leads to a large overshoot and oscillatory response.

Nowadays, meta-heuristic techniques are implemented to obtain a better PID parameters in the gantry crane system. Genetic Algorithm (GA) has been applied to tune PID controller for finding optimal automatic gantry crane [17]. Not only that, Particle Swarm Optimization (PSO) is also utilized as a technique for researching for an optimal PID parameters.

Priority Fitness Scheme (PFS) is introduced as the combination of PFS and optimization. This method is developed to set any of the transient response characteristics (settling time (Ts), overshoot (OS) or steady-state error (SSE)) based on the priority issue of the system. PFPSO is a combination of the PFS and PSO which have been implemented in gantry crane system [18]-[19]. Other than that, these combination has been transform in the binary number which known as Priority Fitness Scheme in Binary Particle

Swarm Optimization (PBPSO) [20]-[21]. Besides, PFS also has been combined with the Firefly Algorithm (PFFA) to obtain the optimal parameters of PID controller in order to achieve a satisfactory performance [22]. However, this technique is performed for simulation purpose only.

This paper presents a mathematical modeling structure that provides a closed-form dynamic equation of motion of the gantry crane system which is implemented by PID controller tuned by PFPSO. The proposed method is examined in the experimental platform by using 3D INTECO gantry crane system as shown in Figure 1. The performance of the system has been compared with two of tuning methods which are ZN and PSO.

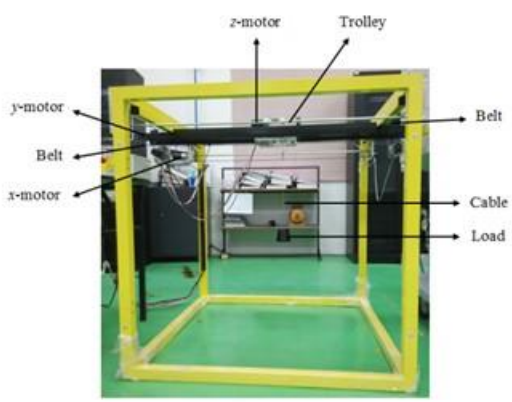

Figure 1: 3D INTECO gantry crane system.

II. METHODOLOGY

Figure 2 shows the schematic representation of 3D INTECO gantry crane system [7]. There are five identical encoders measuring five state variables; x_w represents the distance of the rail with the cart from the center of the construction frame; y_w is the distance of the cart from the center of the rail; R denotes the length of the lift-line; α represents the angle between the y axis and the lift-line; β is the angle between the negative direction on the z-axis and the projection of the lift-line onto the xz-plane.

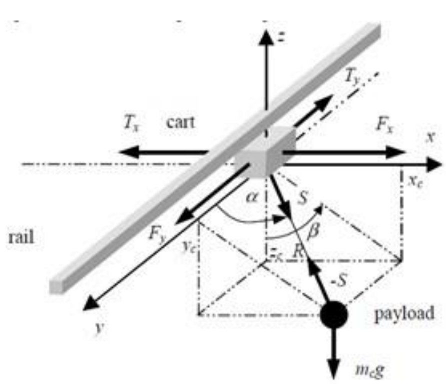

Figure 2: Schematics of 3D INTECO gantry crane system.

The dynamic equations of motion in gantry crane system in the y-direction obtained as in equation (1) and equation (2) where y_t is position of trolley and y_p is position of payload oscillation [7]. Parameters of the gantry crane system are tabulated as in Table 1.

$$\ddot{y}_t = \left(\frac{F_x}{m_w} - \frac{T_x}{m_w}\right) + \left(\frac{m_c}{m_w}\right)\left(\frac{F_z}{m_c} - \frac{T_z}{m_c}\right)\cos\alpha \tag{1}$$

$$\ddot{y}_p = \ddot{y}_t + \left(\ddot{R} - R\dot{\alpha}^2\right)\cos\alpha - \left(2\dot{R}\dot{\alpha} + R\ddot{\alpha}\right)\sin\alpha \tag{2}$$

Table 1
Parameters of gantry crane system [7]

Parameters	Unit	Values
Payload mass	m_c	0.46 kg
Trolley mass	m_w	1.16 kg
Moving rail mass	m_s	2.20 kg
Gravity	g	9.81 ms^{-2}
Friction force at x-axis	T_x	100 Nsm^{-1}
Friction force at y-axis	T_y	82 Nsm^{-1}
Friction force at z-axis	T_z	75 Nsm^{-1}
Length of cable	R	0.28 m

A. Proportional-Integral-Derivative (PID) Controller

PID controller is a control feedback structure which is widely used in industrial control system. PID controller involves three parameters which are the proportional (K_P), the integral (K_I) and the derivative (K_D). PID controller is used to calculate an error value as the difference between a measured process variable and a desired set point. It also used to minimize the error by adjusting the process control inputs.

B. Particle Swarm Optimization with Priority Fitness Scheme (PFPSO)

The standard PSO is introduced by Kennedy and Eberhart [23]. It was first proposed for the simulation of social behavior, as representation of the movement of organisms in a bird flock. While looking for food, the birds are either scattered or go together before they spot the place where they can find the food. While the birds are searching for food from one place to another, there is always a bird that can smell the food well, that is the bird is perceptible of the place where the food can be found, having the best food resource information. Because they are transmitting the information, especially the good information at any time while searching the food from one place to another, conducted by the good information, the birds will eventually flock to the place where food can be found [23]. Each particle can be shown by its current velocity and position as shown in equation (3) and equation (4) with 20 of particles and 100 of iterations.

$$\boldsymbol{v}^{i+1} = \omega\boldsymbol{v}^i + c_1\boldsymbol{r}_1(\boldsymbol{P}_{BEST} - \boldsymbol{x}^i) + c_2\boldsymbol{r}_2(\boldsymbol{G}_{BEST} - \boldsymbol{x}^i) \tag{3}$$

$$\boldsymbol{x}^{i+1} = \boldsymbol{x}^i + \boldsymbol{v}^{i+1} \tag{4}$$

where:

$\boldsymbol{v}^{i+1}$	= velocity of particle at iteration k
ω	= inertia weight factor
c_1, c_2	= acceleration coefficients
$\boldsymbol{r}_1$, $\boldsymbol{r}_2$	= random numbers between 0 and 1
$\boldsymbol{x}^{i+1}$	= position of particle at iteration k

In 2012, PFS is introduced by Jaafar for tuning process [18]. The combination of PFS and PSO known as PFPSO is implemented in tuning the PID parameter in order to obtain the optimal parameters. In the PFS, OS was set as the highest priority followed by T_s and SSE. The process of the PFPSO are shown in Figure 3 and Figure 4.

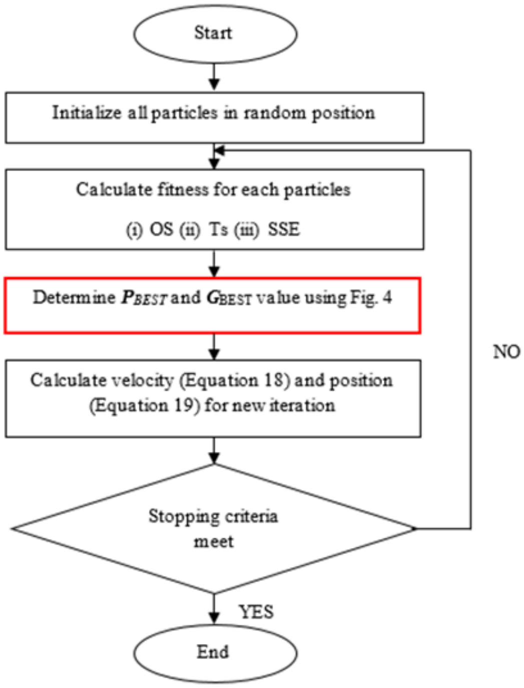

Figure 3: General Process of PFPSO [18]

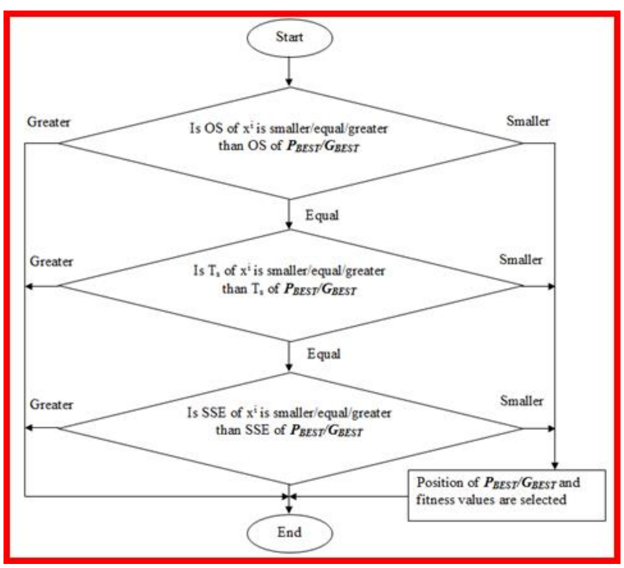

Figure 4: Process of PFPSO according to the priority [18]

III. Results and Discussion

A. Optimized of PID+PD Parameters

PID and PD controller are implemented to control the trolley to reach the desired position and to control the oscillation of the angle which created from the system while moving the payload to the desired position. PID controller is used to control the trolley position whereas PD controller is used to minimize the payload oscillation. The parameters in these controller is optimized by three types of tuning methods which are ZN, PSO and PFPSO as illustrated in Figure 5. These tuning methods are used to obtain the optimal parameters of the PID and PD controller. These tuning methods also being compared to observe the best controller variables that could leads to a great performances in the gantry crane system. The optimized parameters of PID (KP, KI and KD) and PD (KPs and KDs) controller is tabulated in Table 2.

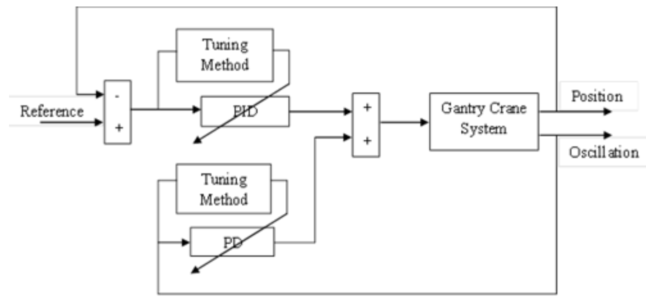

Figure 5: Block Diagram of control structure in gantry crane system.

Table 2
Parameters of PID+PD controller

Parameters	Tuning Method		
	ZN	PSO	PFPSO
K_P	3.0000	20.9716	2.5224
K_I	3.0000	10.8455	0.1076
K_D	1.8750	4.4700	3.0353
K_{Ps}	4.0000	4.9952	2.9549
K_{Ds}	1.1000	0.0714	0.0619

B. Trolley Position

Figure 6 shows the trolley position in the gantry crane system which controlled by the PID controller. In overshoot performance, PID+PD tuned by PFPSO shown a best overshoot compared to ZN and PSO. This is because the response of PFPSO did not create an overshoot in the system. In the settling time, PSO shown the shortest settling time compared to PFPSO. However, there is a steady state error of 0.002 m in PSO compared to the PFPSO which did not create a steady state error.

Table 3
Performance of trolley displacement.

Tuning Method	Performances		
	OS (%)	T_s (s)	SSE (m)
PID+PD (ZN)	18.00	11.80	0.004
PID+PD (PSO)	20.07	7.70	0.002
PID+PD (PFPSO)	0.00	11.50	0.000

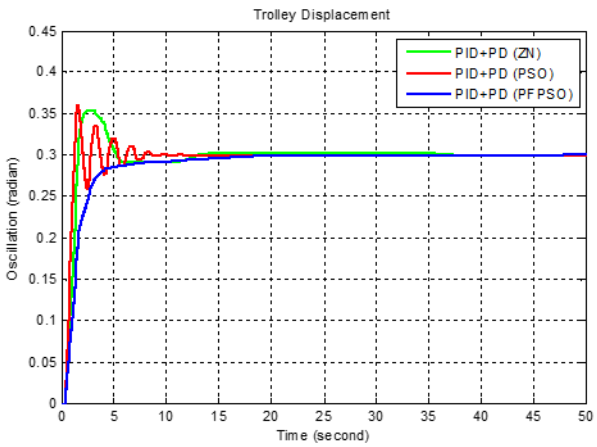

Figure 6: Response of desired position

C. *Payload Oscillation*

Figure 6 shows the payload oscillation in the gantry crane system which controlled by the PD controller to minimize the oscillation while handling the load. The result shows that by using the parameters of PD controller tuned by PFPSO, the maximum oscillation is the smallest which is 0.2 rad at 0.6 s compared to ZN and PSO which are 1.15463 rad and 1.1750 rad respectively. The system is able to minimize the payload oscillation to zero radian in short duration of time taken compared ZN and PSO. The performance of the payload oscillation according to tuning methods is tabulated in Table 4.

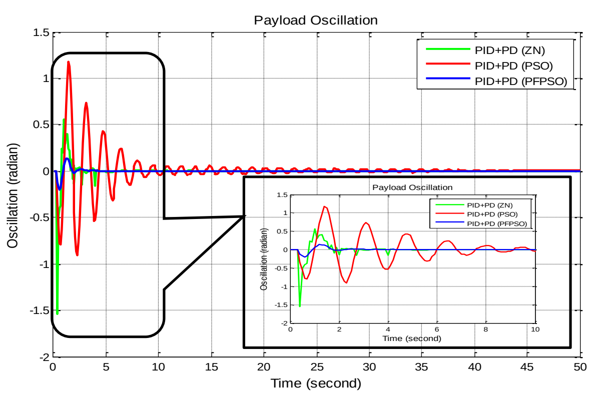

Figure 7: Response of payload oscillation

Table 4
Performances of payload oscillation

Tuning Method	Performance Max Oscillation, θ_{max} (radian)	Time Taken, T (s)
PID+PD (ZN)	1.5463	0.4
PID+PD (PSO)	1.1750	1.4
PID+PD (PFPSO)	0.2000	0.6

IV. CONCLUSION

This paper has presented the design of an optimal PID+PD controller for a gantry crane system. The parameters of PID +PD controller are tuned by using ZN, PSO and PFPSO tuning technique. By comparing these tuning method in an experimental studies, PFPSO shown the best result compared to ZN and PSO. Besides that, the optimal parameters obtain from PFPSO is the smallest and the trolley was able to reach at the desired position without creating the overshoot with low payload oscillation. In future work, a new controller can be introduce and implement in the system for more effective performance.

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