APPLIED GENETIC ALGORITHM DESIGN DUAL PID CONTROLLERS TO CONTROL THE GANTRY CRANE FOR COPPER ELECTROLYSIS

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ABSTRACT

Gantry crane dedicated to copper electrolysis (CE) acts as a robot in factories to transport and assemble cathode and anode plates. Because the electrolyte panels are so thickly arranged that when the crane moves there is a great fluctuation resulting in inaccurate positioning, even causing unsafety. The article proposes to use dual PID controller with optimized parameters adjusted through genetic algorithm (GA) to control the gantry crane. The first PID controller controls the load oscillations, while the second PID controller controls the position of the crane. Dual PID controllers are tested through MATLAB/ Simulink simulations. Simulation results $t_{\_xlvt}$ = 3.5 s, $t_{\_xlgx}$ = 3.3 s, $\theta_{\_max}$ = 0.12 rad show that when using dual PID controllers quality better control when using a PID controller and when changing system parameters, interference impact on the system shows that the crane is still good quality control.

ỨNG DỤNG GIẢI THUẬT DI TRUYỀN THIẾT KẾ BỘ ĐIỀU KHIỂN PID KÉP ĐỂ ĐIỀU KHIỂN GIÀN CẦN TRỤC CHO ĐIỆN PHÂN ĐỒNG

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TỪ KHÓA

Giàn cần trục
Giải thuật di truyền
Điều khiển vị trí
Điều khiển PID
Điều khiển dao động

TÓM TẮT

Giàn cần trục dành cho điện phân đồng (CE) hoạt động như một robot ở các nhà xưởng để vận chuyển và lắp ráp các tấm cathode, anode. Vì các tấm điện phân được sắp xếp dày đặc nên khi cần trục di chuyển có sự dao động lớn dẫn đến khả năng định vị thiếu chính xác, thậm chí gây mất an toàn. Bài báo đề xuất sử dụng bộ điều khiển PID kép với các thông số được điều chỉnh tối ưu hóa thông qua giải thuật di truyền (GA) để điều khiển giàn cần trục. Bộ điều khiển PID đầu tiên kiểm soát sự dao động của tải trọng, còn bộ điều khiển PID thứ hai điều khiển vị trí cần trục. Bộ điều khiển PID kép được kiểm tra thông qua mô phỏng MATLAB/ Simulink. Kết quả mô phỏng $t_{\_xlvt}$ = 3.5 s, $t_{\_xlgx}$ = 3.3 s, $\theta_{\_max}$ = 0.12 rad cho thấy khi sử dụng bộ điều khiển PID kép chất lượng điều khiển tốt hơn khi sử dụng một bộ điều khiển PID và khi thay đổi các thông số hệ thống, tác động nhiễu vào hệ thống cho thấy giàn cần trục vẫn đạt được chất lượng điều khiển tốt.

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1. Introduction

The world is developing more and more, the amount of iron and steel, non-ferrous metals and other basic materials is in high demand more and more, to transport all these materials, gantry cranes are indispensable. Where the copper electrolysis (CE) gantry crane as shown in Figure 1 not only transports the electrolytic plates, but also performs another very important task of assembling the electrolytic plate into the side slots in the electrolysis tank or into slots for other robots. Safe, efficient, and timely transportation and assembly of electrolytic plates into slots is essential. Therefore, there have been many studies to improve the operational efficiency of gantry cranes.

Structurally, Huang et al. [1] shows an overhead gantry crane for copper electrolysis that makes efficient use of the workspace below the crane. The overhead gantry cranes are moved by the forklift and the load is suspended on the forklift via slings [2]. The overhead crane has the functions of lifting, lowering and traveling, but the natural swing of the load makes these functions ineffective, which is a pendulum motion [3].

Figure 1. *Gantry crane for CE*

The swaying of the load is caused by the moving movement of the forklift truck, the frequent change in the length of the load sling, the weight of the load and the impact caused by disturbances such as wind, collision... Therefore, a number of large studies are used to control the operation of automatic cranes with small shaking angle, short transport time and high accuracy such as adaptive control [4], planned trajectory [5], input shape [6], slide mode control [7], dual PD dimming control [8] where the first fuzzy controller controls cart position, while the second dimming controller prevents the shaking angle of the load has the advantage of reaching the desired position quickly, the shaking angle of the load is small but must be controlled with a small distance. The double fuzzy control [9] has the advantage of achieving a small swing angle, but a large overshoot and a long time to reach the desired position exist. PID controller is a controller widely used in industrial control system [10], due to its simple structure, easy adjustment and good stability. The parameters of conventional PID controller are adjusted by applying traditional or empirical method. However, in order to have optimal PID control parameters for complex systems, researchers started to use DE [11], PSO [12] algorithms to optimize controller parameters. PID in [11], there are advantages of large distance control, but there is still overshoot and large swing angle. In [12], it has the advantage of achieving the desired position quickly, the shaking angle is small, but the load fluctuations are constant.

In this paper, dual PID controllers are proposed with optimized parameters adjusted through genetic algorithm (GA) to control the position of the crane and control the shaking angle of the load. The designed controllers are tested through MATLAB/Simulink simulation with good working results.

The rest of the paper is structured as follows. Section 2 presents dynamic model of gantry crane system for copper electrolysis. The design of PID controllers is presented in section 3. Section 4 describes simulation results when changing system parameters. Section 5 gives some conclusions.

2. Dynamic model of crane system for copper electrolysis

A gantry crane system for CE is shown in Figure 2 [8], parameters and values are taken in proportion to the actual value as shown in table 1. The system can be modeled as is a forklift with mass M . A pendulum attached to it has a tonnage of m and l is the length of the load sling, θ is the swing angle of the pendulum, θ is the angular velocity of the load.

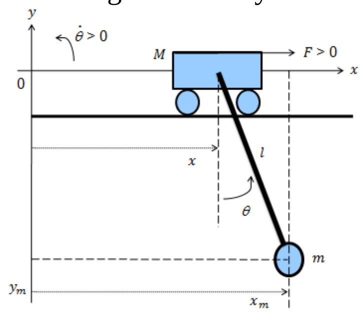


Figure 2. *Diagram of the gantry crane system for the CE*

Table 1. *Symbols and values of crane gantry parameters for CE*

Symbol	Describe	Value	Unit
M	Forklift weight	5	Kg
l	Length of load cable	1	m
m	Load mass	10	Kg
g	Gravitational constant	9.81	m/s^2
μ	Coefficient of friction	0.2	

According to the Lagrangian equation:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right) - \frac{\partial T}{\partial q_i} + \frac{\partial P}{\partial q_i} = Q_i \tag{1}$$

Where: P is the potential energy of the system, q_i is the generalized coordinate system, i is the number of degrees of freedom of the system, Q_i is the external force, and T is the kinetic energy of the system:

$$T = \sum_{j=1}^{n} \frac{1}{2} m_j \dot{x}_j^2 \tag{2}$$

From Figure 2, we have the position components of the forklift and the load as:

$$\begin{cases} X_M = x \\ X_m = x + l\sin\theta \end{cases} \tag{3}$$

From (3) we have the components of the forklift's velocity and the load are:

$$\begin{cases} \dot{X}_M = \dot{x} \\ \dot{X}_m = \dot{x} + l\dot{\theta}\cos\theta \end{cases} \tag{4}$$

The kinetic energy of the cart is:

$$T_M = \frac{1}{2} M \dot{x}^2 \tag{5}$$

The kinetic energy of the load is:

$$T_m = \frac{1}{2} m(\dot{x}^2 + l^2\dot{\theta}^2 + 2\dot{x}l\dot{\theta}\cos\theta) \tag{6}$$

From (5), (6) we have the kinetic energy of the system as:

$$T = T_M + T_m = \frac{1}{2}M\dot{x}^2 \frac{1}{2}m(\dot{x}^2 + l^2\dot{\theta}^2 + 2\dot{x}l\dot{\theta}\cos\theta) \quad (7)$$

The potential energy of the system is:

$$P = mgl(1-\cos\theta) \quad (8)$$

From (7), (8) we have:

$$\frac{\partial T}{\partial \dot{x}} = M\dot{x} + m\dot{x} + ml\dot{\theta}\cos\theta \quad (9)$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial x}\right) = (M+m)\ddot{x} + ml\ddot{\theta}\cos\theta - ml\dot{\theta}^2\sin\theta \quad (10)$$

$$\frac{\partial T}{\partial x} = 0, \frac{\partial P}{\partial x} = 0 \quad (11)$$

Similar calculations (9), (10), (11) and instead of (1) we have the nonlinear equation of motion of the gantry crane system for CE as follows:

$$(M+m)\ddot{x} + ml\ddot{\theta}\cos\theta - ml\dot{\theta}^2\sin\theta = F - \mu\dot{x} \quad (12)$$

$$ml\cos\theta\ddot{x} + ml^2\ddot{\theta} + mgl\sin\theta = 0 \quad (13)$$

Put $x_1 = x, x_2 = \dot{x}, x_3 = \theta, x_4 = \dot{\theta}$ then from (12), (13) we have the system of equations of state of motion of the gantry crane system for CE that has been reduced to the derivative of the following form:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = f_1(x_1, x_2, x_3, x_4, F) \\ \dot{x}_3 = x_4 \\ \dot{x}_4 = f_2(x_1, x_2, x_3, x_4, F) \end{cases} \quad (14)$$

in there

$$f_1 = \frac{\left(lm\sin(x_3)x_4^2 + F - \mu x_2 + gm\cos(x_3)\sin(x_3)\right)}{\left(M + m - m\cos^2(x_3)\right)} \quad (15)$$

$$f_2 = \frac{-\left(gm\sin(x_3) - \mu x_2\cos(x_3) + F\cos(x_3) + lm\cos(x_3)\sin(x_3)x_4^2 + Mg\sin(x_3)\right)}{\left(Ml + ml - ml\cos^2(x_3)\right)} \quad (16)$$

F is external forces acting on the gantry crane system.

3. Design of PID controllers

3.1. Design a PID controller to control the gantry crane for CE

3.1.1. Schematic design using a PID controller to control the gantry crane for CE

The PID controller has a simple structure, and is easy to use, so it is widely used in controlling SISO objects according to the feedback principle. For the gantry crane system for CE, there are two parameters that need to be controlled, namely crane position and load fluctuation, in this section we choose crane position control as the main parameter while the remaining parameter is applied to the action of the main parameter reference point with the control diagram as shown in Figure 3. The PID controller is responsible for bringing the error *e*(t) of the system to zero so that the transition process satisfy basic quality requirements.

The mathematical expression of the PID controller described in the time domain has the following form:

$$u(t) = k_P\left(e(t) + \frac{1}{T_I}\int_0^t e(t)dt + T_D\frac{de(t)}{dt}\right) \quad (17)$$

Where: *e*(t) is the input signal, *u*(t) is the output signal, k_P is the gain, T_I is the integral time constant, and T_D is the differential time constant.

The transfer function of the PID controller is as follows:

$$G_c(s) = k_P + \frac{K_I}{s} + k_D s \tag{18}$$

Parameters k_P, k_I, k_D need to be determined and adjusted for the system to achieve the desired quality.

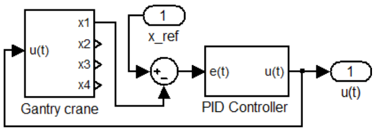


Figure 3. *Structure diagram of matlab using a PID controller to control a gantry crane for CE*

3.1.2. Find the parameters of the PID controller by Ziegler-Nichols method combined with trial and error method

For the gantry crane system model for CE, we use the second Ziegler-Nichols method to adjust the parameters of the PID controller. From Figure 3 with the parameters in table 1 and in case the desired forklift position is x_{ref} = 1m, we assign the initial gain $k_{I\_Z\text{-}N}$ and $k_{D\_Z\text{-}N}$ to zero. The $k_{P\_Z\text{-}N}$ gain is increased to the critical value *ku*, at which the open-loop response begins to oscillate. k_u and oscillation period T_u are used to set the parameters of the PID controller according to the relationship proposed by Ziegler–Nichols in Table 2.

Table 2. *PID parameters according to the 2nd Ziegler-Nichols method*

Controllers	$k_{P\_Z\text{-}N}$	$T_{I\_Z\text{-}N}$	$T_{D\_Z\text{-}N}$
PID	0.6ku	0.5Tu	0.125Tu

After using the above method, we get the values of the PID controller as follows: $k_{P\_Z\text{-}N}$ = 40, $k_{I\_Z\text{-}N}$ = 23.53, $k_{D\_Z\text{-}N}$ = 17.

Based on the results we have just found, we continue to refine the parameters of the PID controller by trial and error method as follows:

Step 1. Keep $k_P = k_{P\_Z\text{-}N}$ = 40.

Step 2. Gradually reduce the k_I parameter as small as possible because the gantry crane system for CE has integral components.

Step 3. Gradually increase k_D to reduce overshoot of crane position response curve.

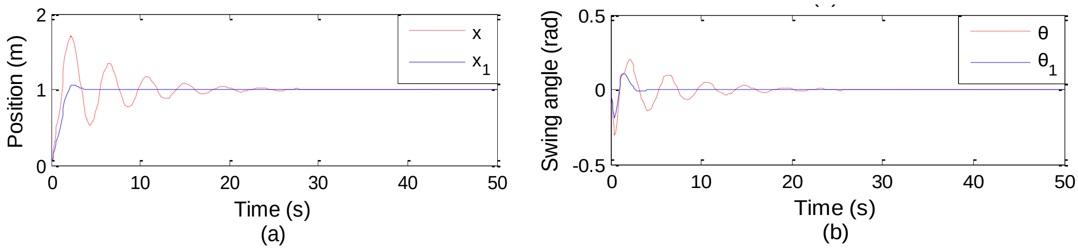


Figure 4. *The characteristic curve (a): for the position of the forklift, (b): the swing angle of the load*

Through trial and error, the following results were obtained: k_P = 40, k_I = 0.01, k_D = 35. The simulation results are shown in Figure 4. In which: x_1, θ_1, is the response characteristic curve, respectively. Forklift position and load swing angle in the case of PID controller parameters found by the 2nd Ziegler–Nichols method, for forklift position with 70% overcorrection (POT), wrong the setting number ($e_{\_xl}$) 0%, the time to establish the position ($t_{\_xlvt}$) 28 s, and for the shaking angle of the load, the largest angle (θ_{max}) 0.3 rad and the time to establish the shaking angle ($t_{\_xlgx}$) 26 s; *x*, θ, respectively, is the response curve of the forklift position and the swing angle of the load in the case of PID controller parameters found by the Ziegler–Nichols method combined with the trial and error method with POT = 5%, $e_{\_xl}$ = 0%, $t_{\_xlvt}$ = 3.8 s, $\theta_{\_max}$ = 0.185 (rad) and $t_{\_xlgx}$ = 4.3 s. It can be seen that in the case of PID parameters found by Ziegler–Nichols method combined with trial and error method, the gantry crane system achieves better control quality.

3.1.3. Finding PID controller parameters by genetic algorithm (GA)

- Genetic Algorithm (GA): is an algorithm for searching and selecting optimal solutions to solve various real-world problems, based on the mechanism of natural selection: From the initial set of solutions and many evolutionary steps, a new set of more suitable solutions is formed, and eventually lead to the globally optimal solution. GA has the following features: First, GA works with populations of many chromosomes (chromosomes - collection of solutions), looking for many extremes at the same time. Second, GA works with symbol sequences (chromosomal sequences). Third, GA only needs to evaluate the objective function to guide the search process.

- Objective function:

In the closed-loop control system of Figure 3, let e(t) be the difference between the reference signal x_{ref} and the response signal x(t) of the system, we have:

$$e(t) = x_{ref} - x(t) \tag{19}$$

The objective function of the PID controller tuning process is defined as follows:

$$J = \frac{1}{N}\sum_{j=1}^{N} e_j^2(t) = e^2(t) \tag{20}$$

The task of GA is to find the optimal values ($k_{P\text{-}GA}$, $k_{I\text{-}GA}$, $k_{D\text{-}GA}$) of the PID controller, where the objective function J reaches the minimum value.

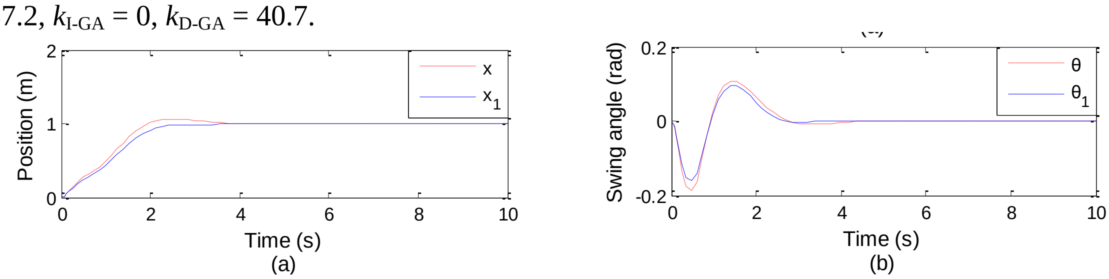
- Search space:

In order to limit the search space of GA, we assume that the optimal values ($k_{P\text{-}GA}$, $k_{I\text{-}GA}$, $k_{D\text{-}GA}$) lie around the value (k_P, k_I, k_D) obtained from the Nichols - Ziegler 2nd method incorporates a trial and error approach. The specific search limits are as follows:

$$\begin{aligned} 0 \le k_{P-GA} \le 50 \\ 0 \le k_{I-GA} \le 0.01 \\ 0 \le k_{D-GA} \le 50 \end{aligned} \tag{21}$$

Tweaking PID controller parameters by genetic algorithm (GA)

Genetic algorithm (GA) supported by MATLAB software is used as a tool to solve the optimization problem, in order to achieve the optimal values of the PID controller satisfying the objective function (20) with search space (21). The parameters of GA in this study were selected as follows: Evolution over 500 generations; population size 5000; hybridization coefficient 0.6; mutation coefficient 0.4. The process of finding the optimal value of the PID controller by GA is briefly described on the algorithm diagram in Figure 6. The search results are as follows: $k_{P\text{-}GA}$ = 37.2, $k_{I\text{-}GA}$ = 0, $k_{D\text{-}GA}$ = 40.7.



(a) (b)

Figure 5. *The characteristic curve (a): for the position of the forklift, (b): the swing angle of the load*

The simulation results are shown in Figure 5. In which: x, θ, are respectively the response curve of the forklift's position and the shaking angle of the load in the case of PID controller parameters found according to the Ziegler–Nichols method combined with trial and error; x1, θ1, respectively, is the response curve of the forklift's position and the swing angle of the load in the case of optimized PID controller parameters through GA with POT = 0%, $e_{\_xl}$ = 0% , $t_{\_xlvt}$ = 3.5 s, $\theta_{\_max}$ = 0.165 (rad) and $t_{\_xlgx}$ = 3.3 s. It can be seen that in case the PID controller parameters are optimized through GA, the gantry crane system achieves better control quality. Obviously, using GA saves time searching for PID controller parameters and gives optimal search results than traditional or empirical methods.

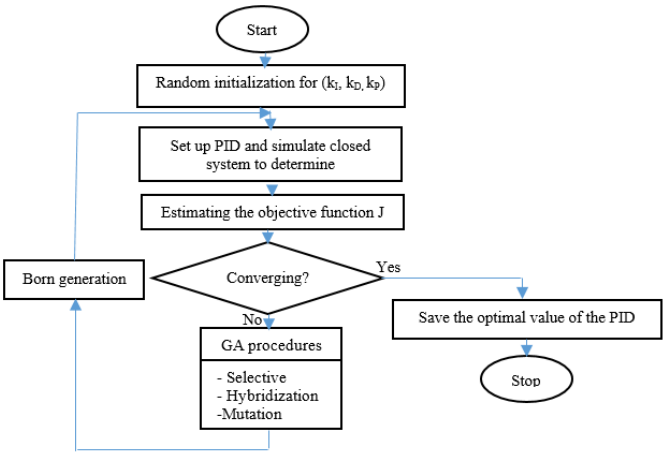


Figure 6. *Flowchart of the GA process algorithm to determine the parameters of the PID controller*

3.2. Design two PID controllers to control gantry cranes for CE

3.2.1. Schematic design using two PID controllers to control gantry cranes for CE

In fact, when the crane gantry for CE was in operation, it caused the electrolytic plates to fluctuate quite large, affecting the ability to accurately position the crane, especially the assembly of the electrolytic plate into the side slots in the electrolysis tank is very difficult. There are also some consequences such as dropping of electrolytic plates, mechanical damage and short circuit accidents. Therefore, in addition to accurate positioning, it is also necessary to control the swing angle of small loads. To do this we have designed compromise dual PID controllers. In which the first PID controller controls the load fluctuations, and the second PID controller controls the crane position with the diagram as shown in Figure 7.

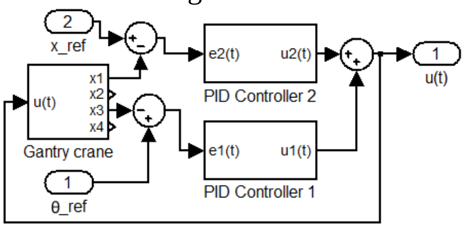


Figure 7. *Structure diagram of matlab using dual PID controllers to control crane gantry for CE*

3.2.2. Finding parameters of dual PID controllers by genetic algorithm (GA)

- Objective function

In the closed-loop control system of Figure 7, there are:

$$e_1(t) = \theta_{\_ref} - \theta(t)$$
$$e_2(t) = x_{\_ref} - x(t) \tag{22}$$

The objective function of the process of tuning dual PID controllers is defined as follows:

$$J = \frac{1}{N}\sum_{j=1}^{N} e_j^2(t) = e_1^2(t) + e_2^2(t) \tag{23}$$

The task of GA is to find the optimal values ($k_{P\text{-}GA1}$, $k_{I\text{-}GA1}$, $k_{D\text{-}GA1}$, $k_{P\text{-}GA2}$, $k_{I\text{-}GA2}$, $k_{D\text{-}GA2}$) of dual PID controllers, when J reaches the extreme value.

- Search space

To limit the search space of GA, we assume that the optimal values ($k_{P\text{-}GA1}$, $k_{I\text{-}GA1}$, $k_{D\text{-}GA1}$, $k_{P\text{-}GA2}$, $k_{I\text{-}GA2}$, $k_{D\text{-}GA2}$) lie approximately in the value ($k_{P\text{-}GA}$, $k_{I\text{-}GA}$, $k_{D\text{-}GA}$) obtained from applying GA to a PID controller. The search limits are as follows:

$$\begin{array}{ll} 0 \le k_{P-GA1} \le 20; & 20 \le k_{P-GA2} \le 40 \\ 0 \le k_{I-GA1} \le 0.01; & 0 \le k_{I-GA2} \le 0.01 \\ 0 \le k_{D-GA1} \le 21; & 21 \le k_{D-GA2} \le 42 \end{array} \tag{24}$$

- Tweaking parameters of dual PID controllers by genetic algorithm (GA)

Apply GA to find the optimal values of satisfying dual PID controllers (23), (24). In which the process of evolution over 1000 generations; population size 5000; hybridization coefficient 0.6; mutation coefficient 0.4. The search process is described as shown in the algorithm diagram in Figure 6. The results are as follows: $k_{P\text{-}GA1} = 9.5$, $k_{I\text{-}GA1} = 0$, $k_{D\text{-}GA1} = 3.7$; $k_{P\text{-}GA2} = 29.1$, $k_{I\text{-}GA2} = 0$, $k_{D\text{-}GA2} = 37.5$.

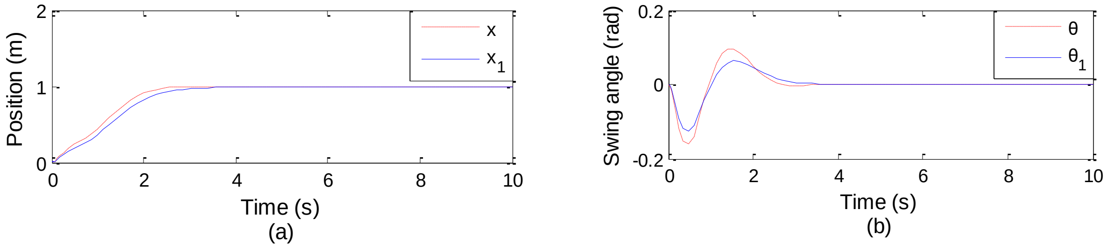


Figure 8. *The characteristic curve (a): for the position of the forklift, (b): the swing angle of the load*

The simulation results with the desired forklift position $x\_{ref} = 1$ m and $\theta\_{ref} = 0$ (rad) are shown in Figure 8. Where: x, θ, are the characteristic curve that responds to the forklift's position and the shake angle of the load in the case of using a PID controller; x1, θ1, respectively, is the response curve of the forklift's position and the swing angle of the load in the case of using two PID controllers with parameters optimized through GA with POT = 0%, $e\_{xl} = 0\%$, $t\_{xlvt} = 3.5$ s, $\theta\_{max} = 0.12$ (rad) and $t\_{xlgx} = 3.3$ s.

By comparing the results when using PID controllers, it can be seen that the controllers achieve good control efficiency. But the use case of two PID controllers has stronger adaptability and better control quality.

To clarify the superiority of the solution, the authors compared two GA-PID controllers designed with other published control methods as shown in Table 3.

Table 3. *Comparison of GA-PID with other published control methods*

Symbol	GA-PID	PID [11]	DE-PID [11]	Fuzzy -PD [8]	PSO-PID [12]	Double Fuzzy [9]
x_ref	**1 m**	5 m	5 m	0.2 m	0.4 m	1 m
POT	**0%**	6%	3%	0%	0%	13%
e_{-xl}	**0%**	0%	0%	0%	0%	0%
t_{-xlvt}	**3.5 s**	13 s	12 s	4.5 s	2.5 s	35 s
t_{-xlgx}	**3.3 s**	25 s	25 s	3.5 s	∞	26 s
$\theta_{-\max}$	**0.12 rad**	1.5 rad	0.65 rad	0.06 rad	0.09 rad	0.02 rad
$\theta_{-\min}$	**0 rad**	0 rad	0 rad	0 rad	0.035 rad	0 rad

Based on the results in Table 3, it can be seen that the controllers have good test performance. In which: double fuzzy [9] has the smallest θ_{max} but large POT, t_{xlvt}, large t_{xlgx} exist. PSO-PID [12] has t_{xlvt}, θ_{max} small however t_{xlgx} approaches ∞. Fuzzy-PD [8] has t_{xlvt}, t_{xlgx}, θ_{max} small however with small *x*_ref. PID and DE-PID [11] control with large *x*_ref however there exist large POT, t_{xlvt}, t_{xlgx}, θ_{max}. GA-PID does not exist POT, t_{xlvt}, t_{xlgx}, θ_{max} small. Since the power distribution is fixed and close to each other, it is best to determine the position of the crane burner first when using the GA-PID controller.

4. Simulation results when changing system parameters

In actual production, when the gantry crane system for CE is in operation, the parameters of the travel distance, the length of the load sling and the weight of the load are constantly changing. To keep abreast of the actual situation and study the impact of dual PID controllers, we in turn change the specific system parameters as follows: Case 1 (TH1) changes the distance traveled with the position the desired forklift $x_{\_ref}$ moves from 0 m to 1 m, then changes from 1m to -0.5 m, and finally changes from -0.5 m to 0m, $\theta_{\_ref}$ = 0 (rad), system parameters in table 1 unchanged. Case 2 (TH2) the desired position of the forklift is the same as TH1 but increases the length of the sling with the load l = 1.5 m, other parameters remain unchanged. Case 3 (TH3) the desired forklift position is the same as TH1 but increases the mass of the load m = 15 kg, other parameters remain the same.

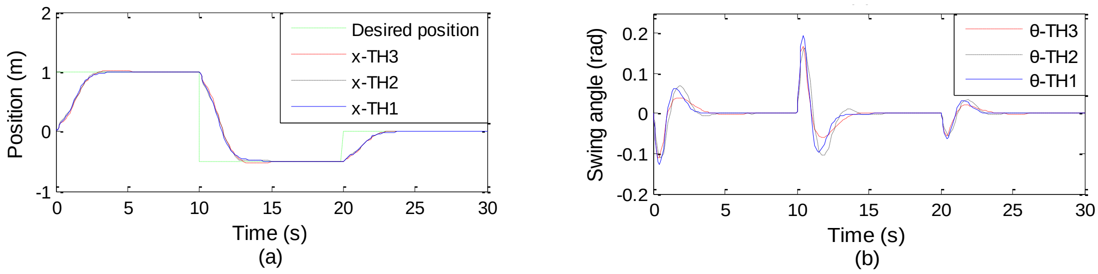


Figure 9. *The characteristic curve (a): of the response of the forklift's position, (b): the swing angle of the load when changing system parameters*

The simulation results are shown in Figure 9. In which: x_{-TH1}, θ_{-TH1}, x_{-TH2}, θ_{-TH2}, x_{-TH3}, θ_{-TH3}, are the corresponding position response characteristic curves of forklift truck and the swing angle of the load for the three cases. It can be seen that when using dual PID controllers for the cases of changing system parameters, the characteristic curves of the response of the forklift's position and the swing angle of the load in TH2, TH3 closely follow the solid line calculated in TH1. The gantry crane system can still achieve accurate position in a short time and control the shaking angle of small loads.

In addition, when the gantry crane system for CE operates, there are external noises affecting the system. Especially at the times when the gantry crane increased speed, reversed rotation and stopped the engine, causing the electrolytic plates to oscillate and at the same time, combined with the pulse effect of the wind and impact, causing the load to fluctuate strongly. than. To test the reliability of dual PID controllers, the authors hypothesized that the noise signal steps [9] affect the crane gantry system at specific times as follows: First at the time of rising speed (step time = 2 s, deflection angle = 0.3 (rad), time = 2 s); second at the time of rotation reversal (step time = 2 s, deflection angle = 0.5 (rad), time = 2 s); third at the moment of motor stop (step time = 2 s, deflection angle = 0.2 (rad), time = 2 s).

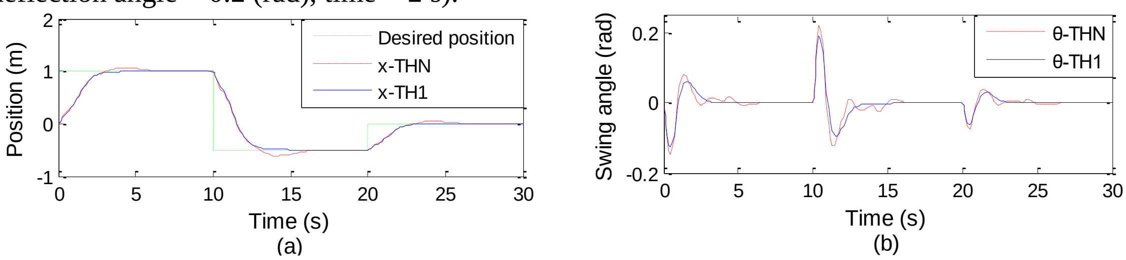


Figure 10. *The characteristic curve (a): of the response to the position of the forklift, (b): and the angle of the load in the presence of noise*

The simulation results are shown in Figure 10, in which x_{-THN}, θ_{-THN} are respectively the characteristic curve that responds to the forklift's position and the shaking angle of the load when there is impact noise, still sticking to the road characteristic x_{-TH1}, θ_{-TH1}. It can be seen that the response of the system does not change despite the small overshoot and the increase in load fluctuations, but the system still achieves good control quality.

5. Conclusion

In this paper, the author has designed a PID controller with the parameters found by the Ziegler–Nichols method combined with the trial and error method as a basis to limit the search space for GA to designed dual PID controllers. The dual PID controllers are tested through MATLAB/Simulink simulation. Simulation results when using a PID controller to control the gantry crane for CE with $t_{\_xlvt}$ = 3.5 s, $\theta_{\_max}$= 0.165 (rad), $t_{\_xlgx}$ = 3.3 s, simulation results when using dual PID controllers to control the gantry crane for CE with $t_{\_xlvt}$ = 3.5 s, $\theta_{\_max}$= 0.12 (rad), $t_{\_xlgx}$ = 3.3 s shows that the control quality when using dual PID controllers is better than when using one PID controller. To check the reliability of the control method, the authors simulated when the system parameters changed and there were disturbances affecting the system. The results show that the gantry crane for CE can still move to the desired position quickly and control the fluctuations of small loads. The investigation of the stability of the system for large loads or the influence of large disturbances needs to be experimented/simulated many times to determine the stability domain of the system, which is also the next development direction of the research.

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