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Anti-Swing Rejection Based on PID Controller Optimized by Firefly Algorithm

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ABSTRACT

Gantry crane systems are often used in a variety of industrial applications to move and raise enormous weights. The process of transferring loads and weights in crane systems has always occupied the interest of researchers because of its importance in maintaining the safety of workers on the one hand and preserving the load itself from damage as a result of its swing and the possibility of it colliding with surrounding objects on the other hand. This paper's primary goal is to use a PID controller to regulate the position and swing of a GCS utilizing genetic algorithms (GA) and firefly algorithms (FA). Analytical techniques are used in the mathematical model, while Simulink in MATLAB is used in the PID model. This technique gave excellent results compared to either using the genetic algorithms (GA).

1. INTRODUCTION

The crane system is an instrument or piece of equipment that allows you to precisely lift and transfer large goods from one point to another. Because of the dominating benefits of high payload capacity, outstanding flexibility, and time–saving capabilities, a gantry crane system (GCS) is regarded as one of the most critical equipment in handling heavy load items in industries**.** As for the crane's acceleration and deceleration during movement, the loads swing back and forth. As a result, when the GCS is propelled into motion, it is susceptible to disturbances such as wind, waves, and environmental distortion [1]. Excessive load swing owing to crane motion and difficulties in trolley placement on the correct trajectory with a rapid response time are two of these challenges [2].

Several gantry crane position and anti-swing control algorithms have been developed and implemented in several published publications. For industrial three-dimensional overhead cranes, [3, 4] suggested a novel fuzzy logic anti-swing control. The proposed control ensures both precise position control and quick load swing damping for the crane's simultaneous travel, traverse, and hoisting actions, according to the experimental findings. To improve the PID parameters in the gantry crane system, meta-heuristic approaches are used. To regulate the position and sway of an overhead crane, the LQR controller's settings are optimized using a genetic algorithm [5]. A combination of PID and fuzzy control creates a stable overhead crane controller [6]. To lower the payload swing angle, a PID+Q controller was created [7]. Abdullah et al. [8] propose a Hybrid Control Scheme (HCS) based on energy balance and fuzzy logic controllers to achieve RIP swing up and stabilization control. The extended method RRT, which is asymptotically optimum, is presented by Karaman and Frazzoli [9]. The paper [10] presents Overhead cranes were subjected to an adaptive-fuzzy SMC for the robust anti-sway pursuit under both system uncertainty and actuator nonlinearity. The FLC parameters are automatically tuned using meta-heuristic optimization techniques. To increase the efficacy of FLC design, the scaling factors of FLC are optimized using three well-known meta-heuristic techniques [11]. The paper [12] is used to regulate the motion of the location of the overhead crane utilizing a PID controller and optimization methods such as Genetic Algorithms (GA) and Bee Algorithms (BA).

In this work, the proportional integral derivative (PID) controller parameters for the Nonlinear Gantry Crane System are modified using the firefly algorithm (FA) and genetic algorithm (GA). It has been demonstrated in tests that FA is more potent and performs better than the Genetic Algorithm (GA). To discover the PID parameters, it has a flexible and adaptable property. By decreasing or maximizing the factors involved in the issues, optimization is a method of discovering the optimal solution to make something as functional and effective as feasible.

2. GANTRY CRANE DYNAMIC MODEL

Figure 1 shows a gantry crane system, it consists of a load, a bridge, a trolley, electric motors, a cargo rope, and a gear motor [13-15]. The most practical tool for calculating the gantry crane model is Lagrange's equation [16]. The trolley displacement from a reference location x(ref), the payload swing angle θ, and the steel wire elongation l are the three key factors that affect the gantry crane system. The following is a description of the system's dynamics [17].

$$\frac{\mathrm{d}}{\mathrm{dt}}\left[\frac{\partial \mathrm{L}}{\partial \dot{\mathrm{q}}_{\mathrm{i}}}\right]-\frac{\partial \mathrm{L}}{\partial \mathrm{q}_{\mathrm{i}}}=\mathrm{Q}_{\mathrm{i}} \tag{1}$$

Lagrangian function, non - conservative conceptual powers, and independence generalized coordinates are represented by L, Qi, and qi, respectively. It can be expressed in writing in a variety of ways.

$$L = T - P \tag{2}$$

The kinetic and potential energies, respectively, are *T* and *P*. This relationship is used to calculate how flexible coordinates are connected. The following are the formulas for kinetic, potential energies.

$$L = \frac{1}{2}\left(m_1 \dot{x}^2 + m_2 \dot{x}^2 + m_1 l^2 \dot{\theta}^2\right) + m_1 \dot{x}\dot{\theta}\, l \cos\theta + m_1 g l \cos\theta) \tag{3}$$

Because a dynamic DC motor is incorporated in this gantry crane model, differential equations must be used and their implications are generated. Taking the dynamic DC motor into account, a thorough nonlinear differential equation of the GCS can be acquired as follows [17].

$$V = \left[\frac{RB\, r_p}{K_{TZ}} + \frac{K_{EZ}}{r_p}\right] + [\frac{RB\, r_p}{K_{TZ}}](m_1 l)[\ddot{\theta}\cos\theta - \dot{\theta}^2 \sin\theta] + [\frac{RB\, r_p}{K_{TZ}}](m_1 + m_2)\ddot{x} \tag{4}$$

$$m_1 l^2 \ddot{\theta} + m_1 l \ddot{x}\cos\theta + m_1 g l \sin\theta = 0 \tag{5}$$

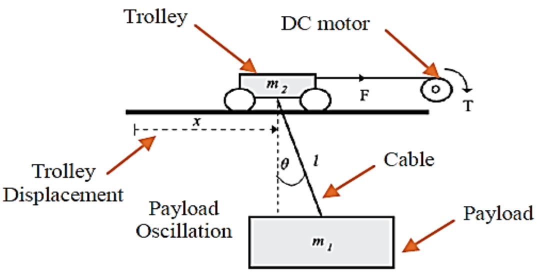

Figure 1. Gantry crane system [13]

3. FIREFLY ALGORITHM

This relatively new algorithm has succeeded in refining and improving a variety of optimization issues, including image processing [18], cutting tool selection [19], motor control [20], energy management for electric cars [21], robot control [22], and steel building design [23]. Yang devised the Firefly algorithm, which Krishnanad initially suggested in 2005 [24], To begin with, fireflies are all unisex. As a result, regardless of gender, any firefly can be attracted to other fireflies. Second, attraction is proportional to intensity, which is a function of the distance between the firefly in question and the others. Finally, the value of the cost function of the problem stated determines the luminance or luminous intensity of a firefly. The FA method may be expressed mathematically using the equations below [25].

$$I(r) = I_0 e^{-\gamma r^2} \tag{6}$$

where, (I_0) denotes the source point's intensity and light absorption coefficient *t*(γ). In the same way, the brightness (β), may be calculated using Eq. (7).

$$\beta = \beta_0 e^{-\gamma r^2} \tag{7}$$

The intensity of light is inversely proportional to the square of the distance, say (*r*), from the source, according to simple physics. Additionally, when light passes through a substance with a light absorption coefficient γ.

Eq. (8) gives a generalized brightness function for ($\omega \geq 1$). In fact, you may use any monotonically declining function [18].

$$\beta = \beta_0 e^{-\gamma\omega} \tag{8}$$

The technique assigns a light intensity to a randomly generated viable s as a result, Using the update process in Eq. (9), if firefly (*j*) is more shining than firefly (*i*), firefly (*i*) will approach firefly (*j*).

$$x_i = x_i + \beta_0 e^{-\gamma r^2} ij\left(x_j - x_i\right) + \alpha(\varepsilon() - 0.5) \tag{9}$$

where, β_0 is *xj*'s allure when r equals 0, [24] recommends β_0=1, is an algorithm parameter for the step length of the random movement, is an algorithm parameter for the degree to which the updating process depends on the separation between the two fireflies, and (ε ( ))is a uniformly distributed random vector with values ranging from 0 to 1. The second formula in Eq. (10) will be deleted to find the shiniest firefly, x_b, as shown in Eq. (10) [25].

$$x_b = x_b + \alpha(\varepsilon() - 0.5) \tag{10}$$

4. SIMULATION RESULTS AND DISCUSSIONS

Anti-swing control's major goal is to transfer the load as quickly as possible without creating an excessive amount of swing in the end position. Figure 2 shows a simplified block schematic of the control strategy used in the research. The PID controller's control objectives include reducing payload oscillation and positioning control of trolley displacement [26]. PID controllers have a straightforward structure that anyone with a foundational understanding of control engineering can easily comprehend and modify [27]. Measure of the system error is used as a performance criterion in order to reduce the system error by predicting the inputs [28]. A collection of excellent control settings for performance criterion minimization can result in a satisfactory step response in the time domain. Eq. (11) Refers to Integral of Time-weighted Absolute Error (ITAE). The (ITAE) is frequently mentioned as a useful tuning criterion for obtaining controller PID settings.

$$ITAE = \int_0^\infty t|e(t)|dt \tag{11}$$

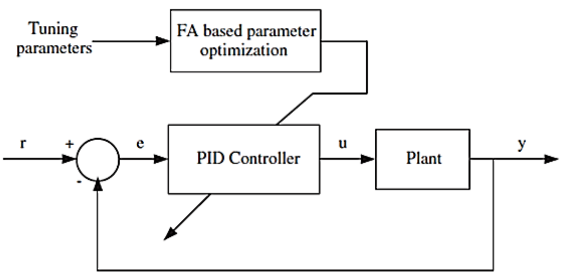

Figure 2. The parameter scheduling mechanism used by PID controllers

Simulink is used to build the gantry crane system's nonlinear model, which includes trolley and sway PID controllers based on FA. The suggested control scheme's goal is to manage the trolley position (X_{act}) such that it advances to the reference position (X_{ref}) as rapidly as possible without causing the load (act) to sway excessively.

Figure 3 shows the designed control scheme, which consists of a trolley controller and a sway controller. Table 1 shows the GCS system's parameter values, which are based on the study [10].

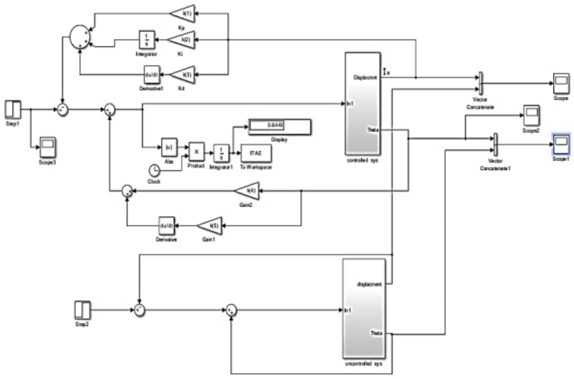

Figure 3. Nonlinear GCS Simulink block model

Table 1. Parameters of the system [17]

Parameters	Value(unit)	Parameters	Value(unit)
Payload (m_1)	0.5 kg	Resistance (R)	2.6(Ω)
Trolley mass (m_2)	2.0 kg	Torque constant (K_T)	0.007 Nm/A
Cable length (l)	0.5 m	Electric constant K_E	0.007 Vs/rad
Gravitational (g)	9.81 m/s^2	Radius of pulley (r_p)	0.02 m
Damping coefficient (B)	0.001 Ns/m	Gear ration (z)	0.15

The GCS simulations were carried out in MATLAB/Simulink. Figures 4, 5 display the simulation results for the trolley displacement and swing angle based on FA. The Firefly Algorithm parameters are configured with the best values of β_0=0.2, α=0.2, γ=1, the number of fireflies is 25, and the number of iterations is 150.

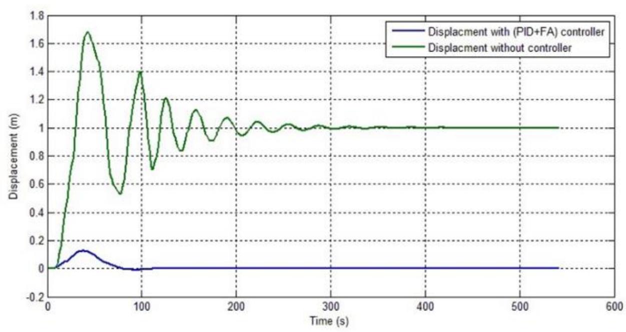

Figure 4. Trolley displacement response based on FA+PID

Figures 6 and 7 display the simulation results for the trolley displacement and swing angle based on GA. The FA and GA were given the same amount of runs. When compared to the GA controller, the FA greatly reduced oscillation that occurred during the trolley motion. The FA reduced the maximum peak overshoot and the steady-state error that happened during the simulation is finally eliminated through FA. According to the findings, the FA has a quicker velocity response and a shorter settling time.

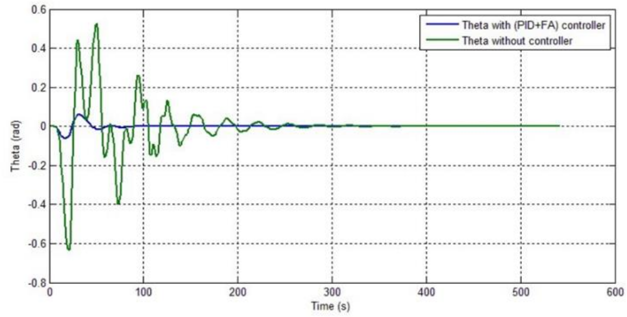

Figure 5. Theta response based on FA+PID

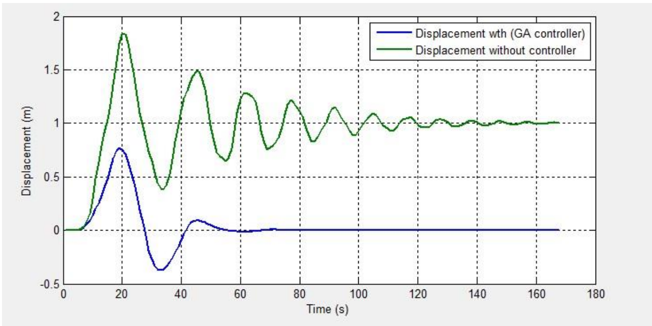

Figure 6. Trolley displacement response based on GA+PID

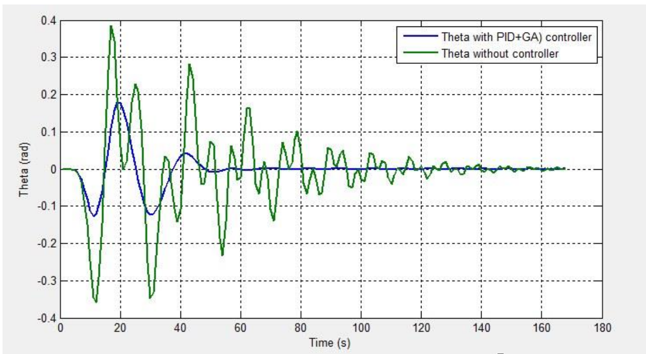

Figure 7. Payload oscillation response based on GA+PID

Table 2. Displacement response data

Performance data	Based FA	Based GA
Rise time	$1.1407e^{-5}$	$5.1234e^{-5}$
Overshoot	$3.364e^{6}$	$2.07e^{7}$
Settling time	6.6642	15.6599

Table 3. Theta response data

Performance data	Based FA	Based GA
Rise time	$6.7803e^{-6}$	$9.166e^{-5}$
Overshoot	$1.092e^{6}$	$7.118e^{6}$
Settling time	5.0048	16.3394

Tables 2 and 3 indicate t the system specifications that were derived using the PID controller based FA and GA algorithm are compiled. Trolley displacement performance is shown in terms of rising time, overshoot, and settling time, whereas payload oscillation is shown as the duration of one cycle oscillation and maximum angle of oscillation. The controller's numerical parameters for displacement and theta response.

5. CONCLUSIONS

In this research paper, the main goal is achieved by reducing the angle swing and load movement time of GCS by adjusting the PID controller parameters using the firefly algorithm (FA) and comparing its result with (GA) as one of the successful and well-known techniques. One of the most important challenges that were encountered is the time it takes to implement the number of iterations on the computer, so future research will be directed towards the use of hybrid algorithms such as hybrid firefly algorithms (HFA), firefly plus cross-entropy method (FA+CE) and more other techniques that add more features to the original techniques, reduce the time spent for iterations and improve performance in general and examined it on anther and more complicated systems.

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