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Journal of Analytical Research

Vol 1-Issue 1, Jan-Jun 2021

www.rsya.org/jar

Intelligent Gantry Crane Position Control Using Priority-Based Fitness and Binary Bat Algorithm

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Abstract

The Gantry Crane System (GCS) moves large gear and materials due to its advanced manufacturing technology. GCS manufacturing takes trolley movement connections and payload oscillation into account. A trolley's rapid speed causes the payload to oscillate. A swinging load can cause equipment damage, decreased production, and accidents. A demanding controller should manage nonlinearity and increase application performance. Engineers use fuzzy logic control (FLC) to create durable controllers that can handle high-dimensional and complex situations in practise. FLC optimization is used to discover an optimal solution for GCS, which employs BBOA to update its parameters with PFS (PFS). PFS prioritises OS, TS, and SSE based on necessity. FLC and Lagrange equations are used to model a system for oscillation and placement. To test the proposed system, we employed PFS and FLC to transmit as much load as feasible in the quickest period possible.

Keywords: Priority Fitness Scheme (PFS), Lagrange equation, Binary Bat optimization (BBOA) algorithm, Gantry Crane System, Fuzzy logic controller (FLC)

1. Introduction

For easy transportation of bulk load from one spot to another, Gantry Crane System (GCS) is used [1]. The place such as shipyard, nuclear facilities, warehouse, factories where précises movement of load needed, gantry cranes are coming into action with more legs show sthe shape and size of phanon scattering effect on the thermal conductivity of nano structures. Furthermore, they have been used in bio, structural, sports, electrical and other applications [2-3]. Until reaching the exact position, the load is moved right or left parallel to the horizontal bridge rail of the crane with the help of the trolley presented at the top of GCS. It is assumed as a pendulum during the process of modeling. Simplified reduces model of the crane is perfect for analysis because of its diverse usage such as inside a factory, at the shipyard and other places by moving it from one place to another nevertheless its bulk and big size [4]. The crane system with a two-dimension trolley (2D) trolley able to move the load in the two-dimension direction such as it moved the load in a horizontal direction after picking it in a vertical direction [5]. The desired characteristic of the crane is to transport the load as quickly as possible without payload sway besides at the destination point. That characteristic is desired and required [6]. Nevertheless, the swing motion happens most of the gantry crane during the load is stopped suddenly after a quick movement. To reduce the mass of the system, flexible hoisting ropes in the crane is used, which provides desirable features such as low power consumption, high motion speed, and high payload ratio [7]. The reduction of swig motion is inversely proportional to time consumption. In order to control and avoid that swing of load at the exact position, the experienced operator should use his experience manually [8]. Recently, many techniques are nominated for the control of the gantry crane system. The better performance uncomplicated structure is the reason for the extensive usage of PID under the various operational condition in industries. The better controller of the overhead crane is achieved by integration with fuzzy control with PID. To reduce the swing of payload, PID+Q is designed, but it is difficult to tune its parameters [9]. To mitigate the tuning difficulty in the PID controller, classical trial and error tuning methods are used, but the result not guaranteed the desired performance. A Ziegler-Nichols tuning method is standard in practice for its simplicity but having many disadvantages such as increased oscillatory response and overshoot along with the aggressive nature of parameter finding, Meta-heuristic methods are preferred to discover the exact parameter value than PID due to its difficulty [10]. Designing a tough controller is necessary in order to deal with non-linearity and improve performance in the controller application. This controller is built with the help of Fuzzy logic control (FLC). FLC is used to design and implementation a variety of applications such as process control and robotics. It gives a touch of Artificial intelligence to the classic PID controllers to some extent. The skill of an experienced operator and heuristic information is utilized to Membership Function (MF) and set of the rule base [11]. Determination of input and output controller variables, setting the rule base which resembles the input and output linguistic relationship, forming input and output variable MF function, and adjustment of parameters to get desired performance is the critical factor in the design of FLC [12].

2 Literature Review

The literature review section discusses the existing technique presents for position control and optimization of nonlinear GCS proposed an application that attains exact payload placement with lesser sway angle by changing the location of poles using pole placement controller application to control 2D GCS. Using a pole placement controller, three poles are placed on the left side of the S-plane to create a linear system model. MATLAB and SIMULINK test the pole placement controller. When the other pole and the dominant are complicated poles, the pole placement controller performs better [13-14] 2D nonlinear gantry crane system predictive controller model with DC motor actuator. Lagrange equation is used to determine gantry crane system dynamics. Prediction cost function and linearized GCS-based predictive controller model reduce oscillation and pinpoint load position. Simulating different system behaviours in MATLAB and SIMULINK tests controller performance. Trolley position, payload mass, and cable length are utilised to study a closed-loop system with superior performance, perfect trolley positioning, and less payload swing within stable input voltage [15]. Introduced, Particle Swarm Optimization (PSO) for tuning the parameter of the PID controller controls the length of rope, anti-swing, and control position of gantry crane. The desired step response of the plant is the requirement of parameter tuning. Based on the obtained model, the parameters are computed. Under the performance of the control system, the simulation output of the controller yielded a better response. proposed a method to decrease the sway angle and vibration in an inverse dynamic analysis. The sway angle mass and position of the trolley are the parameters is discovered from the MATLAB output of the proposed method [16-17]. The fourth-order gantry crane system is developed by feedback look. Due to asymptotic system behavior, the desired output, which is the exponential function in the order of three, is used to determine the input developed an intelligent crane system that is designed and implemented using fuzzy logic controller controls swing angle and payload position. By analyzing the robustness result of the proposed intelligent GCS with the existing traditional PID controller automated GCS, the former achieved better robustness for the variation in the parameters than the latter [18]. Euler Lagrange formula is used to model the 2D GCS dynamic properties in frequency and temporal domains. The uncontrolled system is evaluated with PD controllers, LQR, and DFS in MATLAB simulation. Different payload weights are utilised to test the payload influence in GCS response using the method. The outcome is investigated in frequency and time domain along with feedback controller performance with low sway angle in terms of sway magnitude and time domain response. GCS's response to different payloads is explored [19-20].

3 Methodology

GCS modelling uses a lab-scale gantry crane. To find an ideal solution for GCS, the suggested system combines the optimization techniques of Fuzzy Logic Controller (FLC) and Priority Fitness Scheme (PFS) (PFS). According to the criterion, PFS precedes OS, TS, and SSE. FLC and Lagrange equations model a system's oscillation and placement.

3.1 Gantry system modelling

Figure. 1. Gives GCs schematic diagram where T is the torque, l is the cable length, θ is swing angle, m_1 is payload mass, m_2 is trolley mass, and x is the horizontal position of a trolley. It is assumed that the hanged load and the trolley are massless and to be steady. Table 1. shows the values of parameters in the system model.

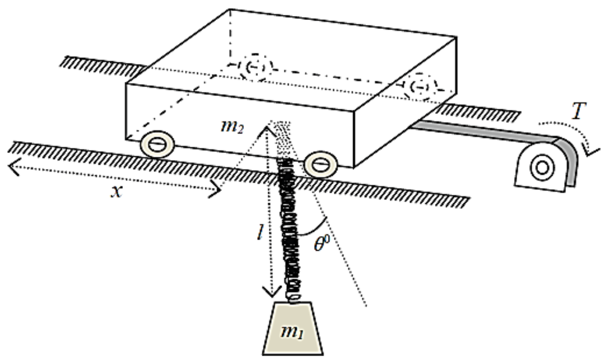

Figure 1 Gantry Crane System

After analysing many aspects, Lagrange's equation is the best way to derive the GCS system's mathematical expressions. The payload oscillation $\theta$and trolley displacement x is two independent generalized coordinates of GCS.

Table 1 System Parameters

Parameters	Values
Payload (M_1)	1 kg
Trolley mass (M_2)	5 kg
Cable length (l)	0.75 m
Gravatioanal (g)	9.81 m/s^2
Damping coefficient (B)	12.32 N/A
Resiatance (R)	2.6Ω
Torque Constant (Kr)	0.007 V/rad
Electric Constant (Ke)	0.007 Nm/A
Radius of pulley (r_p)	0.02 m
Gear ratio (z)	15

Lagrange's equation standard form as follows:

$$\frac{d}{dt}\left[\frac{\partial L}{\partial q_i}\right] - \left[\frac{\partial L}{\partial q_i}\right] = Q_i \qquad (1)$$

Given *qi is* independent generalized coordinates, *Qi* represents non-conservative generalized forces and Lagrangian function. The function Lagrangian is given as:

$$L = T - P \qquad (2)$$

where the energies in potential and kinetic aspect id given by P and T respectively. Figure 2 shows the GCS model's principle and coordinates flexibility obtained from these factors.

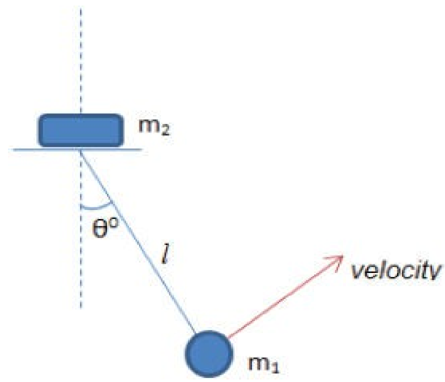

Figure 2 Schematic Diagram of a Pendulum

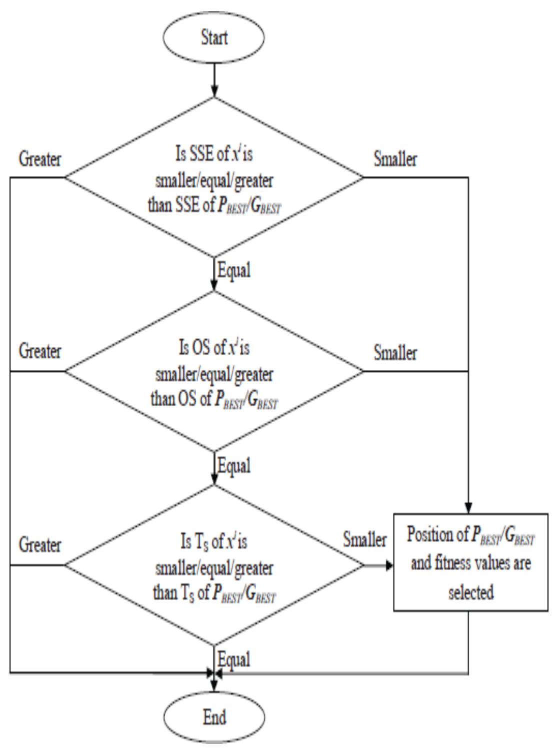

Figure. 3 shows the implementation of the FLC controller in GCS with V as an input voltage.

Lagrangian function derivation related to potential and kinetic energy calculation is given as:

$$L = {}^{1}(m\ \dot{x}^2 + m\ \dot{x}^2 + m\ l^2\dot{\theta}^2) + m\ x\theta l cos\theta + \ddot{m}\quad glcos\theta \qquad (3)$$

Differential equations obtained by solving (1) as follows:

$$(m_1 + m_2)\ddot{x} + m_1 l\ddot{\theta}cos\theta - m_1 l\dot{\theta}^2 sin\theta + B\dot{x} = F \quad (4)$$

$$m_1 l^2\ddot{\theta} + m_1 l\ddot{x}cos\theta + m_1 glsin\theta = 0 \quad (5)$$

Differential equations derivation includes the effect of dynamic DC motor, which is integrated into the GCS model for completed the calculation. The calculation is given as:

$$m_1 l^2\ddot{\theta} + m_1 l\ddot{x}cos\theta + m_1 glsin\theta = 0 \quad (6)$$

3.2 Concept of Priority Fitness Scheme (Pfs)

PFS prioritises SSE, OS, and Ts. Every priority is checked. SSE, OS, and Ts are PFS's highest-to-lowest priorities. PFS only searches for SSE's minimal value. When the new and old SSE in the fitness function are equal, it concentrates on OS. SSE and OS follow the same criteria when comparing Ts parameter values. The new BEST is the best solution and the new GBEST when the new PBEST is smaller than the prior PBEST in the fitness function.

Comparing each fitness's historical and current PBEST determines its new GBEST. PBEST and GBEST patterns for every fitness and set are simply understood. Table 2 shows SSE, OS, and Ts values for five SETs. PBEST is chosen using Fitness 2's coordinates. Set 1 by considering SSE, which is preferable, and discarding OS and Ts according to PFS for SET 1 at stage 1.

Table 2 the Pattern of Pbest and Gbest Selection

		SET 1	SET 2	SET 3	SET 4	SET 5
Fitness 1	SSE	0.002	0.001	0.001	0.000	0.001
	OS	0.157	0.108	0.115	0.084	0.115
	Ts	9.546	9.546	9.546	6.395	8.385
Fitness 2	SSE	0.001	0.001	0.002	0.001	0.000
	OS	0.128	0.137	0.115	8.385	0.108
	Ts	8.385	8.385	8.385	7.953	7.953
Fitness 3	SSE	0.002	0.002	0.001	0.001	0.001
	OS	0.173	0.128	0.108	8.385	0.084
	Ts	7.953	7.953	7.953	6.395	6.395
Fitness:Set		2:1 PBEST	1:2 PBEST	3:3 PBEST	1:4 PBEST	1:4 GBEST

PFS to determine PBEST for SET 2 focuses on minimal value second priority OS by ignoring Ts instead of SSE since the high priority SSE for Fitness 3 (0.002m) is higher than Fitness 1 and 2 (0.001m), which have the same value. SET2 PBEST is from Fitness:1 Set:2. Comparing SET 1 and SET 2's PBEST values shows that SET 2 is better. The new GBEST value is Fitness 1 and SET 2's data. The method continues to identify the third priority, where the SSE and OS priorities are the same for SET 3 and 4, hence SET 5's priority is Ts. If there is no best way to find GBEST from PBEST, GBEST stays the same and the process continues until the system produces a best and minimal solution.

3.3 Fuzzy Logic Controller Parameter Variation

The objective of fuzzy logic controller implementation is to control the quick displacement X(s) of the trolley to the desired location at very minimal possible value of payload swing angle h(s). The gantry crane system fuzzy logic controller integrates anti-swing control along with position control. The MATLAB toolbox of fuzzy logic consists of Mamdani type of FLC implementation for both controllers. The basic fuzzy logic controller design is shown in Figure. 4.

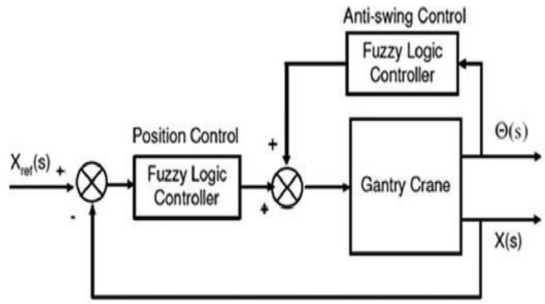

Figure 4 FLCs for Gantry Crane System

3.3.1 Inputs and Outputs of FLCs

Voltage is the output of both the controllers which have the single output for multiple inputs such as swing angle rate and swing angle, an error rate of position and error are the inputs of anti-swing and position controller respectively.

3.3.2 FLCs' Member Functions

The Membership Function Editor determines all input and output membership functions. 3 and 5 linguistic parts are given to the position and anti-swing controllers. 5 sections are Positive Big (PB), Zero (Z), Negative Big (NB), Positive Small (PS), and Negative Small (NS). The 3 sections are Z, P, and N. (N). The membership function form of each linguistic variable and parameter value is set. The swing angle rate, swing angle, and voltage variables in the anti-swing controller are -2.5 to 2.5 rad/s, -1 to 1 rad, and -1.4 to 1.4 V, respectively. For the position controller, the voltage variable, error, and error rate are -1.4 to 1.4 V, -100 to 100 cm, and 12.85 to 12.85 cm/s.

3.3.3 Fuzzy Control Rules

Nine combinations of input are given to position controller for two inputs, having three membership functions each, leads to nine position control rules. Similarly, 25 anti-swing control rules are generated from 25 combinations of input of anti-swing controller where every two inputs have 5 membership functions individually.

3.3.4 Fuzzy logic controller optimization using Enhanced Binary Bat (EBBAO)

- ***Bat Algorithm***
  The Bat Algorithm mimics bat echolocation (BA). Each iteration, a bat's velocity, position, and frequency are updated. The search space that artificial bats employ travels inside the real continuous domain. vi is bat velocity, xi is bat position, and fi is bat position at every step.:

$$v_i(t+1) = v_i(t) + (x_i(t) - gbest)f_i \qquad (7)$$

Where the obtained best solution so far is given by *gbest.* The updated bat position is given by:

$$x_i(t+1) = x_i(t) + v_i(t) \qquad (8)$$

For each iteration, the i^{th}bat frequency is given by:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \qquad (9)$$

is a random number in [0, 1]. A random walk method improves BA's exploitation capability.

$$x_{new} = x_{old} + \varepsilon A^t \qquad (10)$$

Whereloudness is represented as*A* and ε is a random number between [-1, 1]. The adjustment of pulse emission rate and loudness for each iteration is given by the equation as below:

$$A_i(t+1) = \alpha A_i(t) \quad (11)$$

$$r_i(t+1) = r_i(0) + [1 - \exp(-\gamma t) \quad (12)$$

Where α and γ are constants.

BA is simple and effective. Other swarm intelligence techniques employ constants to standardise parameters. According to Equations (11) and (12), pulse rate and loudness are changed for every iteration, allowing the algorithm to alternate between exploitation and exploration.

- ***Binary Bat algorithm***

BA uses binary bat location values to generate binary search space. By swapping pieces, the bat moves. BA binary updates bat position and velocity using different ways. The bat's position is changed from ''0'' to ''1'' or vice versa by using the transfer function.

$$V(v_i^k) = \left| \frac{2}{\pi} \arctan\left(\frac{\pi}{2}\right) v_i^k \right| \quad (13)$$

Where $k_i$is the bat Ivelocity in kth dimension. Ki. The new position of bat is given below:

$$x_i^k = \begin{cases} (x_i^k)^{-1} & if\ V(v_i^k) > \delta \\ x_i^k & if\ V(v_i^k) \le \delta \end{cases} \quad (14)$$

Where xi falls between [0, 1]. Every location update should calculate each bat's fitness function. Unsupervised feature selection uses cluster quality to generate the fitness function from SQE. Fitness is:

$$fitness\ (b_i) = \sum_{j=1}^{k} \sum_{i=1}^{n} \| x_i - m_j \| \quad (15)$$

- ***Binary Bat Algorithm Based on Distributive Factor***

The analysis of the distributed factor-based binary bat algorithm (DBBA) uses a contraction factor to improve convergence efficiency and population variety. This factor is used to make each individual in the population swiftly converge precisely at an optimal global solution and to mitigate the problem of premature convergence, a standard at-bat algorithm problem. Early convergence of bats occurs during optimization as the population flies towards the ideal solution. This diminishes the likelihood of better optimization. The following equations are used to analyze the proposed DBBA:

$$k = \frac{2}{2 - d - \sqrt{d^2 - 4d}} \quad (16)$$

$$V_i^t = V_i^{t-1} + (X_i^{t-1} - X_*) f_i .* k \quad (17)$$

4. Results and Discussion

The Fuzzy Logic Controller (FLC) and the Priority Fitness Scheme are both incorporated into the new control structure that has been proposed for the GCS (PFS). When an anti-swing controller is used, the oscillation of the payload () is reduced, and the primary purpose of using an FLC is to achieve the desired position of the trolley (x) through the process of controlling it. Analyses are performed on the payload oscillation and trolley displacement, both of which are system responses, in addition to the input voltage. Figure 5 illustrates the difference in the performance response of the gantry crane system with and without EBBOA. In the EBBOA optimization process, the step input of 70 cm has been made into a needed location. The result of the simulation compared the optimization scaling factors of the anti-swing control with those of the position control. The conclusion that can be drawn from the analysis of the result is that the position control of the proposed system is superior to the control approaches that are already in use.

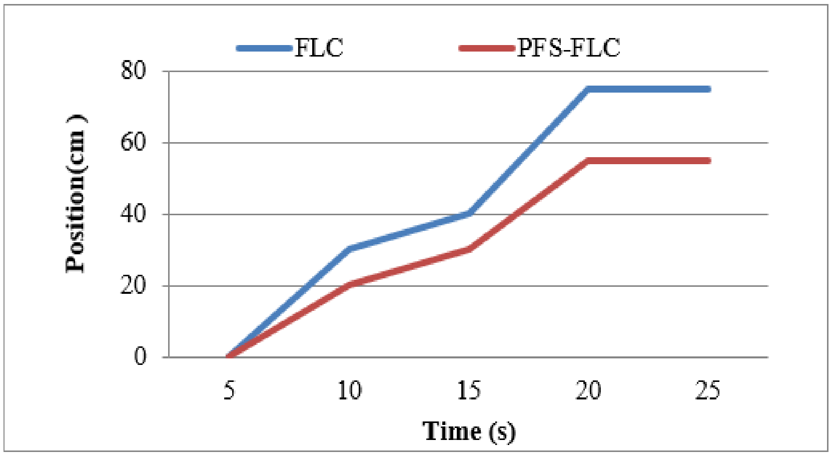

Figure 5 Performance of Position Response

Figure.6 displays the gantry crane system swing response with and without optimization. From the simulation result, it is concluded that, increase in the swing amplitude of the proposed work after optimization is acceptable because only at the beginning of three seconds only the swing angle reaches the maximum and due to decrease in the settling time for load to the desired position compared to result after optimization.

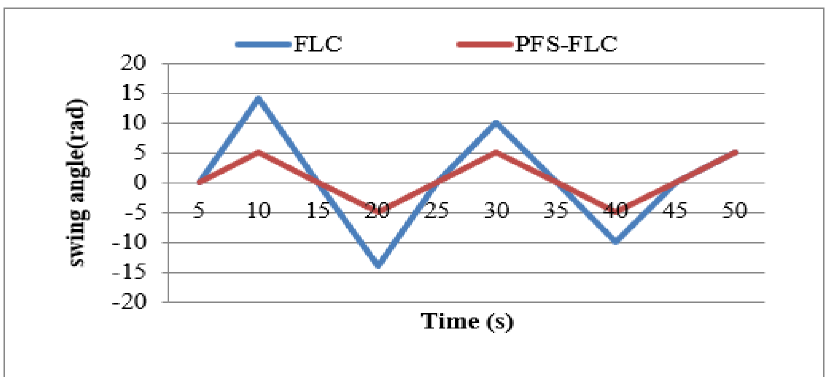

Figure 6 Swing Response.

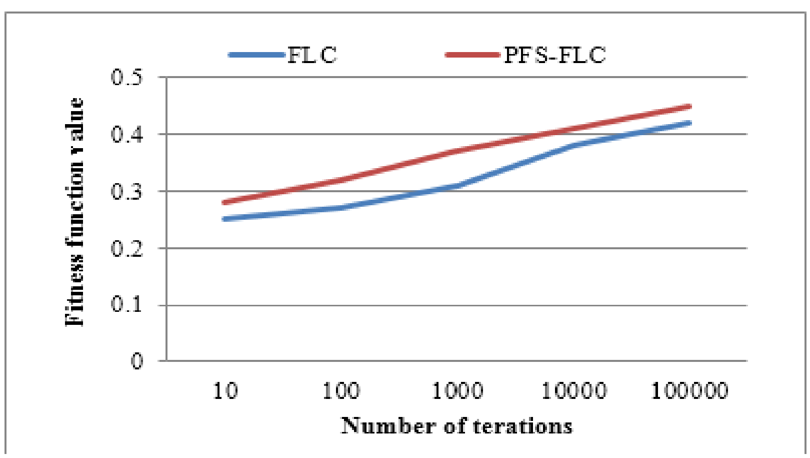

Figure 7 Comparison Convergence for Optimization

The simulation result for the convergence comparison of the PFS-FLS algorithm to obtain the best problem solution is shown in Figure.7. PSO algorithm attains the optimal solution slowly compared to the EBBOA for this problem. The result concluded that the desired and optimal capability and performance to solve the optimization problem of constrained design is achieved by the proposed PFS-FLS algorithm.

5 Conclusion

The dynamic gantry crane system was designed as part of the work that was proposed. For the purpose of controlling the Gantry Crane System (GCS), nonlinear differential equations gantry crane system derived payload oscillation, trolley displacement, and rope length are utilised in the development of the control algorithm. Through the deployment of PFS, it is possible to achieve the levels of performance and stability that are required of the system. Gantry Crane System was controlled by innovative algorithms such as FLC and EBBOA, which helped to reduce payload swing and for position control of nonlinear dynamic gantry crane system. The general control system that has been proposed cuts down on settling time while also preventing payload positions from overshooting and keeping swing angles under anti-swing control. When measured against the various GCS algorithms that are currently in use, the performance of the proposed system is significantly higher. The use of the performance improved PFS-FLC in industrial settings comes with a number of benefits, the most important of which are the enhancement of economic, speed, and reliability priorities.

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