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EFFECTS OF MULTIPLE COMBINATION WEIGHTAGE USING MOPSO FOR MOTION CONTROL GANTRY CRANE SYSTEM

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ABSTRACT

This paper presents the implementation of Multi Objective Particle Swarm Optimization in controlling motion control of Gantry Crane System. Three objective functions are considered to be optimized, named (i) steady state error, (ii) overshoot, and (iii) settling time. Six cases with different setting of weight summation are analyzed in order to obtain five parameters (PID and PD) controller. A combination of PID and PD controller is observed and utilized for controlling trolley movement to desired position and reduced the payload oscillation concurrently. Various cases of weight summation values will affect to the controller parameters and system responses. The performances of the system is conducted and presented within Matlab environment.

Keywords: *Computational Intelligence, Gantry Crane System, Motion Control, PID Controller, Multi Objective Particle Swarm Optimization (MOPSO)*

1. INTRODUCTION

Gantry Crane System (GCS) have two main points to be considered which are position of the trolley and oscillation of the payload. Trolley should move as fast as possible while payload should not give huge impact on the swing angle which can harm the surroundings environment. These two factors will be determining the stability of motion for GCS performance. In dealing with these issues, a control mechanism that account for position of the trolley and oscillation of the payload is required in order to move the trolley as fast as possible with low payload oscillation.

Various control techniques have been proposed previously for controlling the GCS. In industrial control system, PID control schemes based on the classical control theory have been widely used for a long time [1]. GCS is very sensitive to the variation of parameter setting. Thus, development of control algorithms for GCS is very beneficial [2]. Traditional tuning method such as trial and error is an easy way to tune the PID controller. However, it is difficult to determine optimal PID gain parameters and thus satisfactory performances cannot be guaranteed. A well-known tuning method is Ziegler-Nichols (Z-N) and still widely used due to their simplicity. Unfortunately, the way to find the parameters is very aggressive and leads to a large overshoot and oscillatory responses. Due to the difficulties in finding the optimal value of PID parameters, meta-heuristic methods are implemented in finding the most appropriate value.

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Several investigations have been conducted to optimize PID controller parameters especially based on intelligent techniques. For instance, Genetic Algorithm (GA) has been applied to tune PID for automatic GCS [3]. Furthermore, Artificial Bee Colony (ABC) algorithm is introduced to tune the PID controller. It was employed to tune for higher order plant and the results shows that overshoot and settling time can be improved [4]. In addition, Ant Colony Algorithm (ACA) was proposed to optimize the parameter of the controller in designing of a nonlinear PID controller. It has flexible and adaptive characteristic in order to find the PID parameters. Satisfactory overall performance of the system has been demonstrated with the controller [5]. Another optimization technique that can be utilized for finding optimal PID parameters is Firefly Algorithm (FA). It has been tested where FA is more powerful and shows superior performances compared to GA for PID controller parameter tuning of the considered nonlinear control system [6]. Nevertheless, since Particle Swarm Optimization (PSO) is well known as simple optimization compared to the other of some optimization method, thus it is being chosen to be implemented for this work.

Particle Swarm Optimization (PSO) is one of the meta-heuristic methods and introduced in 1995 [7]. The strength of PSO is fast convergence compares with many global optimizations. The calculation is very simple and speed of the researching is very fast [8]. It works effectively to drive nonlinear plant and high order system [9]. In addition, PSO could find for less overshoot and minimize the error [10]. Besides that, PSO is also investigated for obtaining PID parameters for GCS and it is well known for simple optimization compared to the other optimization methods [3, 9, 11-14]. However, most of existing works for controlling GCS by using PSO with a single objective. Thus, Multi Objective PSO (MOPSO) is used in this analysis to balance the impacts of PID tuning process to the GCS performances.

In this work, MOPSO algorithm based on six cases of various weight summation approaches and pattern of five combination parameters (PID and PD) controller will be tested and investigated. The idea of this analysis is based on [13]. The effectiveness of combination values for PID and PD controller parameters is very critical to be discussed. Thus, combination of these parameters will determine whether motion control of GCS will affect to system response or not. Therefore, an increase or decrease in value of controller parameters will be analyzed in this work.

2. MULTI OBJECTIVE PARTICLE SWARM OPTIMIZATION

In the original Particle Swarm Optimization (PSO), only single objective function is considered [7]. Multi Objective Particle Swarm Optimization (MOPSO) is developed based on basic of PSO technique. MOPSO has helped a lot in solving the multi objective problems. Many types of MOPSO have been proposed by researchers [15-18]. The only different between these two methods is on the number of objective function that is trying to be optimized [13].

Linear Weight Summation (LWS) approach is used in MOPSO algorithm due to the simplest and the most popular method. Multi objective function is converted to a single objective function. In MOPSO, a set of particles are initialized in the decision space at random. The process of finding the updating particles' position and velocity are similar as shown in equation (1) and (2) respectively, but the selection on local best (P_{best}) and global best (G_{best}) is depending on "Fitness" value given by equation (3).

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (1)$$

$$v_i^{k+1} = W' v_i^k + c_1 r_1 (P_{best-i}^k - x_i^k) + c_2 r_2 (G_{best}^k - x_i^k) \qquad (2)$$

where:

- I = Particles' number
- W' = Inertia weight
- X_i = Particle position
- c_1,c_2 = Coefficient value for cognitive and social behavior
- r_1,r_2 = Random value from '0' to '1'
- V_i = Velocity of particle.
- k = Number of iteration

For this Gantry Crane System (GCS) model, multi objective optimization problem with three objective functions which are the Steady State Error (SSE), Overshoot (OS) and Settling Time (Ts) are designed. This system response is necessary to ensure the motion and stability of the GCS is well controlled. Thus, the arrangement summation

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equation of these three objective functions is shown in equation (3).

$$Fitness_i = w_{SSE}(SSE)_i + w_{OS}(OS)_i + w_{Ts}(Ts)_i \quad (3)$$

where:

w_{SSE} = weight value for the steady state error
w_{OS} = weight value for the overshoot
w_{Ts} = weight value for the settling time

Figure 1 shows the flow chart for MOPSO in searching the controller value for GCS parameters. According to the figure, the process of weight summation for determining the *Fitness* value is done just before the step to determine the P_{best} and G_{best} (in the Red boxes). After that, the updating process is taking place until reach the stopping criterion; either the fitness value among the particles is less than ε value or the MOPSO algorithm has reached the maximum iteration that is set by the user. By using this algorithm, the optimal PID and PD parameters value for the GCS will be investigated in this study.

In this analysis, MOPSO is used to balance the impacts of PID and PD controller tuning process for GCS performances. By implementation of MOPSO algorithm, various performance results are produced according to desired response. Simulation results have been demonstrated satisfactory responses under various cases of conditions based on control system performances.

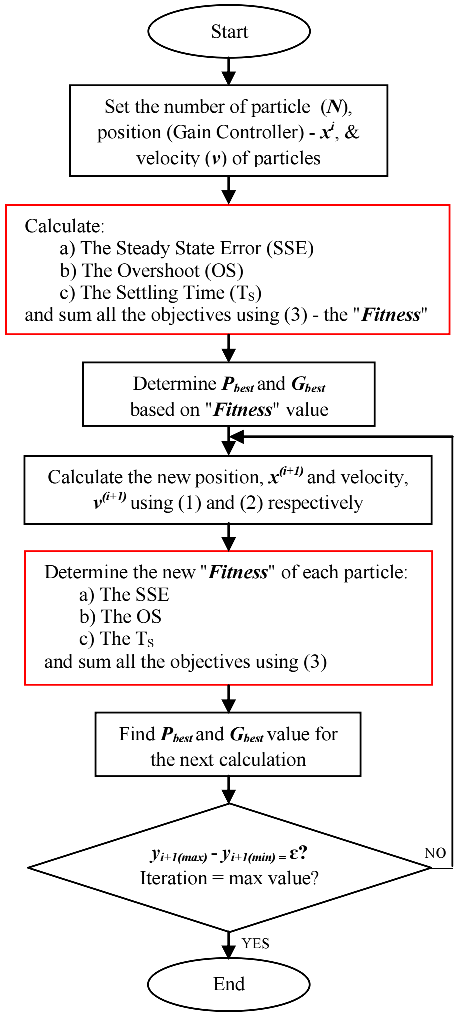

Figure 1: Process of MOPSO in Determining GCS Parameters

3. MODEL OF GANTRY CRANE SYSTEM

In this work, Lagrange's equation is chosen for mathematical modeling of this GCS. GCS is modeled based on [9]. Since there are two motion of GCS need to be controlled, two independent generalized coordinates namely trolley displacement (x) and payload oscillation (θ) are considered. The model of the GCS is illustrated as Figure 2 and parameters values for the system are shown in Table 1.

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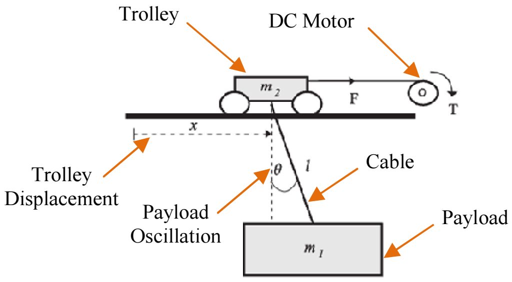

Figure 2: Model of GCS

Table 1: System Parameters for GCS Model.

Parameters	Symbol	Value	Unit
Payload mass	m_1	1	kg
Trolley mass	m_2	5	kg
Cable length	l	0.75	m
Gravitational	g	9.81	m/s^2
Damping Coefficient	B	12.32	Ns/m
Resistance	R	2.6	Ω
Torque constant	K_T	0.007	Nm/A
Electric constant	K_E	0.007	Vs/rad
Radius of pulley	r_P	0.02	m
Gear ratio	z	15	-

4. EQUATIONS

Standard form of Lagrange's equation is given as:

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{q}_i}\right]-\frac{\partial L}{\partial q_i}=Q_i \quad (4)$$

where L, Q_i and q_i represent Lagragian function, nonconservative generalized forces and independent generalized coordinate. The Lagragian function can be written as:

$$L=T-P \quad (5)$$

with T and P are respectively kinetic and potential energies. Thus, kinetic and potential energies can be derived as shown in equation (6):

$$L=\frac{1}{2}\left(m_1\dot{x}^2+m_2\dot{x}^2+m_1l^2\dot{\theta}^2\right)+m_1\dot{x}\dot{\theta}l\cos\theta+m_1gl\cos\theta \quad (6)$$

Solving for equation (4) yields nonlinear differential equations as:

$$(m_1+m_2)\ddot{x}+m_1l\ddot{\theta}\cos\theta-m_1l\dot{\theta}^2\sin\theta+B\dot{x}=F \quad (7)$$

$$m_1l^2\ddot{\theta}+m_1l\ddot{x}\cos\theta+m_1gl\sin\theta=0 \quad (8)$$

By considering the dynamic of DC motor, a complete nonlinear differential equation of GCS can be obtained as equation (9) and (10) where V is an input voltage:

$$V=\left[\frac{RBr_P}{K_Tz}+\frac{K_Ez}{r_P}\right]+\left[\frac{Rr_P}{K_Tz}\right](m_1l)\left[\ddot{\theta}\cos\theta-\dot{\theta}^2\sin\theta\right]+\left[\frac{Rr_P}{K_Tz}\right](m_1+m_2)\ddot{x} \quad (9)$$

$$m_1l^2\ddot{\theta}+m_1l\ddot{x}\cos\theta+m_1gl\sin\theta=0 \quad (10)$$

5. RESULTS AND DISCUSSION

A control structure of GCS is developed for simulation purpose as shown in Figure 3. This model is designed based on Figure 2 with development of mathematical modeling equation in equation (9) and (10). In dealing with motion control, a control mechanism with PID and PD controller are required. The purpose of using PID controller is to control position of trolley displacement while PD controller is for reducing payload oscillation.

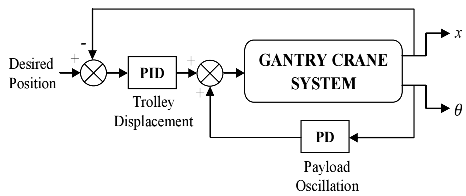

Figure 3: Control Structure with PID and PD Controller

In this MOPSO study, 20 agents are considered with 100 iterations. The initial agents are bounded between 0 to 200. As default values, c_1 and c_2 are set as 2. The combination values of weightage for SSE, OS and Ts are chosen based on 6 cases as shown in Table 2. The highest weight value is set as 0.7 while the lowest value of weight is set as 0.1. Highest weight value is to indicate highest priority. The summation of weight value for all cases must be equal to 1.0. With an input voltage of 5 V, motion control of trolley displacement and payload oscillation are examined.

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Table 2: Six Cases with Different Setting of Weight Summation.

Case	w_{SSE}	w_{OS}	w_{Ts}	Total
1	0.2	0.7	0.1	1.0
2	0.1	0.7	0.2	1.0
3	0.7	0.2	0.1	1.0
4	0.7	0.1	0.2	1.0
5	0.2	0.1	0.7	1.0
6	0.1	0.2	0.7	1.0

Table 3 shows five controller parameters which are represented as K_P, K_I, K_D, K_{PSwing} and K_{DSwing} that obtained by using MOPSO. Various cases of weight summation are studied to observe the pattern of PID and PD parameters for the controller. Based on Figure 4, each case shows almost similar form of increase and decrease for PID and PD parameters. Each of controller parameters is closely interrelated respectively. High value of K_P will effect to the increment of overshoot, OS and never eliminate the steady state error, SSE. In order to eliminate the SSE, K_I is used with very small value of parameter (0.0015) for all cases. It shown that this controller only requires a small value of K_I to ensure the trolley can be arrived at the desired position accurately. However, it may provide high percentages of OS and affect to the settling time, Ts respectively. Thus, K_D is required by implementing smaller value than K_P to reduce the percentages of OS and improving the transient response. It will give the trolley arrived to the right position as fast as possible. This optimal motion control of the trolley displacement will reduced payload oscillation.

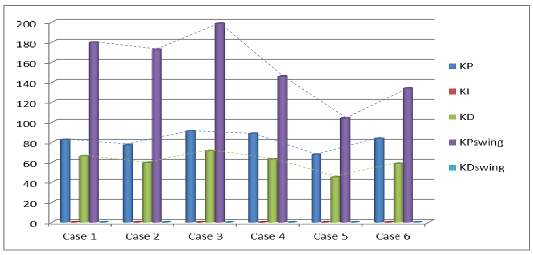


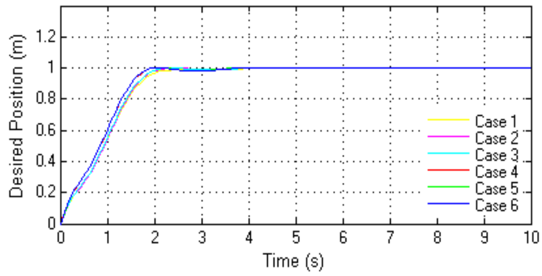
Figure 4: Graph Pattern of Five Controller Parameters (PID and PD)

For oscillation motion control, the value of K_{PSwing} and K_{DSwing} are needed. The value of K_{PSwing} is higher than K_P while K_{DSwing} with small value of parameter to reduce the percentage of OS.

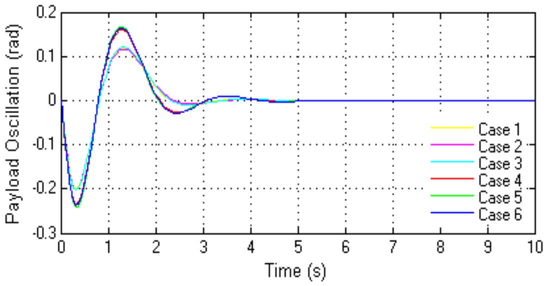
Table 3: Six PID and PD Parameters Using MOPSO Algorithm.

Case	K_P	K_I	K_D	K_{PSwing}	K_{DSwing}
1	82.2784	0.0015	66.1400	179.7369	0.0015
2	77.2547	0.0015	59.5447	172.6070	0.0032
3	91.1707	0.0015	71.2132	198.4202	0.0015
4	88.5097	0.0015	63.0331	145.5495	0.0015
5	67.5542	0.0015	45.0256	104.0231	0.0015
6	83.6594	0.0015	58.6192	133.8354	0.0015

Figure 5 shows the overall performances of GCS with respect to the six cases of different setting weight summation values.



(a)



(b)

Figure 5: Performances of GCS for Different Cases (a) Trolley Displacement (b) Payload Oscillation

According to 5 (a), the trolley is able to move to desired position (1 meter) with zero SSE for all cases. It shown that different setting of weightage is not affect to the position performance. System response specifications including SSE, OS and Ts are studied too. Payload oscillation responses for all cases are shown in Figure 5 (b). Specifications of trolley displacement and payload oscillation performance for all cases are summarized in Table 3.

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5. CONCLUSION

This paper has presented design of GCS for controlling the trolley displacement and payload oscillation. Mathematical modeling of the system has been derived and used for verification of control algorithm. System responses including motion of trolley displacement and payload oscillation have been examined. In this work, MOPSO algorithm based on six cases of various weight summation approaches to find PID and PD controller parameters has been used. Based on the analysis, the combination weight values will affect to the system responses. The new finding about this method is the trolley is able to move to desired position (1 meter) with zero SSE for all cases. Furthermore, the advantage about MOPSO technique is any selection of weight values depending on the needs of user whether SSE, OS or Ts are set as priority. Results have shown that each of controller parameters is closely interrelated and MOPSO is able to control the motion of trolley displacement and payload oscillation according to the needs and circumstances.

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