"I hereby declare that I have read through this report entitle "*The Effect of Priority Fitness Scheme for Controlling Robustness of Gantry Crane System*" and found out that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

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Date : 24 JUNE 2015

THE EFFECT OF PRIORITY FITNESS SCHEME FOR CONTROLLING ROBUSTNESS OF GANTRY CRANE SYSTEM

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This Report Is Submitted In Partial Fullfillment Of Requirements For The Bachelor Degree Of Electrical Engineering (Control, Instrumentation and Automation)

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2015

I declare that this report entitle "*The Effect of Priority Fitness Scheme for Controlling Robustness of Gantry Crane System*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

In the industrial application, Gantry Crane System (GCS) plays an important role to control the trolley movement and payload oscillation in order to reduce the percentage of accident occurs to the surrounding. To solve the problem, the development of the actual behavior of the dynamic nonlinear GCS is presented by implementing with and without using PID+PD controller. In dynamic model system, Lagrange equation is derived. A combination of the PID+PD controller are used to control the desired position of trolley movement and minimize the angle of payload oscillation. The Particles Swarm Optimization (PSO) is used for tuning the PID+PD controller parameter in term of Overshoot (OS), Settling Time (Ts) and Steady-State Error (SSE) via Priority Fitness Scheme (PFS). Those three type of transient response will be rearranged according to the priority implementation. Then, the simulation show that the system have a better performance when the OS is set as a highest priority followed by Ts and SSE. Finally, the investigation of the robustness of GCS is accomplished by adjusting various desired position, payload mass and cable length.

ABSTRAK

Dalam permohonan perindustrian, Sistem Crane gantri (GCS) memainkan peranan yang penting untuk mengawal pergerakan troli dan muatan ayunan untuk mengurangkan peratusan kemalangan berlaku ke persekitaran. Untuk menyelesaikan masalah ini, pembangunan tingkah laku sebenar tak linear GCS dinamik dibentangkan dengan menggunakan dan tanpa menggunakan PID+PD pengawal. Dalam sistem model dinamik, persamaan Lagrange diperolehi. Gabungan pengawal PID+PD digunakan untuk mengawal kedudukan yang dikehendaki gerakan troli dan mengurangkan sudut muatan ayunan. *Particle Swarm Optimization* (PSO) digunakan untuk memperhalusi PID+PD pengawal parameter dari segi terlajak (OS), Penyelesaian Masa (Ts) dan Steady-State Ralat (SSE) melalui *Priority Fitness Scheme* (PFS). Tiga jenis sambutan fana akan disusun semula mengikut keutamaan pelaksanaan. Kemudian, simulasi menunjukkan bahawa sistem yang mempunyai prestasi yang lebih baik apabila OS ditetapkan sebagai keutamaan tertinggi diikuti oleh Ts dan SSE. Akhirnya, penyiasatan keteguhan GCS dicapai dengan melaraskan kedudukan diingini pelbagai, muatan besar-besaran dan panjang kabel.

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GSC	**-**	Gantry Crane System
PFS	**-**	Priority Fitness Scheme
PID	**-**	Proportional, Integrator and Derivative
PSO	**-**	Particle Swarm Optimization

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CHAPTER 1

INTRODUCTION

This section will give an introduction of the project with a few explanations about Gantry Crane System (GCS). This chapter includes the problem statement, objectives, scopes, motivation and the project outcomes for the whole project.

1.1 Gantry Crane System

Gantry Crane System (GCS) is one of the most widely used for the movement of heavy loads such as in shipyards, industrial workshops, production lines and compartment terminals that commonly used to transfer the load from one area to another area. The control of GCS needs a skillful operator and manually conducted to get the best performance of the operation. However, when the GCS moves as fast as possible, the payload will give a huge impact on the payload oscillation if it suddenly stopped. This result can harm the surroundings environment and also might cause accident to worker around the area.

Figure 1.1: Example of a Gantry Crane System

By having the GCS application, it can control the desired position of trolley movement and minimize the angle of payload oscillation. The controller become more effective to move the trolley in the fast motion to the various desired position with low payload oscillation based on Priority Fitness Scheme (PFS) [6]. The implementation of PFS will observe the sensitivity toward motion where it is practical due to the complexity of real world problem in order to improve safety features.

The GCS can beneficiate greatly from the use of the computer based techniques, both as the operator support system and safety reasons, automatic control and disturbances compensator [1]. In this system, both feedforward and feedback control, as suspended load attached to the trolley is a practical application of the classical gravitational pendulum which can present by second order dynamics.

The main purpose of this project is controlling a robustness of GCS by using PID and PD controller. Robustness is an important performance in the practical applications of the crane system since the most of the crane systems are characterized by parameter variations [7]. The robustness of the overall system performances can be verified via PFS. Therefore, in order to tune and finding the optimal parameter of PID and PD controller, Particles Swarm Optimization (PSO) will be applied.

1.2 Problem Statement

List of problem statement:

i. It is complicated when most of GCS is operate in manually in order to control the payload oscillation and trolley movement at desired position. Many probabilities can cause an accident that related to human carelessness.

ii. The length of cable and the weight of load can affect the performances of the system. It can cause the larger swing angle while carrying the maximum load. The higher payload oscillation can cause an accident to surrounding.

1.3 Motivation

In this project, PID and PD controller will be implemented to control the payload oscillation and trolley movement of the GCS. By using controller, it can reduce the percentage of accident that can be occurred. Then, Particles Swarm Optimization (PSO) will be applied to tune the controller in order to improve the performance. The robustness of the overall system performances will be verified by adjusting various payload, desired distances and cable length via Priority Fitness Scheme (PFS). Upon the sort of system considered, this project may help to improve the operation of GCS application in real world problem.

1.4 Objectives

There are several objectives of this project, which are:

i. To develop and observe the actual behavior of the dynamic nonlinear GCS using PID+PD controller to control desired position of trolley movement and minimize the angle of payload oscillation.

ii. To implement Particles Swarm Optimization (PSO) in the GCS performance in terms of Overshoot, Settling Time and Steady State Error via Priority Fitness Scheme (PFS).

iii. To investigate the robustness of GCS by adjusting various desired position, payload mass and cable length.

1.5 Scopes

The scopes on this project are stated as below:

i. Develop the nonlinear modeling of the gantry crane using Lagrange's equation and implement at SIMULINK in MATLAB environment software 2012.

ii. Implement the optimal PID+PD controller. The optimal PD controller for control the swing-angle and optimal PID controller for movement of trolley to the desired position.

iii. Observe the PSO implementation and the robustness of GCS based on priority based fitness for tuning the PID+PD controller.

1.6 Project Outlines

There are project outline, as listed below:

Chapter 1 is a brief introduction regarding the actual development of GCS in real life environment. The problem statement, objectives, and scopes of project are clearly states in report.

Chapter 2 is an explanation about GCS which consists of discussion based on several papers about GCS research. Moreover, the discussion on the controller and optimization also state in this chapter.

Chapter 3 is about the methodology of the whole project that includes PSM 1 and PSM 2. In this chapter, consist of model of the GCS which is referring to the other researchers model. The GCS was developed by the derivation of mathematical expression. The software for simulation also state in this chapter.

Chapter 4 state the simulation results and discussion which are consists of design and execution of the project. In this stage, result will be divided into two parts. The first part is regarding on implementation of GCS without any controller and the second part is implementation with PID+PD controller to GCS.

Chapter 5 consists of conclusion of the overall work and recommendation for the future works.

CHAPTER 2

LITERATURE REVIEW

This chapter will discuss regarding the previous research for controlling the GCS. Many type of controller will be exposed in this chapter. Firstly, the basic theory for PID controller and Particle Swarm Optimization (PSO) will be described. Other than that, the research about the robustness of GCS was included in this chapter.

2.1 Theory and Basic Principle

In order to control GCS, PID controller will be implemented. The tuning methods of controllers are used to develop the controller of GCS by using Particle Swarm Optimization (PSO) via PFS.

2.1.2 PID controller

PID controller also known as Proportional-Integral-Derivative is widely used in industrial control system. The three basic coefficients, proportional, integral and derivative which are used to get optimal response. The reason of using PID controller in many situation is because a proportional controller may not give SSE performance needed in a system. An integral controller may eliminate SSE performance, but slow down a system. By adding a derivative term, it may help cure both of those problems. Table 2.1 shows the effect of performance on a closed-loop system.

Table 2.1: Effect of Performances

Parameter	Rise Time, (Tr)	Steady-state Error, (SSE)	Overshoot, (OS)	Settling Time, (Ts)
Proportional, P	Decrease	Decrease	Increase	Small change
Integral, I	Decrease	Eliminate	Increase	Increase
Derivative, D	Small change	Small change	Decrease	Decrease

PID controller is used to calculate the error exist between measured process variable and a desired set point by calculating and outputting a correct action that can be used to adjust the process accordingly, the equation shown as below.

$$u(t) = K_P e + K_i \int e \, dt + K_d \left(\frac{de}{dt} \right) \tag{2.1}$$

2.1.3 Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a meta-heuristic global optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995 [33]. It is inspired by social behavior of bird flocking or fish schooling. Where it state that optimization performance was improved, and the parameters were easier to tune and they performed more consistently across different optimization problems. In PSO, simple software agents, called particles, move in the search space of an optimization problem. The position of a particle represents a solution to the optimization problem at hand. Each particle searches for better conditions in the search space by changing its velocity according to rules originally inspired by behavioral models of bird flocking.

2.2 Previous Research

2.2.1 Controller of GCS

Nowadays, the performance of GCS can be controlled using various types of controller. The example of controller that have been proposed such as Linear Quadratic Regulator (LQR), Sliding Mode Controller (SMC), Delayed Feedback Signal (DFS), Fuzzy-Logic Controller (FLC), Fuzzy Sliding Mode Control (FSMC), H-infinity, Proportional-Derivation (PD) and Proportional Integrative Derivation (PID).

Many researcher was discussed to find the best controller to design the techniques for the anti-sway of the GCS. Then for varying the payload weight at rope tip, there are 3 feedback controller used which is LQR, DFS and PD. According to [2], LQR gave a better performance in minimize the overshoots and settling time even weight of payload is increased. Besides that, PD controllers have the slowest system response and give the low sensitivity to disturbance and higher steady state error. Other than that, PD controller has provided the smallest overshoot compared to LQR and DFS [3].

In additional, an Adaptive Fuzzy Logic Sliding Mode Controller (AFSMC) was proposed to approximate the uncertain parts of the underactuated nonlinear GCS and designed based on Lyapunov [4]. Besides, the stability of the closed-loop system is presented in the Lyapunov sense. The result showed the performances of AFSMC give high robust control performance when the system is subject to parametric uncertainties, external disturbances and parameter variations.

Furthermore, H-infinity is one of a good controller which is synthesis with pole clustering based on LMI techniques that used to control the position of payload with minimal swing. This type of controller is better because it can handle various type of control objectives such as disturbances cancellation, robust stabilization of uncertain systems, input tracking capability or shaping of the open-loop response. All of behavior was discussed in [5]. However, the weakness of H-infinity controller is in handling with transient response behavior and closed-loop pole location instead of frequency aspects.

Many researchers are using the implementation of the PID controllers into the system of GCS. The speed of the response is slightly improved at the expenses of decrease in the level of swing angle reduction by using the PID-PD control compared to PD with Input Shaping (IS) [6]. Recent work on GCS was proposed PD controller for both position and payload oscillation. But, for controlling position by using PD controller cause higher steady state error and low sensitivity to disturbances [7]. So that, PID controller was proposed for controlling GCS.

Another technique involved the use of the feedforward Posicant control and feedforward-feedback with PID controller to GCS in open loop condition [1]. This controller achieves the performance with no overshoot, but it is not effective in eliminating the steady state error for load disturbances.

The implementation of output-delayed feedback control (ODFC) technique is to control the oscillation of payload in GCS. This design contain prior knowledge of the controller gain for the time delay is treated as design parameter [8].

The Tensor Product (TP) model transformation and LMI framework is used to control nonlinear rotary pendulum gantry in two position which are hanging and upright [9]. By comparing both position, steady state error due friction effect were neglected in controller synthesis.

The optimal Composite Nonlinear Feedback (CNF) control show an effective result in controlling the trolley position and payload oscillation to achieve desired performances [10]. The Particle swarm optimization (PSO) was applied to search the optimal parameter. The finding is CNF control law shows better performances than the optimal linear control in GCS.

The combined finite element and analytical method is used to set up the motion equation to obtain the dynamic responses of gantry crane for load movement with suspension element in system [11]. The result shows machine performances should have accompanied with strong dynamical analysis. This is cause by the different parameter that can affect its behavior.

NURBS (Non-Uniform Rational B-Spline) interpolation is proposed to achieve high speed and high accuracy performances. Input shaper is a method to reduce the vibration in the system [12]. To increase the robustness of the system, a number of impulses can be added in the input shaper.

The Reach Control Problem (RCP) is formulate to solve the crane obstacle problem on a polytope state space [26]. The controller can be merged with an iterative control synthesis method to obtain an aggressive, safe and robust, maneuver without a predefined open-loop trajectory.

In order to control these three objective which are to reduce the vibration of the flexible cable, to move the payload to desired position and to guarantee the boundary tension constraint, the Internal-Barrier Lyapunov function system are used for the control design and stability analysis [14].

In this project, PID and PD controller are used to develop the dynamic nonlinear of GCS. The optimal PD controller is used for controlling payload oscillation and PID controller is used for controlling trolley movement to the desired position. It is seen a reliable controller performance and widely used in industries in term of simple structure and robust performance.

Nevertheless, since PID controller is well known compared to the other control techniques, thus it is being chosen to be implement for this project.

2.2.2 Tuning Method on Gantry Crane System

Tuning method is a systematic adjusting procedure of the controller parameters to obtain a desired performance of the control system. In this research, the traditional tuning method and intelligent method was applied. The traditional tuning method such as trial and error is an easy way to tune the PID controller but is difficult to determine optimal PID parameter and the performance cannot be guaranteed [3]. This method is not applicable for processes when open loop is unstable. Some simple processes do not have ultimate gain such as first order and second order processes without dead time.

The example of traditional method is Ziegler-Nichols (Z-N). This tuning method is widely used but the disadvantages are it has a larger overshoot and oscillatory responses. This method also may lead to unstable operation or a hazardous situation due to set point changes or external disturbances. For that reasons, recently many researches implement the meta-heuristic methods using modern optimization on GCS to find the most appropriate and optimal value of PID parameter.

The optimization techniques is divide into two such as heuristic and mete-heuristic. Heuristic technique is more on derivation of mathematical equation compared to meta-heuristic that will find and solve the solution for the system. Many type of meta-heuristic technique, for example are Genetic Algorithm (GA), Practical Swarm Optimization (PSO), Artificial Bee Colony (ABC), Ant Colony Algorithm (ACA), and Firely Optimization.

Many advantages of PSO including simplicity and easy implementation, the algorithm can be used widely in the fields such as function optimization, the model classification, machine study, neutral network training, the signal procession, vague system control and automatic adaptation control [15].

In this project, PSO is used as optimization tools because it was established since year 1995 until now and also known as simple optimization compared to others. By referring the