"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)"

Signature : …………………………………………

Supervisor's Name : MR. HAZRIQ IZZUAN BIN JAAFAR

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)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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.

Signature : ....

Name : NOORLIEYANA BINTI RAMELE

Date : 24 JUNE 2015

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Assalamualaikum w.b.t.

In the name of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this final year project 1. First and foremost, I would like to take this opportunity to express my sincerely gratitude and appreciation to my parents and my family for the moral support.

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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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LIST OF ABRREVIATION

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

LIST OF APPENDICES

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 existing research, PSO is used with a single objective and multi objective. Multi Objective Practical Swarm Optimization (MOPSO) is used to balance the impacts of PID tuning process to the GCS. By implementing the MOPSO algorithm, various performances results are produced according to desired position based on linear weight summation approach [16].

There are many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optimal by updating generations. PSO has no evolution operators likes crossover and mutation compared to GA it is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas such as function optimization, artificial neural network training and fuzzy system control.

PFS is the latest method used to improve the optimization. Priority Fitness Scheme (PFS) was used to improve the Binary PSO algorithm in performance analysis for GCS in finding optimal PID+PD parameter [18]. PFS is proposed to study the system performances in term of Ts, OS, and SSE. In this research, settling time is set as highest priority, followed by steady-state error and overshoot.

By having that priority, the trolley movement and payload oscillation can be control effectively for GCS. The main strength of PSO is its fast convergence compares with many optimizations. Because of that, PSO is highly demand by researcher and makes them interesting to do more research about that optimization.

2.2.3 Robustness of the GCS

Robustness is an important issue in controlling the system design. Robust control theory is a method to measure the stability and the performance changes of a control system with a changing system parameter. In order to increase the efficiency and reliability of the system, these control system are required to give more accurate and better performance in the face of difficult and changing operating conditions.

Active Disturbance Rejection Control (ADRC) is proposed to control the payload position [19]. The external disturbance and unknown internal dynamics was added to the system and tested on hardware platform, then overcome with more excellent robustness result. The disturbance rejection minor loop was designed to compare the effects of external disturbance between the modeled dynamics and real plant. ADRC also used to design effectiveness decentralized in interconnected nonlinear system constituted by non-feedback subsystem of local trajectory tracking problem [20].

Other than that, input shaping was used with system inversion method is proposed to control the vibration and precise position in 3 dimensions system [21]. With the reducing of vibration on GCS, it will increase the robustness of this system.

The control law was introduced into the crane dynamic by varying periodically its cable length. Furthermore, this vibration control is feasible for gantry crane applications since it considered small frequencies in the control design [22].

A new anti-swing control scheme is proposed to control performances over existing method and shows strong robustness with unmodeled uncertainties and external disturbances [23].

The robust right coprime factorization design is applied to a planar gantry crane to avoid the influence of the unknown uncertainties for the nonlinear system [24]. The influence of motion friction and viscous friction of the linear motor and the cable is considered.

The control system is robust when it has low sensitivities, stable over the range of parameter variations and the performance continuous to meet the specifications in the presence of a set of changes in the system parameter.

In GCS, the performance and robustness of the feedback controllers in minimizing the sway angle was proposed in term of time response specifications and magnitude of sway [25]. The author evaluated the robustness on three feedback controls which are DFS, LQR and PD. The shorter settling time is important to prevent the rope swing too large. DFS and LQR show the faster settling time compared to PD controller.

In research by Wahyudi, he said that intelligent GCS is more robust to parameter variation compared the automatic gantry crane system [7]. In this paper, Fuzzy logic controller were adopted and designed for the intelligent GCS. In other hand, the automatic GCS is controlled by classical PID controllers. The parameter change in this system is the length variation of the cable.

Furthermore, the robustness of pendulum system control on GCS was investigated by using feedback controller design via constrained optimization [26]. The system robustness is measuring by optimization techniques which are Particle Swarm Optimization (PSO) and Differential Evolution (DE). This research is compared in term of repeatability and computation time and shows that DE is a better repeatability compared to PSO. However, the computational time much longer than PSO.

Other researcher investigates the robustness of the controller using Kharitonov's Stability [27]. In this research, the Genetic Algorithm (GA) is implemented to find the stable robust of PID. The controller is tested using Kharitonov's polynomials robust stability criterion to deal with the parametric uncertainly appears in GCS. The robustness of anti-swing controller is seen by variations of parameter, the cable length and payload mass. However, it is effectively works in specified range of variations parameter.

2.3 Summary and Discussion

In this project, an optimal PID+PD controller is develop for controlling the nonlinear GCS. The optimal parameter of PID+PD controller is obtained by Particle Swarm Optimization (PSO) algorithm and improved using Priority Fitness Scheme (PFS) as fitness function. As well known, many controllers have been implemented to get a better performance of GCS. PID controller was chosen because it is widely implemented in industry and also known as the easier controlling method to tune the system operation. Compares to other controller, PID controller make of simple design and easy to understands. PFS is the latest method to find optimal parameter in term of settling time, steady state error and overshoot. Usually, the latest method always is better and good performance compared to other method. In conclusion, the robustness of the GCS is investigated using PFS approach.

Figure 2.1 shows the k-chart obtains from the previous research. It shows the summaries flow of previous techniques used for controlling the GCS. The type of controller and optimization method use in this project also clearly observes in this figure.

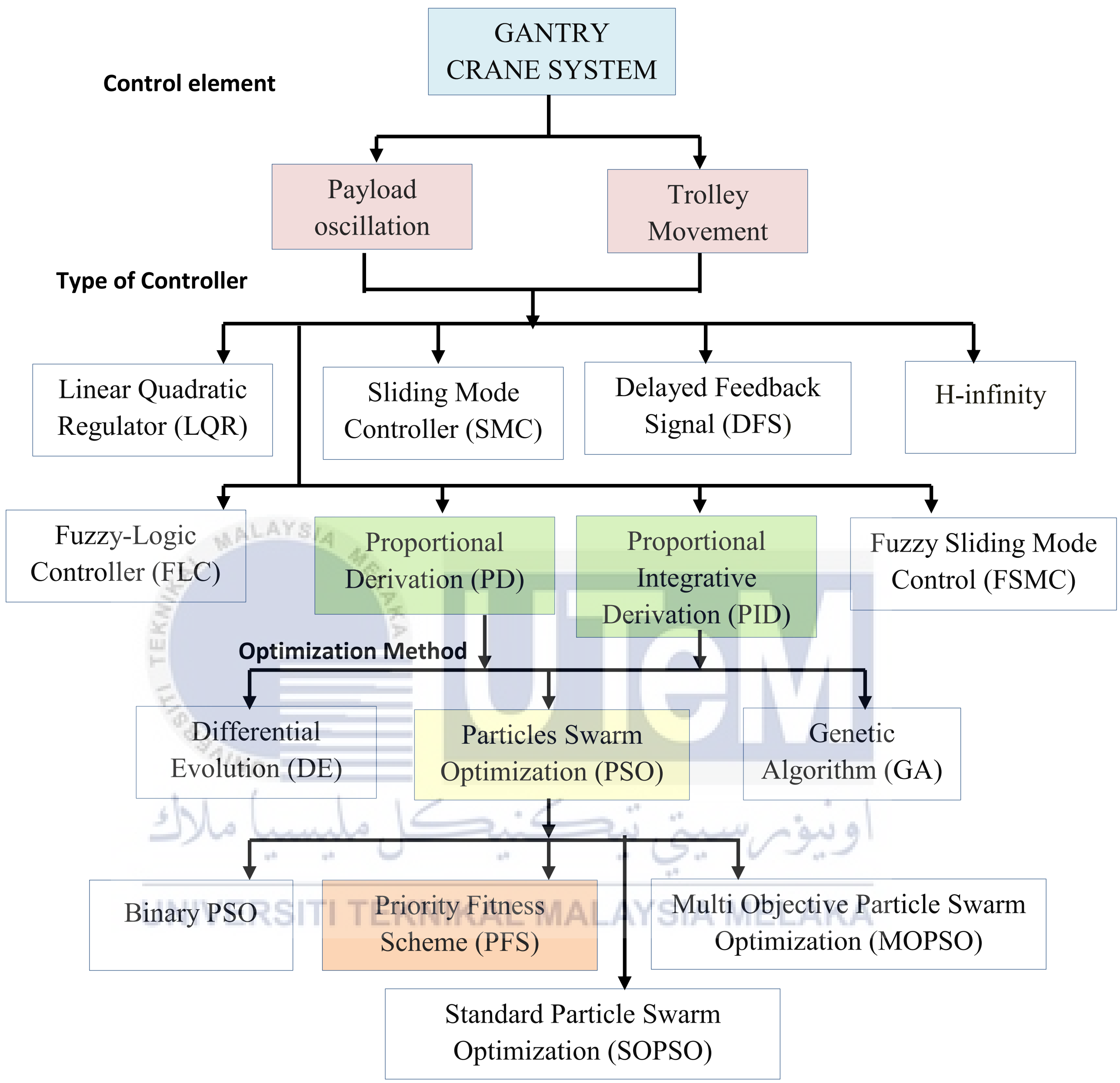


Figure 2.1: K-chart obtains from previous researches

CHAPTER 3

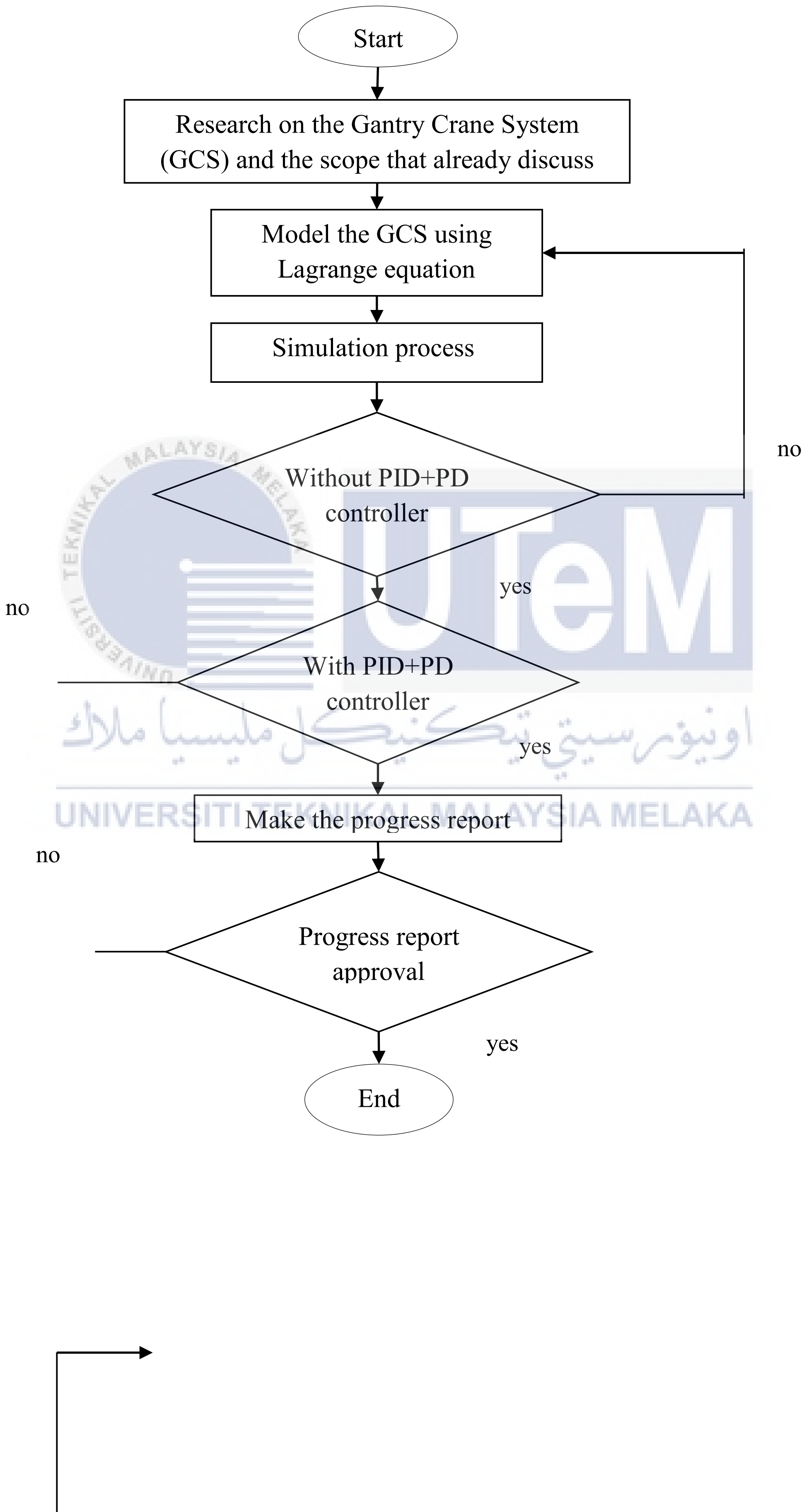
METHODOLOGY

In this section, it consist of process workflow for the whole project. The PSO algorithm based on a priority fitness shceme will be implemented for finding optimal PID+PD parameter. The robustness of GCS is investigated by adjusting various desired position, payload mass and cable length using PFS.

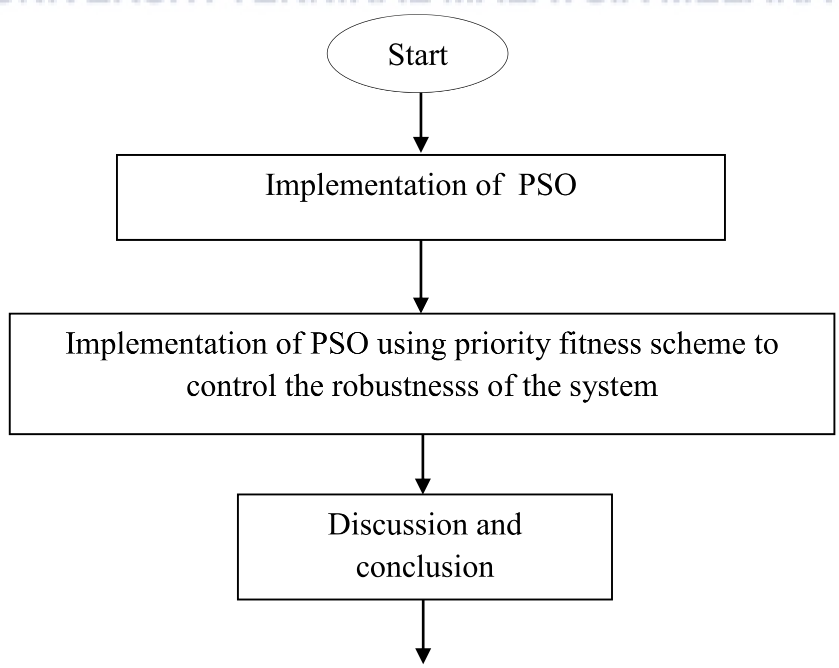
3.1 Flow chart

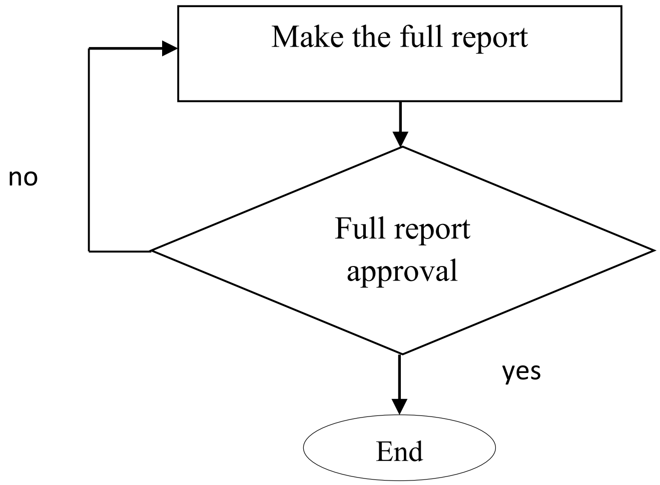
The flow chart shown in Figure 3.1 is for the overall process of this project. The flow chart consists of two stages which are stage 1 for FYP 1 and stage 2 for FYP 2. For this section only stage 1 will be carried out and the process will end until the progress report is submitted.

The stage 1 is the derivation of the equation using Lagrange's Equation. Moreover, the Simulink in MATLAB environment is used to complete the simulation part. simulation is done by investigated the performance of GCS with PID+PD controller and without PID+PD controller in order to observe the difference between it.


Start
Research on the Gantry Crane System (GCS) and the scope that already discuss
Model the GCS using Lagrange equation
Simulation process
Without PID+PD controller
no
yes
With PID+PD controller
no
yes
Make the progress report
Progress report approval
no
yes
End

(a)


Start
Implementation of PSO
Implementation of PSO using priority fitness scheme to control the robustnesss of the system
Discussion and conclusion



(b)

Figure 3.1: (a) Stage in FYP 1 (b) Stage in FYP 2 in Project Workflow

3.2 Gantt Chart and Project Milestone

Table 3.1: Gantt Chart for FYP 1

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Deal with Supervisor and Confirmation of Title													
Research about GCS													
Research about PSO via PFS													

Research about robustness of GCS													
Write Progress Report													
Model the GCS and derive lagrange equation													
Design PID Controller for GCS													
Analysis Response when using PID Controller and without controller													
Submit project proposal													
Presentation Project Proposal and PSM Seminar													

Table 3.2: Gantt Chart for FYP 2

Task/Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Simulation on PSO via PFS													
Collect data of simulation													
Write Progress Report													
Analysis about the effect of rearrangement of PFS on the system													

Analysis about robustness of GCS													
Submit the Final report													
Final Presentation													

Table 3.3: Project Milestone

TASK	DATE
Deal with Supervisor and Confirmation Project Title	08/09/2014 - 24/09/2014
Model GCS with derive the Lagrange Equation	23/10/2014
Simulation with PID Controller	31/10/2014
Seminar and Presentation Project Proposal	19/11/2014
Implement PSO in GCS	1/3/2015
Due Date for Send Full Report	1/6/2015
Presentation of Project	9/6/2015

3.3 Nonlinear Model of GCS

The dynamic nonlinear of the GCS is model [6]. Lagrange equation is used in order to derive the GCS. Figure 3.2 shows the schematic diagram of the GCS where consists of $m_1,\ l,\ m_2, x, \theta, T$ and F denote as payload mass, cable length, trolley mass, horizontal position of trolley, swing angle, torque and driving force respectively. Parameters of the system show in Table 3.4 [6].

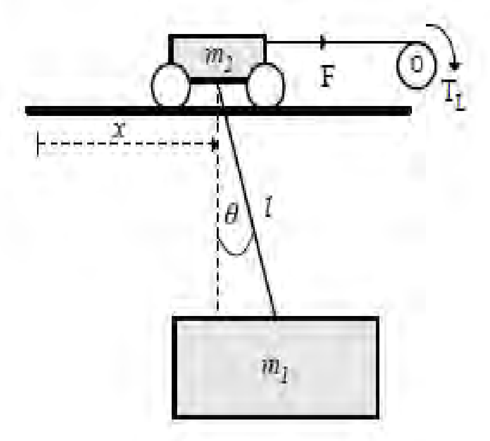


Figure 3.2: Schematic diagram of a GCS [6]

Table 3.4: System Parameter for GCS

Parameters	Value	Unit
Payload mass(m_1)	1	kg
Cable length (l)	0.75	m
Trolley mass(m_2)	5	kg
Gravitational (g)	9.81	m/s^2
Damping coefficient (B)	12.32	Ns/m
Radius of pulley (r_p)	0.02	m
Torque constant (K_T)	0.007	N_m/A
Electric constant (K_E)	0.007	V_s/rad
Radius of pulley (r_p)	0.02	m
Gear ratio (z)	15	-

3.3.1 Lagrange's equation for Modeling of GCS

Lagrange's equation was selected to model the gantry crane system (GCS) instead of several method. The equation is useful to provide the good system that will operate in GCS. In this system, two parameters used which is payload oscillation, θ and trolley displacement, x. Equation (3.1) is the standard Lagrange's equation:

$$\frac{d}{dt}\left[\frac{\delta L}{\delta \dot{\theta}_i}\right]-\frac{\delta L}{\delta \dot{\theta}_i}=Q_i \tag{3.1}$$

The derivation of Lagrange equation used the mathematical expression of kinetic and potential energy that related to the operation of GCS. The lagrange function is :

$$T = L - V \tag{3.2}$$

$$T = \frac{1}{2}mv^2 \tag{3.3}$$

$$V = \frac{1}{2}ky^2 + mgh \tag{3.4}$$

which T and V are respectively kinetic and potential energies. To find the position noted as v, the illustraction as Figure 3.2 is used and solve by trigonometry rule.

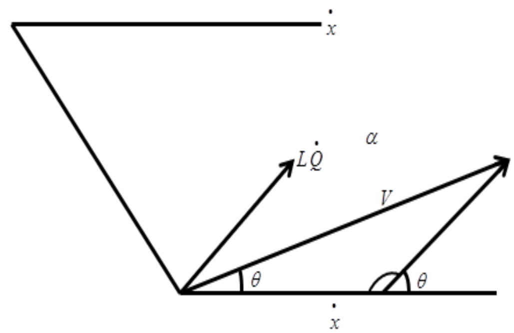


Figure 3.3 The Illustration of finding v

$$V_2^{\,2} = \dot{x}^{\,2} + \left(\dot{\theta}\right)^2 - 2\dot{x}\,l\,\dot{\theta}\cos\alpha \tag{3.5}$$

$$\cos\alpha = -\cos\theta$$

$$V_1^{\,2} = \dot{x}^{\,2} + \left(\dot{\theta}\right)^2 - 2\dot{x}\,l\,\dot{\theta}\cos\theta \tag{3.6}$$

find the total kinetic energy by substitute the behavior of payload oscillation, and trolley displacement:

$$T = T_{trolley} + T_{payload}$$

$$T = \frac{1}{2}m_1\dot{x}^2 + \frac{1}{2}m_2\dot{x}^2 + \frac{1}{2}m_1\dot{x}\,l\,\dot{\theta}^2 + \frac{1}{2}m_1\dot{x}\,l^2\,\dot{\theta}\cos\theta \tag{3.7}$$

because of the gravity at trolley is zero. The total potential energy is

$$= -mgl\cos\theta \tag{3.8}$$

Largangian equation

$$L = T - V$$

$$= \frac{1}{2} m_1 \dot{x}^2 + \frac{1}{2} m_2 \dot{x}^2 + \frac{1}{2} m_1 \dot{x} l^2 \dot{\theta} + \frac{1}{2} m_1 \dot{x} l \dot{\theta} \cos\theta + mgl\cos\theta \tag{3.9}$$

From above the position, $\dot{x}$ and payload oscillation, $\dot{\theta}$ can be obtained:

For trolley displacement, $\dot{x}$:

$$\frac{dl}{dx} = 0 \tag{3.10}$$

$$\frac{d}{dt}\left[\frac{dl}{d\dot{x}}\right] = m_1 \ddot{x} + m_2 \ddot{x} - m_1 \ddot{x} - m_1 l \dot{\theta} \sin\theta + m_1 l \ddot{\theta} \cos\theta \tag{3.11}$$

For payload oscillation, $\dot{\theta}$:

$$\frac{dl}{d\theta} = m_1 l \dot{\theta} + m_1 \dot{x} l \cos\theta \tag{3.12}$$

$$\frac{dl}{d\dot{\theta}} = m_1 l^2 \dot{\theta} - m_1 \dot{x} l \dot{\theta} \sin\theta + m_1 \ddot{x} l \cos\theta \tag{3.13}$$

substitute Equation (3.12) and (3.13) in Equation (3.1). The equation of motion of GCS is

$$m_1 \ddot{x} + m_2 \ddot{x} - m_1 \ddot{x} - m_1 l \dot{\theta} \sin\theta + m_1 l \ddot{\theta} \cos\theta + B\dot{x} = F \tag{3.14}$$

$$m_1 l^2 \dot{\theta} - m_1 \dot{x}\, l\, \dot{\theta} \sin\theta + m_1 \ddot{x}\, l \cos\theta + m_1 g l \sin\theta = 0 \quad (3.15)$$

3.3.2 The DC motor derivation

Since the DC motor is used in this GCS model as shown in Figure 3.4, derivation of DC motor is needed to drive the movement of trolley. The force equation is derived as below

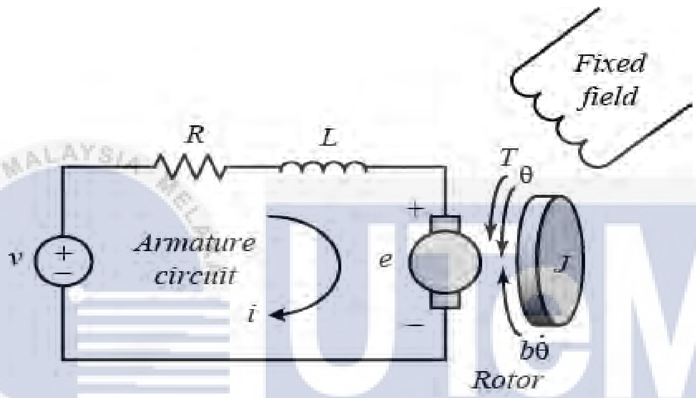


Figure 3.4: DC Motor

$$T_m = J_m \frac{d^2\theta_m}{dt^2} + D_m \frac{d\theta_m}{dt} \quad (3.16)$$

Since moment inertia of motor, J_m inversely small, therefore:

$$T_m = D_m \frac{d\theta_m}{dt} = \frac{T_L}{r} \quad (3.17)$$

V is an input voltage

$$V = R_1 + L\frac{di}{dt} + V_b \quad (3.18)$$

L can be neglected

$$V = R_i + V_b \tag{3.19}$$

$$= R\left(\frac{T_m}{K_t}\right) + \left(K_e \frac{d\theta_m}{dt}\right) \tag{3.20}$$

$$= R\left(\frac{T_L/r}{K_t}\right) + K_e \frac{d}{dt}\left(\frac{r}{r_P}\dot{x}\right) \tag{3.21}$$

$$r = \frac{RF_{rp}}{K_{tr}} + \frac{K_{er}}{r_p}\dot{x} \tag{3.22}$$

$$F = \frac{VK_{tr}}{R_{rp}} - \frac{K_e K_{tr}^{\ 2}}{R_{rp}^{\ 2}}\dot{x} \tag{3.23}$$

so, a complete nonlinear equation for the GCS can are [15]:

$$V = \left[\frac{R_{rp}B}{K_t r} + \frac{K_e r}{r_p}\right]\dot{x} + \left[\frac{R_{rp}}{K_t r}\right]m_1 + m_2\ddot{x} + \left[\frac{R_{rp}}{K_t r}\right]m_1 l\left[\ddot{\theta}\cos\theta - \dot{\theta}^2 \sin\theta\right] \tag{3.24}$$

$$m_1 l^2 \dot{\theta} - m_1 \dot{x} l \dot{\theta} \sin\theta + m_1 \ddot{x} l \cos\theta + m_1 g l \sin\theta = 0 \tag{3.25}$$

where V is input voltage. Therefore, these two equations are represent for this nonlinear GCS as shown in Figure 3.2.

3.4 Simulation on Gantry Crane System

In this project, Simulink in MATLAB environment is used. The dynamic nonlinear model of GCS model is developed using (3.24) and equation (3.25). The GCS is tested with input voltage and two types of output, which is payload oscillation, θ and trolley movement, x was examined.

The GCS have two model of simulation. One is without controller and other is with PID+PD controller. The result is to examine the behavior of system by changing different parameters and the efficiency of PID controller with tuning method in Simulink MATLAB environment.

3.4.1 Simulation on Gantry Crane System without Controller

Firstly, the nonlinear of GCS is modeled without controller to observe the actual behavior of the system. The subsystem of GCS is created by inserting the lagrange equation that has been developed previously. All the parameter is set according to Table 3.4 to complete the simulation. The block diagram is designed below as shown in Figure 3.5 and 3.7.

In simulation of GCS without controller, the bang-bang input voltage signal is applied as an input voltage that allowed the trolley to accelerate, decelerate and immediately stop at certain position. This is because bang-bang input combination of two pulses to form a positive and negative period of the system.

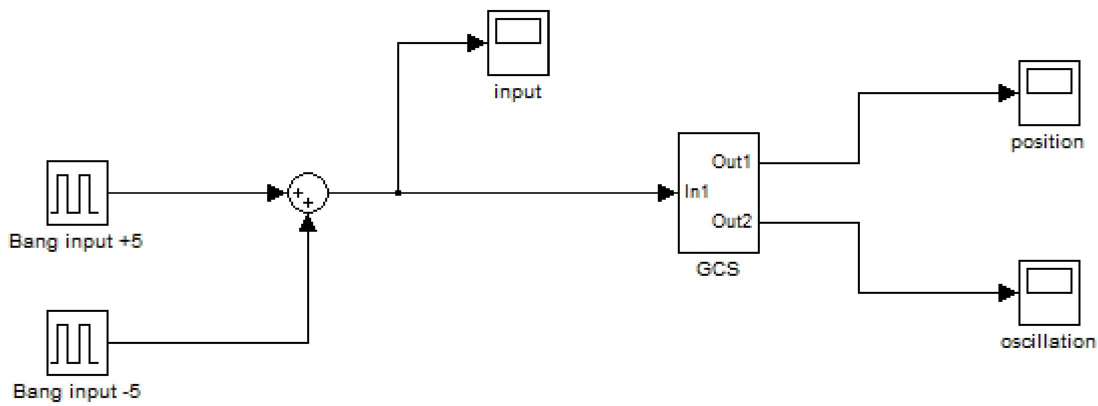


Figure 3.5: The GCS without controller

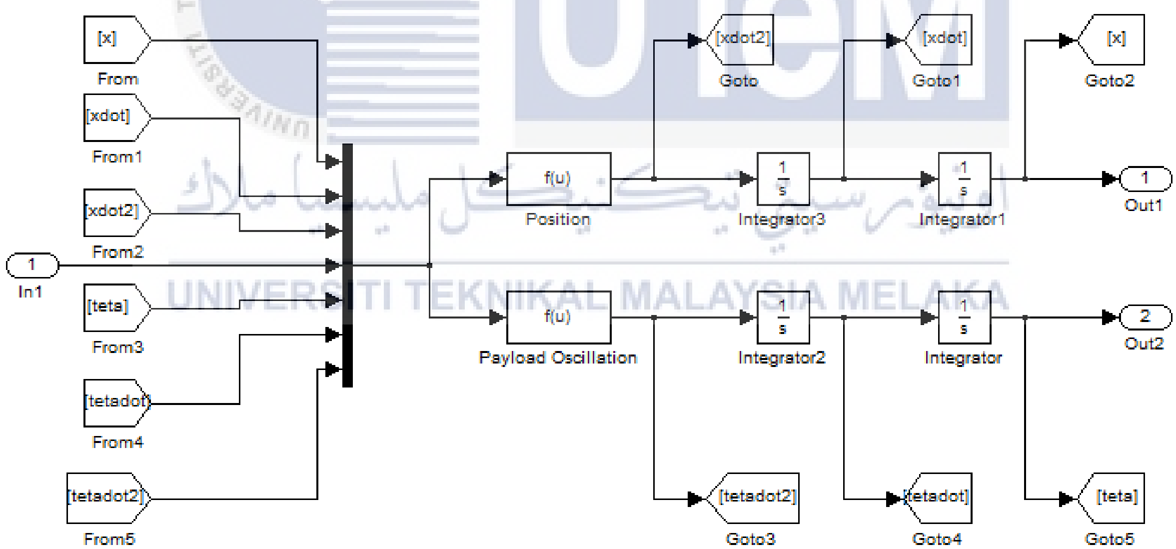


Figure 3.6: The subsystem of GCS

3.4.2 Simulation on Gantry Crane System with PID-PD Controller

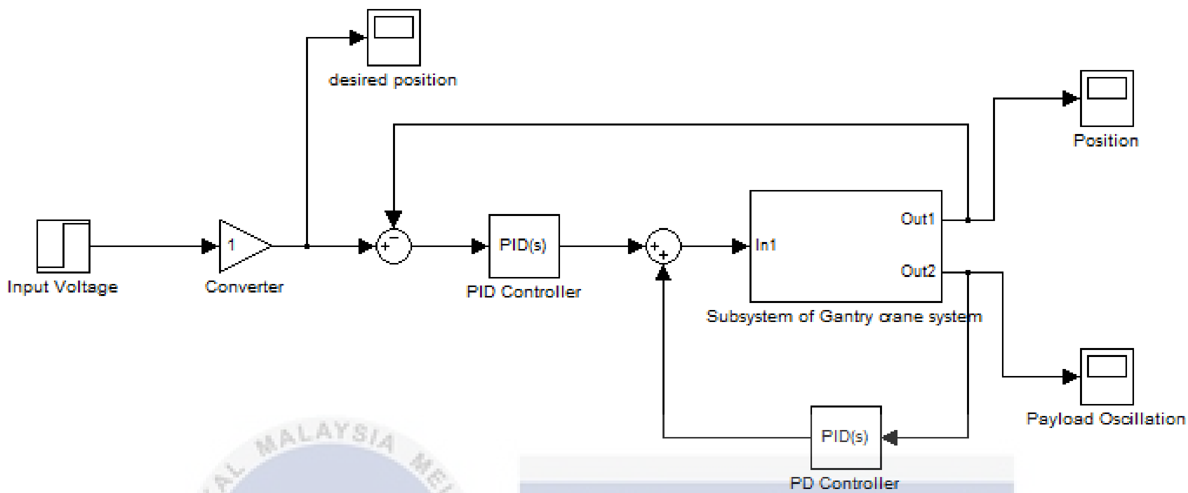


Figure 3.7: The GCS with PID + PD controller

As shown in Figure 3.7, the input source used is the step input. The function of converter is to convert the input voltage to get the input in position or displacement value such as 1 V (voltage) is convert to 1 m (meter) since the Simulink do not have the unit of meter as an input.

Moreover, the PID controller was used to control the position of the trolley and PD controller used to control the output of payload oscillation. Based on understanding and theory from Table 2.1, the PID controller used to reduce the overshoot percentage of the system and minimize the time of the system. The important part is to eliminate the steady-state error because the system must achieve the desired position. Then, the PD controller is used to decrease the precent of overshoot in the payload oscillation while the steady-state error can not be eliminate. The subsystem is used similar with Figure 3.6. The system was automated tune using both controller to get the best performance of GCS.

3.5 PSO Implementation

PSO is an intelligent algorithm that search the best solution which relies on exchanging information through social interaction among particles. The basic concept of PSO is each particle will memorizes its personal best solution (P_{best}) which is corresponding to the best fitness value in the searced space. The particle also can access the global best solution (G_{best}) that is overall found by one member of the swarm.

It is initially conduct searching using swarm particles randomly. The initialization of particles is calculated using

$$x^i = x_{\min} + rand(x_{\max} - x_{\min}) \tag{3.26}$$

where $x_{\max}$ and $x_{\min}$ are the maximum and minimum values in the search space. After finding the two best values, the modified position and velocity of each particle is calculated by the current velocity and the distance from pbest and gbest using (3.27) and (3.28)

$$v^{i+1} = \omega v^i + c_1 r_1 (P_{best} - x^i) + c_2 r_2 (G_{best} - x^i) \tag{3.27}$$

$$x^{i+1} = x^i + v^{i+1} \tag{3.28}$$

where:

$\mathbf{v}^{i+1}$ = velocity of particle at iteration k

ω = inertia weight factor

c_1, c_2 = acceleration coefficients

$\mathbf{r}_1$, $\mathbf{r}_2$ = random numbers between 0 and 1

$\mathbf{x}^{i+1}$ = position of particle at iteration k

For this system, the particle position in PSO is modeled as Eq. 3.29.

$$x^i = [K_P, K_I, K_D, K_{PS}, K_{DS}] \tag{3.29}$$

there are five optimal value of parameter should be find where x is the particle position, K_P, K_I, K_D are the PID parameter to control the trolley displacement of the GCS and K_{PS}, K_{DS} are the value of PD parameter to control the payload oscillation of GCS.

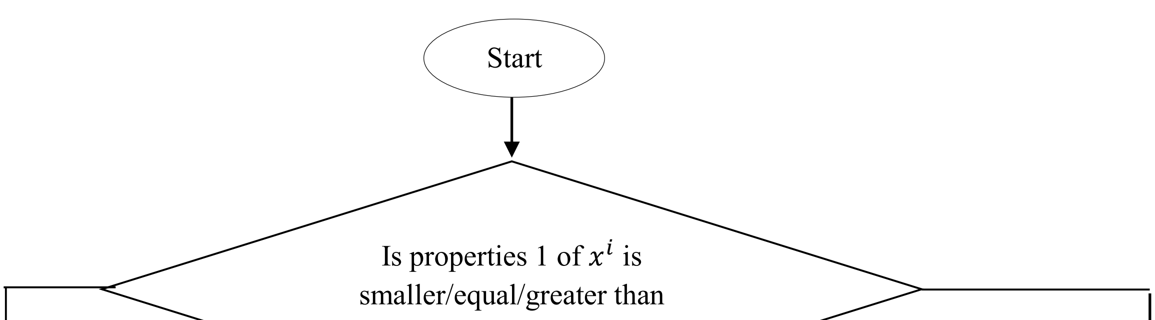
3.6 Priority Fitness Scheme (PFS)

The PFS is implemented on PSO algorithm to improved the tuning of PID parameters in term of Overshoot, OS, Setling Time, Ts and Steady-state Error, SSE. Those three transient responses will be rearranged to investigate which is properties that have the highest priority and the best arrangement to obtain the better performances. All properties are rearranged into 6 cases which are :

Table 3.5: Six cases of Transient Response

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
Properties 1	TS	TS	SSE	SSE	OS	OS
Properties 2	OS	SSE	TS	OS	SSE	TS
Properties 3	SSE	OS	OS	TS	TS	SSE

Figure 3.8 shows the P_{best} and G_{best} in PSO updated according to the priority of those three properties.



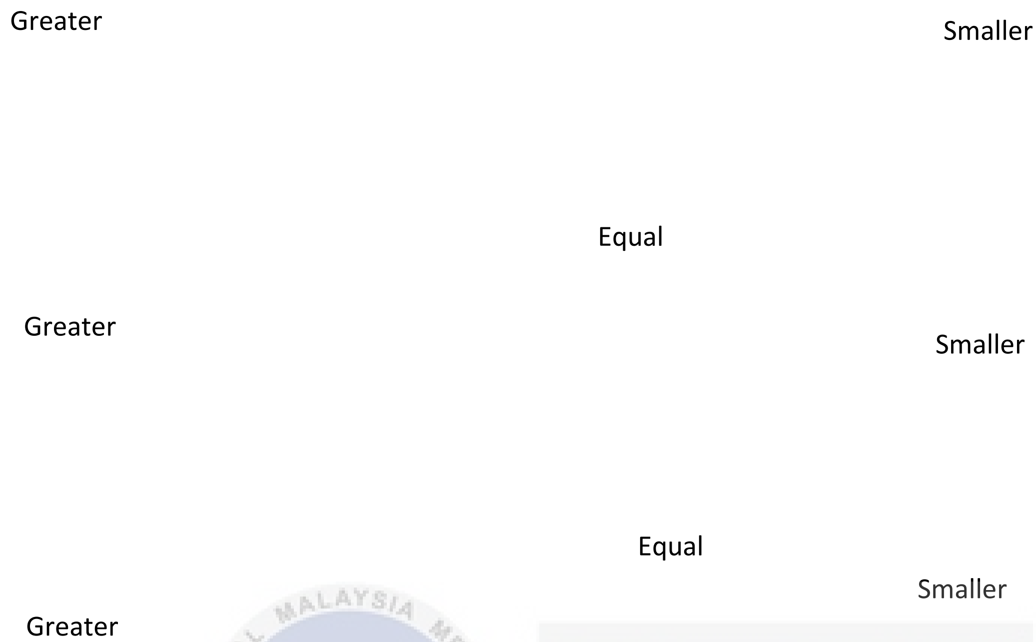


Figure 3.8 : The process of PSO via Priority Fitness Scheme

3.7 Controlling Robustness

The robustness of GCS is examined by adjusting the variable parameter. In PSM 1, the parameter of input voltage, payload mass, trolley mass and cable length will be varied to observe the robust of the system without any controller implemented.

In second part after the implementation of PID+PD controller, the one of best parameter will be choosen from the six cases of transient responses properties to study the robustness of GCS in term of variation of desired position, payload mass and cable length.

3.8 Conclusion

This chapter consists of the method used in modeling the nonlinear system of GCS by using Simulink block diagram. The simulation of GCS is done with and without controller. The flow of project was described to show the process occur in this project included PSM 1 and PSM 2. The PSO is applied in the GCS performance in terms of OS, Ts and SSE via PFS and will be proceed in controlling the robustness of GCS.

CHAPTER 4

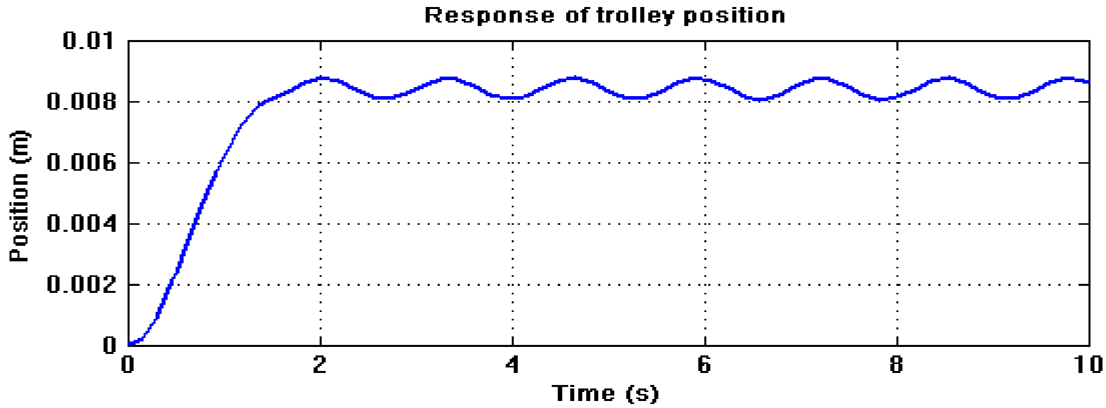
RESULTS AND DISCUSSIONS

This chapter will discuss on result of whole project. For the first part is regarding on without any controller implementation to GCS and second part is implementation with PID+PD controller to GCS. Next, the system performance is improved by applying the PSO algorithm via PFS. The robustness of GCS is investigated.

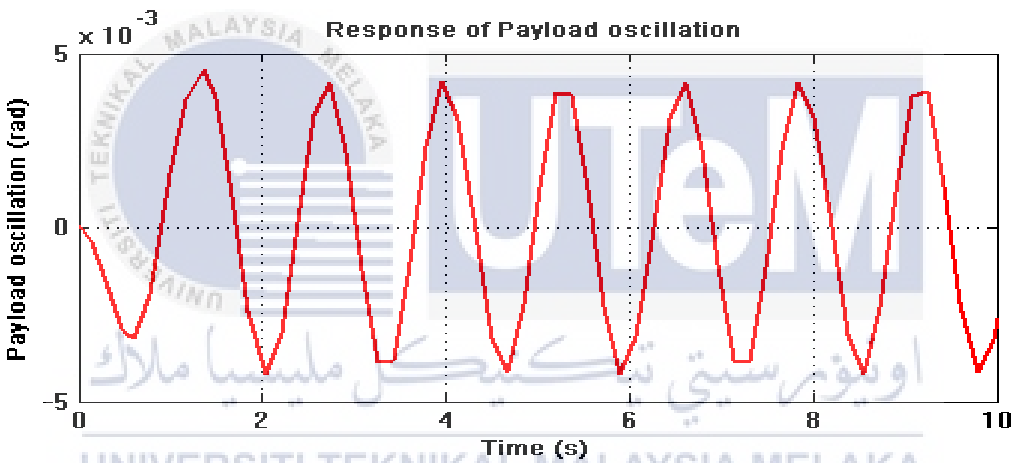
4.1 Result of simulation without using Controller.

The simulation is conducted by Simulink block in MATLAB environment software as mention in Chapter 3. There are a four parameters have been examined such as variety of input voltage, cable length, payload mass and trolley mass in order to determine the actual behavior of the system. In simulation result, it should be produce various responses with setting the different value of parameter in GCS.

Trolley displacement and payload oscillation are observed to analyze the responses of GCS. Figure 4.1 shows the responses of dynamic nonlinear of GCS. All the parameters have been set up as in Table 3.1.



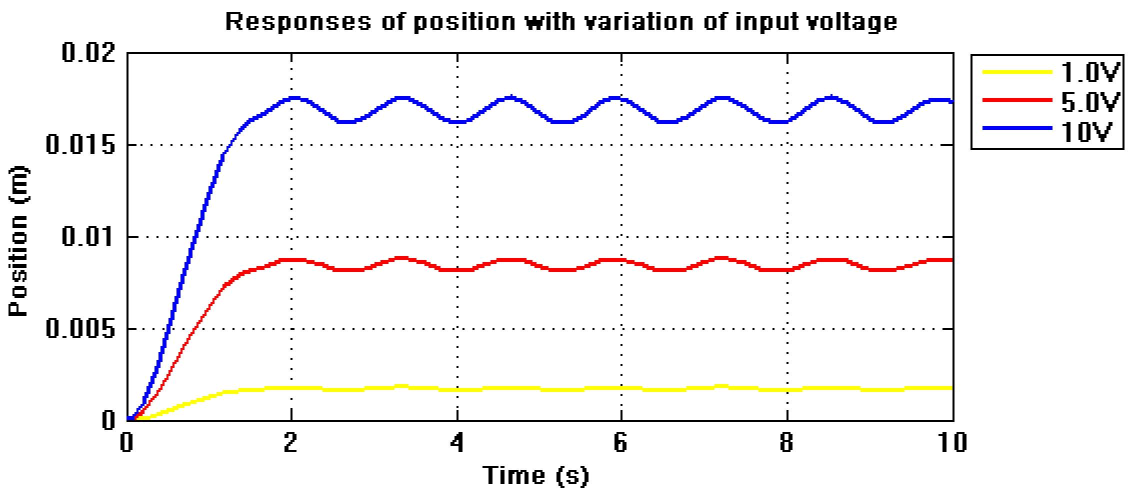
(a)



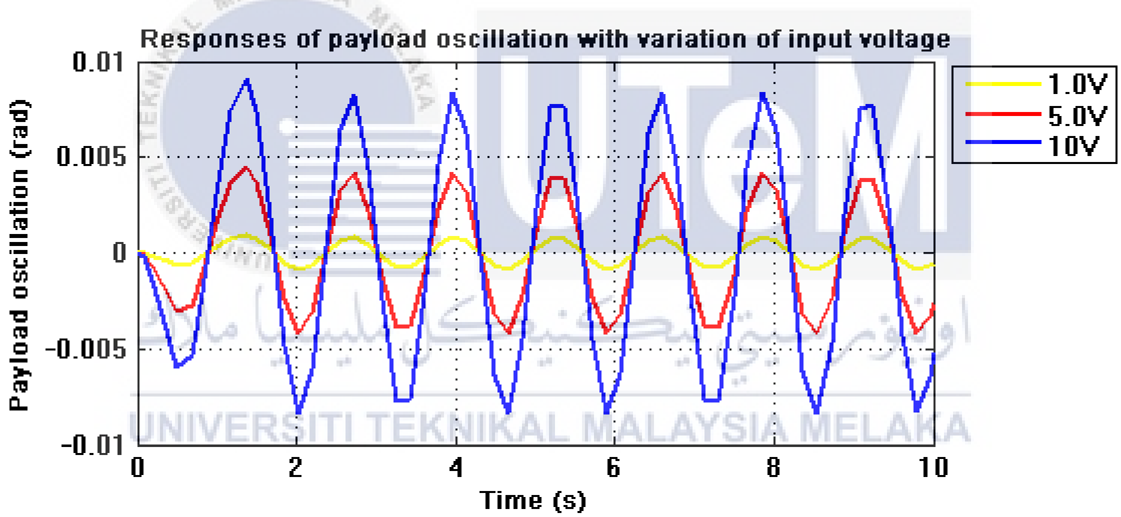
(b)

Figure 4.1: The responses of (a) Trolley position (b) Payload oscillation

Subsequently, it is desirable to examine the actual behavior of GCS performance under various parameters such as input voltage (v), payload mass (m_1), trolley mass (m_2) and cable length (*l*). Figure 4.2 shows the responses of the trolley position and payload oscillation.



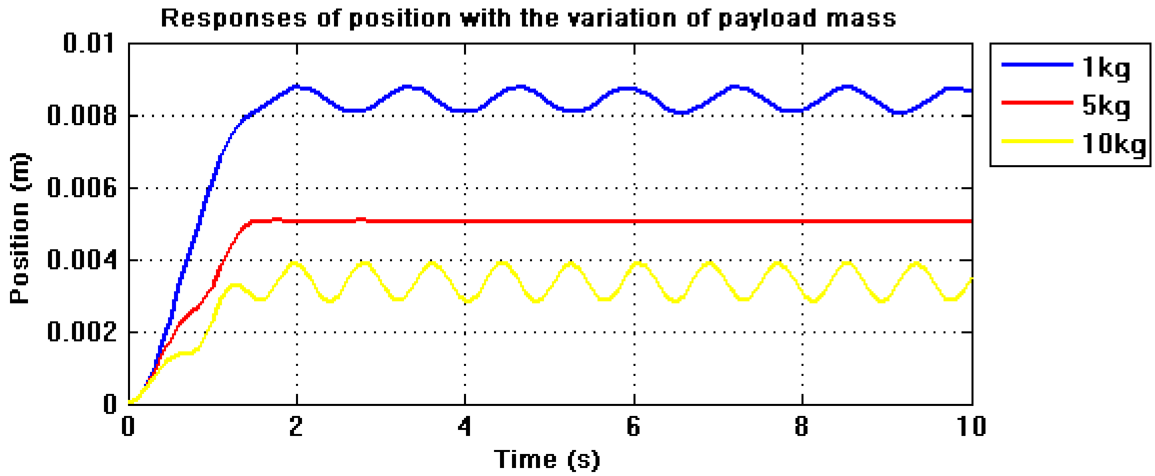
(a)



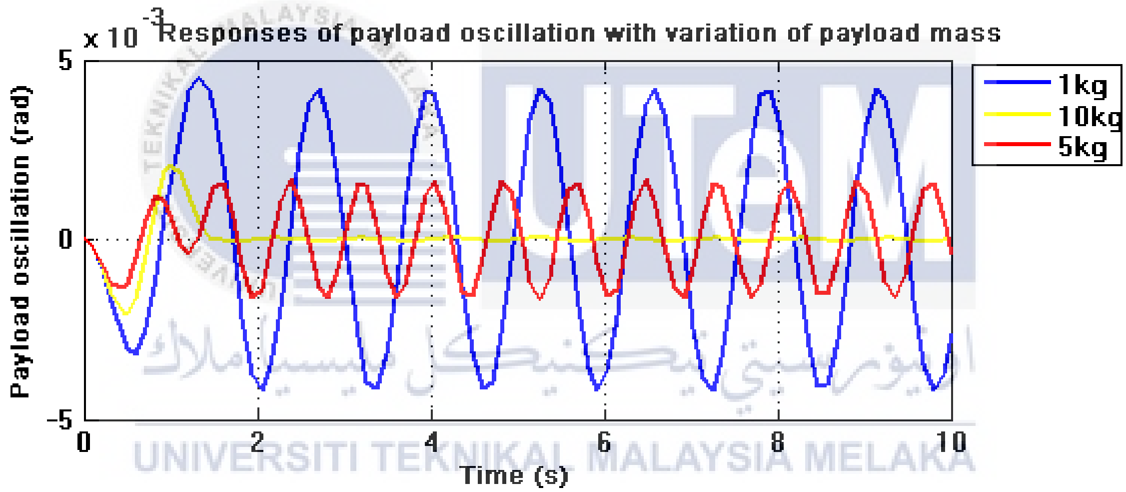
(b)

Figure 4.2: The responses of system with input voltage of 1 V, 5 V and 10 V

(a) Trolley position (b) Payload oscillation



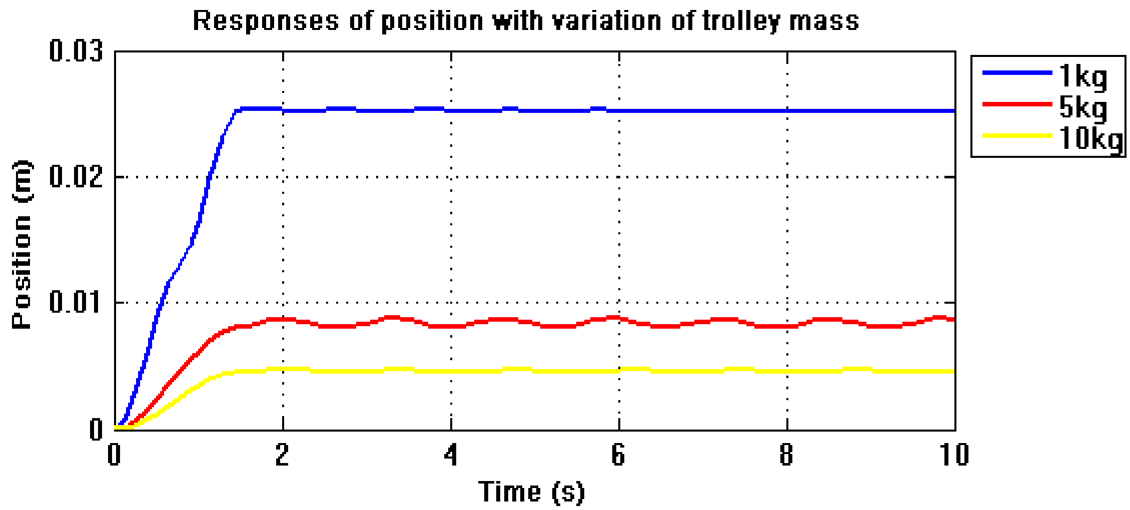
(a)



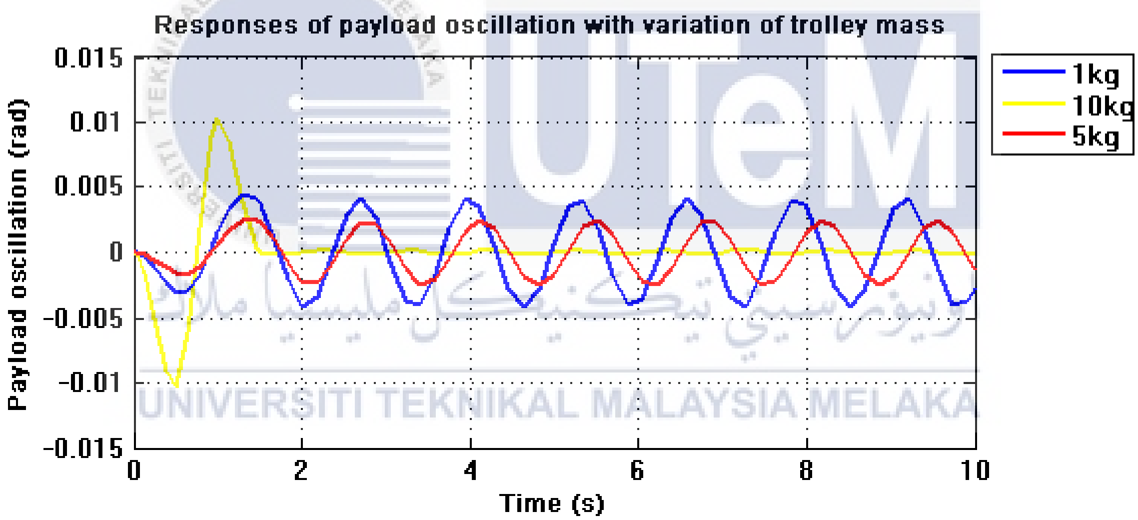
(b)

Figure 4.3: The responses of system with payload mass of 1 kg, 5 kg and 10 kg

(a) Trolley position (b) Payload oscillation

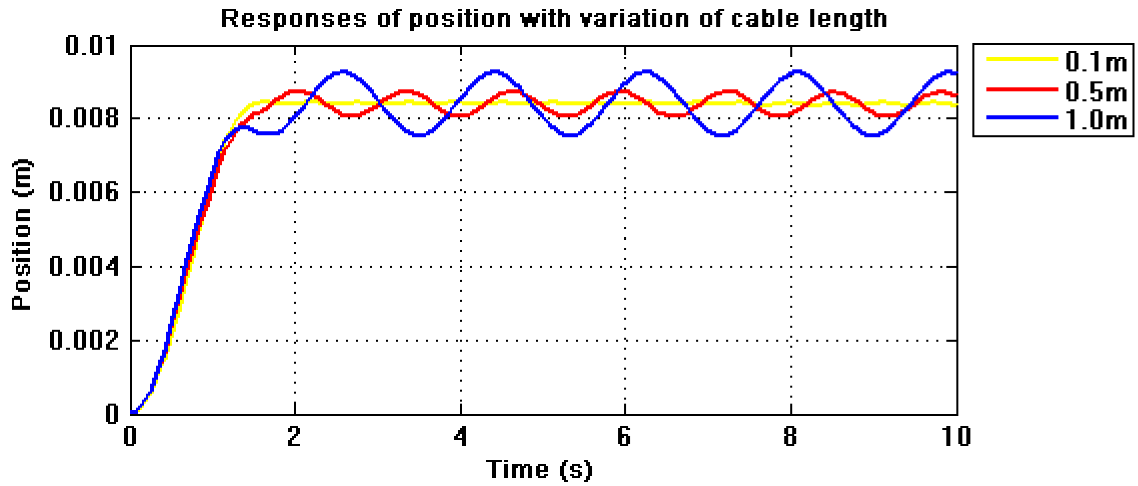


(a)

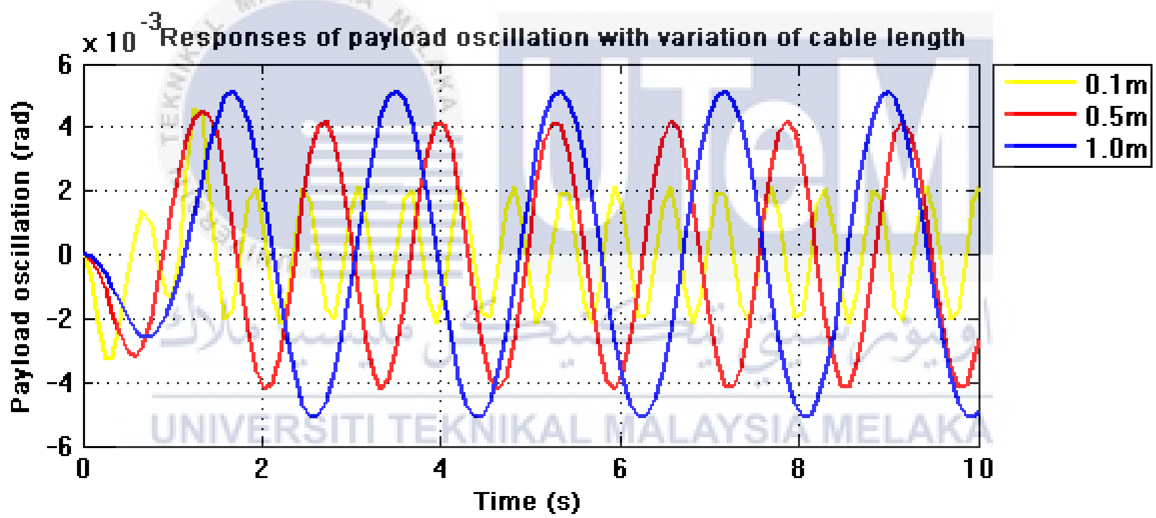


(b)

Figure 4.4: The responses of system with trolley mass of 1 kg, 5 kg and 10 kg
(a) Trolley position (b) Payload oscillation



(a)



(b)

Figure 4.5: The responses of system with cable length of 0.1 m, 0.5 m and 1.0 m

(a) Trolley position (b) Payload oscillation

Table 4.1: Reading of simulation results without controller

Parameter	Value	Trolley Position,(m)	Payload Oscillation, (rad)
Voltage, V	1.0 V	0.002	0.001
	5.0 V	0.008	0.004
	10.0 V	0.017	0.009
Payload mass,m_1	1 kg	0.009	0.004
	5 kg	0.005	0.002
	10 kg	0.003	0.001
Trolley mass, m_2	1 kg	0.025	0.004
	5 kg	0.009	0.0025
	10 kg	0.005	0.0009
Cable length, l	0.1 m	0.0085	0.002
	0.5 m	0.009	0.0045
	1.0 m	0.0095	0.005

In Table 4.1 show the summaries of simulation reading for input voltage, payload mass, trolley mass and cable length. Based on Table 4.1, several observations can be analyzed from the result:

i. When small input is applied to the system it produces a long distance of position while the oscillation is low. Moreover, once viewing at high input voltage it shows low distance of trolley position and also high oscillation is made.
ii. Higher mass of payload was affect the distance of trolley position become shorter while the payload oscillation is decreasing.

iii. Higher distance of trolley position can be reached with the lower mass of trolley itself. The maximum payload oscillation is also decrease.

iv. Lastly, by increasing the length of cable can be not much affect to the distance of trolley position. Then, increasing of payload oscillation can be seen when the cable length is increase.

4.2 Result of simulation using PID +PD controller.

The PID+ PD controller was applied in auto-tuning method to control the performance responses of GCS to complete the first objective in this project. This section show the simulation result. The configuration of the MATLAB Simulink model for PID+PD controller combines with GCS is shown as in Figure 3.9. The PID parameter is setting by using auto tuning as shown in Figure 4.6. The value of controller parameter that selected is choose by the best and the minimum value of performance parameter.

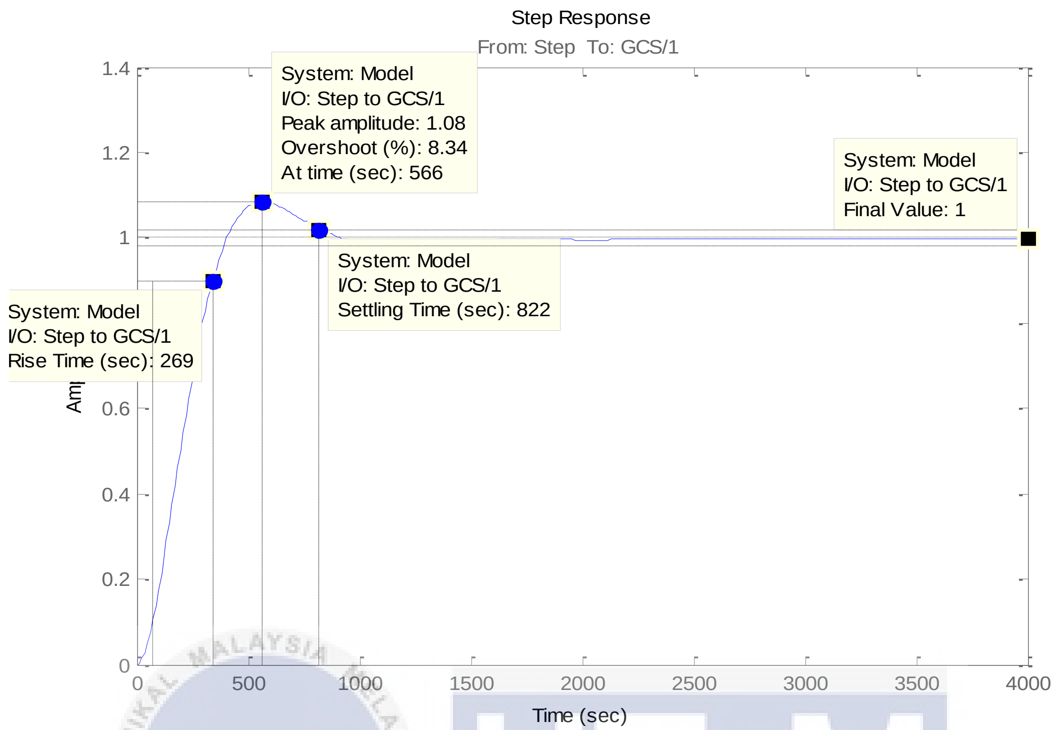
Controller parameters

	Tuned	Block
P	0.00033228	6.1433e-005
I	1.1851e-008	2.6346e-009
D	2.0669	0.33099
N	0.010499	0.0018132

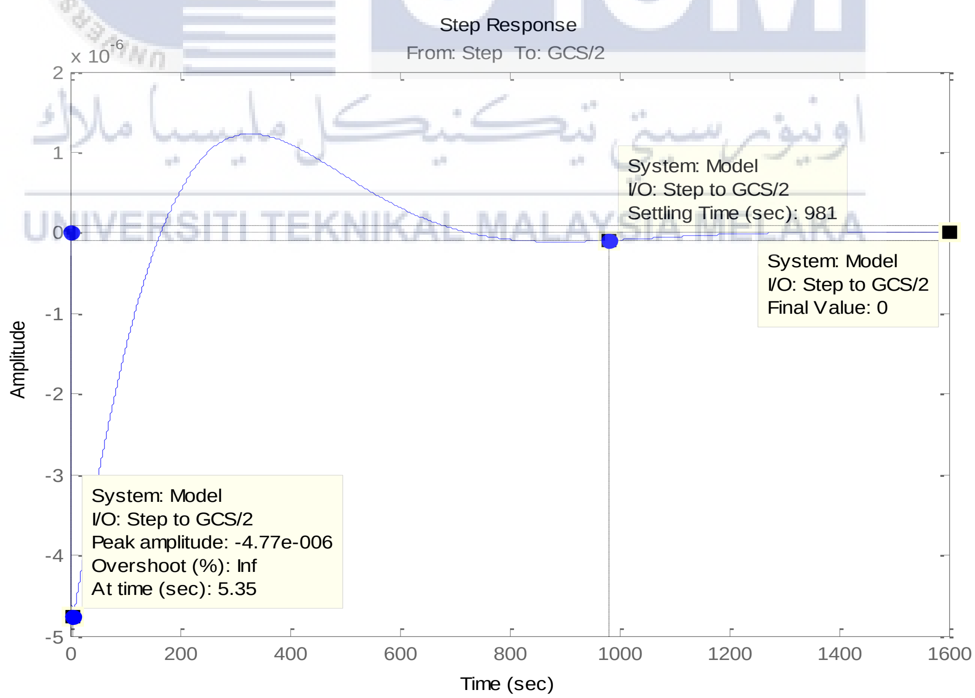
Performance and robustness

	Tuned	Block
Rise time (sec)	219	1.26e+003
Settling time (sec)	685	2.4e+004
Overshoot (%)	8.66	9.4
Peak	1.09	1.09
Gain margin (db @ rad/sec)	-Inf @ 0	149 @ 4.29
Phase margin (deg @ rad/sec)	60 @ 0.0061	60 @ 0.00105
Closed-loop stability	Stable	Stable

Figure 4.6: Setting of PID controller parameter using auto-tuning method



(a)



(b)

Figure 4.7: (a) Response of trolley position (b) Response of payload oscillation

Figure 4.6 shows the result of simulation to responses of trolley position and payload oscillation with PID+PD controller. Table 4.2 shows the performance result for each parameter are also been observed based on OS, Ts and SSE.

Table 4.2: The performance result of GCS with PID+PD controller

Performances				
Trolley Position			Payload oscillation	
SSE (m)	OS (%)	Ts (s)	θ max (rad)	T (s)
0.00	8.34	822	4.47×10^{-3}	981

Based on Table 4.2, OS response of payload oscillation is infinity. This result shows the unacceptable condition for payload oscillation response. However, overshoot response for trolley position is acceptable. Both responses have higher settling time and also take a long time to reach the stable condition.

4.3 Analysis Responses of GCS Performance without Optimization

From the first part of the result show in the simulation of GCS without control, it shows the trolley position and payload oscillation with various system parameters. It is noted that the system dynamic behaviors are affected by the system parameters. Moreover, the system shows that the result could not reach the stable condition.

In the second part, the responses show with the implementation combination PID+PD controller. The result obtained and the system shows in stable condition even the responses time is higher. The responses of the system in Figure 4.7 can be conclude that PID and PD controller cannot control the trolley position and payload oscillation in simultaneously. Even though the auto-tuning method is the simplest method but the value obtained from this method does not refer on the respective parameter. Thus, the optimization will be used for handling this issue.

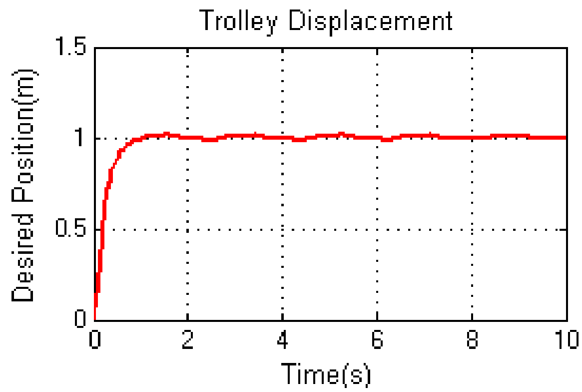
4.4 Implementation of PSO via PFS

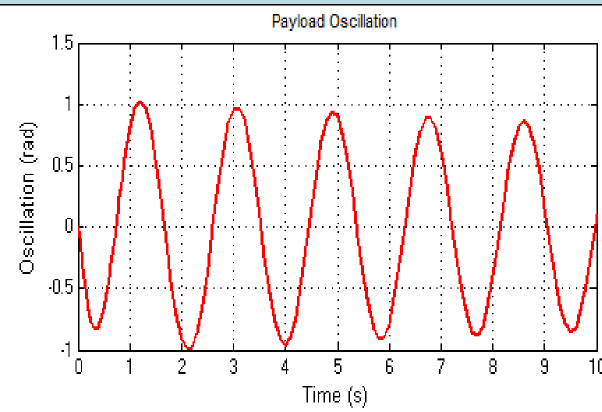
PSO algorithm is proposed to find and tune the optimal parameter of PID+PD controller. In this project, 20 particles are simulated with 100 iterations. The initial particles are bounded at 0 to 200, $c_1$and c_2 are set as 2. The initial value of ω is 0.9 and linearly decreased to 0.4 at some stage in iteration [28].

The of six cases of transient response shown in Table 3.5 in term of arrangement properties in PFS was done with 50 data collected for each cases. Table 4.3 shows the best result that selected from each cases. The result is show in Appendix A.

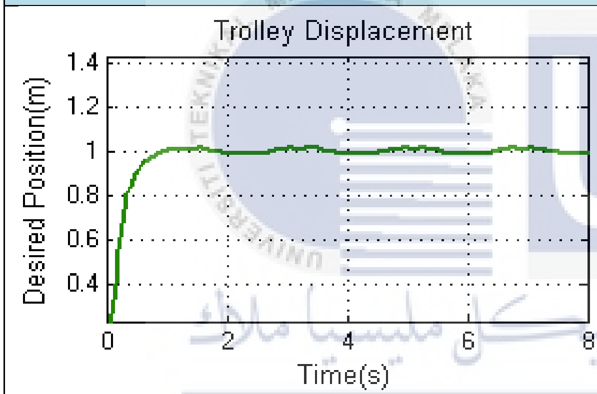
Table 4.3: The system response of six cases

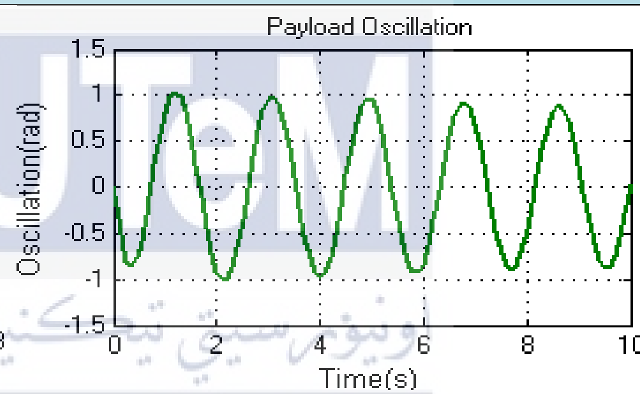
Case 1



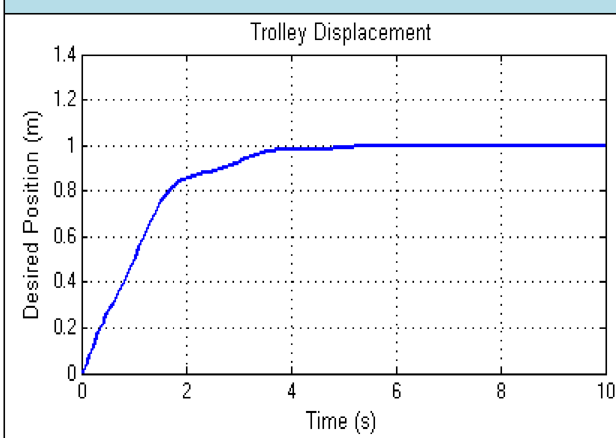


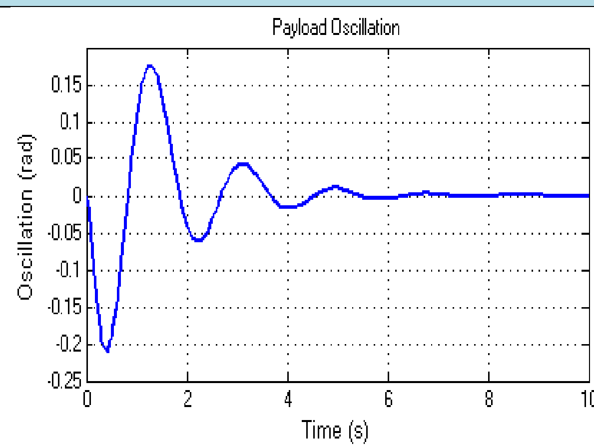
Case 2



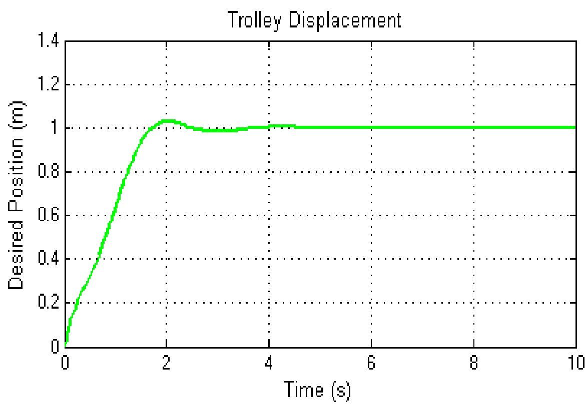


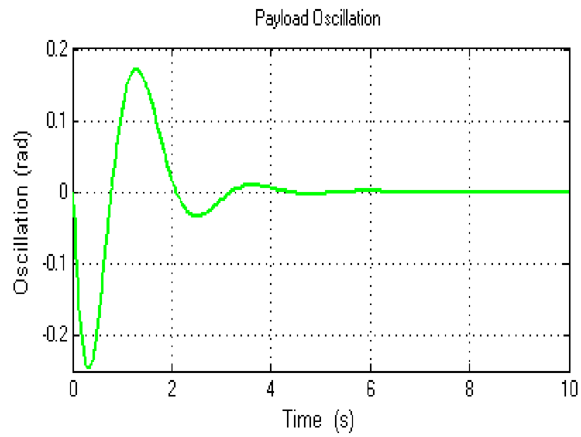
Case 3



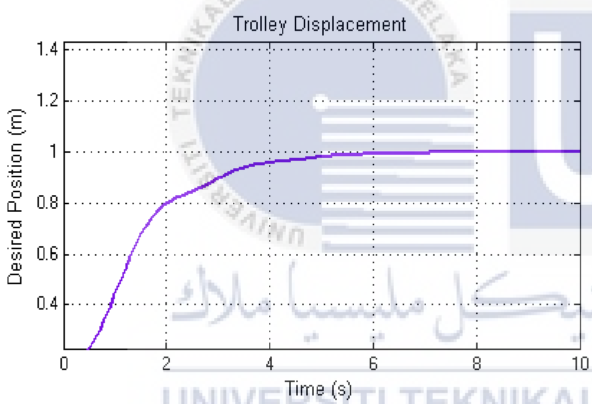


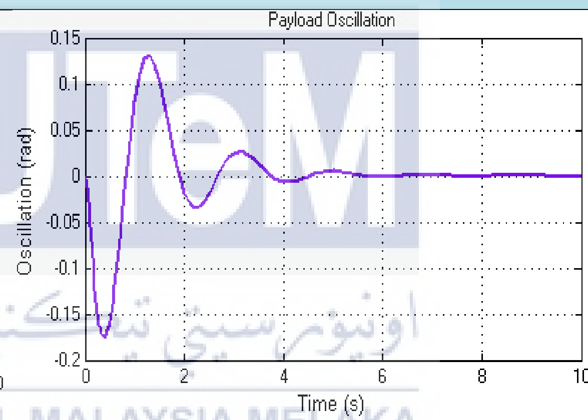
Case 4



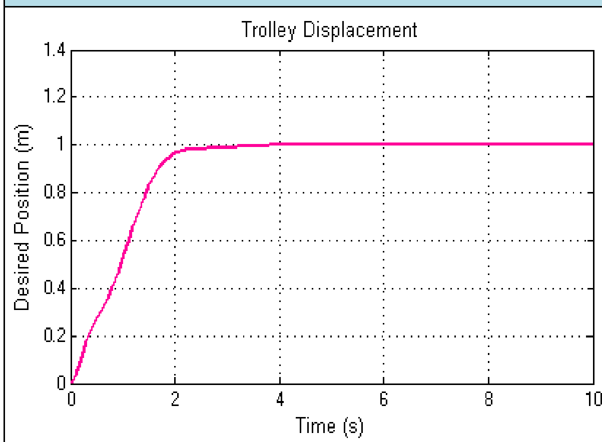


Case 5





Case 6



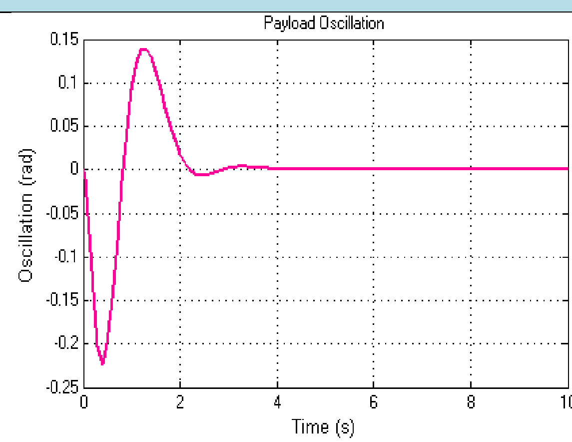


Table 4.4: The summary performances of six cases on GCS

	Trolley Displacement			Payload Oscillation	
	OS (%)	Ts (s)	SSE	Θ_{max}	T(s)
Case 1	1.9592	0.7984	0.0099	1.0253	1.6680
Case 2	1.9680	0.7642	0.0101	1.0381	1.6700
Case 3	0.0147	4.3039	0.0000	0.2100	1.8533
Case 4	2.913	2.247	0.0000	0.246	2.125
Case 5	0.0000	4.9239	0.0000	0.1753	1.8977
Case 6	0.0000	2.2325	0.0000	0.2227	2.2035

	1st Priority		2nd Priority		3rd Priority

Table 4.5: PID and PD parameter of six cases

	PID Controller			PD Controller	
	K_P	K_I	K_D	K_{PS}	K_{DS}
Case 1	248.5908	0.0154	46.4062	0.0787	0.1049
Case 2	249.7825	0.0115	44.4295	0.0243	0.2074
Case 3	37.7647	0.0044	32.8556	41.9819	0.0520
Case 4	125.1931	0.0012	84.7052	197.9454	0.0032
Case 5	35.5036	0.0077	37.4201	56.2508	0.0554
Case 6	26.9260	0.0022	14.1940	44.4394	0.0566

The simulation with the PSO-tuned controller parameter via PFS is executed. Based on Table 4.3 and 4.4, several observations can be analyzed from the result of rearrangement properties of transient responses:

a) In case 1 and 2, Ts is set to be the highest priority. The result provide the lowest value of Ts but the trolley not arrived at the desired position and unstable oscillation.
b) In case 3 and 4, SSE is set as the first priority. The result shows the value of SSE is zero, means that the system is achieved accordingly at the desired position and the value of oscillation is minimum.
c) In case 5 and 6, OS is set as the highest priority. The value of OS is clearly reduce to zero. The system is achieved at the desired position with the zero SSE and stable payload oscillation.

By referring the Table 4.3 and 4.4, it is clearly shows that case 6 is the best result of trolley position and the payload oscillation by tuned by PSO via PFS. The trolley can arrived the desired position with a zero SSE and zero percent of overshoot. Hence, it can archive the desired position which is 1 m without any OS. It also takes very minimum time to arrive at desired position in 2.2325 second.

Moreover, the payload oscillation result shows that the system provide a quite better result between the others. The GCS produce payload oscillate about 0.2227 radian at 2.2035 second. This value of oscillation is related to the trolley position when the system shows there is delay in time in order system going to archive the desired position.

Finally, it can be conclude that the best result of performances with the minimum values of transient responses is case 6. So that, in this system, OS is the highest priority, followed by Ts and SSE. Appendix B shows the result of global best fitness of Case 6 that followed the process of PSO via Priority Fitness Scheme.

4.5 The effect of PFS for controlling robustness

In this part, by taking the best value of PID+PD parameter as shown in Table 4.6, the result of trolley displacement and payload oscillation is varied by the variation of desired position, payload mass and cable length to study the robustness of GCS.

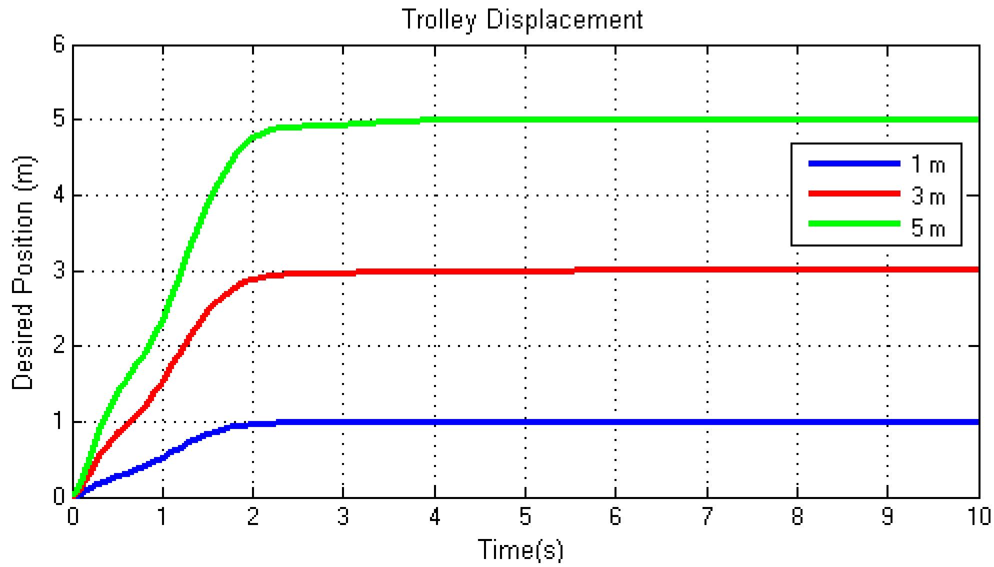
Table 4.6: PID+PD parameters PSO via PFS

PID Gains	Parameters
Kp	26.9260
Ki	0.0022
Kd	14.1940
Kps	44.4394
Kds	0.0566

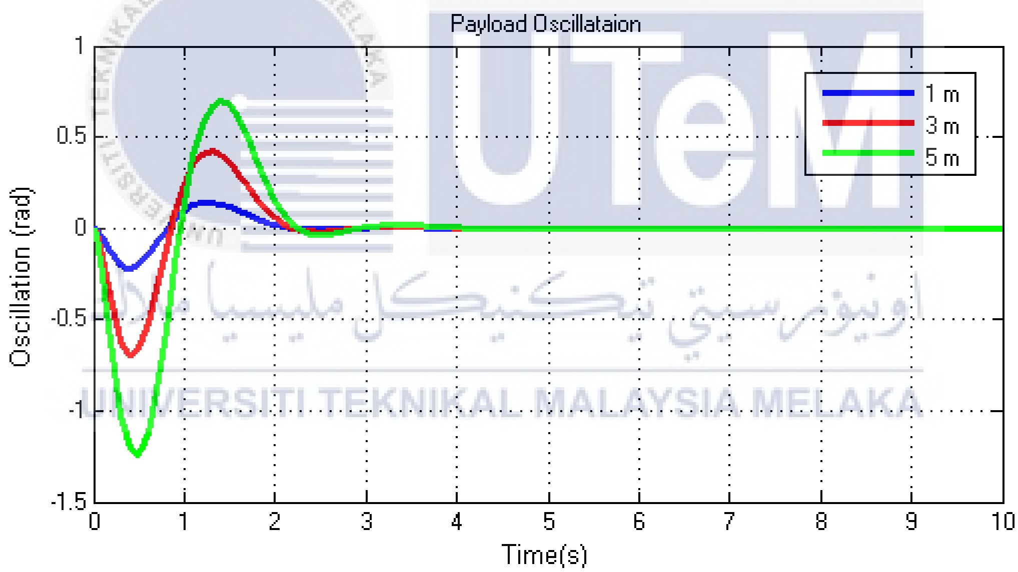
Table 4.7: The performance result of GCS

Performances of GCS				
Trolley Position			Payload oscillation	
OS (%)	Ts (s)	SSE (m)	θ max (rad)	T (s)
0.0000	2.2325	0.0000	0.2227	2.2035

In this part, by taking the best value of PID+PD parameter as shown in Table 4.6, the result of trolley displacement and payload oscillation is varied by the variation of desired position, payload mass and cable length to study the robustness of GCS.



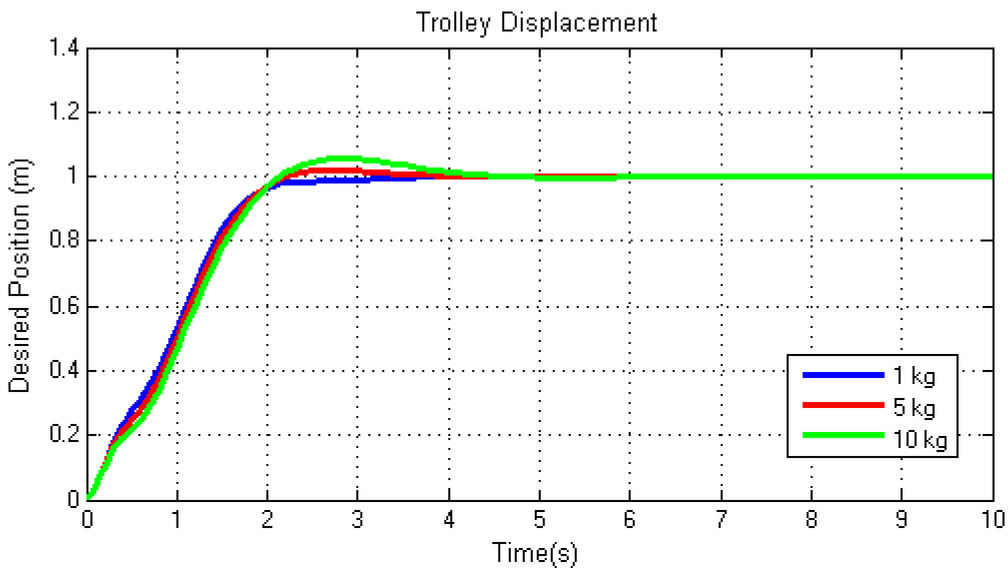
(a)



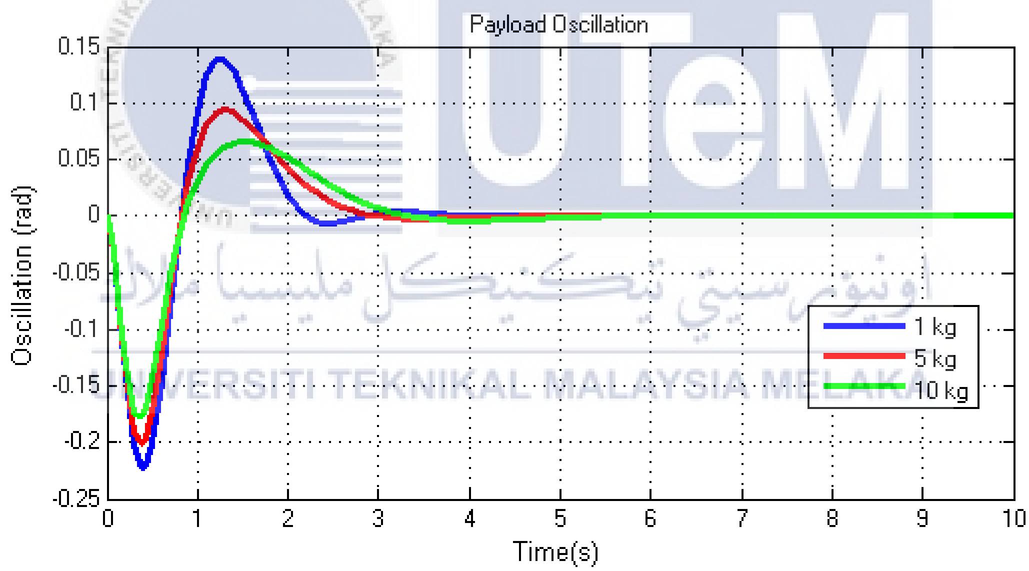
(b)

Figure 4.8: System Response with variation of Desired Position

(a) Trolley displacement (b) Payload Oscillation



(a)

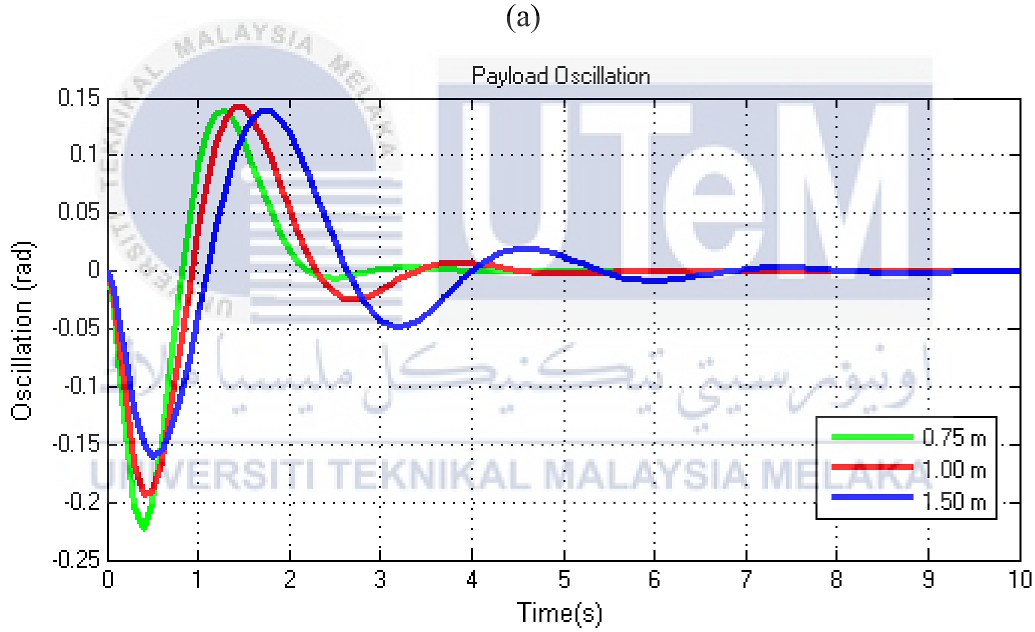


(b)

Figure 4.9: System Response with variation of Payload Mass

(a) Trolley displacement (b) Payload Oscillation

(a)



(b)

Figure 4.10: System Response with variation of Cable length

(a) Trolley displacement (b) Payload Oscillation

Table 4.8: Reading of simulation results for controlling robustness

	Performances of GCS				
	Trolley Position			Payload oscillation	
Desired Position	OS (%)	Ts (s)	SSE (m)	θ max (rad)	T (s)
1.0 m	0.0000	2.2325	0.0000	0.2227	2.1961
3.0 m	0.0000	3.3275	0.0000	0.6905	2.1997
5.0 m	0.0000	3.6130	0.0000	1.2379	2.2527
Payload mass					
1 kg	0.0000	2.2325	0.0000	0.2227	2.2035
5 kg	2.0000	2.7000	0.0000	0.2205	2.9691
10 kg	5.5500	3.8450	0.0000	0.1763	3.3310
Cable length					
0.75 m	0.0000	2.2325	0.0000	0.2227	2.2035
1.00 m	0.800	2.3901	0.0000	0.1943	2.2955
1.50 m	5.100	3.467	0.0000	0.1610	2.6328

In Table 4.1 show the summaries of simulation reading for input desired position, payload mass and cable length. Based on Table 4.7, several observations can be analyzed from the result:

i. For trolley displacement, when short desired position is applied to the system it produces a lower Ts while the value of SSE and OS is zero. However, the oscillation is increasing but the time is reduced.

ii. Higher mass of payload is increase the value of OS and Ts of trolley displacement with a zero SSE while the payload oscillation is decreasing but required more time to settle down.

iii. Lastly, by increasing the length of cable it will be increased the value of OS of trolley displacement with a zero SSE. Then, decreasing of payload oscillation can be seen when the cable length is increased.

4.6 Conclusions

Based on the result, it shows that the performance of result of the GCS without controller and the GCS with PID+PD controller implementation. The analysis shows the better performance occur when applying the controller to the system. However, the result of trolley position and payload oscillation cannot be control in the same time.

PSO algorithm is applied via PFS to improve the parameter of PID+PD controller. The system responses changed with the rearrangement of properties of OS, Ts and SSE that which one are chosen to be set as first, second and third priority.

As the result, OS has the highest priority followed by Ts and SSE. However, the value of SSE clearly show a zero value even it is set as third priority. The effect of PFS for controlling the robustness of this system have been evaluated by those best parameter to achieve the better performances of GCS.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

As a conclusion, PID and PD controller had been successfully designed to control movement of trolley to the desired position and minimizing the payload oscillation on GCS. Nonlinear equation of the system has been derived using Lagrange's equation. The actual behavior of dynamic nonlinear of GCS was discussed by comparing both simulation with and without controller. The performance of the system may achieve the good performance but it quite difficult to control both PID and PD controller in the same time. Furthermore, to overcome the problem, PSO algorithm is implemented via PFS to find the optimal parameter of PID and PD controller. The effect of PFS have been examined by using the best transient response arrangement which is Overshoot, OS% is the first priority, followed by Settling Time, Ts and the Steady state error, SSE to control the robustness of GCS. Finally, the simulation result shows the system performances become more effective to move the trolley as fast as possible to the desired position with low payload oscillation.

5.2 Recommendation and Future Work

From the conclusion, PID and PD controller shows a better performance in controlling the trolley position and payload oscillation. However, when control the PID for the trolley position, the PD controller will definitely disturbed the result of payload oscillation. Therefore, PSO algorithm will be implement via PFS to tuned the PID and PD controller for better performance. Future research about the robustness of GCS in term of external disturbance is recommended.

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APPENDIX A

DATA COLLECTIONS

DATA CASE 1

	Trolley Displacement			Payload Oscillation	
No.	Ts (s)	0S (%)	SSE	θ_{max} (rad)	T (s)
1	0.7455	1.9957	0.8107	1.0500	1.6740
2	0.8388	1.9617	0.4698	1.0100	1.6648
3	0.8397	1.9990	0.6591	1.0025	1.6650
4	0.8374	1.8808	0.6351	1.0080	1.6637
5	0.8156	1.9800	0.7112	1.0183	1.6650
6	0.8791	1.8119	0.5668	0.9906	1.6608
7	0.8112	1.9919	0.7218	1.0217	1.6650
8	0.8235	1.9758	0.7037	1.0161	1.6645
9	0.8235	1.9758	0.7037	1.0159	1.6645
10	0.8044	1.9880	0.7250	1.0236	1.6659
11	0.7709	1.9921	0.7624	1.0332	1.6700
12	0.8856	1.7572	0.5528	0.9885	1.6597
13	0.8735	1.8125	0.5638	0.9913	1.6613
14	0.9341	1.5326	0.3993	0.9629	1,6585
15	0.8701	1.8609	0.5979	0.9940	1.6616
16	0.7984	1.9592	0.7298	1.0253	1.6680
17	0.8098	1.9772	0.7104	1.0204	1.6657
18	0.8164	1.9439	0.6943	1.0179	1.6650
19	0.9616	1.5864	0.3824	0.9550	1.6565
20	0.7895	1.9965	0.7219	1.0286	1.6678
21	0.7887	1.9848	0.7494	1.0287	1.6677
22	0.8450	1.8378	0.6307	1.0077	1.6628
23	0.8276	1.9992	0.6608	1.0037	1.6673
24	0.8683	1.8234	0.5884	0.9959	1.6616
25	0.8902	1.7128	0.5330	0.9862	1.6692
26	0.8878	1.7194	0.5339	0.9870	1.6597
27	0.8878	1.7194	0.5339	0.9870	1.6597
28	0.8131	2.0000	0.7164	1.0183	1.6659
29	0.8477	1.8540	0.6391	1.0060	1.6627
30	0.8396	1.9999	0.6771	1.0060	1.6647
31	0.8601	1.9107	0.6266	0.9993	1.6621
32	0.8368	1.9463	0.6812	1.0107	1.6632
33	2.4222	0.7329	0.1225	0.6332	1.6784

34	0.8872	1.7931	0.5456	0.9845	1.6600
35	0.8608	1.9978	0.6303	0.9935	1.6644
36	0.8245	1.9674	0.6937	1.0134	1.6651
37	0.8446	1.9999	0.6679	1.0043	1.6640
38	0.8416	1.9054	0.6582	1.0085	1.6628
39	1.6551	1.9927	0.4173	0.2131	1.9500
40	1.6551	1.9927	0.4173	0.2131	1.9500
41	0.8263	1.9921	0.6902	1.0125	1.6650
42	0.7937	1.9993	0.7377	1.0265	1.6673
43	0.8472	1.9502	0.6603	1.0040	1.6630
44	0.8810	1.8481	0.5765	0,9885	1.6600
45	0.8563	1.8648	0.6278	1.0018	1.6622
46	0.8229	1.9914	0.7031	1.0142	1.6655
47	0.8023	1.9926	0.7322	1.0245	1.6660
48	0.9696	1.5460	0.4101	0.9566	1.6563
49	0.8202	1.8604	0.6690	1.0167	1.6650
50	0.7935	1.9771	0.7398	1.0270	1.6670

DATA CASE 2

	Trolley Displacement			Payload Oscillation	
No.	Ts (s)	SSE	0S (%)	θ_{max} (rad)	T (s)
1	1.2661	0.0115	1.7252	0.7825	1.6566
2	0.8296	0.6725	1.8989	1.0145	1.6641
3	0.8160	0.6996	1.9788	1.0185	1.6650
4	0.8362	0.6764	1.9319	1.0111	1.6635
5	0.7764	0.7723	1.9955	1.0350	1.6687
6	0.9212	0.4576	1.7024	0.9706	1.6578
7	0.7802	0.7514	1.9756	1.0320	1.6687
8	0.8473	0.6590	1.9962	1.0014	1.6648
9	1.6577	0.7103	1.9696	0.1934	2.0071
10	0.8591	0.6308	1.9468	0.9991	1.6624
11	0.9930	1.1379	1.9815	0.9160	1.6635
12*	1.6718	0.1505	1.9671	0.1780	2.0611
13	0.8944	0.5231	1.7465	0.9825	1.6600
14	0.9841	0.3701	1.6025	0.9393	1.6578
15	0.8814	0.5409	1.7491	0.9885	1.6606
16	0.8388	0.6450	1.9097	1.0082	1.6633
17	0.8340	0.6795	1.9953	1.0086	1.6650
18	0.8186	0.6864	1.9555	1.0150	1.6655
19	0.8752	0.3377	1.9577	0,9920	1.6629
20	0.8434	0.6667	2.0000	1.0050	1.6642
21	0.8414	0.6754	1.9692	1.0071	1.6637
22	0.8090	0.7053	1.9357	1.0020	1.6653

23	0.8663	0.5948	1.8302	0.9985	1.6610
24	0.9177	0.5216	1.8741	0.9896	0.9685
25	1.7330	0.2962	1.9990	0.2756	1.8465
26	0.8881	0.4139	1.5405	0.9813	1.6601
27	1.7585	0.1113	1.9388	0.2912	1.9145
28	0.8267	0.6845	1.9986	1.0100	1.6656
29	0.7642	0.7789	1.9680	1.0381	1.6700
30	1.6510	0.1402	1.9995	0.2355	1.8935
31	0.8530	0.6461	1.9988	0.9981	1.6644
32	0.8609	0.6052	1.8959	0.9970	1.6623
33	0.9033	0.5558	1.9697	0.9715	1.6630
34	0.7917	0.7046	1.8792	1.0256	1.6655
35	0.8097	0.7272	1.9938	1.0222	1.6649
36	0.8612	0.6072	1.8153	1.0005	1.6610
37	0.8698	0.5852	1.8555	0.9928	1.6619
38	0.8832	0.5573	1.8084	0.9871	1.6601
39	0.8333	0.6714	1.9929	1.0065	1.6658
40	0.8279	0.6881	1.9953	1.0105	1.6660
41	0.7978	0.7376	1.9896	1.0250	1.6655
42	1.0753	0.2438	1.3861	0.9050	1.6560
43	0.8325	0.6732	1.9215	1.0115	1.6635
44	1.6463	0.1551	1.9996	0.2110	1.9454
45	0.8215	0.6892	1.9150	1.0170	1.6650
46	0.7958	0.7332	1.9778	1.0265	1.6650
47	0.9198	0.4613	1.6148	0.9750	1.6605
48	0.7782	0.7653	1.99557	1.0323	1.6685
49	0.8301	0.6815	1.9533	1.0155	1.6648
50	0.8847	0.3448	1.9054	0.9889	1.6618

DATA CASE 3

	Trolley Displacement			Payload Oscillation	
No.	SSE	Ts (s)	0S (%)	θ_{max} (rad)	T (s)
1	0.0000	3.8697	40.5659	0.3195	2.3415
2	0.0001	3.4219	12.7473	0.3253	2.0233
3	0.0000	5.8376	0.0000	0.2603	1.7200
4	0.0000	4.7362	0.4836	0.2663	1.7320
5	0.0001	5.2734	30.4834	0.3409	2.0125
6	0.0000	4.0213	46.0947	0.3573	2.2745
7	0.0000	4.6017	6.0995	0.4810	1.8452
8	0.0020	4.8360	0.4267	0.2772	1.7708
9	0.0001	5.4041	56.0487	0.4120	2.1573
10	0.0000	4.7404	33.9153	0.3239	2.0748
11	0.0000	4.8724	0.2033	0.2069	1.7700
12	0.0000	3.2345	9.3091	0.3125	1.9385
13	0.0003	4.9125	0.4035	0.2650	1.7440

14	0.0000	6.3851	0.0550	0.2242	1.7574
15	0.0000	5.4244	8.5673	0.5525	1.8357
16	0.0000	5.1454	0.0136	0.2855	1.7180
17	0.0000	3.0411	1.4214	0.2913	1.8122
18	0.0003	4.3407	1.0471	0.3776	1.7108
19	0.0000	4.6020	0.5768	0.3174	1.7606
20	0.0002	4.5923	5.9039	0.4727	0.4727
21	0.0025	5.0323	32.9464	0.2706	2.1926
22	0.0017	4.5934	39.7445	0.3571	2.1269
23	0.0007	5.6828	0.0000	0.2664	1.7176
24	0.0001	6.7137	35.0474	0.4900	1.9000
25	0.0000	5.4079	8.4222	0.5420	1.8389
26	0.0000	4.5332	0.7153	0.3224	1.7500
27	0.0000	4.5258	0.5808	0.3314	1.7557
28	0.0000	4.7555	0.3550	0.2380	1.7525
29	0.0000	4.6811	0.0703	0.2118	1.8128
30	0.0000	4.2465	21.2902	0.6715	1.7433
31	0.0000	3.0531	1.2395	0.2861	1.8025
32	0.0000	3.0878	0.9021	0.2610	1.8066
33	0.0000	2.6105	1.8056	0.6610	1.6975
34	0.0003	3.0756	0.9875	0.2973	1.7665
35	0.0005	3.3170	9.9048	0.2972	1.7666
36	0.0002	5.7136	0.1740	0.2572	1.7455
37	0.0003	6.4766	28.1048	0.3683	2.2563
38	0.0000	3.7940	7.3284	0.3697	1.8037
39	0.0000	4.2752	42.9249	0.4449	1.9661
40	0.0005	4.3186	1.9582	0.5252	1.6869
41	0.0000	3.4037	10.5047	0.2983	2.0504
42	0.0000	4.2246	1.8740	0.5330	1.6964
43	0.0003	9.8127	48.1879	0.6790	1.6798
44	0.0003	6.1643	0.1600	0.2410	1.7265
45	0.0000	4.3039	0.0147	0.2100	1.8533
46	0.0000	2.5787	1.7023	0.6650	1.6978
47	0.0003	4.1713	21.2124	0.6567	1.7455
48	0.0002	4.7048	14.0372	0.6432	1.8150
49	0.0004	5.2150	3.8516	0.1234	1.4657
50	0.0000	6.4102	0.1191	0.1995	1.7485

DATA CASE 4

	Trolley Displacement			Payload Oscillation	
No.	SSE	0S (%)	Ts (s)	θ_{max} (rad)	T (s)
1	0.0000	0.4836	4.7363	0.2664	1.7320
2	0.0000	30.4834	5.2734	0.3408	2.0126
3	0.0000	6.0995	4.6017	1.4820	1.8460
4	0.0020	0.4267	4.8460	0.2771	1.7708

5	0.0000	56.0487	5.4041	0.4071	2.1575
6	0.0000	0.2033	4.8724	0.2070	1.7700
7	0.0000	9.3091	3.2345	0.3220	1.9387
8	0.0004	0.4035	4.9125	0.2650	1.7440
9	0.0000	8.5673	5.4244	0.5546	1.8356
10	0.0000	1.4214	3.0411	0.2760	1.8120
11	0.0000	2.913	2.247	0.246	2.125
12	0.0000	0.5768	4.6020	0.3178	1.7600
13	0.0002	5.9039	4.5923	0.4728	1.8450
14	0.0025	32.9464	5.0323	0.2705	2.1925
15	0.0017	39.7445	4.5934	0.3576	2.1268
16	0.0000	0.4836	4.7362	0.2664	1.7320
17	0.0001	30.4834	5.2734	0.3400	2.0000
18	0.0000	6.0995	4.6017	0.4800	1.8450
19	0.0001	56.0487	5.4041	0.4070	2.1555
20	0.0000	0.2033	4.8724	0.2070	1.7700
21	0.0000	9.3091	3.2345	0.3212	1.9384
22	0.0003	0.4035	4.9125	0.2650	1.7440
23	0.0000	8.5673	5.4244	0.5526	1.8357
24	0.0000	1.4214	3.0411	0.2915	1.8121
25	0.0000	0.5768	4.6020	0.3174	1.7600
26	0.0003	5.9039	4.5923	0.4726	1.8472
27	0.0025	32.9464	5.0323	0.2706	2.1926
28	0.0017	39.77445	4.5934	0.3576	2.1267
29	0.0000	8.4222	5.4079	0.5420	1.8391
30	0.0000	0.7153	4.5332	0.3224	1.7500
31	0.0000	0.3550	4.7555	0.2380	1.7522
32	0.0000	0.0703	4.6811	0.2120	1.812
33	0.0000	21.2902	4.2465	0/6716	1.7433
34	0.0000	1.2395	3.0531	0.2860	1.8000
35	0.0000	0.9021	3.0878	0.2610	1.8070
36	0.0000	1.8056	2.6105	0.6610	1.6955
37	0.0000	0.4836	4.7362	0.2664	1.7321
38	0.0001	30.4834	5.2734	0.2400	2.0127
39	0.0000	6.0995	4.6017	0.4810	1.8460
40	0.0020	0.4267	4.8369	0.2772	1.7700
41	0.0001	56.0487	5.4041	0.4070	2.1577
42	0.0000	33.9153	4.7404	0.3240	2.0749
43	0.0000	0.2033	4.8724	0.2070	1.7700
44	0.0000	9.3091	3.2345	0.3213	1.9384
45	0.0000	0.0550	6.3851	0.2250	1.7574
46	0.0000	8.5673	5.4244	0.5525	1.8357
47	0.0000	1.4214	3.0411	0.2914	1.8120
48	0.0000	0.5768	4.6020	0.3174	1.7600
49	0.0003	5.9039	4.5923	0.4727	1.8456
50	0.0025	32.9464	5.0323	0.2706	2.1923

DATA CASE 5

	Trolley Displacement			Payload Oscillation	
No.	0S (%)	SSE	Ts (s)	θ_{max} (rad)	T (s)
1	0.0000	0.0001	5.4760	0.1088	2.900
2	0.0000	0.0000	5.3760	0.1088	2.900
3	0.0000	0.0013	8.7457	0.0829	1.8955
4	0.0000	0.0007	5.6701	0.2660	1.7203
5	0.0000	0.0000	5.6636	0.1555	1.8645
6	0.0000	0.0000	6.6917	0.1356	1.8900
7	0.0000	0.0000	6.2602	0.2382	1.7303
8	0.0000	0.0000	6.2727	0.2375	1.7287
9	0.0000	0.0000	6.7630	0.1582	1.800
10	0.0000	0.0009	9.8556	0.1200	2.1588
11	0.0000	0.0000	5.4136	0.2730	1.7210
12	0.0000	0.0001	6..7379	0.1918	1.7762
13	0.0000	0.0002	7.2796	0.1650	1.7962
14	0.0000	0.0007	5.2838	0.2809	1.7157
15	0.0000	0.0008	9.6870	0.0329	2.6550
16	0.0000	0.0002	5.2850	0.1660	1.8523
17	0.0000	0.0000	5.7945	0.2619	1.7220
18	0.0000	0.0003	6.4358	0.1546	1.8000
19	0.0000	0.0002	6.3511	0.2318	1.7339
20	0.0000	0.0000	5.7518	0.2628	1.7250
21	0.0000	0.0004	4.3321	0.1875	1.9290
22	0.0000	0.0000	5.7951	0.2620	1.7200
23	0.0000	0.0000	6.5167	0.1005	1.9745
24	0.0000	0.0005	9.8749	0.2689	1.7860
25	0.0000	0.0000	5.1077	0.1711	1.8635
26	0.0000	0.0000	4.9239	0.1753	1.8977
27	0.0000	0.0000	5.1419	0.1745	1.8355
28	0.0000	0.0001	6.0087	0.1548	1.8410
29	0.0000	0.0000	6.1358	0.2460	1.7271
30	0.0000	0.0000	5.92253	0.2567	1.7236
31	0.0000	0.0000	6.8496	0.1859	1.7665
32	0.0000	0.0003	6.4527	0.2250	1.7345
33	0.0000	0.0000	6.6223	0.2087	1.7540
34	0.0000	0.0006	3.5861	0.1429	1.9748
35	0.0000	0.0000	5.7566	0.2635	1.7988
36	0.0000	0.0019	6.5642	0.2100	1.7575
37	0.0000	0.0019	5.7869	0.2627	1.7155
38	0.0000	0.0013	6.8014	0.0676	1.5466
39	0.0000	0.0002	7.3250	0.1221	1.8551
40	0.0000	0.0000	5.7445	0.2640	1.7255
41	0.0000	0.0000	6.5968	0.2041	1.7655
42	0.0000	0.0000	5.4368	0.2725	1.7200
43	0.0000	0.0012	6.8210	0.1844	1.7821
44	0.0000	0.0000	9.8738	0.2789	1.7988
45	0.0000	0.0000	6.3896	0.2260	1.7500

46	0.0000	0.0000	6.2541	0.2379	1.7400
47	0.0000	0.0001	8.6858	0.0477	1.7548
48	0.0000	0.0004	7.7561	0.0841	1.9781
49	0.0000	0.0004	7.7561	0.0882	1.7641
50	0.0000	0.0004	5.4892	0.2723	1.7200

DATA CASE 6

	Trolley Displacement			Payload Oscillation	
No.	0S (%)	Ts (s)	SSE	θ_{max} (rad)	T (s)
1	0.0000	2.2605	0.0000	0.1943	2.5225
2	0.0000	2.2453	0.0000	0.1928	2.5382
3	0.0000	2.2555	0.0000	0.1893	2.5600
4	0.0000	3.6780	0.0000	0.4643	2.5630
5	0.0000	2.3383	0.0000	0.1790	2.7530
6	0.0000	4.6901	0.0012	0.3213	1.7114
7	0.0000	3.2932	0.0009	0.1943	2.2127
8	0.0000	2.2605	0.0001	0.1943	2.5222
9	0.0000	2.2453	0.0001	0.1928	2.5388
10	0.0000	2.2555	0.0000	0.1893	2.5608
11	0.0000	8.8698	0.0000	0.1456	2.7860
12	0.0000	2.3382	0.0004	0.1790	2.7537
13	0.0000	4.6901	0.0028	0.3212	1.7110
14	0.0000	3.2932	0.0008	0.1943	2.2129
15	0.0000	2.3031	0.0001	0.1809	2.5900
16	0.0000	2.4541	0.0001	0.1606	2.7120
17	0.0000	2.5534	0.0000	0.1597	3.4700
18	0.0000	2.3028	0.0002	0.1787	2.6075
19	0.0000	2.9466	0.0010	0.1545	3.0000
20	0.0000	2.3534	0.0003	0.1714	2.8800
21	0.0000	2.2325	0.0000	0.2227	2.2035
22	0.0000	4.5169	0.0006	0.3385	1.7356
23	0.0000	2.7956	0.0001	0.2183	2.1030
24	0.0000	2.3430	0.0005	0.1736	2.8010
25	0.0000	2.2539	0.0000	0.1930	2.7200
26	0.0000	2.3671	0.0001	0.1904	2.8900
27	0.0000	2.6571	0.0001	0.1937	4.0000
28	0.0000	2.5785	0.0000	0.1857	2.9900
29	0.0000	3.1017	0.0007	0.1865	2.4000
30	0.0000	3.2735	0.0000	0.1732	2.5700
31	0.0000	2.2568	0.0001	1.9100	2.6155
32	0.0000	2.6937	0.0005	1.5181	3.5000
33	0.0000	4.2470	0.0002	0.1325	1.8963
34	0.0000	2.3370	0.0000	0.1901	3.0300
35	0.0000	2.3231	0.0003	0.1804	2.6060
36	0.0000	5.2124	0.0015	0.2250	1.7172

37	0.0000	4.7356	0.0006	0.3175	1.7120
38	0.0000	2.7853	0.0004	0.1644	3.3300
39	0.0000	2.2900	0.0000	0.1999	2.6900
40	0.0000	2.3337	0.0004	0.1750	2.8000
41	0.0000	2.2308	0.0003	0.1880	2.5821
42	0.0000	5.2030	0.0018	0.2850	1.7160
43	0.0000	2.5405	0.0002	0.1698	2.8650
44	0.0000	4.6403	0.0000	0.1827	1.9000
45	0.0000	3.2200	0.0001	0.1740	2.8620
46	0.0000	2,4015	0.0001	0.1903	2.4834
47	0.0000	2.3253	0.0001	0.1740	2.8620
48	0.0000	4.3873	0.0042	0.1770	1.9680
49	0.0000	2.3376	0.0002	0.1876	2.7445
50	0.0000	2.3351	0.0000	0.1725	2.8667

APPENDIX B

GLOBAL BEST FITNESS OF CASE 6

	Global Best Fitness

27	0.0000	4.9610	0.0270

Iteration	OS	Ts	SSE
1	0.0000	9.8374	121.6166
2	0.0000	9.4358	95.5988
3	0.0000	9.4319	102.7679
4	0.0000	9.4319	102.7679
5	0.0000	9.4319	102.7679
6	0.0000	9.4319	102.7679
7	0.0000	9.4319	102.7679
8	0.0000	9.4319	102.7679
9	0.0000	9.4319	102.7679
10	0.0000	9.4319	102.7679
11	0.0000	9.4319	102.7679
12	0.0000	9.4319	102.7679
13	0.0000	9.4319	102.7679
14	0.0000	9.4319	102.7679
15	0.0000	9.4319	102.7679
16	0.0000	9.4319	102.7679
17	0.0000	9.4319	102.7679
18	0.0000	9.4319	102.7679
19	0.0000	9.4319	102.7679
20	0.0000	9.3686	105.3466
21	0.0000	8.3308	2.0887
22	0.0000	5.6922	0.0124
23	0.0000	5.6922	0.0124
24	0.0000	4.9610	0.0270
25	0.0000	4.9610	0.0270
26	0.0000	4.9610	0.0270
28	0.0000	4.9610	0.0270
29	0.0000	4.9610	0.0270
30	0.0000	4.9610	0.0270
31	0.0000	4.9610	0.0270
32	0.0000	2.7820	0.0265
33	0.0000	2.7820	0.0265
34	0.0000	2.7820	0.0265
35	0.0000	2.7820	0.0265
36	0.0000	2.7820	0.0265
37	0.0000	2.7820	0.0265
38	0.0000	2.7820	0.0265
39	0.0000	2.7820	0.0265
40	0.0000	2.7820	0.0265
41	0.0000	2.7820	0.0265
42	0.0000	2.7097	0.0059
43	0.0000	2.7097	0.0059
44	0.0000	2.7097	0.0059
45	0.0000	2.7097	0.0059
46	0.0000	2.7097	0.0059
47	0.0000	2.7097	0.0059
48	0.0000	2.7097	0.0059
49	0.0000	2.7097	0.0059
50	0.0000	2.7097	0.0059
51	0.0000	2.7097	0.0059
52	0.0000	2.7097	0.0059
53	0.0000	2.7097	0.0059
54	0.0000	2.7097	0.0059
55	0.0000	2.7097	0.0059
56	0.0000	2.7097	0.0059
57	0.0000	2.7097	0.00599
58	0.0000	2.7097	0.0059
59	0.0000	2.7097	0.0059
60	0.0000	2.7097	0.0059
61	0.0000	2.7097	0.0059
62	0.0000	2.7097	0.0059
63	0.0000	2.7097	0.0059
64	0.0000	2.7097	0.0059
65	0.0000	2.2324	0.0079
91	0.0000	2.2324	0.0079
92	0.0000	2.2324	0.0079
93	0.0000	2.2324	0.0079
94	0.0000	2.2324	0.0079
95	0.0000	2.2324	0.0079
96	0.0000	2.2324	0.0000
97	0.0000	2.2324	0.0000
98	0.0000	2.2324	0.0000
99	0.0000	2.2324	0.0000
100	0.0000	2.2324	0.0000

66	0.0000	2.2324	0.0079
67	0.0000	2.2324	0.0079
68	0.0000	2.2324	0.0079
69	0.0000	2.2324	0.0079
70	0.0000	2.2324	0.0079
71	0.0000	2.2324	0.0079
72	0.0000	2.2324	0.0079
73	0.0000	2.2324	0.0079
74	0.0000	2.2324	0.0079
75	0.0000	2.2324	0.0079
76	0.0000	2.2324	0.0079
77	0.0000	2.2324	0.0079
78	0.0000	2.2324	0.0079
79	0.0000	2.2324	0.0079
80	0.0000	2.2324	0.0079
81	0.0000	2.2324	0.0079
82	0.0000	2.2324	0.0079
83	0.0000	2.2324	0.0079
84	0.0000	2.2324	0.0079
85	0.0000	2.2324	0.0079
86	0.0000	2.2324	0.0079
87	0.0000	2.2324	0.0079
88	0.0000	2.2324	0.0079
89	0.0000	2.2324	0.0079
90	0.0000	2.2324	0.0079