"I hereby declare that I have read through this report entitle "*The Effectiveness of Variation Weight Summation Approach for Gantry Crane System via Multi Objective Gravitational Search Algorithm (MOGSA)"* and found that it has comply partial fulfillment for awarding the degree of Bachelor of electrical Engineering (Control, Instrumentation & Automation)"

Signature : ……………………………………

Supervisor's Name : En. Hazriq Izzuan bin Jaafar

Date : 1st June 2015

THE EFFECTIVENESS OF VARIATION WEIGHT SUMMATION APPROACH FOR GANTRY CRANE SYSTEM VIA MULTI OBJECTIVE GRAVITATIONAL SEARCH ALGORITHM (MOGSA)

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

"I declare that this report entitle "*The Effectiveness of Variation Weight Summation Approach for Gantry Crane System via Multi Objective Gravitational Search Algorithm (MOGSA)*" is the result of my own research except as cited in th references. The report has not been accepted for any degree and is not concurrently submitted in candidature of other degree.

Signature : ……………………………………………

Name : Anis Sofea binti Ahmad Tamizi

Date : 1st June 2015

To my beloved father and mother

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First and foremost, thanks to Allah s.w.t for giving me this healthy body that enables me to complete this report in the frame of time as well as gaining new knowledge and experience.

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ABTRACT

Gantry Crane System (GCS) is known as an object that able to lift heavier load horizontally from one point to another point. It is commonly used in industry for heavy load related in transporting and loading large objects. Moreover, the applications of GCS also are not perfect since that there are always have disturbance when transporting the load. Regarding to this, the probabilities to cause dangerous to the surrounding area are high. Thus, to prevent this, many researchers try to investigate on how to prevent this problem. By using various kind of algorithm, the result shows which kind of algorithm are better to obtain high optimization of GCS. This report focuses the implementation a new algorithm known as Gravitational Search Algorithm (GSA) into GCS. This algorithm gain interest by many researchers since the introduced in 2009. Therefore, the GSA will be implemented with 5 controllers of (PID+PD) into GCS to obtain a good optimization. By using MATLAB R2012a, the simulations of block diagram GCS will be modeled by using mathematical function of Lagrange Equation. This algorithm will be implemented Multi Objective Gravitational Search Algorithm (MOGSA) technique and the result will be compared with another algorithm from previous journal known as Multi Objective Particle Swarm Optimization (MOPSO). The result obtained shows that MOGSA are better in optimization than MOPSO.

ABSTRAK

Gantri Kren Sistem (GCS) dikenali sebagai satu objek yang mampu mengangkut beban dari satu tempat ke tempat yang lain. Ia biasanya digunakan dalam industri untuk beban berat yang tertumpu dalam pengangkutan objek yang besar. Selain itu, aplikasi GCS juga tidak sempurna kerana terdapat gangguan apabila mengangkut beban. Sehubungan dengan itu, kebarangkalian system ini menyebabkan bahaya kepada kawasan sekitarnya adalah tinggi. Oleh itu, ramai para penyelidik cuba untuk menyiasat mengenai bagaimana untuk mengelakkan masalah ini berlaku. Dengan menggunakan pelbagai jenis algoritma, hasil yang ingin dinyatakan bahawa algorithma yang terbaik adalahan algorithma yang mampu mendapatkan pengoptimuman yang tinggi. Laporan ini memberi tumpuan pelaksanaan algoritma baru yang dikenali sebagai Carian Graviti Algorithma (GSA) ke dalam GCS. Algorithma ini amat dikenali oleh ramai penyelidik semenjak ia diperkenalkan pada tahun 2009. Oleh itu, GSA akan dilaksanakan dengan menggunakan 5 kawalan (PID + PD) ke dalam GCS untuk mendapatkan pengoptimuman yang baik. Dengan menggunakan MATLAB R2012a, simulasi gambarajah blok GCS akan dimodelkan dengan menggunakan fungsi matematik Persamaan Lagrange. Algoritma ini akan menggunakan teknik Multi Objektif Carian Graviti Algorithma (MOGSA) sebagai hasil dimana ianya akan dibandingkan dengan algoritma lain yang dikenali sebagai Multi Objektif Pengoptimunan Kumpulan Zarah (MOPSO).Hasil menunjukkan MOGSA mempunyai pengoptimunan yang baik berbanding MOPSO.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

x	-	Displacement
θ	-	Oscillation
V	-	Voltage
L	-	Inductance
B	-	Damping Ratio
R	-	Resistance
K_t	-	Torque constant
K_e	-	Electric constant
z	-	Gear ratio
r_p	-	Radius of pulley
g	-	Gravity
i	-	Armature current
m	-	Mass
l	-	Length
θ_m	-	Rotor angle position
T_m	-	Motor torque
T_L	-	Load torque

LIST OF ABBREVIATIONS

AB	-	Armed Bandit
BGSA	-	Binary Gravitational Search Algorithm
BPSO	-	Binary Particle Swarm Optimization
DGSA	-	Discrete
DFS	-	Depth First Search
FACTS	-	Flexible AC Transmission System
FL	-	Fuzzy Logic
GA	-	Genetic Algorithm
GABSA	-	Gravitational Algorithm Based on Simulated Annealing
GCPSO	-	Guaranteed Coverage Particle Swarm Optimization
GCS	-	Gantry Crane System
GSA	-	Gravitational Search Algorithm
LMI	-	Linear Matrix Inequalities
LMQ	-	Lloyd-Max Quantization
MGSA	-	Memory Gravitational Search Algorithm
MOGSA	-	Multi Objective Gravitational Search Algorithm
MOPSO	-	Multi Objective Particle Swarm Optimization
NOGSA	-	Non-dominated Sorting Gravitational Search Algorithm
MAS	-	Multi Agent System
PCB	-	Printed Circuit Board
PSO	-	Particle Swarm Optimization
UPFC	-	Unified Power Flow Controller
WSN	-	Wireless Sensor Network

LIST OF APPEDICES

CHAPTER 1

INTRODUCTION

1.1 Gantry Crane System

The Gantry Crane System (GCS) is a lifting object by a hoist which can move horizontally on a rail or pair of rails fitted under a beam. GCS is suited to lift a heavy objects and huge gantry cranes that are mostly used for ship building. GCS is commonly used in industry for heavy load that related with the process of transporting and carrying the load.

Figure 1.1: Gantry Crane System (GCS)

GCS consists of trolley, which in horizontal plane. The payload is attached to the trolley by a cable vertically, whose length can be varied by a hoisting mechanism. The load with the cable is treated in one-dimensional pendulum and moves in linear direction. The operations of GCS in many industrial are achieved based on the skill of the experienced crane operators. The precise payload positioning is difficult to control due to the fact that the payload is free to swing in a pendulum-like motion. If the payload performance is not concern, it may cause damage to the surrounding environment and personnel. Thus, the controllers are always used to achieve fast and reliable response with reduced cost and high precision positioning.

1.2 Problem Statement

There are several problem statements as listed below:

1. Moving the payload using the crane is not an easy task especially when strict specifications on the swing angle and on the transfer time need to be satisfied.

2. The usage of GCS to transfer the load are not safety due to the natural characteristic such as swing, robustness or error that might be occur and cause incident.

3. Conventional tuning technique of PID controller parameter is a constraint for finding the optimum condition value. Finding the optimal value for PID controller parameter is significantly contributed to the advancement of control system knowledge and fulfills with industrial needs.

1.3 Objectives

There are three objectives need to be achieved:

- To model the linear and nonlinear of Gantry Crane System (GCS) using Lagrange Equation.
- To analyze the linear weight summation approach for obtaining optimal PID+PD controller parameters and performance in terms of overshoot, settling time and steady-state error.
- To compare the performance of overshoot, settling time and steady-state error response between Multi Objective Gravitational Search Algorithm (MOGSA) and Multi Objective Particle Swarm Optimization (MOPSO).

1.4 Scopes

This research focuses more on:

1. Derivation and modeling the linear and non-linear equation of the GCS via Lagrange equation.

2. Apply the optimal PID+PD controller to control the performance of payload by using PD controller and various desired position of trolley displacement by using PID controller.

3. Observe the simulation of overshoot, settling time and steady-state error on trolley displacement with different payload oscillation.

4. Implement the Multi Objective Gravitational Search Algorithm (MOGSA) to solve highly optimization problems in GCS.

1.5 Motivation

One of the most priorities when dealing a real work environment is safety. Many cases and accident can occur during handling the crane. On 2nd February 2012, at Port Mann Bridge, Canada, it was reported where 700 tons of Gantry Crane fell down. The distinctive yellow Gantry Crane was holding about 90 tons sections of the bridge deck. Due to this situation, it causes danger to people nearby and employee. Thus, many factors must be considered not only to reduce the accident but also to prevent the loss of innocent life.

1.6 Report Outlines

Chapter 1 is an introduction about GCS in real life environment where the problem statement, objectives, scopes and motivation of projects are stated clearly.

Chapter 2 discusses the review from previous researchers on GSA applications from 2009 until 2015. The advantages of GSA are determined and conclude as a reason to implement this algorithm to GCS.

Chapter 3 is about methodology that will be used for this project. The mathematical calculation for Lagrange equation for linear and non-linear are derived. GCS is modeled by using MATLAB Simulink software. The GSA technique also will be implemented in GCS

Chapter 4 focuses on the result obtained from the simulation. The block diagram of GCS is modeled and the performance responses from the output are included in the graph. The different output response are discussed and analyzed between linear and non-linear equations for the first phase. At the second phase, the result of GCS with five parameter controller (PID+PD) will be shown. Lastly, the result involves the analysis of the linear weight summation performance by using MOGSA technique and will be compared with MOPSO technique performance.

Chapter 5 is a conclusion from the overall report done and some recommendations for future works also are stated.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter focuses the review from previous research about the system that has been implemented via Gravitational Search Algorithm (GSA). Based on the previous review, this GSA is known as one of the technique in algorithm that suitable to solve optimization problem in engineering system.

2.2 PID Control Systems

PID controller has been widely used in various industries and known as a control feedback mechanism controller. It involves three term parameters which consist of proportional (P), integral (I) and derivative (D). The PID is used to minimize the error by adjusting the process control inputs and improve the error value that occur between a measured process variable and a desired set point.

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

In PID controller, three parameters need to be tuned. A proportional controller (***K_P***) has the effect of decreasing the rise time and steady state error but the percentage of overshoot in the system was increased. For the integral controller (***K_I***), the rise time also decrease but it will eliminate the steady state error in the system while the percentage of overshoot remains high together with settling time as well. Another parameter known as derivative controller (***K_D***) has the ability to improve the transient response and increase the stability of the system. This characteristic of P, I and D performance can be summarized as Table 2.1 below:

Table 2.1: PID Controller Properties

Controller	**Effect of performance**			
	Rise Time (T_r)	**Steady State Error (SSE)**	**Overshoot (OS)**	**Settling Time (T_s)**
Proportional (P)	Decrease	Decrease	Increase	Small Change
Integral (I)	Decrease	Eliminate	Increase	Increase
Derivative (D)	Small Change	Small Change	Decrease	Decrease

The performances of ***K_P***, ***K_I*** and ***K_D*** are dependent on each other. If one of these changes, it might be affecting the other two controller performances as well. Thus, Table 2.1 is used as a reference to obtain high stability and short transient response of the system.

2.3 Gravitational Search Algorithm

Gravitational Search Algorithm (GSA) is one of the latest meta-heuristic algorithms introduced by Rashedi *et al*. in 2009 that inspired by the Newtonian Law of Gravity: "Every particle in the universe attracts each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them"

[1]. The GSA has been applied mostly in complex engineering system such as hole drilling process, simulated annealing, retaining structure, real power loss and voltage deviation optimization, hexagonal honeycomb sandwich plate, discrete optimization problem and etc. Typically, GSA is a standard algorithm that can be applied in various systems. Since the introduction, due to the great interest by lots of researcher around the world, this algorithm has been enhanced to be more specified cases such as Binary Gravitational Search Algorithm (BGSA), Memory Gravitational Search Algorithm (MGSA), Non-dominated Sorting Gravitational Search Algorithm (NOGSA) and Multi Objective Gravitational Search Algorithm (MOGSA). In this project, the MOGSA will be applied to the GCS and compare the performance response result between Multi Objective Particle Swarm Optimization (MOPSO).

2.4 Research on Gravitational Search Algorithm

In order to get a better optimization, Rashedi et al. have introduced a new optimization based on the law of gravity and mass interactions [1]. The agents are considered as objects where their performances are measured by their masses. The agents consist of four specifications: position, inertia mass, active gravitational mass, and passive gravitational mass. In other word, this mass presented as an optimum solution in the search space. The heavier of the mass indicates as a better agent which has higher attractions and walk more slowly. This can cause a faster convergence rate and search the space more locally.

Hassanzadeh et al. proposed a MOGSA that focuses the methods on how close the obtained result are to the global optimum [2]. The optimizations problems are not aimed to single objective but rather to maximize a set of objective exist as MOPSO. By using the MOGSA, the optimization problems can be recognize as this technique are able to set a balance between two important factor by tuning K-parameter.

For Muneendra Ojha, the GSA has been modified by implementing the Multi Agent System (MAS) to find the optimum strategy in managing demand supply chain management and observes the pattern of product usage [3]. The result of GSA shows functionally useful for optimized solution to a non-linear and dynamic problem domain, where MAS have capability choose to perform the action that of result in the optimal outcome for itself among all feasible actions.

In addition, Sudin et al. modified the GSA known as Discrete Gravitational Search Algorithm (DGSA) for discrete optimization problems based on its direction and velocity [4]. The DGSA shows its advantages as it is superior rather than the existing BGSA in terms of quality of solution found and speed of convergence as well as less likely to trap in local minima.

Other researchers also use this kind of technique to presents an effective optimization method for nonlinear constrained of retaining structures. Khajehadeh et al. applied GSA controls all geotechnical and structured design constraints while reducing the cost of retaining walls [5]. The optimization result shows that the GSA required far fewer iteration and less computational time when compared with Particle Swarm Optimization (PSO) and GA. Thus, it is extremely well for solving the economic design of retaining structure.

To achieve high optimization, Suresh et al. have applied the GSA for real power loss and voltage deviation optimization to solve multi constrained optimal reactive power flow problem in power system [6]. The performance of GSA is tested on standard IEEE-30 bus test system using MATLAB. By using the parameter, the results are compared with other method to prove the effectiveness of the new algorithm like PSO and BBO. The result stated that GSA takes less number of iterations while maintaining the global best result. The GSA also is capable to achieving global optimal solution and good in dealing with power system optimization problems.

Shendi et al. proposed a commitment of hydro thermal generation scheduling of a large power system with cooling-banking constraint by using GSA [7]. Since that the objective is to minimize the total system operating cost, GSA is applied and demonstrated. The result shows that the GSA is capable to finding highly near global solutions. It also states that, the application of GSA is cheaper in optimal cost usage rather than other published work applied.

The applications of GSA have been widely used in industrial field, thus the researchers Saucer et al. have proposed an Optimizing Nano photonic cavity design with the Gravitational Search Algorithm [8]. This journal focuses on the designing photonic crystal cavities with high quality factor. The GSA is applied as they randomly place “agents” in eight dimensional parameter spaces to evaluate the quality factor and mode volume. GSA proves that it is able to solve complex problem.

The researcher by Norlina et al. focuses more about an outlook on Gravitational Search Algorithm (GSA) to determine how far the research and development has been done since the introduction of the algorithm [9]. Four parameter which are position, inertia mass, active gravitational mass and passive gravitational mass are set up as agents. Based on result, it shows that GSA are able to solve highly optimization problems of complex engineering system where it can produce result more consistently with high precision. Moreover, it has stable convergence characteristic compared to Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). In contrast of this, there are some disadvantages regarding to this algorithm as it using complex operators and long computational time. It is difficult to appropriate selection of gravitational constant parameter, G and does not guarantee a global solution all the time.

Other than that, there are some researcher that giving an idea to improve the GSA method. Tong Cheng YI proposed a new improved algorithm of Simulated Annealing called Gravitational Search Algorithm Based on Simulated Annealing (GABSA), where it is effectiveness to overcome the randomness of the individual moves and enhance the local search ability if the algorithm [10]. The GSA itself may cause damage to the individual position and local search ability, thus introduce new improved algorithm that has obvious advantages in convergence speed, convergence accuracy and etc. The GSA based on Simulated Annealing are able to renter the algorithm both global and local search capabilities. The performance result shows that GABSA is better than usual GSA in convergence speed and accuracy due to higher speed employed by annealing algorithm. This gives the advantages as the annealing operation capable to improve the convergence speed and search accuracy.

Furthermore, the application of GSA can be used for design a structure. The researcher by Boudjemai et al. use this algorithm to deals the design of hexagonal honeycomb sandwich plate optimization using GSA technique [11]. The design of hexagonal honeycomb consists of large number of design variables including material design, shape and geometry. Hence, to get the design optimization, the GSA is applied to get optimization process and compare with Genetic Algorithm (GA) and gradient-based algorithm. As a result, the GSA performs very well in speed of convergence and ability to make high-aspect ratio core than GA and gradient-based algorithm.

Omar et al. proposed an experimental study of the application of GSA has been used in solving route optimization problem for holes drilling process on Printed Circuit Board (PCB) using MATLAB R2011a [12]. By using the changes parameter of beta(β) and zeta(Ɛ), the GSA shows a better average fitness and managed to find the optimal route with smaller average iteration number than Guaranteed Coverage Particle Swarm Optimization (GCPSO), PSO and Binary Particle Swarm Optimization (BPSO).

The GSA technique also has been used in Flexible AC Transmission System (FACTS) to find the optimal location of Unified Power Flow Controller (UPFC). Nandakumar et al. used GSA to improve the voltage profile of system and reduce real power losses [13]. As a result, the location of UPFC was optimized as well as able to reduce real powerless and improve the voltage stability in power transmission system. Thus, the implementation of GSA shows its capability to find the best optimal solution in UPFC.

Recently, Yuvaraya et al. proposed a Fuzzy and Gravitational Search Based Routing Protocol for Lifetime Enhancement in Wireless Sensor Network (WSN) due to the increasing mobile users [14]. The GSA is applied to solve the problem for searching the path as well as find the global optimum faster and high convergence rate. The fuzzy is used to estimate the node cost. The researcher divided into two phase of methodology; starts from fuzzy in the first phase and GSA at the second phase. As a result, GSA efficiently works to find optimal solution in search space and shows a good convergence rate in WSN.

2.5 Summary

Table 2.2: Summary of the system applied in GSA

No.	Year	System	Researcher
[1]	2009	GSA: A Gravitational Search Algorithm	Esmat Rashedi et al.
[2]	2010	A Multi Objective Gravitational Search Algorithm	Hamid Reza Hassanzadeh et al.
[3]	2012	Optimizing Supply Chain Management using Gravitational Search Algorithm and Multi Agent System.	Muneendra Ojha
[4]	2012	A Modified Gravitational Search Algorithm for Discrete Optimization Problem	Shahdan Sudin et al.
[5]	2012	Gravitational Search Algorithm for optimization of retaining structure	Mohammad Khajehzadeh et al.
[6]	2013	Application of Gravitational Search Algorithm for Real Power Loss and Voltage Deviation Optimization	R. Suresh et al.
[7]	2013	Application of UPFC Tuned Based on Gravitational Search Algorithm to Damping Low Frequency Oscillations	Ahad Jahandided Shendi, Ali Ajami
[8]	2013	Optimizing Nano Photonic Cavity Design with the Gravitational Search Algorithm	Timothy W. Saucer and Vanesa Sih
[9]	2013	A Review of Gravitational Search Algorithm	Norlina et al.
[10]	2014	Gravitational Search Algorithm using Simulated Annealing	Tong Cheng Yi
[11]	2014	Hexagonal Honeycomb Sandwich Plate Optimization using Gravitational Search Algorithm	A. Boudjemai et al.
[12]	2014	An experimental study of the application of GSA in solving route optimization problem for holes drilling process	Norhaizat Omar et al.

[13]	2014	Optimal Location of UPFC in Power System Using Gravitational Search Algorithm	E. Nandakumar, R. Mani
[14]	2015	Fuzzy and Gravitational Search Based Routing Protocol for Lifetime Enhancement in Wireless Sensor Networks	M.Yuvaraja, M. Sabrigiriraj

2.6 Advantages of GSA

Table 2.3: Advantages of GSA

Advantages	References
Able to set a balance between two important factors by tuning K-parameter.	[10]
Inspires by a physical phenomenon.	[1]
Able to find the best route for holes drilling process.	[9]
Obvious advance in convergence speed and convergence precision.	[6][13]
Suitable for optimization of retaining structures and find a better optimal solution	[8]
Ability to make high-aspect ratio cores	[7]
Less number of iterations while maintaining the global best result.	[5]
Ability to solve highly optimization problems of complex engineering systems.	[2][14]
Produce result more consistently with high precision.	[2]
Useful for optimized solution to a non-linear and dynamic problem domain.	[3]
Less likely to trap in a local minima.	[4]

Based on the previous researcher, it can be conclude that GSA has its own advantages to solve highly optimization problem in complex engineering system. Since the introduction of GSA, most of the researcher found out that GSA technique performs the best result in the optimal outcome compared with other algorithms. The result from various applications shows that GSA is functionally useful to solve optimization problem while maintaining the global best result. Thus, it is one of the factors why GSA technique will be implemented in GCS.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter focuses the methodology that will be used for MOGSA in GCS. The model of the GCS will be derived by using mathematical equation. Next, the simulation for modeling the GCS also is conducted by using MATLAB Simulink software.

3.2 Flow Chart

Upon completion of this research, steps of process are made according to this flow chart. The Figure 3.1 shows the flow chart for this research methodology from Phase 1 until Phase 2.

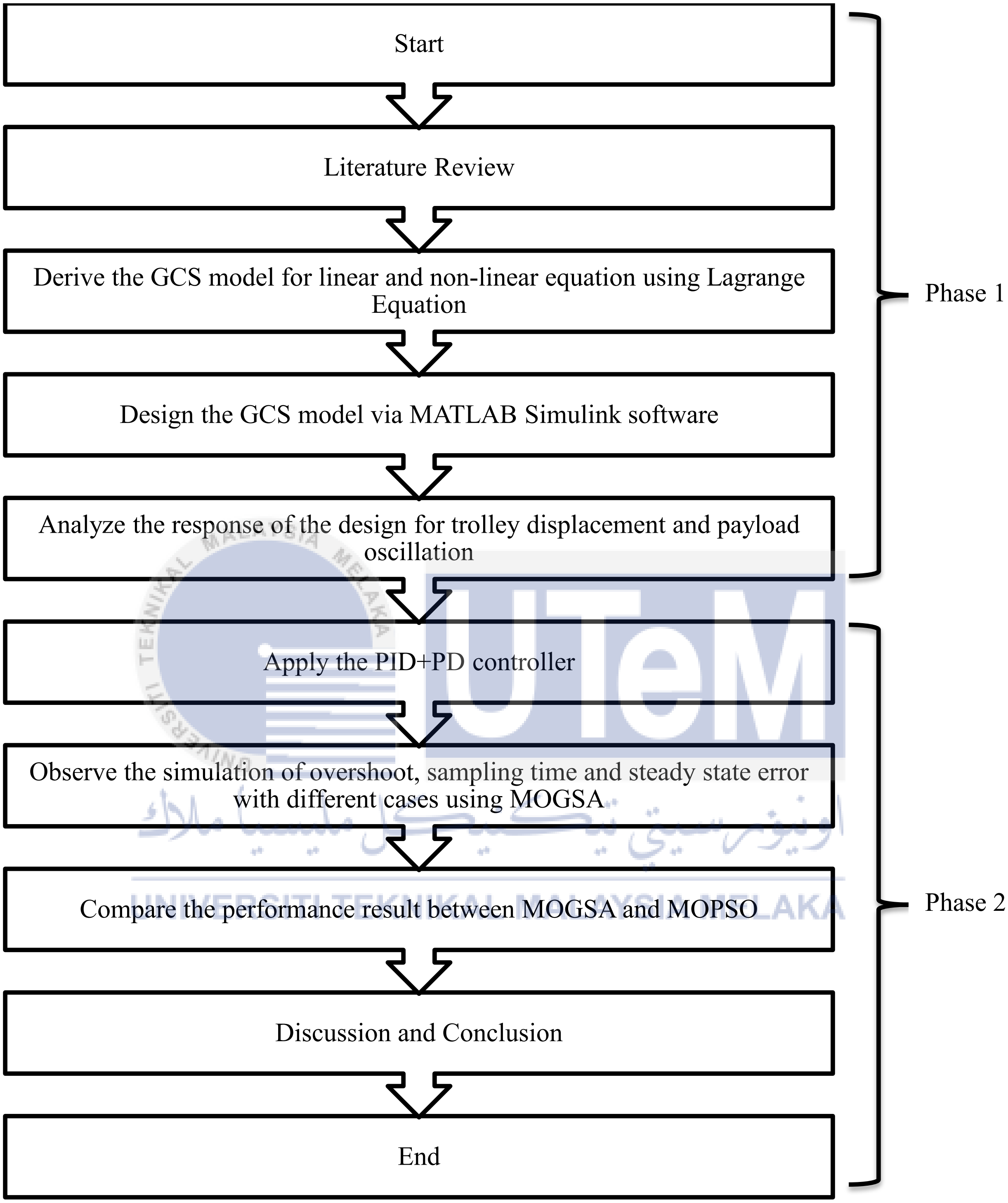

Figure 3.1: Process of the overall project

In Phase 1, the information and data required to conduct this research are gathered and presented in Chapter 2. After gathered some data, the GCS model for linear and non-linear system are derived using Lagrange equation. Then, the model for GCS is designed in block diagram using MATLAB Simulink, where the equation is implemented into the subsystem. The subsystem consists of two parts which are for linear and non-linear, thus giving a different output to each subsystem. These to subsystem are analyzed based on the output for trolley displacement and payload oscillation.

After completing the analysis for GCS, the model will be added by using PID+PD controller to achieve the objective for Phase 2. The simulation of the overshoot, settling time and steady state error with different cases will be analyzed using MOGSA. Lastly, all the result, analysis and discussion will be presented in research report.

3.3 Project Summary

In this methodology, the project summary also used to show the process of overall selection in completing this project as shown in Figure 3.2.

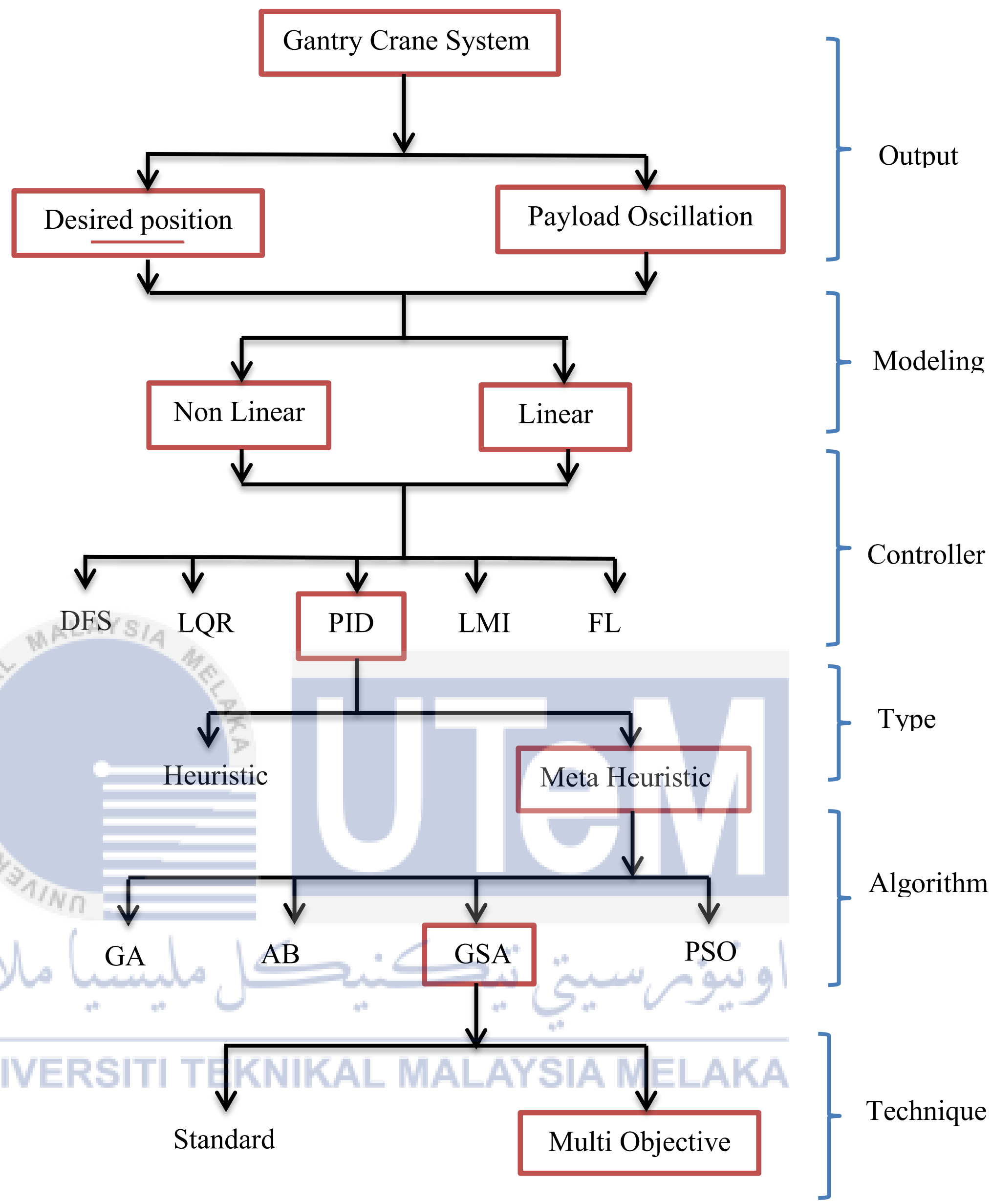

Figure 3.2: Project summary of Gantry Crane System (GCS).

Based on the Figure 3.2, the GCS consists of system response with desired position and payload oscillation that will be used via MATLAB to verify the performance of the controller. There are two types equation that will considered which are linear and non-linear. Then, the controller used five parameters (PID+PD) controller for utilized position and oscillation control of the system. This controller specified using meta-heuristic technique of

Gravitational Search Algorithm (GSA). Meta-heuristic is a mathematical optimization that provides a sufficiently good solution to an optimization problem and the result based on computer experiments with the algorithms. The implementation of multi objective into GSA will be analyzed and the result can be compared to MOPSO.

3.4 Modeling of GCS

Figure 3.3 shows the block diagram model of Gantry Crane System (GCS). The block diagram consist PID controller for trolley displacement and PD controller for payload oscillation. The output of x is considered as the performance of trolley displacement while θ considered as the performance of payload oscillation.

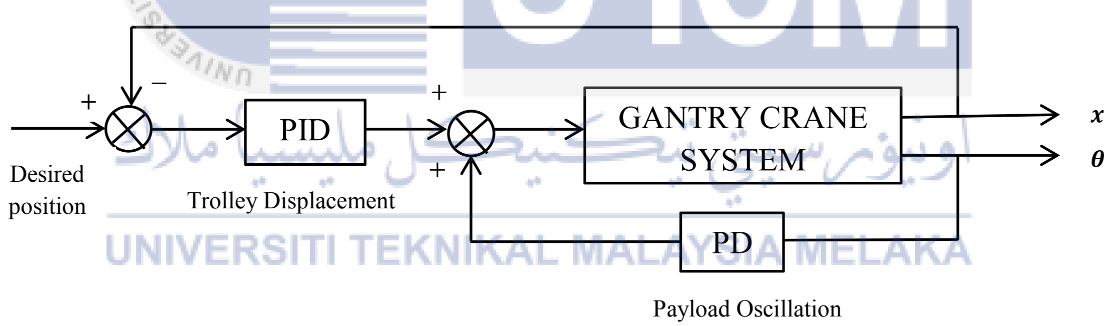

Figure 3.3: Block diagram model of Gantry Crane System (GCS)

Table 3.1 shows the system parameter that will be applied for GCS. The system parameters are based from previous journal by Jaafar et al. that applied this parameter value for GCS via Multi Objective Particle Swarm Optimization (MOPSO) technique [15]. By using the same parameter with different technique, the performance of nonlinear GCS via Multi Objective Gravitational Search Algorithm (MOGSA) and MOPSO will be compared.

Table 3.1: System parameters [15]

Parameter	Value (Unit)
Payload mass (*m1*)	0.5 kg
Trolley mass (*m2*)	2.0 kg
Cable length (*L*)	0.5 m
Damping coefficient (*B*)	0.001 Ns/m
Torque constant (*Kt*)	0.007 Nm/A
Electric constant (*Ke*)	0.007 Vs/rad
Resistance (*R*)	2.6 Ω
Gear Ratio (*z*)	0.15
Radius of Pulley (*rp*)	0.02 m
Gravitational (*g*)	9.81 m/s^2

3.5 Mathematical modeling of Lagrange equation

The Lagrange equation is a technique that has been developed by Joseph-Louis Lagrange, a French mathematician who derived this equation in the early 19^{th} century. This method used to find equations of motion for mechanical system and able to express the kinetic energy and potential energy of rigid body, as well as the virtual work done by non-conservative external force referred to as generalized forces.

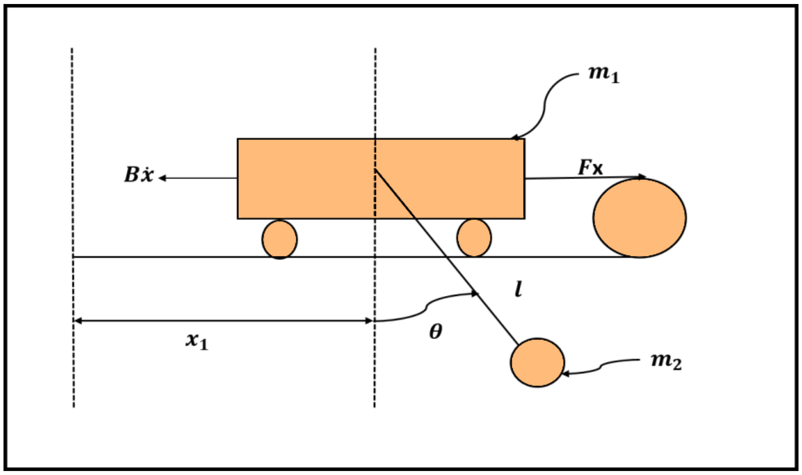

Figure 3.4: Schematic diagram of nonlinear GCS.

The Lagrange Equation,

$$\frac{d}{dt}\left[\frac{\partial L}{\partial \dot{q}_i}\right] - \left[\frac{\partial L}{\partial q_i}\right] = Q_i \tag{3.1}$$

where L, Q_i and q_i represent Lagrange function.

The Lagrange function is defined as:

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

$$L = \frac{1}{2}\left(m_1\dot{x}^2 + m_2\dot{x}^2 + m_1 l^2\dot{\theta}^2\right) + m_1\dot{x}\dot{\theta}l cos\theta + m_1 g l cos\theta \tag{3.3}$$

where T and V are respectively kinetic energy and potential energy.

<u>The equation motion of GCS:</u>

For $q_1 = x$

$$(m_1 + m_2)\ddot{x} + m_1 l\ddot{\theta}cos\theta - m_1 l\dot{\theta}^2 sin\theta + B\dot{x} = F \tag{3.4}$$

For $q_2 = \theta$

$$m_1 l^2 \ddot{\theta} + m_1 l \ddot{x} cos\theta + m_1 g l sin\theta = 0 \qquad (3.5)$$

The equation of F represents force. From the DC motor, the equation of F is obtained as below:

$$F = \frac{V K_t r}{R r_p} - \frac{K_e K_t r^2}{R {r_p}^2} \dot{x} \qquad (3.6)$$

Substitute the equation (1.6) into (1.4); a complete nonlinear differential equation of the GCS can be obtained as:

$$V = \left[\frac{R r_p B}{K_t \dot{r}} + \frac{K_e r}{r_p}\right] \dot{x} + \left[\frac{R r_p}{K_t r}\right] (m_1 + m_2) \ddot{x} + \left[\frac{R r_p}{K_t r}\right] (m_1 l) \left[\ddot{\theta} cos\theta - \dot{\theta}^2 sin\theta\right] \qquad (3.7)$$

$$m_1 l^2 \ddot{\theta} + m_1 l \ddot{x} cos\theta + m_1 g l sin\theta = 0 \qquad (3.8)$$

To make simpler analysis, this model can be linearized by assuming small θ during control system.

$$\therefore \sin\theta \approx 0$$
$$\cos\theta = 1$$

Therefore, the linear equation is obtained as:

$$V = \left[\frac{R r_p B}{K_t \dot{r}} + \frac{K_e r}{r_p}\right] \dot{x} + \left[\frac{R r_p}{K_t r}\right] \ddot{x} + \left[\frac{R r_p}{K_t r}\right] (m_1 l) \ddot{\theta} \qquad (3.9)$$

$$l \ddot{\theta} + \ddot{x} + g\theta = 0 \qquad (3.10)$$

where:

l = *cable length*
V = *Input Voltage*
R = *Resistance*
L = *Inductance*
i = *Armature current*
g = *gravity*
K_t = *torque constant*
K_e = *electric constant*
θ_m = *Rotor angle position*
R = *gear ratio*

T_m = Motor torque *r_p = radius of pulley*

T_L = Load torque

By deriving and substituting the equation, the mathematical model for nonlinear system for trolley displacement equation and payload oscillation equation are obtained.

1) Nonlinear trolley displacement equation

$$\ddot{x} = \left[\frac{K_t r}{Rr_p(m_1+m_2-m_1 cos^2\theta)}\right] V - \left[\frac{B}{m_1+m_2-m_1 cos^2\theta} + \frac{K_e K_t r^2}{Rr_p(m_1+m_2-m_1 cos^2\theta)}\right]\dot{x} + \left[\frac{m_1 sin\theta cos\theta}{m_1+m_2-m_1 cos^2\theta}\right] + \left[\frac{m_1 \theta^2 sin\theta}{m_1+m_2-m_1 cos^2\theta}\right] \quad (3.11)$$

2) Nonlinear payload oscillation equation

$$\ddot{\theta} = -\left[\frac{K_t r cos\theta}{Rr_p l(m_1+m_2-m_1 cos^2\theta)}\right] V - \left[\frac{B cos\theta}{l(m_1+m_2-m_1 cos^2\theta)} + \frac{K_e K_t r^2 cos\theta}{Rr_p{}^2 l(m_1+m_2-m_1 cos^2\theta)}\right]\dot{x} + \left[\frac{m_1 g sin\theta cos^2\theta}{l(m_1+m_2-m_1 cos^2\theta)}\right] + \left[\frac{m_1 l \theta^2 sin\theta}{m_1+m_2-m_1 cos^2\theta}\right] - \frac{g sin\theta}{l} \quad (3.12)$$

Next, the mathematical model for linear system for trolley displacement equation and payload oscillation equation are obtained.

1) Linear trolley displacement equation

$$\ddot{x} = \left[\frac{K_t r}{Rr_p m_2}\right] V + \left[\frac{B}{m_2} + \frac{K_e K_t r^2}{Rr_p{}^2 m_2}\right]\dot{x} - \left[\frac{m_1 g}{m_2}\right]\theta \quad (3.13)$$

2) Linear payload oscillation equation

$$\ddot{\theta} = \left[\frac{K_t r}{Rr_p l m_2}\right] V + \left[\frac{B}{l m_2} + \frac{K_e K_t r^2}{Rr_p{}^2 l m_2}\right]\dot{x} - \left[\frac{g(m_1+m_2)}{l(m_2)}\right]\theta \quad (3.14)$$

3.6 Modeling of subsystem GCS

Figure 3.5 shows the subsystem in the GCS. Based on the Lagrange equation, all the equation are implemented to two functions which are for trolley displacement and payload oscillation.

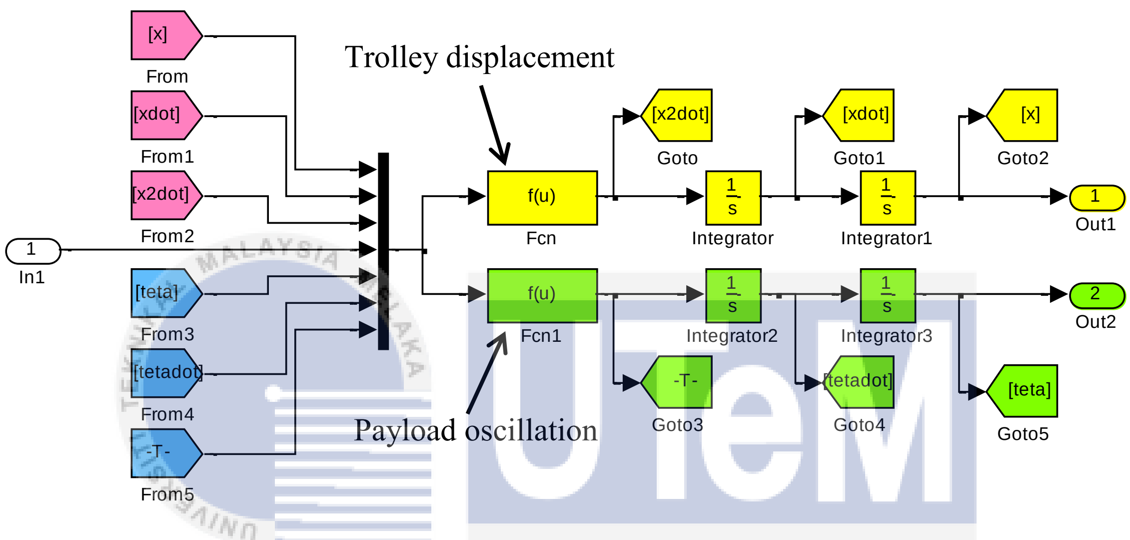

Figure 3.5: Nonlinear and linear of GCS

Figure 3.5 shows the modeling of nonlinear and linear GCS. This subsystem needs two block diagram for nonlinear and linear equation. The two functions are used for trolley displacement and payload oscillation. The mathematical equation for trolley displacement and payload oscillation are inserted to the function for nonlinear and linear model of GCS.

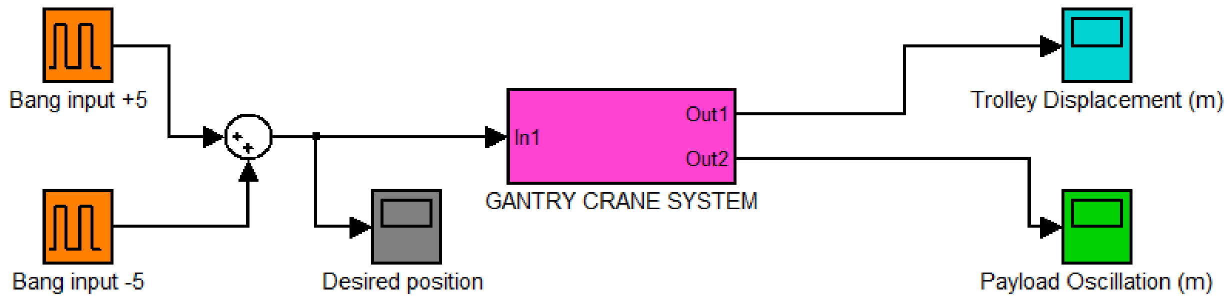

Figure 3.6: Block diagram subsystem of GCS

Figure 3.6 shows the one block diagram subsystem of GCS with one input and two outputs. The Bang-Bang input is selected as an input of the system. Bang-bang input is a feedback controller that used to switch dramatically between two points of input and characterized by turning the control element of ON-OFF using higher and lower limit to bound input signal. It represents as a voltage in real application. The derived nonlinear and linear equations are applied to the function of the system.

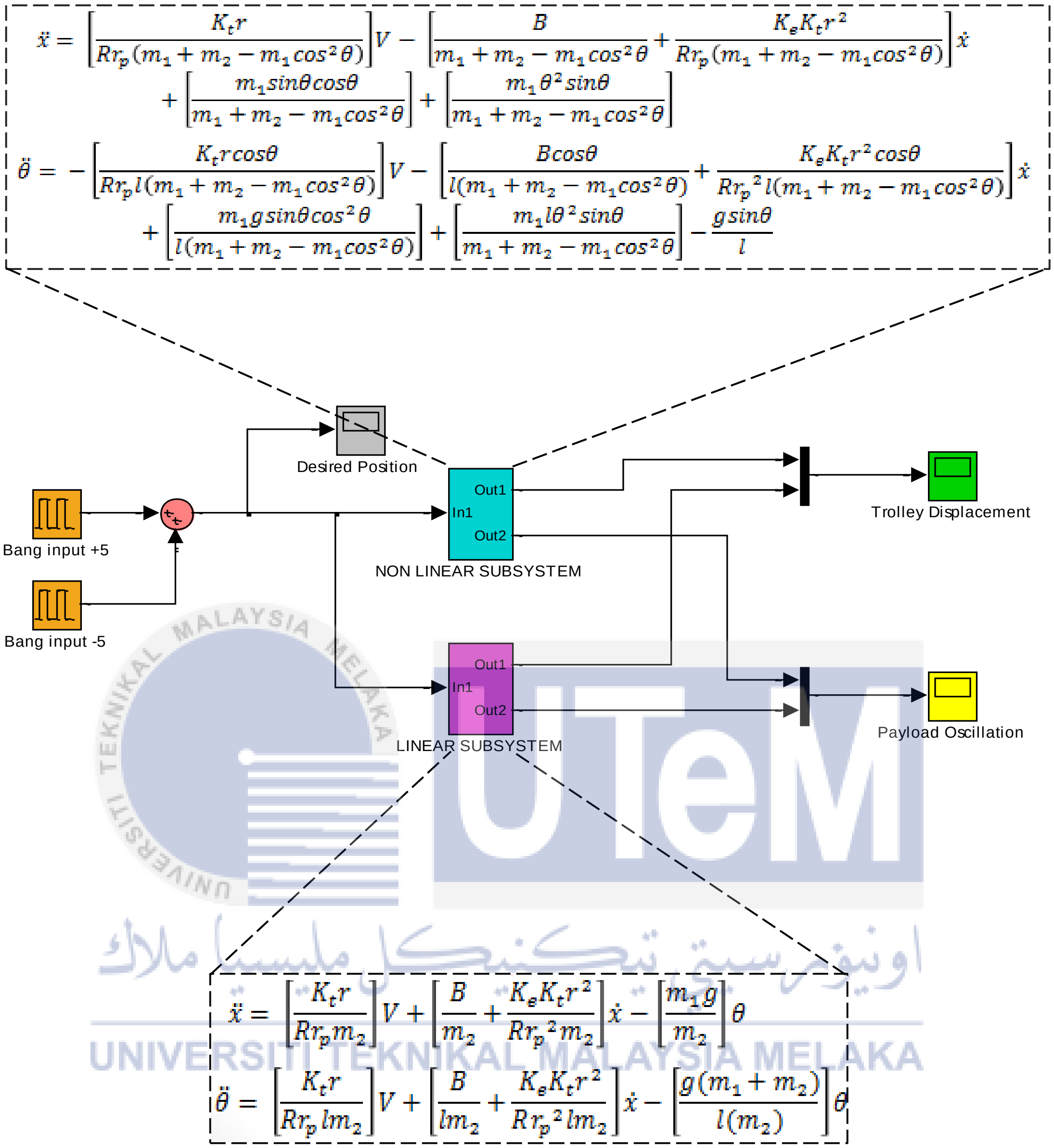

Figure 3.7: Combination of nonlinear and linear subsystems.

Figure 3.7 shows the nonlinear and linear subsystem are combined with one bang-bang input producing two outputs of trolley displacement and payload oscillation. The output of this system can be determined from the graph of trolley displacement and payload oscillation.

3.7 Modeling of GCS with Controller (PID+PD)

For second phase, the controllers (PID+PD) are applied in GCS. The simulation of GCS model with controller (PID+PD) is designed as Figure 3.8 below.

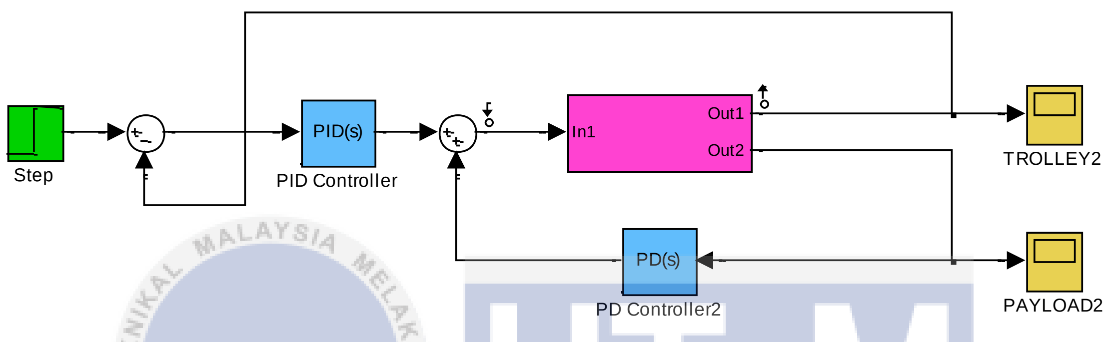

Figure 3.8: GCS model with PID + PD controller

3.8 Implementation of Multi Objective Gravitational Search Algorithm (MOGSA)

During the implementation of MOGSA, the input voltage is set up in 5 V. Based on the Figure 3.9, the output result from the simulation will be saved to file in MATLAB. Figure 3.10 shows the details block parameter for step input of input voltage 5 V. The gain of 0.2 is inserted as a converter of voltage input. The gain used is the position sensor.

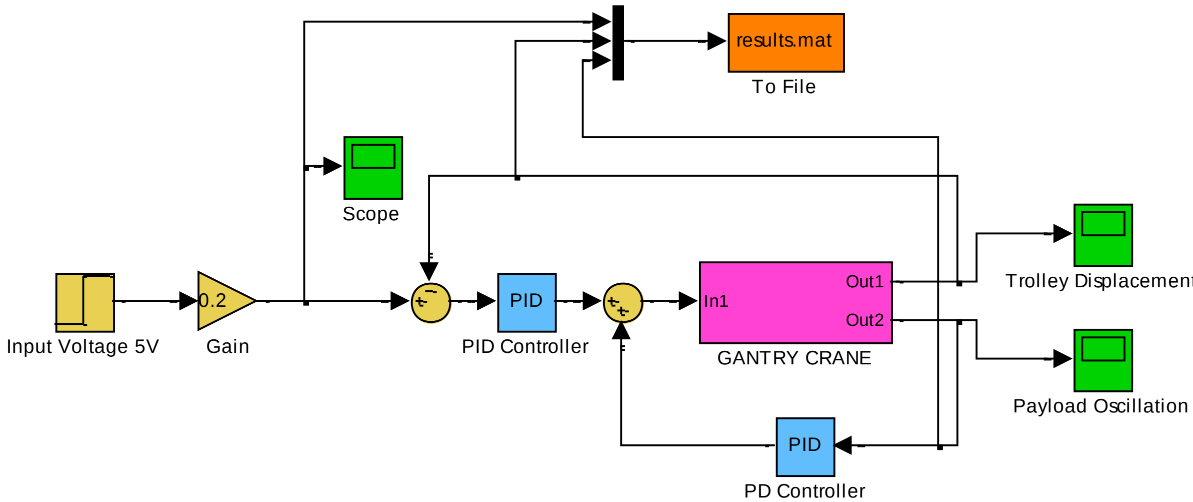

Figure 3.9: GCS with the implementation of MOGSA

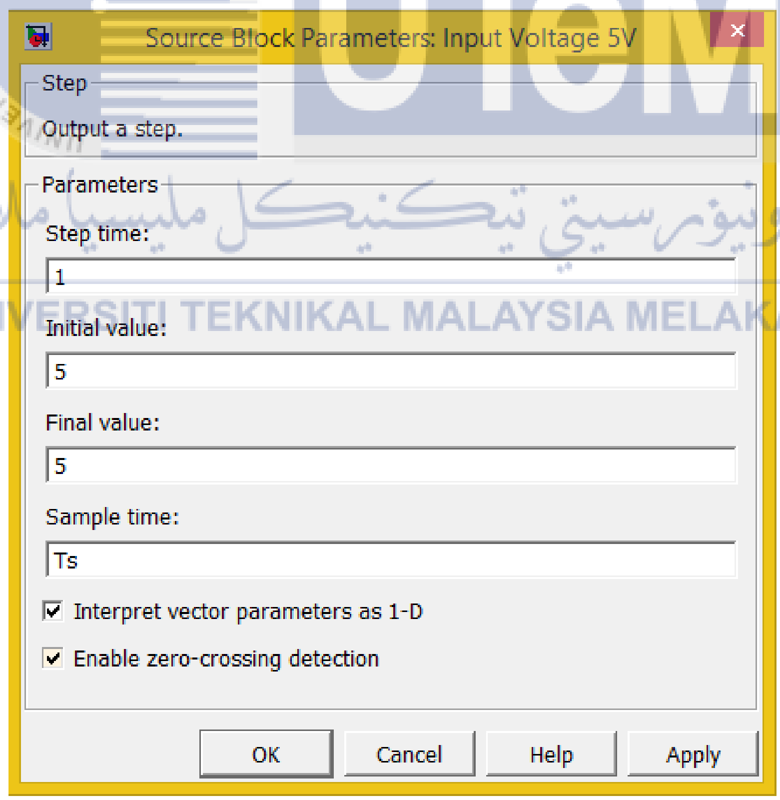

Figure 3.10: Block parameter of input voltage 5 V

3.9 Simulation of Multi Objective Gravitational Search Algorithm

The proposed MOGSA in GCS can be summarized based on the following pseudo code steps below:

Step 1: Search space identification, $t=0$;

Step 2: Randomized initialization, $X_i(t)$;

For $i=1, \ldots, N$

Step 3: Fitness evaluation of agents.

Step 4: Update the parameter of G(t), $best(t)$, $worse(t)$ and $M_i(t)$;

For $i=1, \ldots, N$

Step 5: Calculation of the force on each object;

Step 6: Calculation of acceleration and velocity of each object;

Step 7: Updating agent's position.

Step 8: Repeat step 3 to step 7 until the stop criteria is reached.

Step 9: End.

3.10 Process of MOGSA

Figure 3.11 shows the process of MOGSA. The process of MOGSA is implemented by using MATLAB R2012a.

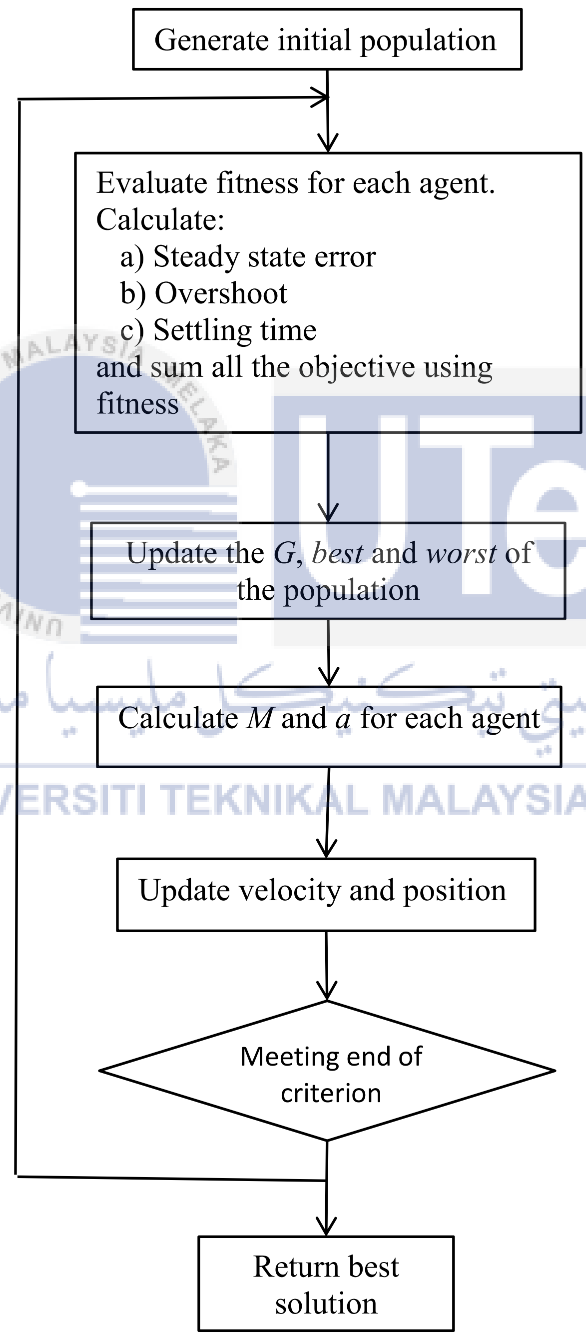

Figure 3.11: Process of MOGSA

CHAPTER 4

RESULT AND DISCUSSION

4.1 Overview

This chapter covers the behavior of model GCS in term of trolley displacement and payload oscillation. In first phase, the difference value between nonlinear and linear subsystem are observed and calculated. For the second phase, the implementations of five controllers (PID+PD) are observed for nonlinear subsystem only. Then, the MOGSA is applied in nonlinear GCS by using Linear Weight Summation approaches. The result of performance between trolley displacement and payload oscillation will be compared with previous journal of nonlinear GCS via MOPSO [15].

4.2 Analysis of GCS without controller

The simulation result of payload oscillation and trolley displacement are shown in Figure 4.1 and Figure 4.2. At the first phase, the GCS model which consists of nonlinear model and linear model are simulated without using any controller. The nonlinear and linear graphs for trolley displacement and payload oscillation are represented to differentiate the response performances.

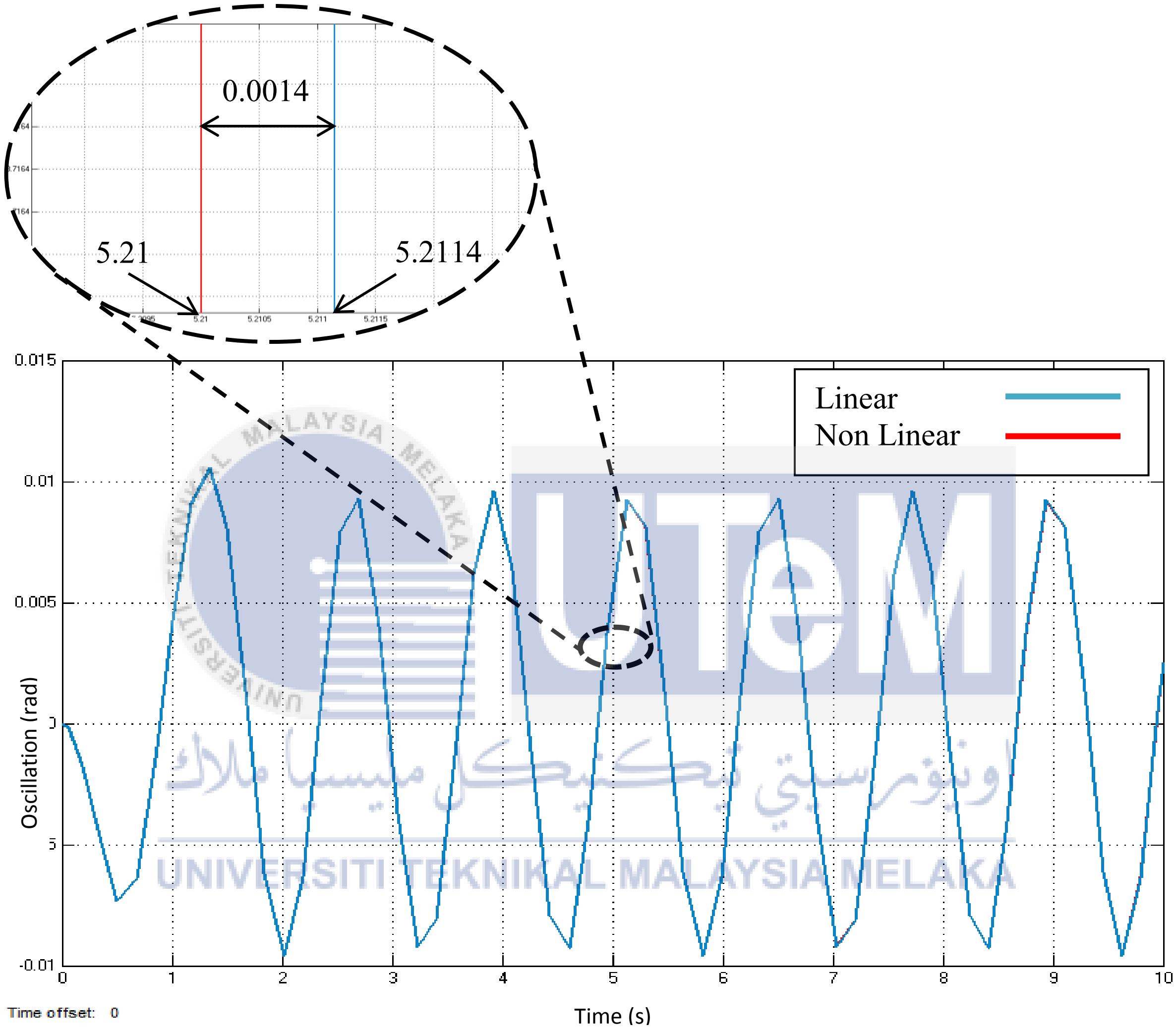

Figure 4.1: Payload oscillation graph

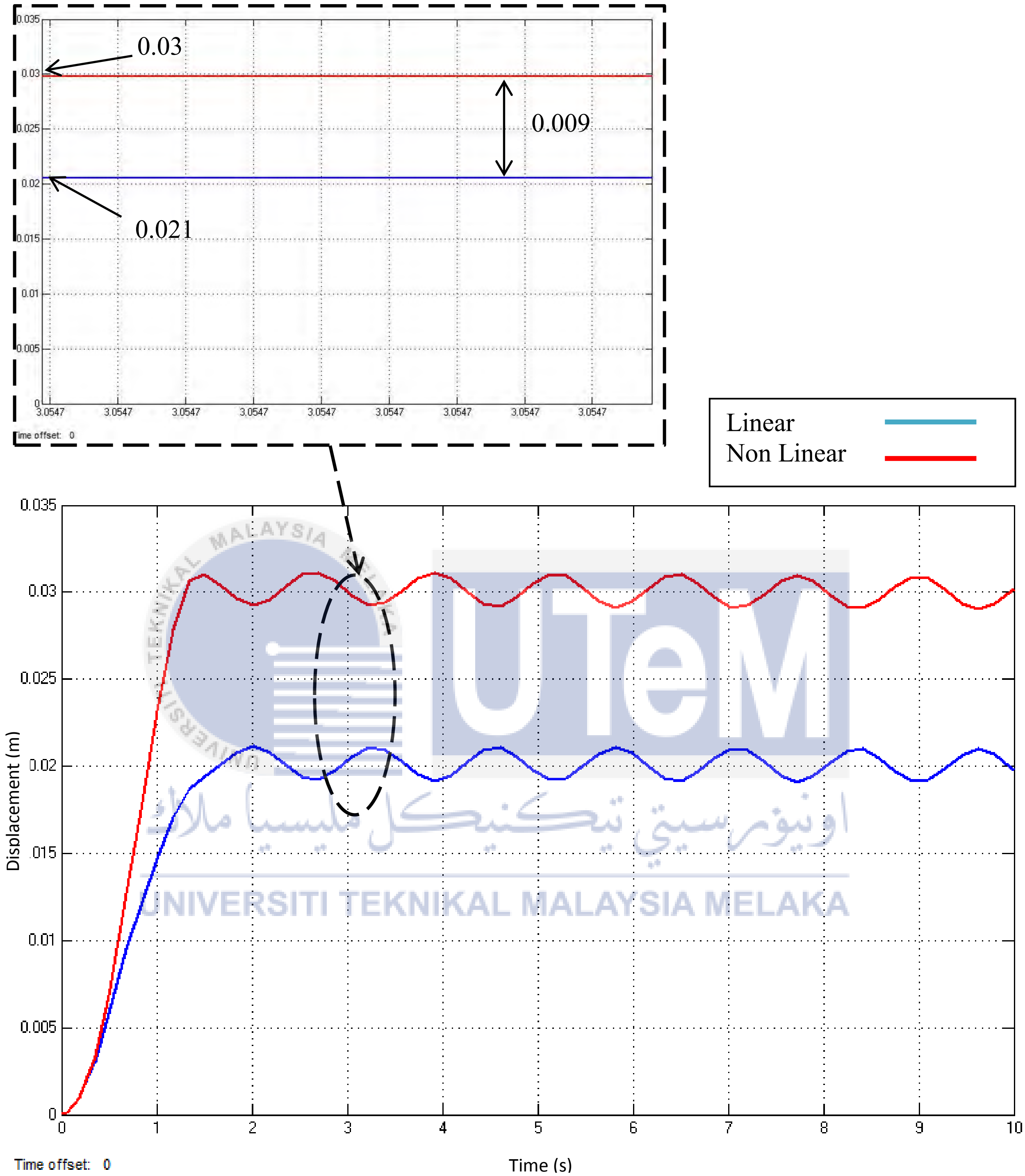

Figure 4.2: Trolley displacement graph

Table 4.1: Difference between nonlinear and linear value

Output	Difference value
Trolley Displacement	0.03 – 0.021 = 0.009
Payload Oscillation	5.2114 – 5.21 = 0.0014

Based on the Figure 4.1 and Figure 4.2, the differences between nonlinear and linear graphs are shown in Table 4.1. The result shows that linear and nonlinear graphs achieved similarities as the flow of the graph approximately same.

4.3 Analysis of GCS with controller (PID+PD)

In order to gain the stability and short transient response of GCS, the response can be adjusted by using PID tuning. Since that the stability of the system need to be obtained as Table 2.1 from Chapter 2, it is difficult to achieve the best performance. Thus, the PID auto tuning is one of the useful and easy methods to implement in Gantry Crane System to obtain the best parameter of PIC controller.

Figure 4.3 shows the performance response of trolley displacement in GCS when PID tuning method is applied. The performance shows the adjusting value of PID controller (**K_P, K_I** and **K_D**) able to achieve the desired position of trolley displacement which is 1 meter.

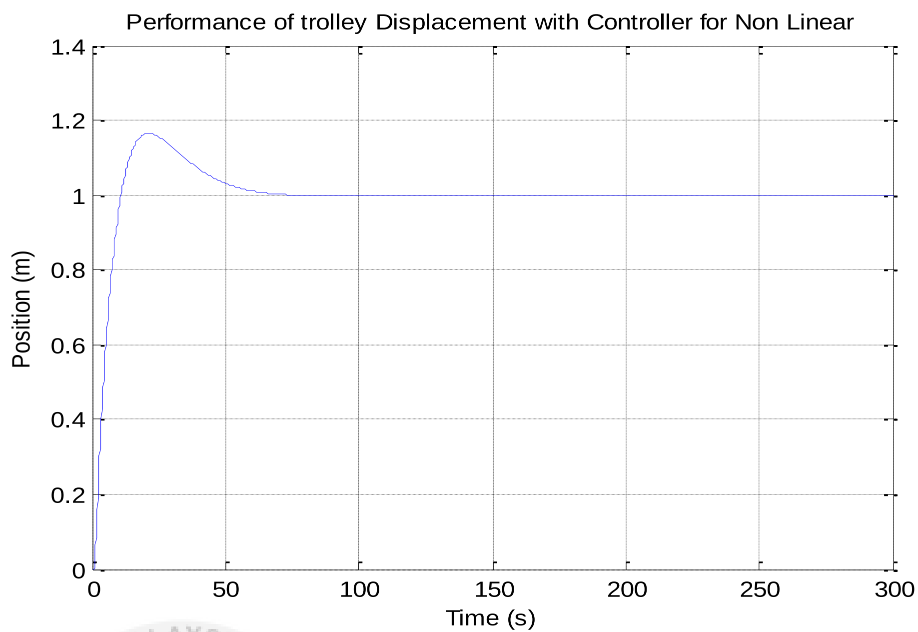

Figure 4.3: Performance of trolley displacement with controller

Figure 4.4 shows the performance of payload oscillation with PD controller (**K_P** and **K_D**). The PD controller is used to minimize the amplitude of payload oscillation.

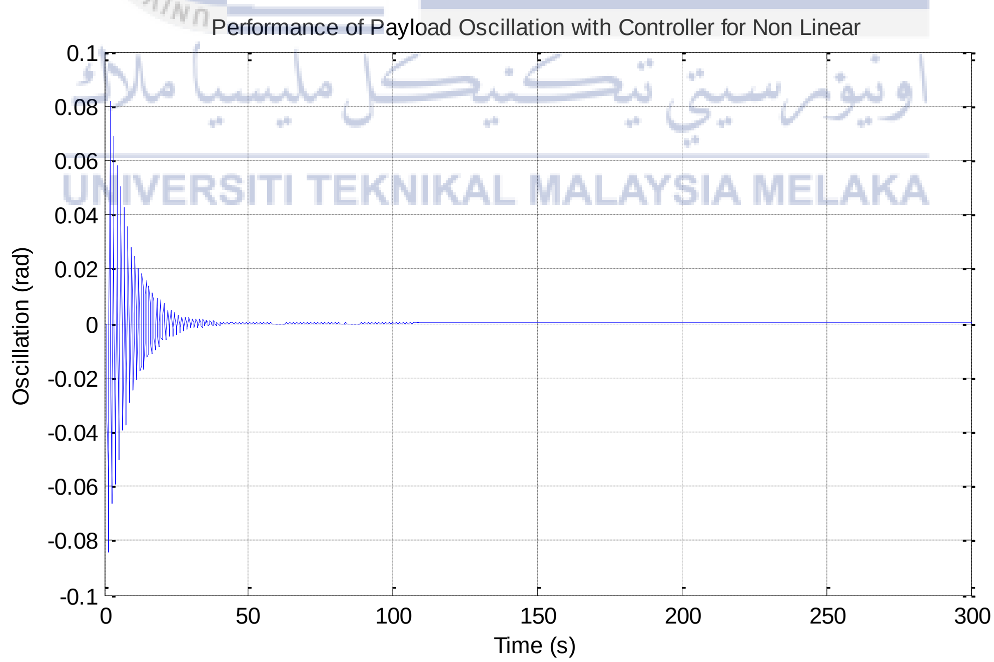

Figure 4.4: Performance of payload oscillation with controller

Table 4.2: The parameter values with PID and PD controller

Parameter	Value
K_P	1.33028
K_I	0.00915
K_D	23.6196
K_{PS}	25.0128
K_{DS}	11.4528

Table 4.2 shows the parameter value of $\mathbf{K_P}$, $\mathbf{K_I}$ and $\mathbf{K_D}$ when the PID tuning controller is applied GCS for trolley displacement and the parameter of $\mathbf{K_{PS}}$ and $\mathbf{K_{DS}}$ when PD controller is applied for payload oscillation.

4.4 Analysis of MOGSA

In order to achieve the multi objective of GSA, three cases with different setting summation is observed as Table 4.3 below. Since that the overall summation of weight value must be equal to 1, the setting value set of 0.7 is considered as the highest weight value while 0.1 is the lowest weight value. For Case 1, the highest value of 0.7 is set in W_{OS} to show that the overshoot is more priority. For Case 2, the priority goes to W_{SSE}, while W_{TS} are set as priority for Case 3.

$$Fitness = W_{SSE}\,(SSE) + W_{OS}\,(OS) + W_{TS}\,(Ts) \tag{4.1}$$

where:

W_{SSE} = weight value for steady state error

W_{OS} = weight value for overshoot

W_{TS} = weight value for settling time

Table 4.3: Three cases with different setting of weight summation

	W_{SSE}	W_{OS}	W_{TS}
Case 1	0.1	0.7	0.2
Case 2	0.7	0.2	0.1
Case 3	0.2	0.1	0.7

Table 4.4 shows the value of five parameters controller which is PID and PD parameter that represented as K_P, K_I, K_D for trolley displacement while K_{PS} and K_{DS} for payload oscillation. The value of parameter changed for every case after each case has been tested in Simulink. The lowest performance value of each case will be resulted based on its priority. The performance value of trolley displacement and payload oscillation are resulted in Table 4.5. The performance of trolley displacement represented as steady-state error (SSE), overshoot (OS) and settling time (Ts) while payload oscillation represented as maximum angle ($\theta\, max$) and period of 1 cycle payload oscillation (*T*).

Table 4.4: Value of PID and PD based on Linear Weight Summation Approach

	K_P	K_I	K_D	K_{PS}	K_{DS}
Case 1	74.6284	0.00428	57.8746	165.609	0.00318
Case 2	65.1454	0.00130	47.7985	133.419	0.00256
Case 3	76.4401	0.00288	54.2458	135.011	0.00326

Table 4.5 shows the performance value of trolley displacement and payload oscillation based on different cases. The values obtained are the lowest value performance based on each priority.

Table 4.5: Performance value of Trolley Displacement and Payload Oscillation

Cases	**Performance**				
	Trolley Displacement			**Payload Oscillation**	
	SSE (m)	***OS (%)***	***Ts (s)***	***θ max (rad)***	***T (s)***
Case 1	0.000	0.035	3.351	0.199	2.386
Case 2	0.000	0.050	3.298	0.214	2.251
Case 3	0.000	0.150	1.752	0.226	2.154

Based on the Table 4.5, W_{OS} are set as priority for Case 1. Hence, the lowest percentage value of overshoot becomes the most priority. As the result, Case 1 has lowest percentage overshoot but the time take to oscillate in one cycle is longer than Case 2 and Case 3. For Case 2, W_{SSE} become priority and most value of steady state error can be reach to zero. According to the Case 3, as the W_{TS} become a major priority, the value of overshoot is higher than Case 1 and Case 2. Although the Ts can be minimized and the time taken to oscillate in one cycle can be decrease, the maximum angle of payload oscillation will be rise up.

The performance of trolley displacement with three different cases is shown in Figure 4.5 while the performance of payload oscillation with three different cases is shown in Figure 4.6.

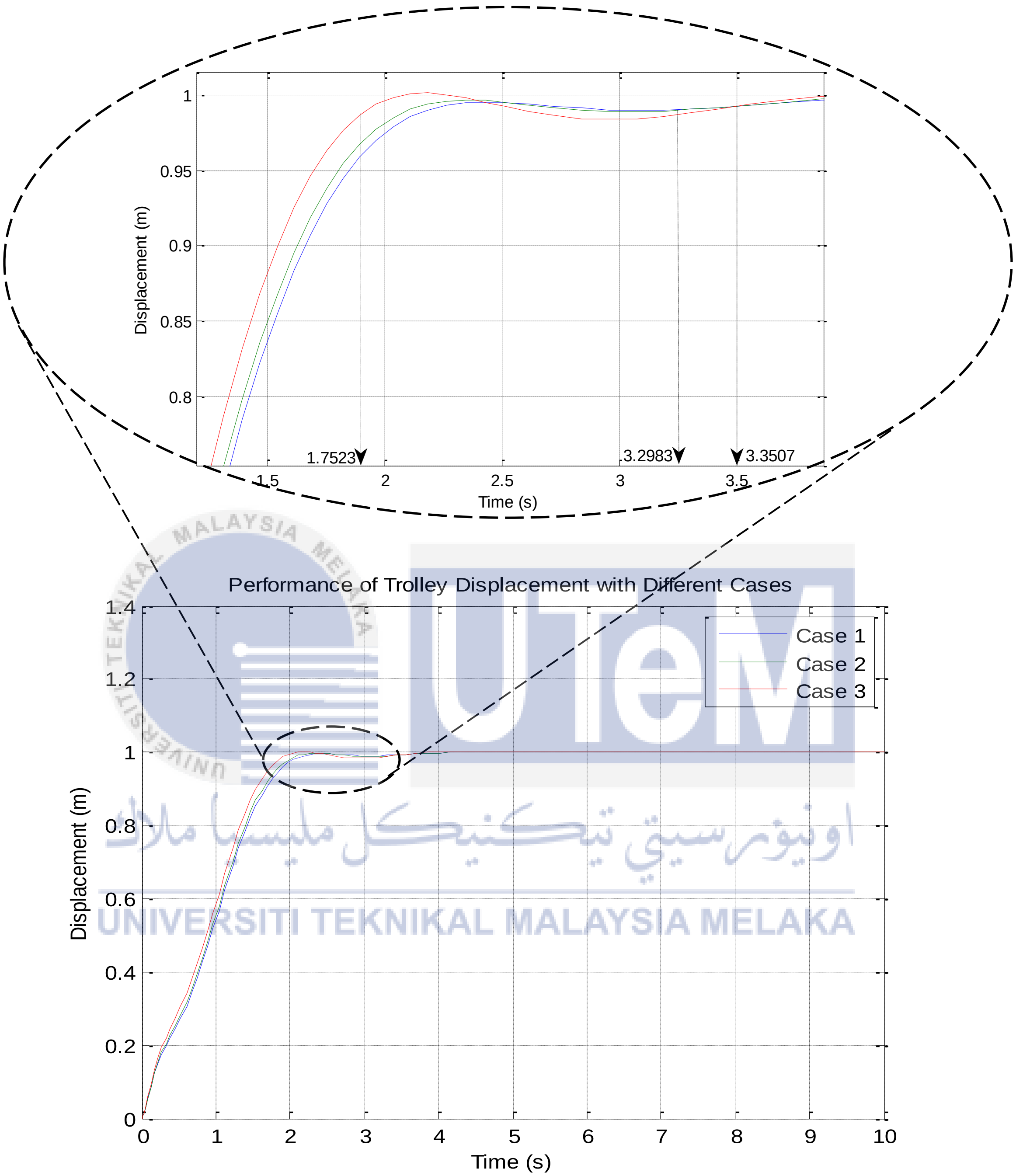

Figure 4.5: Performance of trolley displacement with three different cases

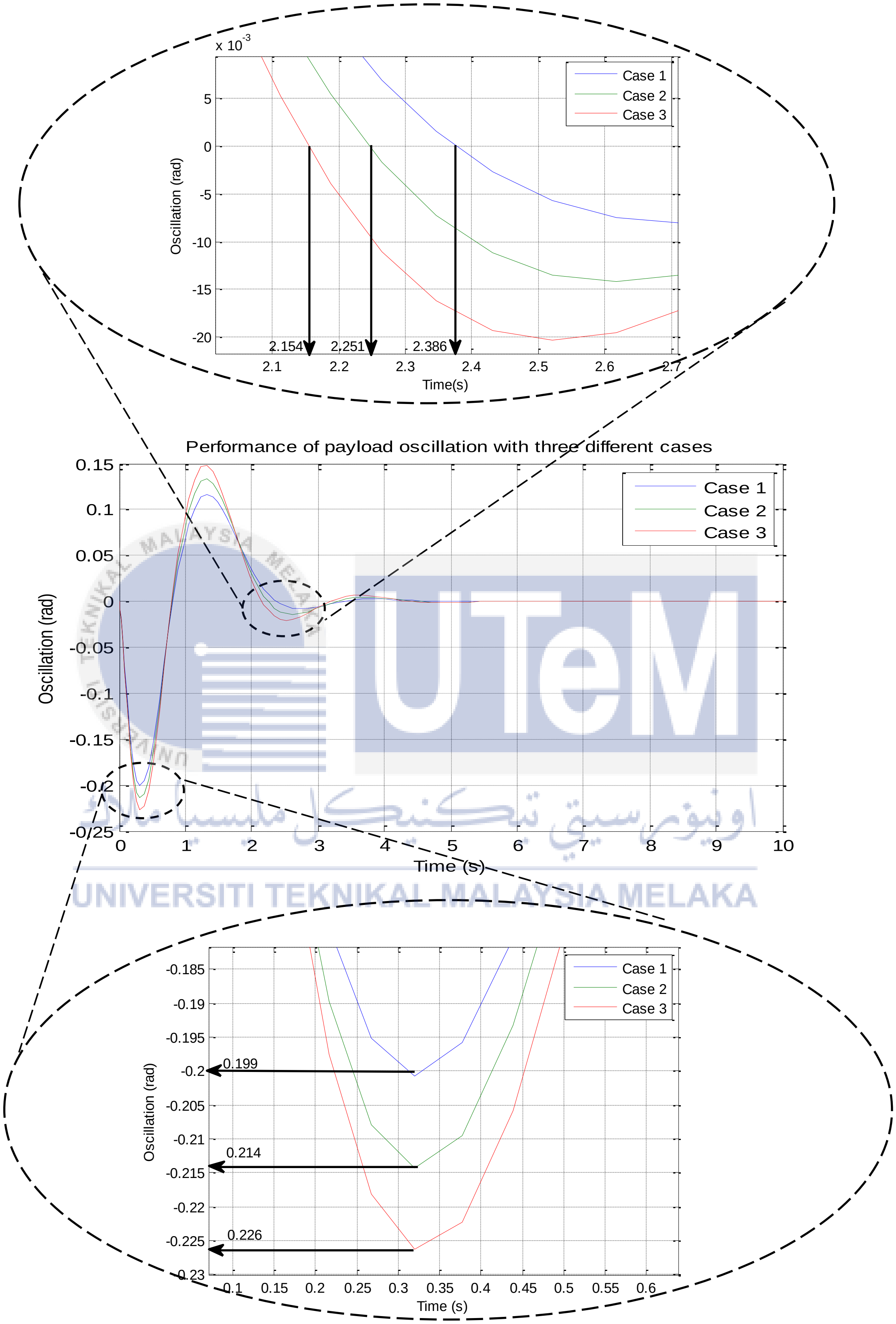

Figure 4.6: Performance of payload oscillation with three different cases

4.5 Comparison Result and Simulation Analysis between MOGSA and MOPSO

The result from MOGSA and MOPSO [15] are compared in order to identify which algorithm is highly better in optimization of GCS. The comparisons for both algorithms are identified based on three cases.

4.5.1 Case 1

Table 4.6: Comparison of PID and PD parameters between MOGSA and MOPSO for Case 1

	K_P	K_I	K_D	K_{PS}	K_{DS}
MOGSA	74.6284	0.0043	57.8746	165.6085	0.0032
MOPSO	77.2547	0.0015	59.5447	172.6070	0.0032

Table 4.6 shows the comparison of PID and PD between MOGSA and MOPSO. The value of PID and PD controller based on implementation of MOGSA and MOPSO are collected.

Table 4.7: Comparison of performance between MOGSA and MOPSO for Case 1

CASE 1	**Performance**				
	Trolley Displacement			**Payload Oscillation**	
	SSE (m)	***OS (%)***	***Ts (s)***	***θ max (rad)***	***T (s)***
MOGSA	0.000	0.035	3.351	0.199	2.386
MOPSO	0.000	0.032	2.002	0.201	2.399

Table 4.7 shows the comparison of performance response between MOGSA and MOPSO for Case 1. Based on the Table 4.7, both steady state errors are achieved to zero. For the overshoot performance, it can be seen that MOPSO have less value than MOGSA. Since that the priority for Case 1 are $\boldsymbol{W_{os}}$, MOPSO have better priority value in overshoot as well as settling time. In contrast of that, MOGSA have a better performance in payload oscillation where maximum angle value and time oscillation for 1 cycle are slightly less than MOPSO.

The performance response between MOGSA and MOPSO can be clearly shown in Figure 4.7 and Figure 4.8. Figure 4.7 shows the trolley displacement response while Figure 4.8 shows the payload oscillation response. It can be conclude that MOPSO are better in $\boldsymbol{W_{OS}}$ instead of MOGSA.

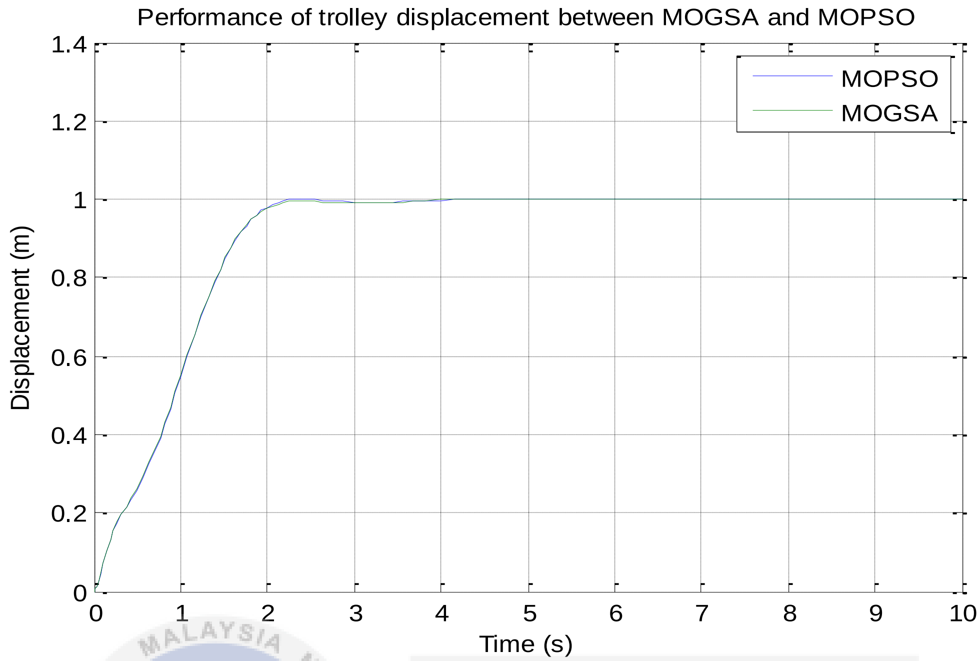

Figure 4.7: Performance of trolley displacement between MOGSA and MOPSO for Case 1

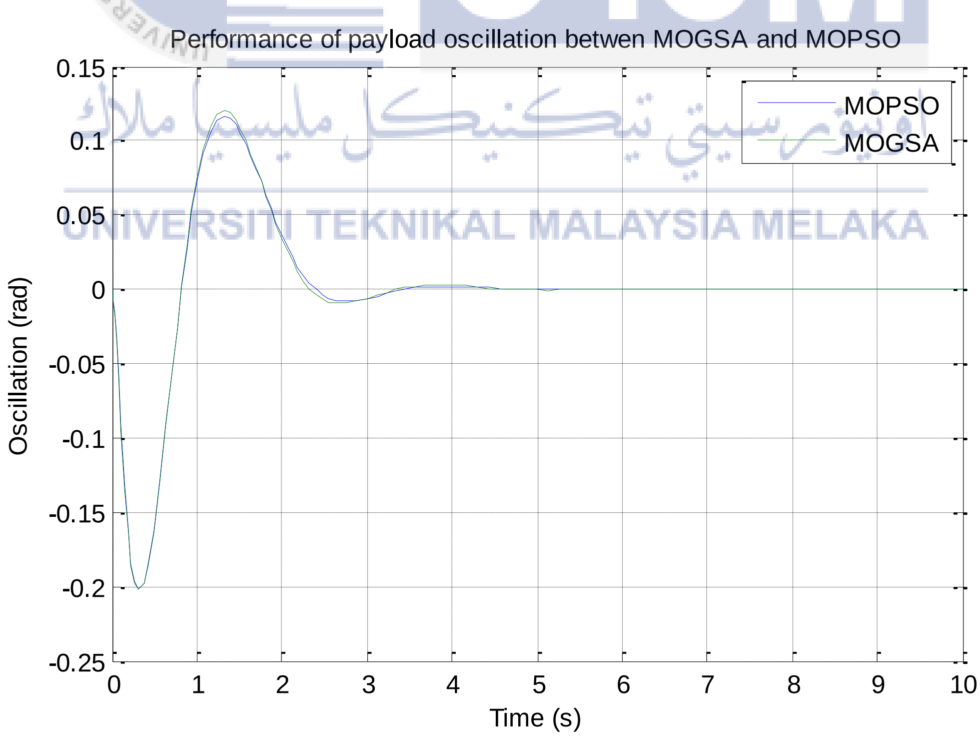

Figure 4.8: Performance of payload oscillation between MOGSA and MOPSO for Case 1

4.5.2 Case 2

Table 4.8: Comparison of PID and PD parameters between MOGSA and MOPSO for Case 2

	K_P	K_I	K_D	K_{PS}	K_{DS}
MOGSA	80.1140	0.0043	59.3391	158.1160	0.0015
MOPSO	91.1707	0.0015	71.2132	198.4202	0.0015

Table 4.8 shows the comparison of PID and PD parameter between MOGSA and MOPSO for Case 2. The five parameters value of MOGSA and MOPSO are collected.

Table 4.9: Comparison of performance between MOGSA and MOPSO for Case 2

CASE 2	**Performance**				
	Trolley Displacement			**Payload Oscillation**	
	SSE (m)	***OS (%)***	***Ts (s)***	***θ max (rad)***	***T (s)***
MOGSA	0.000	0.050	3.298	0.214	2.251
MOPSO	0.000	0.050	1.970	0.204	2.346

Table 4.9 shows the comparison of performance response between MOGSA and MOPSO for Case 2. The priority for Case 2 is W_{SSE}. Based on the result, both value of steady state errors are achieved to zero. Since the values are similar, the percentage of overshoot is declared as second priority. It can be seen that both percentage of overshoot are same and achieved approximately to zero. In contrast, the settling time of MOGSA is higher than MOPSO. Based on payload oscillation, MOGSA has short value of time taken to oscillate in 1 cycle although the maximum angle is a bit higher than MOPSO.

Figure 4.9 and Figure 4.10 show the performance of trolley displacement and payload oscillation between MOGSA and MOPSO in term of graph response.

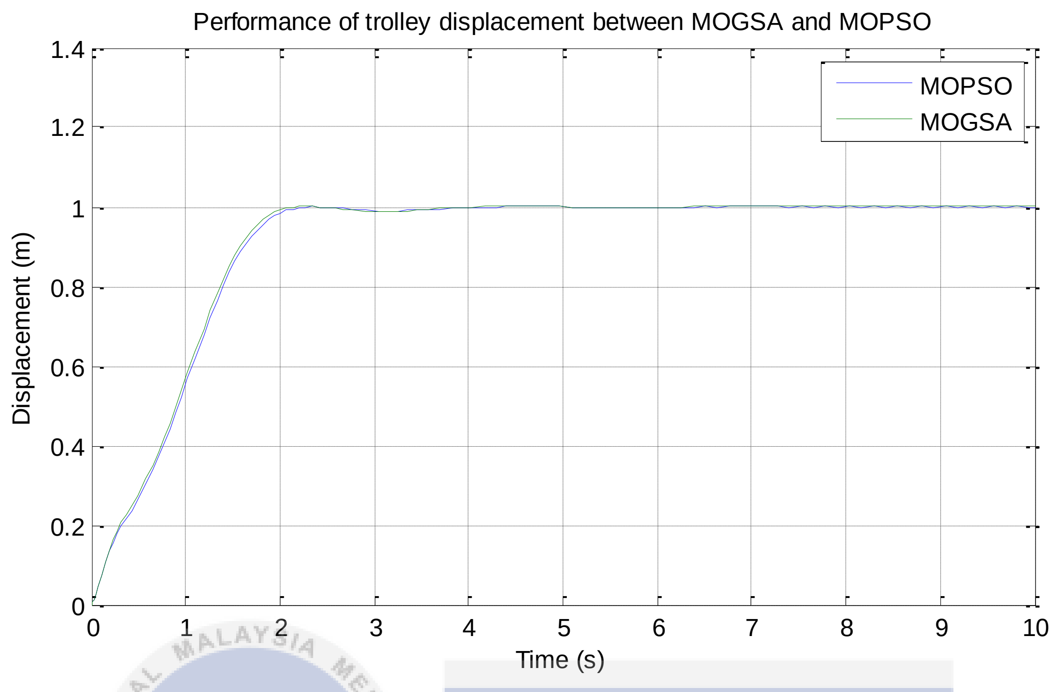

Figure 4.9: Performance of trolley displacement between MOGSA and MOPSO for Case 2

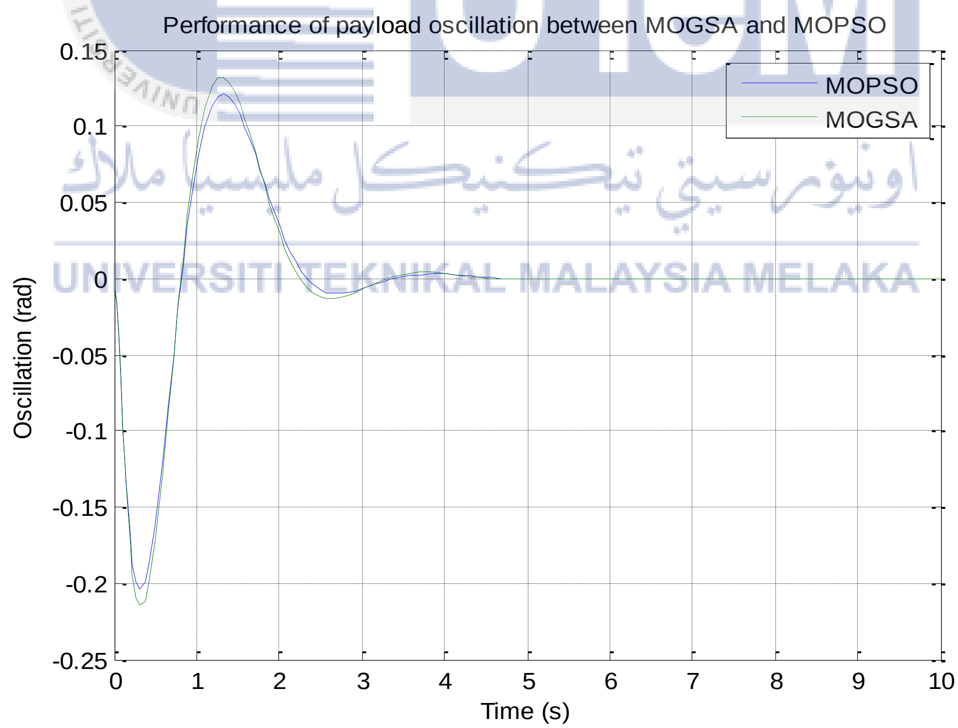

Figure 4.10: Performance of payload oscillation between MOGSA and MOPSO for Case 2

4.5.3 Case 3

Table 4.10: Comparison of PID and PD parameters between MOGSA and MOPSO for Case 3

	K_P	K_I	K_D	K_{PS}	K_{DS}
MOGSA	76.4401	0.0029	54.2458	135.0109	0.0032
MOPSO	67.5542	0.0015	45.0256	104.0231	0.0015

Table 4.10 shows th comparison of five parameters (PID and PD) between MOGSA and MOPSO for Case 3.

Table 4.11: Comparison of performance between MOGSA and MOPSO for Case 3

CASE 3	**Performance**				
	Trolley Displacement			**Payload Oscillation**	
	SSE (m)	***OS (%)***	***Ts (s)***	***θ max (rad)***	***T (s)***
MOGSA	0.000	0.120	1.752	0.226	2.154
MOPSO	0.000	0.237	1.788	0.242	2.069

Based on the Table 4.11, the settling time, W_{TS} recognized as the priority for Case 3. By compare the result from both algorithms, MOGSA has lower value in settling time instead of MOPSO. At the same time, the maximum angle of payload oscillation for MOGSA is less than MOPSO as well as percentage of overshoot value. For settling time response, MOGSA are slower than MOPSO. Thus, MOGSA still achieved better performance due to better priority for Case 3.

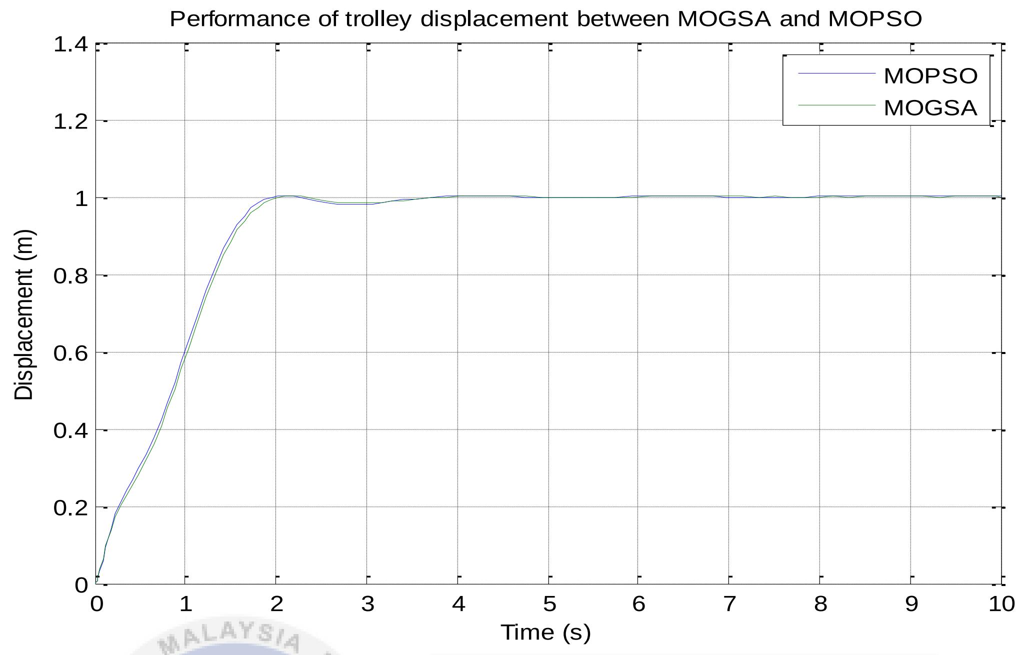

Figure 4.11: Performance of trolley displacement between MOGSA and MOPSO for Case 3

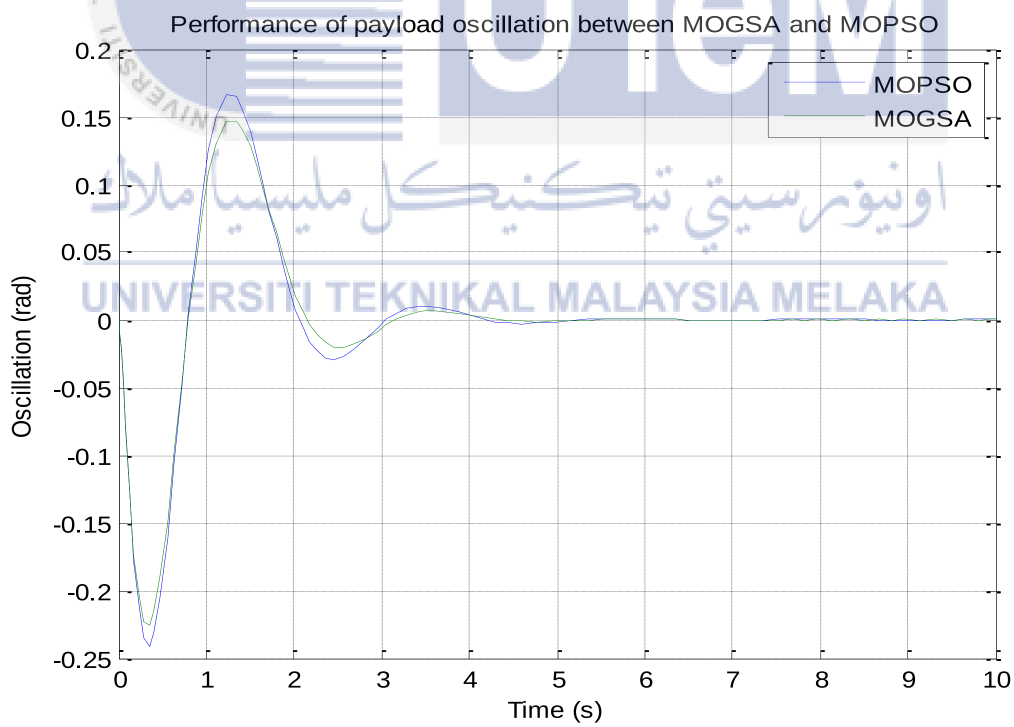

Figure 4.12: Performance of payload oscillation between MOGSA and MOPSO for Case 3

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The GCS is a useful application that functionally works as lifting heavy object that mostly used in industrial system. It can reduce the time and help human in transfer and loading the heavier object from one point to another. Generally, although the system is useful, some error may be happen during the operation. As a precaution, many researchers discover the solution in order to overcome this problem.

Most of the researcher uses algorithm as a solution when solving the critical problem. In this case, the GSA is used to solve highly optimization problem. Thus, to obtain the performance response of GSA for GCS, the model of GCS must be done first. The model involved with linear and nonlinear system based on mathematical Lagrange Equation. These equation is used as a function to create GCS system. Next, the controllers of PID+PD are implemented in GCS model. The five parameter of controller (PID+PD) are used to obtain the stability of the system. The PID tuning method is used because it provides fast and widely useful to achieve desired response in control system.

In the second phase, the MOGSA is implemented in GCS. The algorithm is applied based on linear weight summation. By using three different linear weight summations, each of the performance responses data is collected. There are three cases applied in GCS where each case indicates their own priority. The systems are repeatedly run until the best value of each priority meets the best criteria. Afterwards, the performance value of trolley displacement and payload oscillation are resulted to compare with MOPSO [15] algorithm.

From the overall result, it can be determined that MOGSA are better optimization. Although some cases of MOGSA did not achieved the best value based from priority compared to MOPSO, but regarding to the performance of payload oscillation, MOGSA able to reduce the time as well as minimize the oscillation of the payload. Thus, it shows that the MOGSA able to find optimum value in a short time compared to MOPSO technique.

5.2 Recommendation/ Future Work

For the future purpose, it is recommended to implement other meta-heuristic algorithms in GCS for to find a better optimization. Since that the GSA will be more popular due to its advantages, combine two algorithms or advances the GSA for intelligence approaches in order to solve one problem and provide more effective solutions for people to solve their real work based problem. Other than that, test the tuning method by using heuristic technique for nonlinear and linear for understanding purpose.

REFERENCES

[1] E. Rashedi, H. Nezamabadi-pour and S. Saryazdi. "GSA: A Gravitational Search Algorithm". *Information Sciences*. vol. 179, no. 13, (2009), pp 2232-2248.

[2] H.R. Hassanzadeh et al. "A Multi Objective Gravitational Search Algorithm". *2010 Second International Conference on Computational Intelligence, Communication System and Networks.*(2010) pp 7-12.

[3] Muneendra Ojha. "Optimizing Supply Chain Management using Gravitational Search Algorithm and Multi Agent System". (2012).

[4] S. Shahdan et al. "A Modified Gravitational Search Algorithm for Discrete Optimization Problem'.

[5] M. Khajehzadeh and M. Eslam. "Gravitational Search Algorithm for optimization of retaining structure". *Indian Journal of Science and Technology.* vol. 5, no. 1, (2012), pp 1821-1827.

[6] R.Suresh and C.Kumar. "Application of Gravitational Search Algorithm for Real Power Loss and Voltage Deviation Optimization". *International Journal of Engineering Science and Innovative Technology (IJESIT).* vol. 2, no. 1,(2013), pp 2319-5967.

[7] A. J. Shendi and A. Ajami. "Application of UPFC Tuned Based on Gravitational Search Algorithm to Damping of Low Frequency Oscillations". *International Journal of Advanced Research in Computer Science and Software Engineering.* vol. 3 no. 7, (2013). pp 762- 771.

[8] T. W. Saucer and V. Sih. “Optimizing nanophotonic cavity designs with the gravitational search algorithm”. *Optical Society of America.* vol. 21, no. 18, (2013), pp 1-6.

[9] M.S. Norlina, P. Mazidah, and R.M. Mohamad. “A Review of Gravitational Search Algorithm”. *SRJC Publication.* vol. 5, no. 3, (2013), pp 2074-8523.

[10] T. ChengYi. “Gravitational Search Algorithm using Simulated Annealing”. *Journal of Convergence Information Technology (JCIT).* vol. 9, no. 2, (2014), pp 231-237.

[11] A. Boudjemai, A. Zafrane and R. Hocine. “Hexagonal Honeycomb Sandwich Plate Optimization using Gravitational Search Algorithm”. *International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering.* vol. 8, no. 6, (2014), pp 1148-1153.

[12] Noraizat et al. “An Experimental Study of the Application of GSA in Solving Route Optimization Problem for Holes Drilling Process”. *International Conference Recent treads in Engineering & Technology (ICRET’2014).*(2014) pp 7-10.

[13] E. Nandakumar and R. Mani, “Optimal Location of UPFC in Power System Using Gravitational Search Agorithm”, *International Journal of Innovative Research Technology & Science (IJIRIS)*. vol. 3, no. 2, pp 25-28

[14] M. Yuvajaya and M. Sabrigiriraj. “Fuzzy and Gravitational Search Based Routing Protocol for Lifetime Enhancement in Wireless Sensor Networks”. *Research Journal of Applied Sciences, Engineering and Technology.* vol. 9, no. 3, (2015), pp 205-214

[15] H. I. Jaafar, Z. Mohamed, M. F. Sulaima and J. J. Jamian. “Optimal PID Controller Parameters for Nonlinear Gantry Crane System via MOPSO Technique”. *2013 IEEE*

Conference on Sustainable Utilization and Development in Engineering and Technology. (2013) pp 86-91.

APPENDIX A

GANTT CHART

Project Planning

ACTIVITIES / MONTH	SEPT		OCT				NOV				DEC				JAN
FYP 1 (Sept 2014 – Jan 2015)															
Choosing a Title	■														
Gather the information		■	■												
Research				■	■	■	■								
Analysis						■	■	■	■	■					
Preliminary Result						■	■	■	■	■	■				
Report				■	■	■	■	■	■	■	■	■	■	■	■
Presentation													■		
FYP 2 (Feb 2015 – June 2015)	FEB		MAR				APR				MAY				JUN
Simulation	■	■	■	■											
Troubleshooting				■	■	■	■	■	■						
Result						■	■	■	■	■	■	■	■	■	
Report	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Presentation															■

APPENDIX B

DATA COLLECTION

CASES 1 :

NO.	TROLLEY DSPLACEMENT			PAYLOAD OSCILLATION	
	SSE	OS	TS	θmax	T(s)
1	0.0001	4.4944	5.8111	0.2092	2.2883
2	0.0009	33.6094	9.8867	0.2033	2.3563
3	0.0001	0.9296	1.8114	0.2043	2.2891
4	0.0001	16.3275	8.1666	0.2058	2.322
5	0.0001	0.0644	3.2089	0.2018	2.3414
6	0.0015	4.106	6.7067	0.2132	2.1855
7	0.0006	0.4611	2.1407	0.2084	2.9999
8	0.0001	2.729	9.7656	0.2075	2.264
9	**0.0001**	**0.0352**	**3.3507**	**0.1997**	**2.386**
10	0.0001	1.5841	1.8457	0.2017	2.3072
11	0.0003	15.2558	7.668	0.2037	2.2611
12	0.0012	8.5276	7.9417	0.2172	2.1978
13	0.0043	5.6760	7.2496	0.1916	2.5113
14	0.0040	3.4364	5.9614	0.2161	2.1625
15	0.0003	6.0609	7.2211	0.2075	2.1718
16	0.0001	12.6301	7.7269	0.2048	2.3295
17	0.0001	0.2935	3.1383	0.2010	2.3915
18	0.0001	1.3317	1.8666	0.2142	2.2027
19	0.0001	2.0803	4.2689	0.2071	2.2368
20	0.0025	6.1353	6.5827	0.1702	2.985
21	0.0009	6.7101	6.9562	0.2013	2.2866
22	0.0001	0.3284	3.3361	0.2205	2.1795
23	0.0001	10.6587	8.2772	0.1931	2.4978
24	0.0001	5.7189	7.4853	0.1973	2.448
25	0.0001	19.2234	8.2792	0.2012	2.3675
26	0.0001	6.1695	7.3217	0.2074	2.2467
27	0.0001	6.8805	7.0025	0.2010	2.3409
28	0.0001	55.7789	8.4292	0.2060	2.2501
29	0.0001	3.7349	5.0801	0.2095	2.2933
30	0.0001	0.3092	3.3619	0.1941	2.4799

31	0.0001	0.2431	3.1512	0.2041	2.3522
32	0.0001	15.4532	7.7942	0.1773	2.6950
33	0.0001	1.1998	3.2284	0.2313	2.0882
34	0.0001	5.8905	7.8675	0.2105	2.2080
35	0.0010	5.6175	9.9413	0.2184	2.1692
36	0.0077	5.2856	7.4189	0.1989	2.4156
37	0.0141	5.0132	6.8315	0.2182	2.1560
38	0.0121	0.3182	1.8887	0.2142	2.2233
39	0.0015	0.4720	2.0201	0.1969	2.3839
40	0.0123	8.6820	7.8675	0.1983	2.3540
41	0.0080	37.2924	8.9320	0.2057	2.3550
42	0.0050	7.0102	7.7093	0.2037	2.3435
43	0.0001	5.4942	6.9073	0.2114	2.2249
44	0.0038	9.1502	7.1710	0.2164	3.0558
45	0.0005	7.4315	8.0458	0.1865	2.2569
46	0.0003	8.5527	10.2947	0.2079	2.2549
47	0.0001	5.9879	7.5124	0.2089	2.2605
48	0.0001	2.8955	5.0042	0.2154	2.2164
49	0.0001	8.9445	7.0243	0.2050	2.3236
50	0.0038	2.7529	4.5197	0.2263	2.1341

value selected

priority of the case

CASES 2 :

NO.	TROLLEY DSPLACEMENT			PAYLOAD OSCILLATION	
	SSE	OS	TS	θmax	T(s)
1	0.0001	5.8608	7.5618	0.2088	2.2542
2	0.0002	3.3739	5.8038	0.1987	2.4054
3	0.0058	16.3484	8.1953	0.1987	2.4052
4	0.0012	3.2903	6.5781	0.212	2.2705
5	0.0166	4.1665	6.4372	0.215	2.1705
6	0.0006	39.5461	9.4306	0.2071	2.2863
7	0.0017	8.3674	4.6926	0.1935	2.3358
8	0.0040	3.6605	6.2814	0.1877	2.5952
9	0.0000	0.9618	1.7736	0.2154	2.1748
10	0.0001	3.7745	2.4629	0.2154	2.1748
11	**0.0000**	**0.05**	**3.2622**	**0.2132**	**2.256**
12	0.0005	10.5917	6.5028	0.2111	2.1958
13	0.0003	0.0081	3.3583	0.2123	2.2504
14	0.0112	2.1465	2.1638	0.2127	2.2585
15	0.0003	107.8647	9.7907	0.1967	2.3401
16	0.0002	17.6766	7.6307	0.2177	2.1966
17	0.0001	11.9481	6.8143	0.2206	2.1789
18	0.0001	21.3338	8.3301	0.1769	2.7593
19	0.0001	17.617	8.0553	0.2016	2.3875
20	0.0001	8.0178	8.0813	0.1843	2.5824
21	0.0011	4.9469	6.9816	0.2118	2.2628
22	0.0002	29.3552	7.4617	0.2060	2.2271
23	0.0021	17.7662	8.6762	0.2091	2.1997
24	0.0001	0.9283	3.3901	0.2227	1.9436
25	0.0035	11.1664	8.1868	0.2045	2.3531
26	0.0001	8.8183	4.9628	0.2110	2.2478
27	0.0077	0.3684	3.1414	0.2101	2.2644
28	0.0118	0.1078	3.2405	0.2074	2.2878
29	0.0001	9.9257	7.7958	0.2087	2.3440
30	0.0003	3.1978	2.4003	0.2052	2.2920
31	0.0005	5.2771	7.0488	0.1978	2.3540
32	0.0010	15.9005	8.1588	0.2058	2.3220
33	0.0000	36.6502	7.2529	0.2222	2.0623
34	0.0000	8.4180	8.2894	2.2027	2.2805
35	0.0000	0.4459	3.2983	0.2084	2.2993
36	0.0001	1.9803	2.6983	0.209	2.2706
37	0.0001	8.0021	8.9399	0.2193	2.1704

38	0.0000	9.23120	8.005	0.2047	2.3686
39	0.0029	8.41870	7.637	0.2002	1.9749
40	0.0001	15.9005	8.1588	0.2058	2.3220
41	0.0002	0.30660	2.9441	0.2101	2.2749
42	0.0000	36.6502	7.2529	0.2027	2.2805
43	0.0001	8.4180	8.2894	0.2084	2.2993
44	0.0000	0.44590	3.2983	0.2108	2.2827
45	0.0001	2.23950	4.9603	0.2053	2.3242
46	0.0002	31.4811	5.1883	0.2172	2.1976
47	0.0001	9.43770	7.7671	0.2172	2.1978
48	0.0001	17.0736	7.7317	0.2158	2.2472
49	0.0005	14.1490	7.6238	0.2160	2.1625
50	0.0004	6.40860	7.4759	0.2177	2.1670

value selected

priority of the case

CASES 3 :

NO.	TROLLEY DSPLACEMENT			PAYLOAD OSCILLATION	
	SSE	OS	TS	θmax	T(s)
1	0.0015	6.3458	7.7314	0.188	2.6866
2	0.0001	19.9038	8.6167	0.2366	2.0949
3	0.0008	5.1962	7.3482	0.2085	2.3637
4	0.0001	20.4219	8.8499	0.225	2.1511
5	0.0025	20.6178	7.983	0.2139	2.314
6	0	9.2859	7.9307	0.218	2.207
7	0.0003	2.412	2.358	0.2248	2.1523
8	0.0001	2.6963	4.8418	0.222	2.2367
9	0.0003	1.9669	1.8838	0.2247	2.1756
10	0.0002	37.0972	9.6504	0.2076	2.3413
11	0.0001	3.345	6.078	0.2198	2.186
12	0.0001	6.3317	7.5394	0.2197	2.1854
13	0	12.1206	8.0237	0.2276	2.1276
14	0.0001	9.3351	7.8005	0.2345	2.1224
15	0	12.4215	8.0293	0.2202	2.2085
16	0	0.15	1.7523	0.2252	2.1588
17	0.0036	14.1608	8.184	0.2526	2.2132
18	0.0001	11.5713	8.438	0.2278	2.1528
19	0.0001	3.5482	6.4818	0.2315	2.0993
20	0.0001	12.7008	7.492	0.2125	2.239
21	0.0001	0.4779	1.7845	0.224	2.1376
22	0.0128	14.5104	8.5247	0.2183	2.2018
23	0.0035	11.3929	7.5602	0.2303	2.0954
24	0.0002	12.5163	8.0375	0.2435	2.0743
25	0.0004	4.0266	7.4759	0.2276	2.1257
26	0.0038	21.2282	9.9795	0.2334	2.1553
27	0.0002	8.4406	7.7538	0.2012	2.3695
28	0.0015	14.504	8.543	0.2239	2.1262
29	0.0017	5.3041	4.4755	0.2283	2.1584
30	0.0012	1.6858	3.0037	0.24	2.0656
31	0.0002	21.6588	7.5448	0.2303	2.0994
32	0.0003	20.437	7.7688	0.2151	2.2424
33	0.0002	8.018	7.1098	0.2266	2.1524
34	0.0002	0.2872	3.1342	0.2366	2.0918
35	0.0002	6.1597	7.4177	0.2205	2.1906
36	0.0024	1.4683	1.8634	0.2241	2.1649
37	0.0056	2.7618	4.6819	0.2369	2.0861

38	0.0002	0.2155	3.3581	0.2335	2.0875
39	0.0005	7.8143	7.8856	0.2323	2.1213
40	0.0011	14.3264	8.7658	0.224	2.188
41	0.0017	5.6144	6.8248	0.2301	2.1176
42	0.0132	16.8473	7.8435	0.2268	2.1732
43	0.0026	4.188	6.8254	0.2157	2.1709
44	0.0006	8.5324	8.1557	0.2093	2.2506
45	0.0079	2.7719	5.7154	0.2183	2.235
46	0.0003	5.7175	7.6579	0.2135	2.2792
47	0.0093	30.534	8.5181	0.2215	2.1695
48	0.0013	3.9518	6.7148	0.2274	2.1269
49	0	3.2885	2.5303	0.2264	2.1501
50	0.0002	3.8351	5.5981	0.2346	2.1248

value selected

priority of the case