

MODELING AND VIBRATION CONTROL OF A GANTRY CRANE

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To my beloved family,  
mum, dad, Faizal and Ani,  
thank you for your support and encouragement  
that you have given in my life. Also to my fiancée, Saleha,  
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## **ABSTRACT**

The aim of this project is to model industrial gantry cranes for investigations of dynamic behavior of the system. A gantry crane incorporating a payload is considered. The modeling technique which is easier in terms of mathematical derivation is chosen. Comparison between the mathematical model derived and previous work is conducted to validate the dynamic model. A simulated time response and vibration frequency of the system to an input command is presented. Furthermore, a vibration control scheme based on an open-loop filtering technique is developed. Finally, the effectiveness of the controller is investigated in terms of time response, level of vibration reduction, robustness and the capability of handling a payload.

## **ABSTRAK**

Objektif projek ini adalah untuk melaksanakan permodelan terhadap kren yang disokong oleh rangka besi dengan tujuan untuk mengkaji sifat-sifat dinamik sistem tersebut. Pertimbangan terhadap kren yang melibatkan beban akan dilaksanakan. Kaedah permodelan dipilih daripada beberapa kaedah yang telah dikenalpasti, dimana persamaan matematik bagi sistem tersebut dapat ditunjukkan dalam bentuk yang paling ringkas. Perbandingan di antara model matematik dan kerja-kerja yang telah dilaksanakan pada masa lampau dilakukan. Simulasi berkaitan dengan tindakbalas masa dan frekuensi getaran sistem terhadap masukan akan dikaji. Selain daripada itu, kawalan getaran berdasarkan pada gelung bukaan teknik penapisan akan dibangunkan. Pengawal yang telah dibangunkan akan dikaji keefektifannya dari sudut tindakbalas masa, kadar pengurangan getaran, ketegapannya dan kebolehan untuk membawa beban.

**CONTENTS**

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
<b>1</b>	<b>INTRODUCTION</b>	
	1.1 Crane: Overview	1
	1.2 Gantry Crane	4
	1.3 Motivation, Rational, Significance and Need for the Study	5
	1.4 Objectives and Work Methodology	6
	1.5 Thesis Outline	8
<b>2</b>	<b>LITERATURE REVIEW</b>	
	2.1 Modeling and Control of Gantry Cranes	10
	2.2 Modeling of Gantry Cranes	12
	2.3 Control of Gantry Cranes	14
	2.4 Conclusion	17
<b>3</b>	<b>GANTRY CRANE</b>	
	3.1 Introduction	18

	3.2 Assumption and Limitation	19
<b>4</b>	<b>MODELING OF A GANTRY CRANE</b>	
	4.1 Introduction	21
	4.2 Modeling Techniques	23
	4.3 Mathematical Modeling for a Gantry Crane	29
	4.4 Simulation of the Gantry Crane	39
	4.4.1 Model Setup	39
	4.5 Verification of the Mathematical Model	46
	4.5.1 Model Verification	49
	4.6 Model Characteristics	51
<b>5</b>	<b>VIBRATION CONTROL FOR A GANTRY CRANE</b>	
	5.1 Prologue	56
	5.2 Controlling the Crane via Feed-Forward Control Strategy	59
	5.3 Command Shaping: Filter Design's Implementation	65
	5.4 Comparative Performance Assessment	121
<b>6</b>	<b>CONCLUSION AND RECOMMENDATION FOR FUTURE WORK</b>	
	6.1 Conclusion	133
	6.2 Recommendation for Future Work	134
	<b>REFERENCES</b>	136

**LIST OF TABLES**

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
5.1	System Response for Designed Filter with Exact Natural Frequency (Cart Displacement)	122
5.2	System Response for Designed Filter with Exact Natural Frequency (Load Swing)	124
5.3	System Response for Designed Filter with 20% Error in Exact Natural Frequency (Cart Displacement)	125
5.4	System Response for Designed Filter with 20% Error in Exact Natural Frequency (Load Swing)	127



## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Overhead crane	2
1.2	Gantry crane	2
1.3	Work Methodology	7
3.1	Gantry crane model	19
4.1	Block diagram of linear system	27
4.2	$F(t)$ approximated by sequence of pulses	29
4.3	Cart's free body diagram	30
4.4	Load's free body diagram	31
4.5	Block diagram based on state-space equation	35
4.6	Modified block diagram	36
4.7	System's block diagram (a) System configuration (b) Configuration inside the crane dynamics block	39

4.8	Configuration for crane dynamics (a) system's parameter variable (b) state-space model configuration	40
4.9	Input setting	41
4.10	Settings of parameter variable	41
4.11	Cart displacement	42
4.12	Load oscillation	43
4.13	New system's configuration	44
4.14	Input modifications	44
4.15	Cart displacement	45
4.16	Load oscillation	45
4.17	Frequency response of the system	50
4.18	Load parameter setting (0.5 kg)	52
4.19	Load mass parameter setting (10 kg)	52
4.20	Simulation results for load mass 0.5 kg (a) cart displacement (b) load oscillation	53
4.21	Simulation results for load mass 10 kg (a) cart displacement (b) load oscillation	54
5.1	Feed-forward control configuration	65
5.2	Bang-bang force input	66
5.3	Filtered input using 1 <sup>st</sup> order Butterworth low-pass filter (with cut-off frequency at 25% of the exact natural frequency (1.29 rad/s))	67

5.4	Filtered input using 3 <sup>rd</sup> order Butterworth low-pass filter (with cut-off frequency at 25% of the exact natural frequency (1.29 rad/s))	67
5.5	Filtered input using 1 <sup>st</sup> order Butterworth low-pass filter (with cut-off frequency at 75% of the exact natural frequency (3.87 rad/s))	68
5.6	Filtered input using 3 <sup>rd</sup> order Butterworth low-pass filter (with cut-off frequency at 75% of the exact natural frequency (3.87 rad/s))	68
5.7	Response of the gantry crane to unshaped input with exact natural frequency (a) cart displacement (b) load oscillation	69
5.8	Response of the gantry crane to low-pass filtered input (1 <sup>st</sup> order Butterworth filter with cut-off frequency at 25% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	70
5.9	Response of the gantry crane to low-pass filtered input (3 <sup>rd</sup> order Butterworth filter with cut-off frequency at 25% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	71

5.10	Response of the gantry crane to low-pass filtered input (1 <sup>st</sup> order Butterworth filter with cut-off frequency at 75% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	72
5.11	Response of the gantry crane to low-pass filtered input (3 <sup>rd</sup> order Butterworth filter with cut-off frequency at 75% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	73
5.12	Filtered input using 1 <sup>st</sup> order elliptic low-pass filter (with cut-off frequency at 25% of the exact natural frequency (1.29 rad/s))	74
5.13	Filtered input using 3 <sup>rd</sup> order elliptic low-pass filter (with cut-off frequency at 25% of the exact natural frequency (1.29 rad/s))	75
5.14	Filtered input using 1 <sup>st</sup> order elliptic low-pass filter (with cut-off frequency at 75% of the exact natural frequency (3.87 rad/s))	75
5.15	Filtered input using 3 <sup>rd</sup> order elliptic low-pass filter (with cut-off frequency at 75% of the exact natural frequency (3.87 rad/s))	76

5.16	Response of the gantry crane to low-pass filtered input (1 <sup>st</sup> order elliptic filter with cut-off frequency at 25% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	77
5.17	Response of the gantry crane to low-pass filtered input (3 <sup>rd</sup> order elliptic filter with cut-off frequency at 25% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	78
5.18	Response of the gantry crane to low-pass filtered input (1 <sup>st</sup> order elliptic filter with cut-off frequency at 75% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	79
5.19	Response of the gantry crane to low-pass filtered input (3 <sup>rd</sup> order elliptic filter with cut-off frequency at 75% of natural frequency) with exact natural frequency (a) cart displacement (b) load oscillation	80
5.20	Magnitude response of 1 <sup>st</sup> order Butterworth band-stop filter	82
5.21	Magnitude response of 3 <sup>rd</sup> order Butterworth band-stop filter	82

5.22	Magnitude response of 1 <sup>st</sup> order elliptic band-stop filter	83
5.23	Magnitude response of 3 <sup>rd</sup> order elliptic band-stop filter	84
5.24	Filtered input using 1 <sup>st</sup> order Butterworth band-stop filter	85
5.25	Filtered input using 3 <sup>rd</sup> order Butterworth band-stop filter	85
5.26	Filtered input using 1 <sup>st</sup> order elliptic band-stop filter	86
5.27	Filtered input using 3 <sup>rd</sup> order elliptic band-stop filter	86
5.28	Response of the gantry crane to 1 <sup>st</sup> order Butterworth band-stop filter's filtered input with exact natural frequency (a) cart displacement (b) load oscillation	87
5.29	Response of the gantry crane to 3 <sup>rd</sup> order Butterworth band-stop filter's filtered input with exact natural frequency (a) cart displacement (b) load oscillation	88
5.30	Response of the gantry crane to 1 <sup>st</sup> order elliptic band-stop filter's filtered input with exact natural frequency (a) cart displacement (b) load oscillation	89

5.31	Response of the gantry crane to 3 <sup>rd</sup> order elliptic band-stop filter's filtered input with exact natural frequency (a) cart displacement (b) load oscillation	90
5.32	Power spectral density for the system with unshaped input and exact natural frequency	91
5.33	Power spectral density for the system with exact natural frequency and filtered input using 1 <sup>st</sup> order Butterworth low-pass filter (cut-off frequency at 25% of natural frequency)	91
5.34	Power spectral density for the system with exact natural frequency and filtered input using 3 <sup>rd</sup> order Butterworth low-pass filter (cut-off frequency at 25% of natural frequency)	92
5.35	Power spectral density for the system with exact natural frequency and filtered input using 1 <sup>st</sup> order Butterworth low-pass filter (cut-off frequency at 75% of natural frequency)	92
5.36	Power spectral density for the system with exact natural frequency and filtered input using 3 <sup>rd</sup> order Butterworth low-pass filter (cut-off frequency at 75% of natural frequency)	93

5.37	Power spectral density for the system with exact natural frequency and filtered input using 1 <sup>st</sup> order elliptic low-pass filter (cut-off frequency at 25% of natural frequency)	93
5.38	Power spectral density for the system with exact natural frequency and filtered input using 3 <sup>rd</sup> order elliptic low-pass filter (cut-off frequency at 25% of natural frequency)	94
5.39	Power spectral density for the system with exact natural frequency and filtered input using 1 <sup>st</sup> order elliptic low-pass filter (cut-off frequency at 75% of natural frequency)	94
5.40	Power spectral density for the system with exact natural frequency and filtered input using 3 <sup>rd</sup> order elliptic low-pass filter (cut-off frequency at 75% of natural frequency)	95
5.41	Power spectral density for the system with exact natural frequency and filtered input using 1 <sup>st</sup> order Butterworth band-stop filter	95
5.42	Power spectral density for the system with exact natural frequency and filtered input using 3 <sup>rd</sup> order Butterworth band-stop filter	96
5.43	Power spectral density for the system with exact natural frequency and filtered input using 1 <sup>st</sup> order elliptic band-stop filter	96



5.44	Power spectral density for the system with exact natural frequency and filtered input using 3 <sup>rd</sup> order elliptic band-stop filter	96
5.45	Filtered input for 1 <sup>st</sup> order Butterworth low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 25% of the natural frequency)	98
5.46	Filtered input for 3 <sup>rd</sup> order Butterworth low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 25% of the natural frequency)	98
5.47	Filtered input for 1 <sup>st</sup> order Butterworth low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 75% of the natural frequency)	99
5.48	Filtered input for 3 <sup>rd</sup> order Butterworth low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 75% of the natural frequency)	99
5.49	Filtered input for 1 <sup>st</sup> order elliptic low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 25% of the natural frequency)	100

5.50	Filtered input for 3 <sup>rd</sup> order elliptic low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 25% of the natural frequency)	100
5.51	Filtered input for 1 <sup>st</sup> order elliptic low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 75% of the natural frequency)	101
5.52	Filtered input for 3 <sup>rd</sup> order elliptic low-pass filter designed with 20% error in exact natural frequency (cut-off frequency at 75% of the natural frequency)	101
5.53	Filtered input for 1 <sup>st</sup> order Butterworth band-stop filter designed with 20% error in exact natural frequency	102
5.54	Filtered input for 3 <sup>rd</sup> order Butterworth band-stop filter designed with 20% error in exact natural frequency	102
5.55	Filtered input for 1 <sup>st</sup> order elliptic band-stop filter designed with 20% error in exact natural frequency	103
5.56	Filtered input for 3 <sup>rd</sup> order elliptic band-stop filter designed with 20% error in exact natural frequency	103

5.57	Response of the gantry crane to 1 <sup>st</sup> order Butterworth low-pass filter's filtered input with cut-off frequency at 25% of natural frequency (filter consists 20% error in exact natural frequency)	104
5.58	Response of the gantry crane to 3 <sup>rd</sup> order Butterworth low-pass filter's filtered input with cut-off frequency at 25% of natural frequency (filter consists 20% error in exact natural frequency)	105
5.59	Response of the gantry crane to 1 <sup>st</sup> order Butterworth low-pass filter's filtered input with cut-off frequency at 75% of natural frequency (filter consists 20% error in exact natural frequency)	106
5.60	Response of the gantry crane to 3 <sup>rd</sup> order Butterworth low-pass filter's filtered input with cut-off frequency at 75% of natural frequency (filter consists 20% error in exact natural frequency)	107
5.61	Response of the gantry crane to 1 <sup>st</sup> order elliptic low-pass filter's filtered input with cut-off frequency at 25% of natural frequency (filter consists 20% error in exact natural frequency)	108

5.62	Response of the gantry crane to 3 <sup>rd</sup> order elliptic low-pass filter's filtered input with cut-off frequency at 25% of natural frequency (filter consists 20% error in exact natural frequency)	109
5.63	Response of the gantry crane to 1 <sup>st</sup> order elliptic low-pass filter's filtered input with cut-off frequency at 75% of natural frequency (filter consists 20% error in exact natural frequency)	110
5.64	Response of the gantry crane to 3 <sup>rd</sup> order elliptic low-pass filter's filtered input with cut-off frequency at 75% of natural frequency (filter consists 20% error in exact natural frequency)	111
5.65	Response of the gantry crane to 1 <sup>st</sup> order Butterworth band-stop filter's filtered input (filter consists 20% error in exact natural frequency)	112
5.66	Response of the gantry crane to 3 <sup>rd</sup> order Butterworth band-stop filter's filtered input (filter consists 20% error in exact natural frequency)	113
5.67	Response of the gantry crane to 1 <sup>st</sup> order elliptic band-stop filter's filtered input (filter consists 20% error in exact natural frequency)	114

5.68	Response of the gantry crane to 3 <sup>rd</sup> order elliptic band-stop filter's filtered input (filter consists 20% error in exact natural frequency)	115
5.69	Power spectral density for the system with filtered input using 1 <sup>st</sup> order Butterworth low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 25% of natural frequency)	116
5.70	Power spectral density for the system with filtered input using 3 <sup>rd</sup> order Butterworth low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 25% of natural frequency)	116
5.71	Power spectral density for the system with filtered input using 1 <sup>st</sup> order Butterworth low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 75% of natural frequency)	117
5.72	Power spectral density for the system with filtered input using 3 <sup>rd</sup> order Butterworth low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 75% of natural frequency)	117

5.73	Power spectral density for the system with filtered input using 1 <sup>st</sup> order elliptic low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 25% of natural frequency)	118
5.74	Power spectral density for the system with filtered input using 3 <sup>rd</sup> order elliptic low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 25% of natural frequency)	118
5.75	Power spectral density for the system with filtered input using 1 <sup>st</sup> order elliptic low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 75% of natural frequency)	119
5.76	Power spectral density for the system with filtered input using 3 <sup>rd</sup> order elliptic low-pass filter that consists 20% error in exact natural frequency (cut-off frequency at 75% of natural frequency)	119
5.77	Power spectral density for the system with filtered input using 1 <sup>st</sup> order Butterworth band-stop filter that consists 20% error in exact natural frequency	120

5.78	Power spectral density for the system with filtered input using 3 <sup>rd</sup> order Butterworth band-stop filter that consists 20% error in exact natural frequency	120
5.79	Power spectral density for the system with filtered input using 1 <sup>st</sup> order elliptic band-stop filter that consists 20% error in exact natural frequency	120
5.80	Power spectral density for the system with filtered input using 3 <sup>rd</sup> order elliptic band-stop filter that consists 20% error in exact natural frequency	121
5.81	Comparison in term of rise time, settling time and overshoot of the system's response for filter designed with exact natural frequency	123
5.82	Comparison in term of rise time, settling time and overshoot of the system's response for filter designed with 20% error in exact natural frequency	126
5.83	Level of vibration reduction (a) filter with exact natural frequency (b) filter with 20% error in natural frequency	128

**LIST OF SYMBOLS**

$A_p$	-	maximum pass-band loss
$A_s$	-	minimum pass-band loss
$A_1$	-	magnitude response's minimum value when in pass band (dB)
BSF	-	band-stop filter
dB	-	decibels
$g$	-	gravitational acceleration
$H_\infty$	-	H-infinity
kg	-	kilogram
LPF	-	low-pass filter
$l$	-	length of bar
$m$	-	mass
$m_c$	-	mass of the cart
$m_L$	-	mass of the load
N	-	Newton
$n$	-	filter order
PD	-	proportional-derivative



$r$	-	passband ripple
rad	-	radians
s, sec	-	second
$T$	-	kinetic energy
$T_{\max}$	-	kinetic energy (maximum)
$T_n(\omega)$	-	Chebyshev polynomial of order $n$
$U$	-	potential energy
$U_{\max}$	-	potential energy (maximum)
$u$	-	applied force at cart
$\dot{x}$	-	cart velocity
$\ddot{x}$	-	acceleration
$x_1$	-	displacement of cart
$\theta$	-	angle that exists between the bar and vertical axis
$\dot{\theta}$	-	bar's angle rate
$\omega_c$	-	cut-off frequency
$\omega_n$	-	natural frequency
$\omega_p$	-	pass-band cut-off frequency
$\omega_s$	-	stop-band cut-off frequency
$\omega_1$	-	frequency at which the magnitude response first falls below minimum value of magnitude response when in pass band
&	-	and
%	-	percent

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 CRANE : OVERVIEW**

In our environment, there is a necessity to transfer the things like equipment, things etc. from one place to another, whether there are far or not. In the workplace, for example, at construction or industrial sites, ports, railway yards and other similar locations, special equipment is needed to transport the materials. These materials are usually heavy, large and hazardous, which cannot be handling by workers. In order to make the work easier, cranes have been used to lift, move, position or place machinery, equipment and other large objects. There are many types of crane that been used for these purposes, such as tower crane, overhead crane, boom crane, gantry crane and others. Figures 1.1 and 1.2 shows examples of overhead crane and gantry crane, respectively.



Figure 1.1 Overhead crane



Figure 1.2 Gantry Crane

A crane consists of a hoisting mechanism (usually a hoisting line together with a hook) and a support mechanism. A cable with the load hanged on the hook is suspended from a point on the support mechanism. The support mechanism will moves the hanged load around the crane workspace, while the hoisting mechanism will lifts and lowers the load to prevent the obstacles in the path and locate the load at the desired location.

In handling the crane, safety is the most important point to consider while operating the crane. Hence, the crane must be operated in safe operating manner and procedures. For a crane operator, an experience causing by a crane's accidents can be frightening them. There are many cases and incident regarding on the crane's accidents. For example, in April 1993, the crane becomes unbalanced during two separate incidents at DOE sites in United States of America, which is in Hanford Site and Bryan Mound Site. The first incident occurred in 28<sup>th</sup> April 1993, where a crane becomes unbalanced while the boom was being lowered. The second incident occurred 2 days later, on 30<sup>th</sup> April 1993, which while loading the load, the weight of the load caused the crane to tip forward [1]. From these incidents, guidelines have been suggested in using the cranes. Some of the guidelines are:

- i. the weight of load must be checked.
- ii. crane operations should be supervised by qualified personnel.
- iii. crane operators must be familiar with their equipment.
- iv. crane operators must be trained and qualified to operate their equipment.

Although the guidelines have been sketched in order to prevent the accident, the other factors also must be considered so that the probability of accidents occurs is small or reduced at an acceptable value. There are many factors that have to be considered: the braking systems, hydraulic and pneumatic components, electrical equipment, operational aids, operating mechanisms, lifting devices, determining load weight, recognizing immediate and potential hazards, control systems and others. In term of control systems, the important issue is how to control the load swing. This is important in order to have a faster operation while maintaining the safety.

## **1.2 GANTRY CRANE**

Generally, crane can be defined as a machine used for lifting and lowering a load vertically and moving it horizontally and that has a hoisting mechanism as an integral part of it. As mentioned before, a crane type has varies, depend on their application: automatic crane, cab-operated crane, cantilever gantry crane, floor-operated crane, gantry crane, jib crane, mobile crane, overhead traveling crane, power-operated crane, pulpit-operated crane, remote-operated crane, semigantry crane, wall-mounted crane and wall-mounted jib crane. In this project, the work will be focused on a gantry crane.

Gantry crane is similar to an overhead crane, except that the bridge for carrying the trolley or trolleys is rigidly supported on two or more legs running on fixed rails or other runway. To implement the operation, the crane operator will seat inside the cart, and move the cart with the load hanged with it so that the load can achieve the desired location. A real crane may allow a cart movement of 80 to 90 meters [2], regarding on the desired load location.

### **1.3 MOTIVATION, RATIONAL, SIGNIFICANCE AND NEED FOR THE STUDY**

From the previous works, it seems that most researchers have given a lot of efforts in developing a control algorithms and designing controllers that can be used and realized in nature. This includes the study related on how to reduce the vibration, especially in crane, where the controllers that been designed are mostly to control the load swing. Since this is relatively simple and well defined problem in dynamics and control, it is surprising that, it has not been solved exactly, where an exact solution is here understood to be a control strategy that guarantees complete success in a finite time. Most of the crane controllers that have been developed until now have been far from satisfactory. Once tested in actual operation, there found to be ineffective and thus were left unused. This may due to the standard control feedback strategies that are not well suited to this problem. Therefore, the problem of controller synthesis for a crane is still under consideration.

Regarding on this matter, in this study, it seems interesting if multiple point of view can be taken in modeling the crane. For this purpose, gantry crane has been chosen in order to achieve the aim. This will involves in determining the relation between the cart' mass, load's mass and the load swing, in order to looking after the effect of the cart and load's mass to the load oscillation. Because the operation of the gantry crane is related with the movement of the cart and load, the effect that cause a vibration will be, whether from the acceleration that been applied at the cart, or the load and cart's inertia that been exists because the movement of these objects.

#### **1.4 OBJECTIVES AND WORK METHODOLOGY**

The objectives of this project can be divided as following:

- To obtain a mathematical model of the gantry crane for further analysis (including to study the system's natural response, transient behavior etc.).
- To verify the derived mathematical model through comparison with previous work and simulation on the model.
- To investigate the effects of system parameters such as load on the dynamics behavior of the system.
- To design and develop control algorithms for gantry crane based on filtering techniques.
- To investigate the performance of the control technique in term of vibration reduction and robustness.

In term of work methodology, it can be summarized as in Figure 1.3.

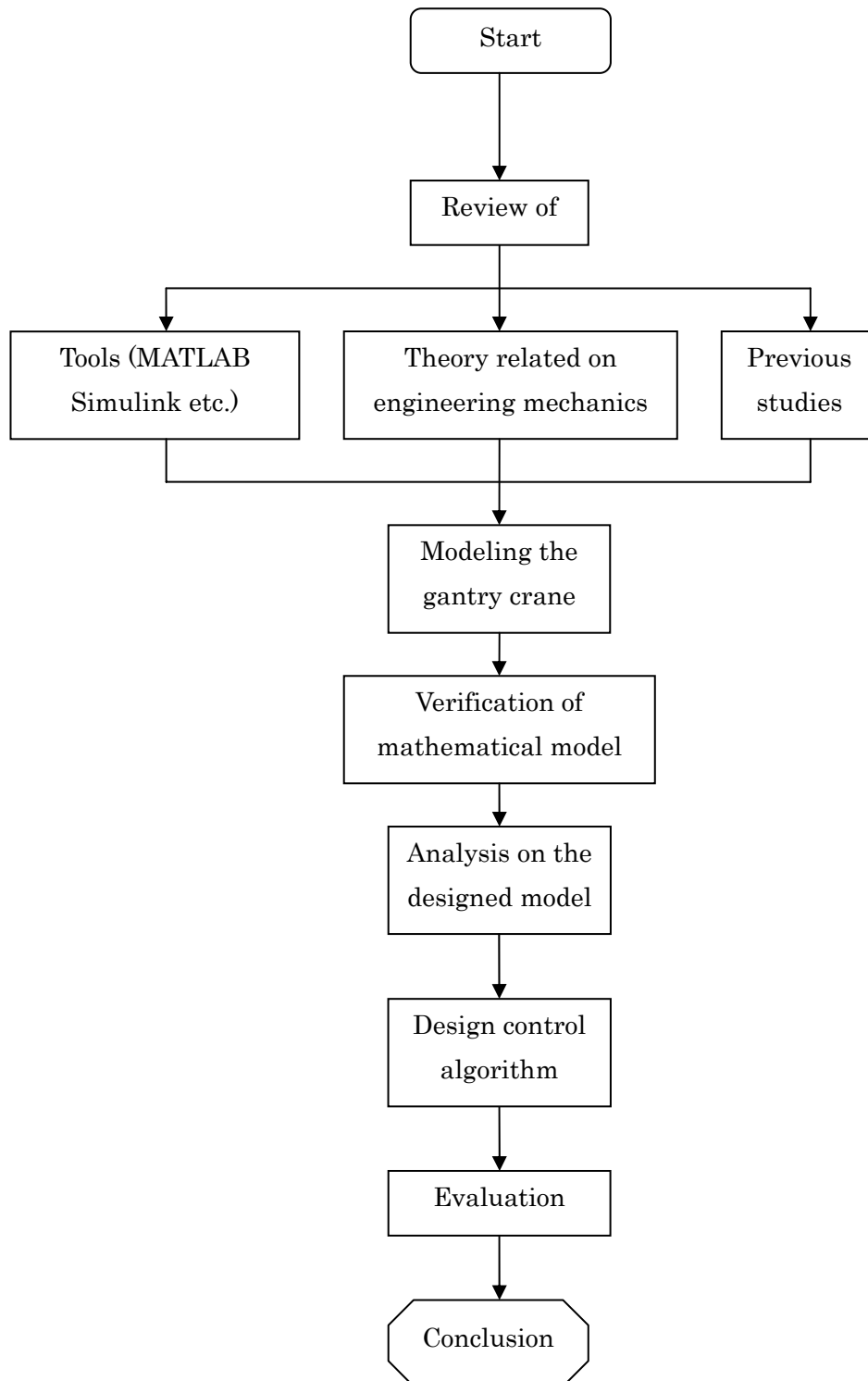


Figure 1.3 Work methodology



## 1.5 THESIS OUTLINE

This section will give an outlines of the structure of the thesis. The following is an explanation for each chapter.

Chapter 2 discusses the previous work that been done around the world about the crane, in term of modeling, or designing the crane. Literature that been done will cover, for instance, modeling, control algorithm design and others. At the end of the chapter, conclusion regarding on previous work that have been surveyed will be showed.

Chapter 3 deals with the gantry crane model, where the mechanical drawing and description related on it will be explained. In addition, the assumption and limitation that been added to the model will be described.

Chapter 4 will discuss along the line regards to model the gantry crane, where mathematical expression will be derived and will be showed. For this work, consideration will be given to the gantry crane with one degree-of-freedom, which its cart and load movement is only along single axis. The derivation will lead to forming the state equation, and the critical aspects, for example, natural frequency will be focused. Furthermore, the derived equation will be compared with previous work and also simulation in order to validate the model. Other than that, the characteristic of

gantry crane will be explored through simulation, where the simulation will take many factors that seems can give an effect to the gantry crane.

Chapter 5 will discuss about control algorithm design for controlling gantry crane. In this topic, consideration is given to develop an algorithm to reduce oscillation of the load. The method that will be proposed is using command shaping via filtering technique, where the method is generally based on open-loop control. Analysis regarding on performance of designed controller will be conducted, and evaluation will be implemented.

Chapter 6 contains conclusion regarding on the topics and recommendation for future works.

evaluate the performances of the gantry crane. With this implementation also, the other aspects perhaps can be observed in order to improve the design.

Finally, is to add other consideration in design, such as to take account the mass of the bar (which relates calculation regards of moment of inertia of the bar and its effect in the system); effect from environment (wind etc). For instance, with adding the mass of the bar, the moment inertia of the bar also need to be considered, which also have its role in load oscillation. As we know, since the body has a definite size and shape, an applied nonconcurrent force system may cause the body to both translate and rotate. This will lead to consideration of adding moment of inertia in calculation, which is a measure of the resistance body to angular acceleration. Regarding on this fact, it is quite beneficial if the other consideration is taken in our design.

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