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DYNAMIC-INVERSION-BASED CONTROL FOR VIBRATION-FREE POSITIONING OF A GANTRY CRANE SYSTEM

AZDIANA BINTI MD. YUSOP

NOOR ASYIKIN BINTI SULAIMAN

SHARATUL IZAH BINTI SAMSUDIN

MOHD SHAKIR BIN MD SAAT

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"I hereby declare that this report is the result of my own work except for quotes as cited in the references."

Signature : ....

Author : AZDIANA BINTI MD. YUSOP

Date : 30 MARCH 2009

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DYNAMIC-INVERSION-BASED CONTROL FOR VIBRATION-FREE POSITIONING OF A GANTRY CRANE SYSTEM

(*Keywords: Input shaping, Inverse dynamic analysis, gantry crane system)*

The inverse dynamic analysis is a simple method that is used for reducing the vibration and the sway angle for the gantry crane system. The shaped input function is derived from the specified output function. Third order exponential function is used as the desired output due to its asymptotic behavior. The simulation has been done to the gantry crane system which is fourth order system by using feedback control. In the proposed method the parameters that need to be defined is the position of the trolley and the sway angle of the mass. Simulated responses of the position of trolley and sway angle of the mass are presented using MATLAB. From the simulation results, satisfactory vibration reduction of a gantry crane system has been achieved using the proposed method.

Key Researchers:

Azdiana binti Md. Yusop
Noor Asyikin binti Sulaiman
Sharatul Izah binti Samsudin
Mohd. Shakir bin Md Saat

E-mail :azdiana@utem.edu.my
Tel. No.: 06-5552044
Vote No.: PJP/2007/FKEKK (5) S276

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LIST OF SYMBOLS

M	- Trolley mass
m	- Payload mass
l	- Length of the hoisting rope
F_x	- Input force
G	- Gravitational acceleration = $9.81ms^{-2}$
G	- Centre point
S	- Point of suspension
x	- Trolley position
$\dot{x}$	- Velocity
$\ddot{x}$	- Acceleration
θ	- Sway angle
$\dot{\theta}$	- Angular velocity
$\ddot{\theta}$	- Angular acceleration

LIST OF ABBREVIATIONS

A/D	- Analog-to-digital
CPU	- Central Processing Unit
D/A	- Digital-to-Analog
DAQ	- Data Acquisition Board
DC	- Direct Current
EEPROM	- Electrically Erasable Programmable Read Only Memory
EIA	- Electronic Industries Alliance
FFT	- Fast Fourier Transform
I/O	- Input / Output
MCU	- Microchip Microcontroller
NI	- National Instruments
PIC	- Peripheral Interface Controller
RAM	- Random-Access Memory
RTW	- Real Time Workshop
RS	- Recommended Standard
ROM	- Read-only Memory
SNA	- Specified Negative Amplitude shaper
UMZV	- Unity Magnitude Zero Vibration Shaper

LIST OF APPENDIXS

CHAPTER I

PROJECT INTRODUCTION

This chapter will emphasize on the gantry crane system with dynamic inversion based control. The project introduction, project objective, problem statement, and scopes of work, methodology and thesis outline will also be presented.

1.1 Introduction

A gantry crane system is a crane carrying the trolley or trolley with a movable or fixed hoisting mechanism, that the bridge is rigidly supported on two or more legs running on fixed rails or other runway. The fundamental motions of a gantry crane consist of traversing, load hosting and load lowering. Gantry cranes are widely used as an efficient means of traversing heavy object in factories, warehouse and shipping yards. Like other crane types, gantry cranes met with some dissatisfactory due to its natural characteristics.

As mentioned, the fundamental motions of a gantry crane consist of traversing, load hosting and load lowering. These significant characteristic is that all motions are performed simultaneous at relatively high speed. Crane traversing motions, particularly when starting or stopping; induce undesirable swinging of the suspended load. This creates another problem that the swing could cause the hosting rope to leave its groove which could lead to over wrapping and damage. One of the characteristics of these cranes is the flexible hoisting ropes used as a part of the structure for the reduction of system mass, which result in favorable features of high payload ratio, high motion speed and low power consumption. However, the flexible hoisting create serious problems, that is the crane acceleration which required for motion will generate undesirable load swing, which is frequently aggravated by load hoisting. Therefore, such load swing should be suppressed as rapidly as possible to maximize the operations.

Several methods of open-loop and closed-loop solutions have been proposed in order to control the vibration. For example, open loop time optimal strategies were applied to the crane by many researchers such as discussed in [1, 2]. They came out with poor results because open loop strategy is sensitive to the system parameters (e.g. rope length) and could not compensate for wind disturbances [3]. The most popular technique for input shaping is to convolve a sequence of impulses and various methods for shaping impulse sequence of impulses have been testified and applied to crane system as in [4]. M N Sahinkaya in his paper [5] also has reported the same inverse dynamic technique in spring-mass-damper system. However all the above method is still an open-loop approach that avoid the system from become less sensitive to disturbances.

Increasingly however, feedback control which is well known to be less sensitive to disturbances and parameter variations also adopted to control the gantry crane system. Work that has been presented by Omar [6] had proposed PD (Proportional-Derivative) controllers for both position and anti-swing controls. Moreover, a Fuzzy Logic Controller had been introduced by Wahyudi and Jamaludin [3]. Fuzzy logic controllers were designed and implemented for controlling payload position as well as the swing angle of the gantry crane. In this paper, robustness of the proposed intelligent gantry crane system is evaluated and compared with an automatic gantry crane controlled by the classical PID (Proportional-Integral- Derivatives) controllers. The result shows that the intelligent gantry crane system has a better performance and more robust to parameter variation compared to the automatic crane system.

However, most of the open loop and feedback methods start with a parametric input function, which usually involves magnitude and time delay. By using the inverse dynamic analysis with a feedback control, the designer can choose the speed and shape of the motion within the limitations of the drive system and can ensure that the system is less sensitive to disturbances and parameter variations.

This research will focus on a feedback control system based on the dynamic model of the gantry crane system. The main idea is to produce vibration free system using inverse dynamic analysis.

1.2 Objective

This research is attempts to:

i. specify an input function that will drive the system from an initial position into a target position as fast as possible without vibration at the target position and within the physical constraints of the drive system.
ii. build the gantry-crane system model.
iii. control the crane using the inverse dynamic analysis by interfacing the input function to the real system.
iv. patent this product and promote to the other higher education institute as to generate income to the University.

1.3 Problem Statement

The safety and efficiency of the operation of a gantry crane are generally reduced by the transient sway and residual oscillation of either the empty hook or the payload. In general, this problem is tackled by the experience and skill of the operators, who try to impose a deceleration law that reduces the oscillation caused by the acceleration. Moreover, a man is often tasked to stop the hook or the payload. Thus, the performances of the system can be significantly improved by using appropriate automatic control architecture, which is capable of reducing the swing effect and minimizing the motion time in order to increase the throughput of the crane.

However, the design of the controller is a challenging problem, since the system, which can be regarded as a single-pendulum, is nonlinear (and hence, if a linearised model is considered for the controller design, then the attained performances have to be verified against a complete nonlinear model) and the value of certain system parameters such as the rope length and the payload mass may significantly vary during the operations. Moreover, in the minimization of the motion time of the payload the trolley driving motor constraints have to be taken into account.

In this research project, the way of deriving the inverse dynamic input must be studied first. Then the actual system of a gantry-crane system must be built. The last problem that should be considered is the interfacing between the controllers and the actual system which is one of the critical parts in this project.

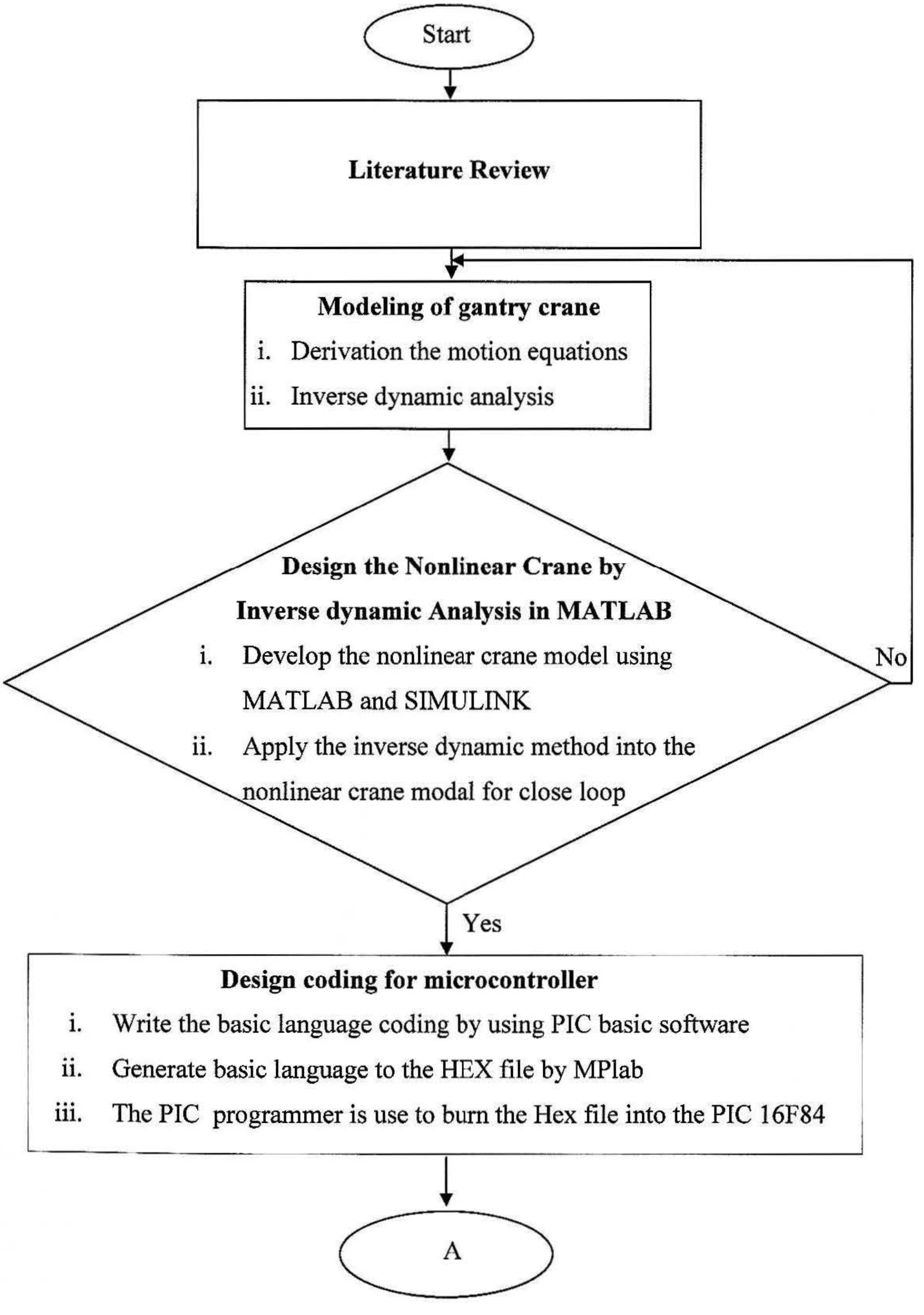
1.4 Research Methodology

At the first stage, the mathematical model of a gantry-crane system must be derived. It is important in order to test the input function effectiveness before interfacing to the actual system. Since the system is nonlinear, thus, it is being linearized by using some assumptions to eliminate some nonlinearities of the system.

Then, the shaped input function will be derived from the specified output function, in this case is a third order exponential function. After completing the deriving process, the input function will be applied into the open loop and closed loop gantry-crane system. The dynamic model will be developed using MATLAB and SIMULINK.

The construction of the real gantry-crane system is one of the most important parts in this research project. One of the characteristics of these cranes that must be taken into account when constructing it is the flexible hoisting ropes that is used as a part of the structure for the reduction of system mass, which result in favorable features of high payload ratio, high motion speed and low power consumption. However, the flexible hoisting create serious problems, that is the crane acceleration which required for motion will generate undesirable load swing, which is frequently aggravated by load hoisting. Therefore, such load swing should be suppressed as rapidly as possible to maximize the operations.

The final stage of this research project is to interface the input function (designing in the PC) to the actual gantry-crane system (hardware). At this point, the controller is performed to control the actual gantry-crane system. The performance comparison of the simulation and experimental will be carried out and minor modification should be made to the controller when applying to the real system.


Start
Literature Review
Modeling of gantry crane
i. Derivation the motion equations
ii. Inverse dynamic analysis
Design the Nonlinear Crane by
Inverse dynamic Analysis in MATLAB
i. Develop the nonlinear crane model using MATLAB and SIMULINK
ii. Apply the inverse dynamic method into the nonlinear crane modal for close loop
No
Yes
Design coding for microcontroller
i. Write the basic language coding by using PIC basic software
ii. Generate basic language to the HEX file by MPlab
iii. The PIC programmer is use to burn the Hex file into the PIC 16F84
A

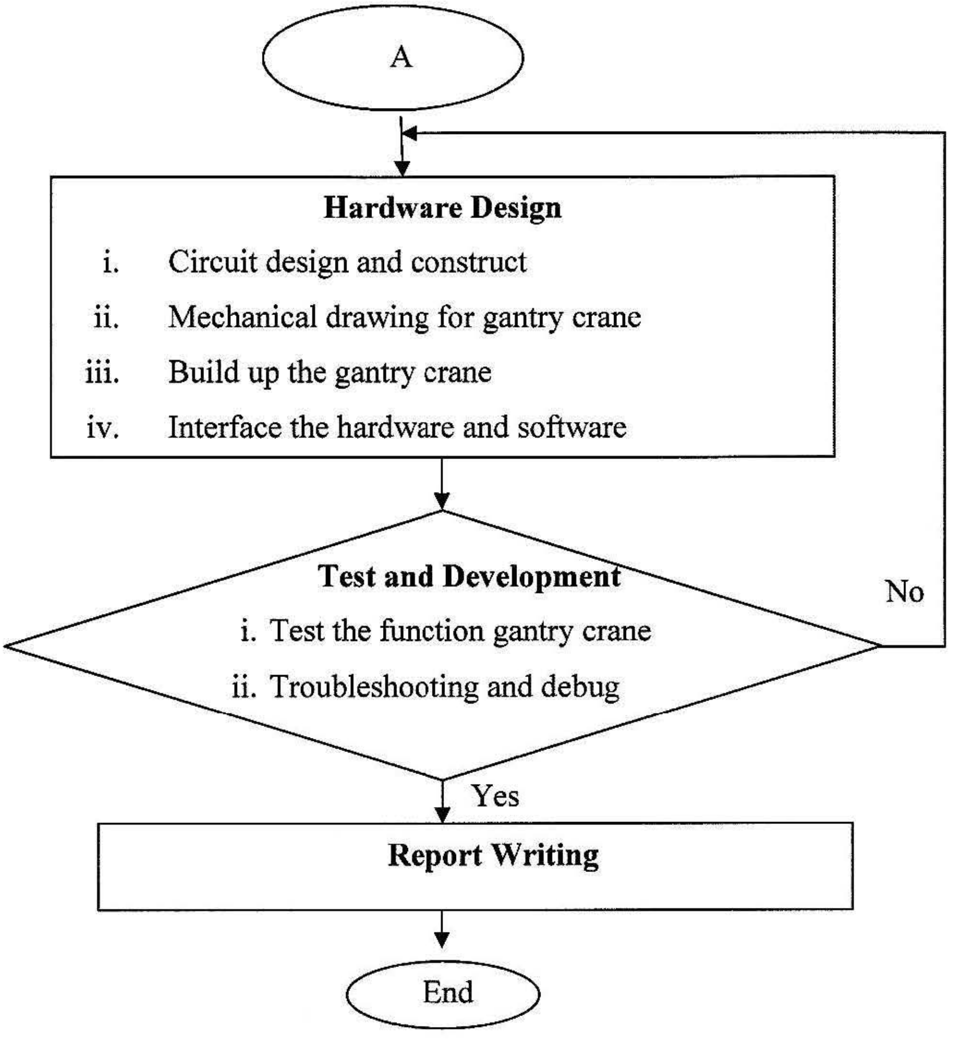


Figure 1.1: Project flow chart

1.5 Report Structure

This report is a documentary to deliver the generated idea, the concepts applied, the activities done, and the product produced. The report consists of seven chapters.

Chapter I is about some background of the project. Furthermore, the objective of project, problem statement, methodology and report outline also will be presented.

Chapter II contain literature review about the precise position control, rapid rest-to-rest motion and the several techniques of input shaping that will reduce the vibration for the gantry crane. On the other hand, this chapter also will clarify the way to choose the suitable motor and PIC microcontroller.

Chapter III will include the derivation of equations of motion for a gantry carne. On the other hand, this chapter will explain more about the equation of motion and represents it in the time domain.

Chapter IV will illustrate the inversion dynamic based control method. This method will reverse the process by specifying the system output function and deriving the input.

In Chapter V contain the methodology for hardware and software. The design flow and construction of the project is introduced. It gives brief description about each procedure in completing the project. This chapter includes a list of tools and approaches used in the project.

Chapter VI will cover the result, analysis and discussion. On the other hand, this chapter will include the result and analysis for the manual control gantry crane.

Finally, Chapter VII is the conclusion of this research. It also contains the application of the project and the recommendation that can be implemented in the future.

CHAPTER II

LITERATURE REVIEW

Literature review is done in this chapter to make a review of the several techniques of input shaping that will reduce the vibration. This chapter also will clarify the way to choose the suitable motor, PIC microcontroller, Data Acquisition Board (DAQ Card) and signal conditioning circuit.

2.1 Input Shaping Techniques

Input shaping is a simple and effective method for reducing the residual vibration when position lightly damped system. One very useful form of command shaping is input shaping. Input shaping is applicable in real time, and input shapers can be designed to have any desirable robustness level. Input shaping is designed to reduce, or eliminate, command-induced system vibration [9]. A desired reference command given to a flexible system will, in general, result in residual vibration. Input shaping is ability to cancel vibration can be viewed as destructive interference of sinusoidal waves [10]. If two sinusoids of the same magnitude, same frequency and correct phase shift between them are added together, the resulting combination will have no oscillations. This effect can be seen in Figure 2.1.