OPTIMAL DYNAMIC INVERSION BASED CONTROL OF AN OVERHEAD CRANE

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This report is submitted in partial fulfillment of the requirements for the award of Bachelor of Electronic Engineering (Industrial Electronics) With Honours

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April 2009

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To my beloved family,
mum, dad, brothers and sisters,
thanks for your support and encouragement
that you have given in my life. Also to my supervisor,
thanks for your guide and the supports that been given
to me in completing this work. And also not
forget to all of my friend and people
around me for your support and
cooperation.

ABSTRACT

A Methodology is proposed to control the transient and residual oscillation of a payload carried by an overhead crane. The design approach is based on a linearised model of the crane and consists of dampening the linearised system by an observer-based controller and applying a dynamic inversion procedure in order to assure a predetermined oscillation free polynomial motion law for the payload. Polynomials functions are adopted in order to guarantee that the input function has a continuous derivative of an arbitrary order. Moreover, the motion time can be minimized, taking into account constraints on the actuator, by means of a simple bisection algorithm. Parameter uncertainties are taken into account during the whole design procedure. Simulation results, based on a nonlinear crane model, show how the method is also effective when the payload is hoisted or lowered during the motion, and when friction effects are considered.

ABSTRAK

Satu kaedah telah dicadangkan untuk mengawal ayunan sementara dan ayunan sisa satu muatan yang dibawa oleh satu kren bergerak ke atas. Pendekatan rekaan ini adalah diasaskan oleh satu model kren yang dilinearkan dan mengandungi perlembapan sistem yang dilinearkan secara satu pemerhati berpangkalan pengawal dan menggunakan satu prosedur songsangan dinamik teratur bagi memastikan satu ayunan yang pratentu mengikut usul hukum polinomial bebas untuk muatan. Fungsi-fungsi Polynomials diambil dengan teratur untuk menjamin fungsi input mempunyai satu terbitan yang berterusan dari satu perintah sembarangan. Tambahan pula, masa usul boleh dikurangkan jika mengambil kira kekangan-kekangan di penggerak oleh cara sederhana pembahagian dua sama algoritma. Ketidakpastian parameter juga diambil kira sepanjang perlaksanaan seluruh reka bentuk. Hasil simulasi adalah berdasarkan satu model tidak linear dan menunjukkan bagaimana kaedah ini adalah juga berkesan apabila muatan dinaikkan atau direndahkan, dan apabila kesan-kesan geseran juga diambil kira.

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M, mc- Trolley mass

m, m*l*- Payload mass

l - Length of the hoisting rope

F_x - Input force

G - Gravitational acceleration = 9.81ms^{-2}

G - Centre point

x - Trolley position

$\dot{x}$ - Velocity

$\ddot{x}$ - Acceleration

θ - Sway angle

$\dot{\theta}$ - Angular velocity

$\ddot{\theta}$ - Angular acceleration

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CHAPTER I

INTRODUCTION

In this chapter there will be a discussion on this project title of optimal dynamic inversion based control of an overhead crane. The project introduction, project objective, problem statement, and scopes of work and methodology will also be presented.

1.1 Introduction

The safety and efficiency of the operation of an overhead 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 through put 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 verified against a complete nonlinear model) and the value of certain 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 constraint have to be taken into account.

In many cases system uncertainties and actuator constraints are not taken into account and often the controller design is done by optimizing only one side of the problem either the traveling time of the payload is minimise or the swinging effect is reduced. Therefore, it seems that a design technique that is capable of achieving different goals in a unified frame work still lacking.

A methodology based on dynamic inversion, for the design of a robust feedforward/feedback control scheme which allows us to significantly reduce the transient sway and residual oscillation of the payload, whilst minimizing the traveling time and taking into account the trolley's actuator constraints. The methodology basically consists of linearising system and dampening it by means of a robust state-feedback controller. Then, after having defined a family of desired smooth polynomial motion laws for the payload depend on the motion time, the corresponding family of reference inputs is subsequently determined by inverting the nominal closed-loop system. Finally, with a worst case approach, the motion time can be opportunely minimized ensuring that limits on the trolley's actuator are not exceeded.

In the literature, the use of dynamics procedures has been proposed for a variety of output tracking problems for applications to mechanical systems.

1.2 Objective

The objective of this project is to develop an optimal dynamic inversion based control for a gantry crane system where this system can reduce the transient sway, residual oscillation, traveling time and reach the target position without vibration.

1.3 Problems Statement

Gantry cranes are widely used for factories, transportation, nuclear installation and also construction. The crane has to move as fast as possible without causing any excessive movement at the final position or during it moves. However, 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. The swing motion when payload is suddenly stopped after a fast motion can be reduced but very wasting time. Moreover, the gantry crane needs a skilful and experience operator to control manually for stopping the swing immediately at the right position. Beside this, the operator also needs time to wait the string stop from vibration after movement the load. The vibration is a serious problem in a mechanical system. A gantry crane system with inverse dynamic method can used to solve this problem

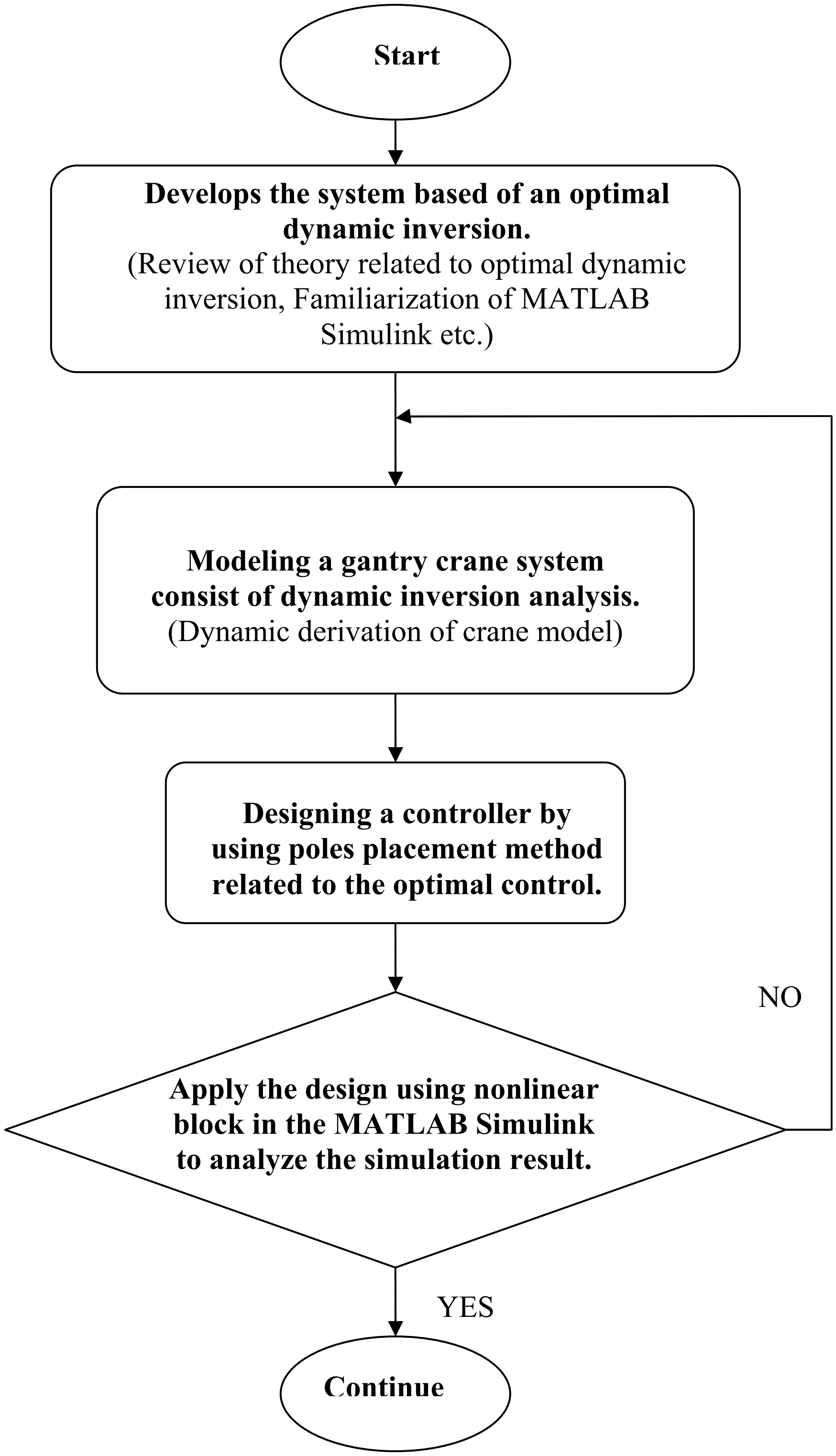
If a linearised model is considered for the controller design, the attained performances have to be verified against a complete non-linear model. The crane has to move the load as fast as possible without causing any excessive movement at the final position or during it moves. Moreover, in the minimization of the motion time of the payload, the trolley driving motor has to be considered. In many cases, system uncertainties and actuator constraints are not considered and often the controller design is done by optimizing only one side problems either the traveling time or swinging effect. So, the design based on dynamic inversion will encounter this problem.

1.4 Scopes of Work

During the project, there a scope of work that will guide student in their project. It's a guideline which student should attain to fulfill the requirement of project. The scopes of work are listed as below:

i. Learn the basic concept of a dynamic inversion analysis.
ii. Develops the system based of an optimal dynamic inversion.
iii. Modeling of a gantry crane consists of dynamic derivations of gantry crane model, dynamic inversion analysis.
iv. Perform a controllability and observability test before designing a controller.
v. Designing a state feedback control using pole placement method related to the optimal control.
vi. Applying the design of nonlinear gantry crane block in MATLAB SIMULINK to analyze to simulation result.
vii. Interface the gantry crane system control design in MATLAB Simulink with the hardware.
viii. Evaluation of any problems in the project.
ix. Come out with the result and analysis of this project.

1.5 Methodology



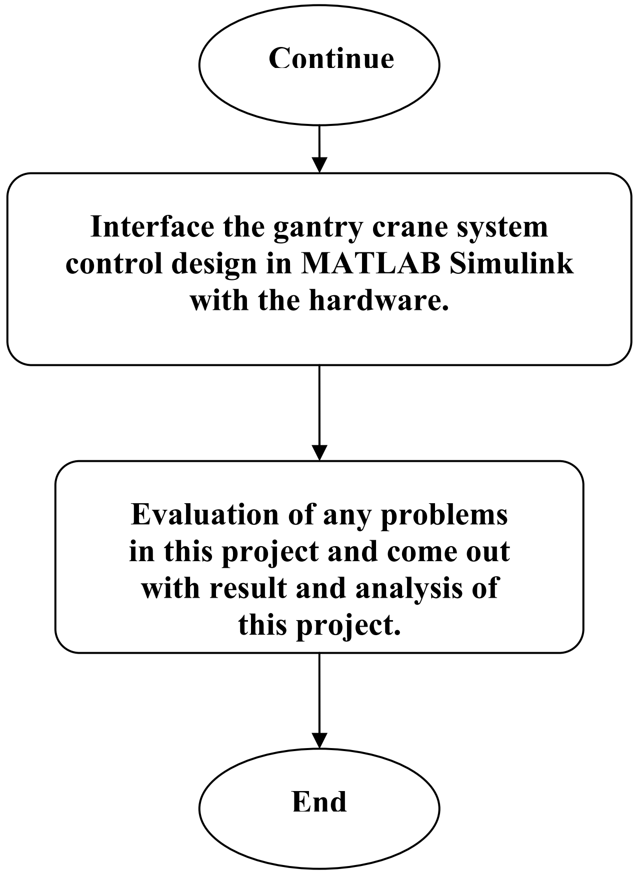


Figure 1.1: Project flow chart

CHAPTER II

LITERATURE REVIEW

This chapter contains the reviews and information about the project on several important concepts on optimal dynamic inversion and tools that were used in this project. Each fact and information is guided by journals and other references. It will be compared and the best method will be choosing for this project. This literature review will also include the review of several types of cranes.

2.1 Optimal Dynamic Inversion Method

The control design methodology, consist of first determining state feedback control law whose aim is to assure the robust stability of the system and to damp it. In this phase it is necessary to augment the system in order to assure a null steady state error is achieved at the end of the motion in spite of possible external disturbances (for example friction effects). Then, after having defined a parameterized family or desired output function which depends on the motion time, the corresponding family of command input function is derived by inverting the closed loop system. The motion time can be minimized taking account actuator constraints and parameter uncertainties.