MODEL PREDICTIVE CONTROL OF AN
OVERHEAD CRANE SYSTEM

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DEDICATION

This thesis is dedicated to all my family members who have been supporting me financially and mentally. Moreover, they have been encouraging me to be consistent in this work from the start of the journey until the end. This thesis is also dedicated to all my colleagues in this MKEM course. They were always there to push me when the going got tough and helped me throughout. Last but not least, my work here is also dedicated to all my friends in Robotic Laboratory, who always inspire me and also encourage me to explore more knowledge and go deeper into this field of study.

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ABSTRACT

This project explores and studies the application of Model Predictive Control (MPC) to an overhead crane system. Overhead crane is a machine used in industrial site such as construction and manufacturing site, in order to move hazardous materials or heavy loads from current place to another desired location. While transporting the payload to desired place, the payload oscillation must be minimized for a safety operation. This makes an overhead crane to be an under-actuated system that need to control more process variables with less manipulated variables. Due to this complexity of the dynamical system, it is very challenging to reduce or eliminate the payload swing angle during the trolley positioning. In addition, constraint is needed to be concerned when designing a controller for the overhead crane system. Therefore, MPC which has the advantage of dealing with constraint, is proposed to have more precise trolley positioning and low payload oscillation during the crane motion. The project starts by deriving the mathematical model using the Euler-Lagrange equation of an overhead crane system. Then, Optimal Predictive Control (OPC), which is one of the type of MPC, was selected for MPC design and then applied to the overhead crane system in a simulation. The result shows that all constraints were satisfied when the overhead crane system was controlled by using OPC. Subsequently, the MPC design was implemented on a laboratory scale crane to investigate the real-time implementation and performance of the controller. The result shows that a desired steady-state value can be achieved in the experiment. However, for transient response, there was a slight deviation for the system responses between the simulation and experiment, which may be due to the deviation between model in simulation and the laboratory crane system.

Keywords: Overhead crane, Model Predictive Control and Optimal Predictive Control.

ABSTRAK

Projek ini bertujuan menerokai aplikasi Kawalan Ramalan Model pada sistem kren jambatan. Kren jambatan adalah mesin yang digunakan di tapak perindustrian seperti tapak pembinaan dan kawasan pembuatan, bagi mengangkut bahan merbahaya atau muatan berat dari tempat semasa ke tempat baru yang dikehendaki. Apabila mengangkut muatan ke tempat yang dikehendaki, ayunan muatan mesti dikurangkan untuk keselamatan semasa operasi. Fenomena ini menjadikan sistem kren jambatan sebagai sistem kurang tindakan yang mana sistem ini perlu menggunakan sedikit pembolehubah manipulasi untuk mengawal pembolehubah proses yang mempunyai kuantiti yang lebih banyak. Oleh kerana kerumitan sistem dinamik yang sebegini, proses mengurangkan ayunan muatan ketika muatan diangkut adalah sangat mencabar. Tambahan pula, kekangan perlu diambil kira ketika mereka bentuk pengawal bagi sistem kren jambatan. Oleh yang demikian, Kawalan Ramalan Model (MPC) yang mempunyai kelebihan dalam mengurus kekangan, dicadangkan untuk digunakan bagi mendapatkan pergerakan kren yang lebih tepat dan juga ayunan muatan yang lebih minimum apabila kren bergerak. Projek ini bermula dengan penghasilan model matematik menggunakan persamaan Euler-Lagrange untuk sistem kren jambatan, diikuti dengan mereka bentuk MPC menggunakan Kawalan Ramalan Optimum (OPC) yang merupakan salah satu jenis dari MPC, untuk diaplikasikan kepada sistem kren jambatan dalam simulasi. Hasilnya, semua kekangan berjaya dipenuhi apabila sistem kren jambatan dikawal menggunakan OPC. Kemudian, proses mereka bentuk MPC diaplikasikan terhadap kren makmal untuk mengkaji aplikasi pada masa sebenar dan prestasi pengawal. Hasilnya, nilai keadaan tunak yang dikehendaki berjaya dicapai dalam eksperimen. Namun yang demikian, bagi respon sewaktu keadaan sementara, wujudnya perbezaan yang sedikit antara respon dari simulasi dibandingkan dengan yang di eksperimen, yang disebabkan oleh perbezaan antara model dari simulasi dan kren makmal.

Kata kunci: Kren jambatan, Kawalan Ramalan Model dan Kawalan Ramalan Optimum.

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LIST OF ABBREVIATIONS

MPC	-	Model Predictive Control
NMPC	-	Nonlinear Model Predictive Control
GPC	-	Generalized Predictive Control
OPC	-	Optimal Predictive Control
AI	-	Artificial Intelligence
2-D	-	Two-dimensional
3-D	-	Three-dimensional
FPGA	-	Field Programmable Gate Array
UTM	-	Universiti Teknologi Malaysia

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Crane is a machine that is used to move hazardous materials or heavy loads from a current place to another desired location. This machine is commonly used in industrial sites such as manufacturing and construction sites. Cranes can be classified into 3 types, according to their motions and their structures: (a) overhead/gantry crane, (b) tower/rotary crane and (c) boom crane. All of these types of crane can be referred as in Figure 1.1.

(a)

(b)

(c)

Figure 1.1 Types of cranes : (a) An overhead/gantry crane
(b) A tower/rotary crane (c) A boom crane

Crane system is actually an under-actuated system [1] since the number of actuators used in the crane are less than its degrees of freedom. So it is difficult to control more process variables with less manipulated variables. For a basic crane system, a force input is applied to move the payload to desired place while minimizing the payload oscillation, in order to ensure safety during operation of crane, and also for a smooth and efficient way to handle the crane during the operation [2]. If the payload oscillation is not minimized, it will affect the accuracy of crane positioning, the safety during operation and also the quality of crane handling [3]. In industrial site, a failure in controlling the payload oscillation can make the operator faces the difficulty during handling the crane, and would also downgrade the condition of the load or the operating environment around that site. Production volume will also be slower if time required to complete this task of moving the payload to desired place while minimizing the payload oscillation, become longer.

In addition, the changes in mass of payload and also the varying length of payload cable due to payload hoisting, may induce payload swinging, twisting and bouncing [4]. These factors will cause an excessive payload swing that makes the operator become more difficult to operate the crane in order to get a good and accurate crane positioning with minimum payload oscillation. Due to this matter, research on payload swing control is still relevant nowadays, and remains as one of the interested research problem among researchers that are involved in designing control algorithm for the under-actuated crane system.

For the proposed controller of MPC, it is actually a discrete closed-loop optimal control algorithm. MPC has been used for controlling many systems, such as control of an overhead crane system [5], [6], [7], [8] which is the main focus in this research work. This controller is widely used because it has lot of advantages compared to conventional controller [9], especially in term of handling with constraints [10], [11]. It has been proved that MPC has achieved not only satisfied performance of stability and robustness [12], but this controller also can deal with nonlinearity as well [13], [14].

1.2 Problem Statement

Overhead crane system is an under-actuated system that need to control more process variables while operating less manipulated variables. Therefore, it is difficult to balance the performance of all output in one time [15]. For example, a specific controller can be designed to get very fast response for the trolley displacement. However, system response for the payload oscillation will get worse due to this controller design. If controller designer put more priority on getting very low oscillation for the payload swing, system response for the trolley displacement will be slower. This is the challenge while designing control algorithm for underactuated system like overhead crane system. While aiming for the best response for all output, input constraint need to be considered to prevent actuator from getting damage. For 2-D overhead crane with hoisting payload [4], [16], the number of actuators has increased from 1 to 2 motors in order to drive both trolley and hoisting movement. The increase of number of actuators will increase the number of constraints needed to be concerned [10], [11], and controller will be more difficult to be designed for more complex multivariable system.

1.3 Research Objectives

The objectives of this research work are as follows :

i. To obtain a dynamic model of an overhead crane with experimental validation.
ii. To design and simulate MPC for control of an overhead crane.
iii. To analyze MPC design at real overhead crane system and validate its performance in real-time implementation.

1.4 Research Scopes

The scopes of this research work are as follows :

i. A single pendulum overhead crane is considered.
ii. Both simulation and experimental work are carried out.
iii. Optimal Predictive Control is considered for control design.
iv. The payload cable is assumed to be inextensible.
v. The payload is considered as a point mass.

1.5 Outline of the Report

This report is organized in five chapters, which are Introduction, Literature Review, Research Methodology, and Results and discussions. Firstly, Introduction is consists of research background, problem statement, objectives, and scopes of this research work. Chapter 2 presents literature review about the application of MPC for an overhead crane system from past research. Chapter 3 is about research methodology which is consists of its guidelines and management for this research work. Chapter 4 highlights results and discussion about the performance of MPC design for an overhead crane system, for both simulation and experimental work. Finally, chapter 5 provides conclusion and future works.

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