INPUT SHAPING FOR VIBRATION-FREE POSITIONING OF FLEXIBLE SYSTEMS

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To my beloved mom and dad

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ABSTRACT

Input shaping is a simple method for reducing the residual vibration in positioning lightly damped systems. For controlling part, a continuous and differentiable function is introduced to define the desired motion and the input is shaped by inverse dynamic analysis. The shaped input function is derived from the specified output function so that the designer can choose the speed and shape of the motion within the limitations of the drive system. Third order exponential function will be used as the desired output due to its asymptotic behavior. The simulation has been done to the spring-mass-damper system which is a second order system to study the application of the technique to the system. The effects of errors in damping ratio and natural frequency are also discussed. Next, the same technique is applied to a gantry crane system which is fourth order system. In the proposed method the parameters that need to be defined is the position of the trolley and sway angle of the mass. Simulated responses of the position of the trolley and sway angle of the mass are presented using MATLAB. The performance of the Bang-bang input technique and the inverse dynamic analysis are compared. From the simulation results, satisfactory vibration reduction of a crane system has been achieved using the proposed method.

ABSTRAK

'Input shaping' merupakan kaedah mudah untuk mengurangkan getaran semasa menggerakkan sesuatu sistem. Pada bahagian pengawal, fungsi persamaan yang berterusan dan boleh beza diperkenalkan untuk mendapatkan respons yang dikehendaki dan persamaan input diterbitkan menggunakan teknik *'inverse dynamic'*. Persamaan input diperolehi daripada respons output yang dikehendaki supaya pengkaji dapat memilih kelajuan dan bentuk respons yang diperlukan supaya berada dalam had maksima sesuatu sistem. Fungsi eksponen kuasa tiga akan digunakan sebagai output disebabkan oleh sifat kestabilan asimptotnya. Simulasi dijalankan ke atas sistem spring-beban teredam iaitu sistem order kedua untuk mengkaji kesan teknik ini kepada sistem tersebut. Kesan ralat pada *'damping ratio'* dan *'natural frequency'* juga dibincangkan. Seterusnya, teknik yang sama diaplikasikan kepada sistem kren *'gantry'* yang merupakan sistem order keempat. Dengan menggunakan teknik ini, parameter yang akan dikaji adalah kedudukan troli dan sudut ayunan beban. Respons bagi kedudukan troli dan sudut ayunan beban akan ditunjukkan menggunakan perisian MATLAB. Prestasi output menggunakan input Bang-bang dan *'inverse dynamic'* dibandingkan. Dari keputusan simulasi didapati pengurangan kadar getaran yang memuaskan telah diperolehi menggunakan teknik yang diperkenalkan.

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ω_n - Natural frequency
ξ - Damping ratio
K - Stiffness
u - Normalized time
α - Speed motion
β - Relationship between α and ω_n
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

CHAPTER I

INTRODUCTION

1.1 Project Introduction

In many machines, load positioning is achieved by simple open-loop control. In the case where structural flexibility is significant, and the load is lightly damped, the vibration may be unacceptable. Many solutions have been proposed to reduce vibration using input shaping technique.

Vibration is a serious problem in mechanical systems that are required to perform precise motion in the presence of structural flexibility. Examples of such systems range from the positioning of disk drives head to large space structures, flexible manipulators and container cranes. In most cases, the residual vibration at the end of a move is the most detrimental and the extent of the residual vibration limits the performance of the system. The effective use of such systems can only be achieved when such vibration can be properly handled. As a result, there is active research interest in finding methods that will eliminate vibration for a variety of mechanical and structural systems.

Traditional closed-loop feedback can be used to reduce end-point vibration. The closed-loop system will then benefit from the inherent advantages of feedback, such as insensitivity to parameter variations, noise attenuation and disturbance rejection. However, such a feedback system can be difficult to implement in practice, as it requires reliable sensor information for feedback. Such sensor information may not be so easily available. For example, in the container crane system problem, it is not a trivial task (nor practical due to reliability of sensors and its environment) to devise a sensor to measure the position at the end-point. Another approach is input shaping technique, in which the input is preshaped such that the resulting residual vibration is reduced or eliminated. These methods are popular in industry because they are relatively simple to implement the preshaped input together with closed-loop feedback strategies to enjoy the benefits of both systems.

Input shaping is a feedforward control technique for improving the settling time and the positioning accuracy, while minimizing residual vibrations, of computer-controlled machines. Input shaping is a strategy for the generation of time-optimal shaped commands using only a simple model, which consists of the estimates of natural frequencies and damping ratios. Hence, input shaping is a simple method for reducing the residual vibration when positioning lightly damped systems. It offers several clear advantages over conventional approaches for trajectory generation:

i) Designing an input shaping does not require an analytical model of the system; it can be generated from simple, empirical measurements of the actual physical system.

ii) Input shaping does not affect the stability of the closed loop system in any way. It simply modifies the command signal to the system so that all moves, regardless of length, are vibration free.

1.2 Objective

This project attempts to 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.

1.3 Methodology

i) Study on the inverse dynamic analysis to shape the input function of the system.

ii) Derive the shaped input function from the specified output function, in this case is a third order exponential function.

iii) Implement the input function into the open loop system.

iv) Develop the dynamic model using MATLAB and SIMULINK.

v) Investigating of the technique to a gantry crane system.

1.4 Project Overview

As a whole, this project considers only one parameter that needs to be defined that is output speed, which is limited only by the physical constraints of the drive system. A continuous and differentiable function is introduced to define the desired motion and the input is shaped by inverse dynamic analysis. The system output function is specified and the shaped input function will be derived. Third order exponential function is used as the desired output due to its asymptotic behavior. Simulation is done using MATLAB to obtain the output response. From the simulation results, under certain circumstances, the design process can be simplified and the need for inverse dynamics is eliminated. In addition, robustness is evaluated by a sensitivity analysis on the simulated examples.

1.5 Thesis Outline

This thesis consists of six chapters. Chapter I provides some background of the project, the objective and the scope of studies. Chapter II contains the literature review on several important concepts of input shaping, technology and tools used in the study. Chapter III entails the principle of system inversion based method including the behaviour of the method on second order system. Chapter IV follows with the design and modelling of the gantry crane system. Simulation results, analysis and discussion of the performance of the technique are presented in Chapter V. The work is then concluded in Chapter VI with some suggestions and future works.

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