Dynamic Modelling and Control of a Flexible Manipulator

Zaharuddin Mohamed

A thesis submitted to the University of Sheffield for the degree of
Doctor of Philosophy

Department of Automatic Control and Systems Engineering
Faculty of Engineering
The University of Sheffield

April 2003

Abstract

This thesis presents investigations into dynamic modelling and control of a flexible manipulator system. The work on dynamic modelling involves finite element and symbolic manipulation techniques. The control strategies investigated include feedforward control using command shaping techniques and combined feedforward and feedback control schemes. A constrained planar single-link flexible manipulator is used as test and verification platform throughout this work.

Dynamic model of a single-link flexible manipulator incorporating structural damping, hub inertia and payload is developed using the finite element method. Experiments are performed on a laboratory-scale single-link flexible manipulator with and without payload for verification of the developed dynamic model. Simulated and experimental system responses to a single-switch bang-bang torque input are presented in the time and frequency domains. Resonance frequencies of the system for the first three modes are identified. The performance and accuracy of the simulation algorithm are studied in comparison to the experimental results in both domains. The effects of damping and payload on the dynamic behaviour of the manipulator are addressed. Moreover, the impact of using higher number of elements is studied.

The application of a symbolic manipulation approach for modelling and performance analysis of a flexible manipulator system is investigated. System transfer function can be retained in symbolic form using this approach and good approximation of the system transfer function can be obtained. Relationships between system characteristics and parameters such as payload and hub inertia are accordingly explored. Simulation and experimental exercises are presented to demonstrate the effectiveness of the symbolic approach in modelling and simulation of the flexible manipulator system.

Simulation and experimental investigations into the development of feedforward control strategies based on command shaping techniques for vibration control of flexible manipulators are presented. The command shaping techniques using input shaping, low-pass and band-stop filters are considered. The command shaping techniques are designed based on the parameters of the system obtained using the unshaped bang-bang torque input.

Performances of the techniques are evaluated in terms of level of vibration reduction, time response specifications, robustness to error in natural frequencies and processing times. The effect of using higher number of impulses and filter orders on the system performance is also investigated. Moreover, the effectiveness of the command shaping techniques in reducing vibrations due to inclusion of payload into the system is examined. A comparative assessment of the performance of the command shaping techniques in vibration reduction of the system is presented.

The development of hybrid control schemes for input tracking and vibration suppression of flexible manipulators is presented. The hybrid control schemes based on collocated feedback controllers for rigid body motion control with non-collocated PID control and feedforward control for vibration suppression of the system are examined. The non-collocated PID control is designed utilising the end-point deflection (elastic deformation) feedback whereas feedforward control is designed using the input shaping technique. The developed hybrid schemes are tested within the simulation environment of the flexible manipulator with and without payload. The performances of the control schemes are evaluated in terms of input tracking capability and vibration suppression of the flexible manipulator. Initially, a collocated PD utilising the hub-angle and hub-velocity feedback signals is used as a feedback controller. Subsequently, to achieve uniform performance in the presence of a payload, a collocated adaptive control is designed based on pole-assignment self-tuning control scheme. Lastly, a comparative assessment of the performance of the hybrid control schemes is presented.