OBSERVER-CONTROLLER DESIGN FOR CRANES VIA POLE PLACEMENT AND GAIN-SCHEDULING

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In this paper we address the design of a controller-observer for a mechanical crane. We consider a linear model of the crane where the lenght of the suspending rope is a time-varying parameter. The set of models given by frozen values of the rope lenght can be reduced to a single time-invariant reference model using a suitable time scaling. We construct a controller and an observer for the reference model assigning the desired closed loop eigenvalues for the both system and estimation error. The time scaling relation can be inverted to derive the corresponding controller and observer law for the time-varying system. This law takes the form of a gain-scheduling as a function of the rope length. The proposed procedure leads to the computation of the desired time-varying gains for controller and observer design in a symbolic parameterized form. Using a Lyapunov-like theorem, it is possible to find relative upper bounds for the rate of change of the time-varying parameter that ensure the stability of the original system.

1. Introduction

The control of a mechanical crane during cargo handling aims to optimize its dynamic performance reducing the swing of the load while moving it to the desired position as fast as possible. Software tools, as reported in [4], have been developed for this purpose, and different control methodologies [1, 5] have been presented in the literature.

In this paper we follow the approach presented in [3] that uses a linear parameter-varying model of the crane. The varying parameter is the length of the rope that sustains the load. The idea is that of considering the set of frozen models given by different constant values of the rope length. Using a suitable time scaling, all these models can be reduced to a single time-invariant reference model [8] that does not depend on the value of the rope length.

In [3] a feedback controller design has been proposed: the control problem for the time-invariant reference model was posed as an LQR, and the corresponding constant feedback gains were computed. By inverting the time scaling, these constant feedback gains gave the corresponding time-varying gains that implement an implicit gain-scheduling. In this paper we use a similar approach, but we design the controller for the reference model by assigning the desired poles of the closed loop reference model. Pole assignment seems a more natural way of computing the controller for the following reasons. Firstly, pole placement allows one to directly assign the damping coefficients of the poles of the reference model that — by a property of the time scaling — can be shown to be the same of the damping coefficients of the poles of all frozen models. Secondly, we are able to derive a closed form expression of the controller gains as a function of the desired closed loop poles, that assume the role of design parameters. Thirdly, we observed that finding by trial-and-error "good" poles — both in terms of performance and of stability — was easier than tuning the coefficient of the weight matrices used in [3] to compute the LQR controller.

The physical realization of such a gain-scheduling controller requires the knowledge of all state variables, of the rope length, and of the load weight. In this paper we address the problem of designing an observer to estimate the unknown system state, while we still assume that the rope length and the load weight are known or measurable. The observer uses as system output the measure of the trolley position, and is implemented, as the controller, by implicit gain-scheduling.

There are two important aspects in the approach we propose. First of all, we use the same framework to design both observer and controller. Secondly, the state-feedback gains and the observer gains are expressed in a parametrized form, as a symbolic function of the desired closed loop dynamics (i.e., the eigenvalues of the reference closed loop system and observer), rope length, rope velocity, trolley and load mass. As these parameters vary, the gains need not be recomputed by reapplying the whole design procedure but can simply be obtained by function evaluation.

Studying the stability of a time-varying system is usually a difficult task. It is well known that the stability of the set of frozen models does not ensure the stability of the time-varying system unless the parameter variation is sufficiently slow [6]. It is often the case that the bounds on parameter variations that give sufficient conditions for stability are too restrictive to be of any practical interest.

We propose to use the general methodology of [3], based on a Lyapunov-like theorem [6], and show that in an ap-