Time-Varying Bandwidth Control of a Single Flexible Link

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Abstract **— This paper presents the design and first real-time implementation of a time-varying bandwidth (TVB) controller using the recently developed parallel differential (PD) eigenvalue assignment methodology for a single flexible link. The PD eigenvalue assignment is based on the differential algebraic eigenvalue theory for LTV systems which includes the conventional eigenvalue theory for LTI systems as a special case. Using this theory, classical results for LTI control design, e. g., the stability criterion, carry over to the time-varying case, which is not true for the frozen-time eigenvalue approach. The resulting time-varying controller shifts the closed-loop eigenvalues along a line of constant damping ratio with variable natural frequency. This strategy allows an adjustment of the bandwidth with respect to environmental parameters. Thus, a large bandwidth for fast tracking can be reduced in steady-state to damp out oscillations due to unmodeled flexible modes which is experimentally demonstrated in this paper. Moreover, potential problems of the more straightforward frozen-time gain scheduling approach are demonstrated in simulations in comparison to the TVB controller.**

I. INTRODUCTION

The system under consideration in this paper is a single flexible link experiment developed by researchers at the University of Waterloo and Quanser Consulting. The system consists of a direct drive motor, 12000 line encoder, EG&G 1024 element linear CCD digital camera, Nikon Lens and a 20 ampere power amplifier.

A high-powered LED is mounted at the free tip of the aluminum link, the other end of the link is fixed to the motor hub. The CCD camera mounted on top of the motor detects the tip deflection. A sensor in the motor shaft encodes the motor angle relative to an initial angle. These two measurements are processed by a personal computer which implements a controller. The controller output is the voltage applied to the motor. This results in a single-input, multiple-output (SIMO) system. However, the two measurements can be combined to describe the net tip position, which leads to a single-input, single-output (SISO) system. For consistency, all plots given in this paper are with respect to the net tip position.

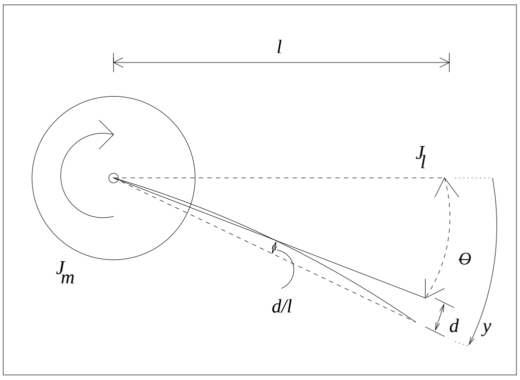

Figure 1: Schematic of the setup

II. SYSTEM MODELING

A fourth order lumped parameter model of the single flexible link can be derived as follows (for a more detailed discussion of the modeling and for an infinite-dimensional state-space model see [1]). Consider Fig. 1 with motor angle θ, angular tip deflection $\alpha \approx d/l$, tip deflection d, link length l, and net tip position y.

The differential equations for this setup are

$$\ddot{\alpha} + \ddot{\theta} = -\frac{C_{stiff}}{J_l}\alpha \tag{1}$$

$$\ddot{\theta} = \frac{C_{stiff}}{J_m}\alpha + \frac{T_{in}}{J_m} \tag{2}$$

where J_l is the inertia of the link (assuming a rigid body) with the LED fixture and J_m is the total inertia seen by the motor, consisting of camera, lens, and motor itself. T_{in} is the torque applied by the motor which is proportional to the motor voltage.

Combining (1) and (2) to a state-space model gives