ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
Technical Specialist
Department of SE&I, Automation & Robotics Group
McDonnell Douglas Space System Company, Space Station Division (Houston)
16055 Space Center Blvd, Mail Code T5H
Houston, TX 77062
Phone: (713)283-1094 Fax: (713)280-1583

373

Outline

- Introduction
- Problem Formulation
- Proposed Approaches
- Simulation Demonstration
- Summary
- Panel Discussion

ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
(Continued)

■ INTRODUCTION

- The Shuttle Remote Manipulator System (SRMS) is a highly flexible dynamical structure which results in vibration in its links, most commonly seen at the end-effector.
- The vibration is caused by several factors: deformable material used for construction of the links, non-rigidity of the brakes and gears at the joints, characteristics of the controllers of the joint servos.
  - In this report, we will address the following:
    - (i) Modeling of a flexible manipulator dynamical structure
    - (ii) Designing control law criterion that minimizes vibration
    - (iii) Candidate Application of Fuzzy Logic Control Law to the Problem

ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

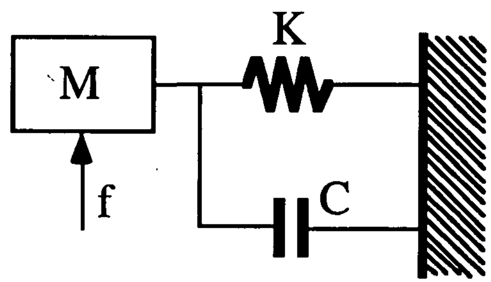
by
Trung T. Pham
(Continued)

■ PROBLEM FORMULATION

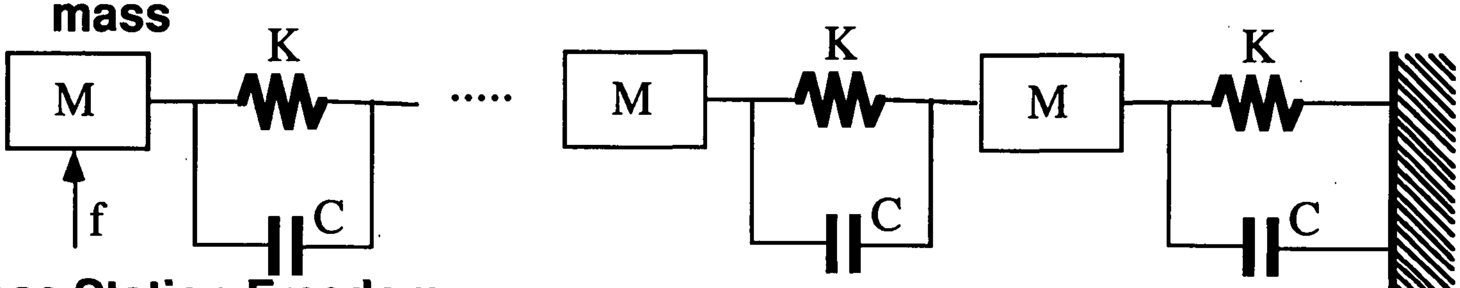
- A point mass in vibration is governed by the equation of motion:

  $M\,a + C\,v + K\,r = f$

  where M is the mass, K the stiffness, C the damping, f the external force, r the displacement, v the rate of displacement, and a the rate of v



- A classical approach in formulating a long flexible rod is to treat the rod as a set of small segments, each representing a point mass



ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
(Continued)

376

- **PROBLEM FORMULATION (cont.)**
  - **Control Laws:**

$$\min \; J(q,u)$$ (J is the cost function)

s.t.

$$\dot{q} = f(q) + g(q)\,T$$ (the equation of motion)

$$\frac{E_i}{\rho_i}\frac{\partial^2 u_i}{\partial x_i^2} - \frac{\partial^2 u_i}{\partial t^2} = \xi(T,q)$$ (the equation of vibration)

where q is the state of the manipulator, u the vibration, T the joint torque vector, E_i the Young's modulus, ρ_i the mass density, and x_i the position on link i with respect to joint i.

ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
(Continued)

- **PROPOSED APPROACHES**
  - Definition of sensor data; type, rate: The followings are assumed provided by external sensors: state (joint angles and joint angular velocities), joint positions, mass of payload; and by analysis: equation of motion of the manipulator, equation of vibration
  - Definition of positive control authority: The manipulator is put into motion by the joint torques. There are limitation in the amount of joint torques, joint angles, and joint angular velocities
  - Formulate the Control Criteria: minimizing vibration, minimizing response time, minimizing error & error rate, minimizing energy

ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
(Continued)

■ PROPOSED APPROACHES (cont.)

- It can be shown that the bang-bang control is one of the most efficient treatment of the previously defined optimal control problem

  if v(q,u) < D then T = Tmax
  else T = Tmin

- Since u is an estimation of the vibration, one can update this model by camera obsevation data, with some relatively confident factor p.

378

C-3

ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
(Continued)

■ SIMULATION DEMONSTRATION

- This simulation illustrates the following concepts:
  - (i) Flexible Model of a Long Rod
  - (ii) Non-Rigid Model of a Joint Brake
  - (iii) PID Controller of a 1-Link, 1-DOF Flexible Manipulator

ACTIVE DAMPING IN A FLEXIBLE MANIPULATOR

by
Trung T. Pham
(Continued)

380

■ SUMMARY

- Techniques to model the flexible dynamics of a manipulator have been identified
- Control Criteria (specifications) for motion control of the flexible manipulator have been formulated
- Fuzzy Logic Control Law has been discussed with application to the Shuttle Remote Manipulator System
- (Opening question for Panel discussion)
  Given the sensor information and the control criterion, can Fuzzy Logic offer an advantage in computational simplicity, and what approach would you recommend, eg. additional sensory information, sensor fusion, and feedback control.

Topic: Active Damping in a Flexible Manipulator
Presenter: Trung Pham

Comment: (Sugeno) To apply fuzzy logic, should not use feed forward because this system should include time data. Feedback is not so good if there is a time delay.

Comment: (Pham) Would be interested in comparing these two approaches.