ABSTRACT

Flexible multibody systems are characterized by their lightweight structure, low weight-to-payload ratio, and reduced power consumption, making them well-suited for efficient manipulator applications. The dynamic modeling and control of such systems are inherently more complex than those of rigid systems due to their intrinsic flexibility; therefore, a thorough understanding of their dynamic behavior is essential for successful control and operation.

The thesis focuses on dynamic modeling using three discretization techniques based on the Decoupled Natural Orthogonal Complement (DeNOC) formulation: the Assumed Mode Method (AMM), the Finite Element Method (FEM), and the Finite Segment Method (FSM). The AMM employs modal analysis of Euler-Bernoulli beams for link discretization. In the FEM approach, each link is discretized using beam elements with two degrees of freedom at each node, representing transverse displacement and slope. The FSM models the links as a series of rigid segments interconnected by torsional springs, with the spring stiffness determined from the general bending equations of beams. The effectiveness of these techniques is evaluated using single-link and two-link flexible manipulator examples, with comparisons performed in both the frequency and time domains. Among the three methods, FSM is found to be the most computationally efficient, whereas FEM is the least efficient computationally but the most versatile in terms of applicability. Additional important aspects of flexible manipulator modeling are also discussed, and the study provides significant insights into torsional vibrations also in flexible manipulators.

Following the development of accurate dynamic models, control techniques are implemented to suppress the vibrations inherent in flexible manipulators while maintaining the desired positions and trajectories. Open-loop command shaping is employed for single-link flexible manipulators, demonstrating effective vibration suppression. For multi-link flexible manipulators, command shaping is combined with closed-loop control strategies, including Proportional-Derivative (PD), Proportional-Integral-Derivative (PID), and Four Element (FE) controllers, to achieve accurate trajectory tracking and satisfactory vibration suppression. Furthermore, the thesis examines the effects of payload and manipulator configuration on the natural frequencies of multi-link flexible manipulators. The performance of the flexible manipulator system is also investigated using a commercially available software, which is later employed for fabrication. The initial phase focuses on validating the simulations through comparison with the developed dynamic models. Subsequently, the manipulators are analyzed for trajectory tracking using two modeling approaches- beam elements and shell elements- and the corresponding significant observations are discussed. The fabrication and experimental investigations on a rigid–flexible manipulator system are conducted. The experimental results are systematically compared with simulation results for both position control and vibration suppression. Vibration suppression is achieved through input shaping by appropriately shaping the input parameters, namely the Pulse Width Modulation (PWM) duty cycles and the desired joint angle. The proposed approach is validated on both single-link and two-link flexible manipulators. The thesis concludes with an analysis of the effect of manipulator configuration on natural frequencies, including bending and torsional modes.