POSITION CONTROL OF FLEXIBLE LINK MANIPULATORS WITH SLIDING MODE CONTROL

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Abstract

Flexible link manipulators represent a class of robotic manipulators known for their lightweight design. The lightweight property of the flexible link manipulators makes them suitable for various applications from land to space. However, along with the lightweight property, there is an inherent link flexibility, which introduces critical challenges in the control design, such as coupled nonlinear dynamics and vibrations at the tip, which complicates the precise tip position control. The control of multi-link flexible manipulators becomes further complicated and computationally demanding due to the interconnected link couplings compared to single link flexible manipulators.

This thesis focuses on designing position control algorithms for single link and multi-link flexible manipulators. The study begins with mathematical modelling of these systems using the Euler-Lagrange equations of motion and assumed modes method, which faithfully captures the distributed nature of link flexibility and provides a strong basis for control design. A functional observer-based sliding mode control design is proposed to effectively control single link flexible manipulators, ensuring robustness to unmodelled dynamics and disturbance. This method achieves accurate tip positioning and vibration mitigation while accommodating system uncertainties. Furthermore, advanced sliding mode control algorithms such as integral sliding mode and fast terminal sliding mode approach complemented with the observers are also proposed to obtain more substantial results in terms of stability and convergence. The control framework is extended to a multi-link flexible manipulator to address the added complexity of flexible links coupling dynamics. A novel robust fixed time integral sliding mode control technique for multi-link flexible manipulator is proposed, ensuring dynamic stability and accurate tip control over interconnected links.

Extensive numerical simulations validate the robustness and efficacy of the proposed control algorithms in tracking and regulation problems, as presented in this thesis. The results also highlight the control design extension from single link to multi-link flexible manipulator. This research advances our understanding of using robust control algorithms for flexible robotic systems, hence assisting in the design of reliable solutions for complicated, dynamic settings. Furthermore, this thesis lays the foundation ground work for future research in advanced control techniques for flexible link manipulators. Potential future directions include experimental validation of physical prototypes, integrating adaptive and learning-based controllers, and exploring energy-efficient control strategies.

This work provides a comprehensive framework for the robust control of flexible link manipulators, offering practical and scalable solutions for applications in industrial automation, space exploration, and precision tasks in surgical robotics.