Abstract

Flexible link manipulators (FLM) are well-known for their small mass and less energy consumption compared to rigid link manipulators (RLM). These advantages of FLM are of greater importance in applications where energy efficiency is crucial, especially in space applications. Flexible structures find application in several fields of engineering which include large telescope mirrors, air craft wings, large satellite structures, robotics, etc. However, FLM typically responds to motion of the joints with undesirable vibrations. Therefore performance of these manipulators is severely limited by the oscillatory response at the tip. Also flexibility of the FLM makes the dynamic model complex and results in uncertain behavior at the free end complicating the control problem. Finding an effective control mechanism that gives control over accurate positioning with minimum tip vibrations is therefore a challenging task. Control of flexible robots has been the area of exploration in recent years.

A single link flexible manipulator (SLFM) is taken as a plant under consideration for developing control. The first step in the control design process is to develop an appropriate mathematical model of a physical system. For an efficient model based control design, it is essential to have a model that can capture adequate system dynamics. A dynamic model of a SLFM is derived using Euler Lagrangian technique by approximating it as a rotary spring.
Designing a control that provides the desired closed-loop system performance in presence of disturbances and uncertainties necessitates a robust controller. With the objective to design a robust control for SLFM, sliding mode control(SMC) has been investigated for controlling FLM. To overcome chattering due to discontinuous control in first order SMC, higher order sliding mode controllers (HOSMC) using twisting and supertwisting algorithm (TA and STA resp) are investigated.

Fractional calculus has been proved to be more useful in modeling and control of the physical systems. Therefore fractional order sliding mode control (FSMC) is developed for controlling the SFLM. FSMC is realized by using fractional order (FO) differentiation and integration in the governing differential equation of the sliding surface. Stability of the proposed fractional sliding surface is proved using Lyapunov approach. Performance of FSMC is compared with the integer order SMC.

To capture better dynamics of the plant, fractional model for SLFM is proposed. Accuracy of the proposed model is compared with the integer order model. Controller is developed using the proposed model. The fractional approach is so used while modeling that it leads to non-commensurate fractional system. This model is validated experimentally. A novel fractional sliding surface is proposed for this non-commensurate fractional model. While designing control, fractional reaching law is used. For implementing the control of the fractional system, information of all the fractional states is needed. Therefore fractional SM observer is designed. The proposed method is validated in simulations and experiments both.

In many of the applications, multi link manipulators are required to perform the desired tasks. For multiple links, the problem of tip control becomes more severe due to the coupled dynamics of the successive links. As a representative case of multiple link manipulators, a two link flexible manipulator (TLFM) is considered as a plant under study.

The model for TLFM is developed using decoupled approach by neglecting the link coupling of the serial mechanism. Therefore both the links are treated as two independent single link plants and independent controls are designed for these two links. To assure accurate positioning of the tip of the TLFM with minimum vibrations, HOSMC is proposed along with the disturbance observer (DO). An estimated signal representing the disturbance is compensated by augmenting the control. This is to limit conservative control.

Although decoupled approach generates simpler model, it is approximate since the flexibility is not adequately captured. Therefore an accurate model is developed for TLFM by adopting the Euler Lagrangian technique in conjunction with the assumed mode approach.

Since flexible modes are not measurable, output feedback control is synthesized. Second order twisting and super twisting algorithms are used to devise the control. Performance of the proposed controllers is analyzed in simulation and experiment both.

For systems with relative degree two, HOSMC using TA stabilizes sliding variable and its derivative to zero in finite time. However TA produces discontinuous control resulting in chattering. A new class of continuous homogeneous generalization of the Twisting Algorithm (CTA) is used for designing the output feedback control for a TLFM plant, which is a system with relative degree two. The sliding surface is taken as a function of output, making the control implementable.

The effectiveness of the theoretical developments is demonstrated via extensive simulations. Detailed stability proofs are derived using proposed Lyapunov functions for all of the developed controllers for FLMs. SLFM and TLFM are considered as the plants for the experimental validations of the proposed controllers.