Chapter 15
Kinematic Modeling and Real-Time Implementation of an Indigenous Control System for a Novel Three-Link Flexible Robot

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ABSTRACT

The domain of flexible robotics is gaining momentum due to its widespread advantages despite major technological barricades, such as in-situ vibration and joint instability. Flexible robotic system (FRS) pertains to unique designs of serial-chain assistive robots that exhibit the said inherent vibration impromptu. This chapter focuses on the control system algorithm of a prototype serial-chain FRS (PARv1.0), backed up by the indigenous firmware of the system controller and run-time software. The chapter also brings out the parametric relationship of the control system hardware over the electromechanical output of the FRS. The design function architecture of the prototype multi-degrees-of-freedom FRS, highlighted in this chapter, is a rare combination of three revolute and one prismatic (RRRP) joints intended for pick and place applications, having a 1500 mm radial span reach in the horizontal plane. A prototype miniature gripper actuated by a mini-servomotor is another novel development of this FRS.

DOI: 10.4018/978-1-6684-5381-0.ch015

INTRODUCTION

The prevalence of in-situ vibration of serial-chain Flexible Robotic System (FRS), manifested through trembling of its slender links and/or twisting of the joints, pose critical bottlenecks in real-time control of the FRS so far as attainment of accuracy of end-of-arm tooling is concerned. The vibration in the FRS in dynamic condition is self-propagating and perpetual in nature and it does not follow much of the rules of analytical modelling.

Quite naturally this in-situ trembling produces prolonged jitter, especially in case of multi-degrees-of-freedom FRS. Hence, we need to go for suitable vibration harnessing mechanism, ideally through the system electronics before deploying such FRS in application-field. Two approaches have been used hitherto to reduce the vibration challenge of FRS, namely: a] input command shaping and b] closed-loop feedback for vibration control. In the present research, the technique of input command shaping has been used in order to reduce run-time vibration in the prototype FRS. Chain of commands have been used judiciously in input command shaping to nullify the own vibration of the FRS. In order to attain the desired degree of vibration attenuation, our work has been focused on a bi-variate approach under input command shaping, viz. velocity and torque shaping of the prototype FRS.

By mirroring the fundamental design-layout of SCARA type static robots, the prototype FRS is conceptualized as a serial-chain system with sufficiently long horizontal reach. Our prototype flexible robot is having 3 degrees-of-freedom (d.o.f) in total, involving worm gear driven revolute joints (2 nos), one spur gear driven revolute joint, two metallic flexible shafts, three links, a recirculating ball screw, a miniature gripper instrumented with sensor, a tripod and electrical actuators, motion controllers & drivers. In order to implement input command shaping on the prototype FRS it is essential to know the nature of the built-in vibration. Vibrational analysis in prototype FRS has been carried out extensively using finite element analysis. The design paradigm of a typical multi-degrees-of-freedom FRS is essentially task-driven, wherein one end of the manipulator is connected to the supporting base while the other end is attached to the end-effector. The relative motions of the joints give the position of the FRS-links in desired orientations. The kinematics of the flexible robot arm deals with the motion of the robot with respect to the fixed reference co-ordinate system. As a matter of fact, it is quite interesting to know a-priori whether there are any obstacles present in the path, prescribed for the FRS.

Vibrational analysis becomes a decisive pre-requisite for real-time control of multi-d.o.f FRS because of the slender lengths of its links and incorporation of flexible shafts. We have duly observed through experimentation that the motor-power transmission in robot-links via flexible shafts is a distinct source of vibration. While the system is in motion, the vibration gets induced in the assembly that gets further intensified by the augmentation of flexible shafts. The ensemble cantilever structure of the planar FRS dictates the amount of such in-situ vibration as well as its modal frequencies. Thus, attenuation of vibration requires very robust control system & program level manipulations for vibration reduction and achieving the required precision at the end-effector.

The control problem of a flexible manipulator is ideally divided into two coherent sub-problems, namely: the trajectory planning and the motion control. Nonetheless, real-time control of inherent randomized vibration of a prototype FRS becomes a challenging problem indeed, if it has multiple degrees-of-freedom. The novelty of our control system architecture is rooted through joint navigation paradigm using trajectory-based control in real-time.