PREFACE

This new book deals with control and learning in robotic systems.

Designs to improve robot performance by the use of lightweight materials in their construction inevitably introduce flexibility into the structure of the system. In general, flexibility exists in both links and joints and leads to substantial control difficulties. The approach taken in Chapter 1 is to develop a generalised, combined Euler-Lagrangian and Assumed Modes formulation as a model of both rigid and flexible motions. This is validated by analysis and computer simulation on different combinations of links and joints. Validation is performed first on manipulators with flexible links and rigid joints and then extended to the case where both links and joints are flexible. Having validated the system model, the control problem is then considered. A fundamental control difficulty is that the system is under-actuated, since the number of possible control inputs to the system (equal to the number of actuators at the robot joints) is considerably less than the number of flexible and rigid modes of motion to be controlled in the system. To meet this control complexity, a singular perturbation, reduced-order, control algorithm is developed that is shown to provide good trajectory tracking performance whilst effectively suppressing both joint and end-effector vibrations.

Most fully-parallel robotic mechanisms encountered today have a common disadvantage, i.e., their low rotational capability. To overcome such a difficulty, Chapter 2 focuses its attention on the proposal of some new three-degree-of-freedom (3-DoF) fully-parallel robotic mechanisms capable of high rotational capability. Parallelogram allows the output link to remain at a fixed orientation with respect to an input link, for which it has many particular roles, especially when creating a desirable DoF output in the design of parallel robotic mechanisms. The role of a parallelogram herein described, is used completely for the design of a new parallel robotic mechanism family. In this family, the moving platform of the parallel mechanism is connected to the base by three non-identical legs. The fact that all joints involved in the rotational DoF are those with single DoF guarantees the high rotational capability performance of these robotic mechanisms. In this paper, the parallelogram is also used to revise some parallel mechanisms to reach a higher rotational capability. Additionally, a new 3-DoF parallel mechanism consists of no parallelogram is also proposed here. Because the legs cannot change the orientation of the multi-DoF joints that attached to the moving platform, the rotational capability of the mechanism can be improved. The parallel robotic mechanisms proposed here have wide applications in industrial robots, simulators, micro-motion manipulators, parallel kinematics machines, and any other manipulation devices that a high rotational capability is needed. The research provides a new methodology of novel parallel robotic mechanisms.

In Chapter 3, in order to control uncertain flexible joint manipulators, Takagi-Sugeno type hierarchical fuzzy controller with the bounded time-varying uncertainties or nonlinearities is proposed. The closed loop system is cast into Diagonal Norm-bound Linear Differential Inclusions form and the overall stability is analyzed with Linear Matrix Inequalities based optimization. The numerical systematic method for finding the maximum stable ranges of T-S type hierarchical fuzzy controller gains with genetic optimization is proposed.

A manipulator with light and thus flexible link would be advantageous over a rigid link in a sense that it is physically safer when it comes into contact with its environment than a manipulator with rigid and thus heavy link, even though it is harder for a flexible link manipulator to be robustly controlled. On the other hand, if an actuator can deliver enough force while maintaining proper compliance, it would be advantageous for the sake of safety. Artificial pneumatic muscle-type actuator is an adequate choice in this case. However, it is difficult to make an effective control scheme for this type of robot, due to the nonlinearity and uncertainties on the dynamics of the actuator and the vibration of the flexible link. In Chapter 4, the dynamic characteristics of the artificial pneumatic muscle-type actuator is investigated by applying it to a simple one d.o.f flexible arm system and position control problem of a two d.o.f. arm system having flexible second link with the actuators, is addressed. A composite controller design method is proposed in the framework of the singular perturbation method. Various robust control schemes are designed in order to meet with payload variation, parameter uncertainty, unmodelled vibration mode, actuator dynamics both in the slow and the fast subsystems.

In Chapter 5, a novel technique based on the continuous genetic algorithms (CGAs) for the solution of the Cartesian path generation problem of robot manipulators is introduced. Given the desired Cartesian path of the end-effector of the manipulator in a free-of-obstacles workspace, off-line smooth geometric paths in the joint space of the manipulator are obtained, where the inverse kinematics problem is formulated as an optimization problem based on the concept of the minimization of the accumulative path deviation. This novel approach possesses several distinct advantages: first, it is the first singularity-free path generation algorithm that can be applied at the path update rate of the manipulator. Second, it can be applied to any general serial manipulator with positional degrees of freedom that might not have any derived closed-form solution for its inverse kinematics. Third, extremely high accuracy can be achieved along the generated path almost similar to analytical solutions, if available. Fourth, the proposed approach can be adopted to any general serial manipulator including both nonredundant and redundant systems. Fifth, when applied on parallel computers, the real time implementation is possible due to the implicit parallel nature of genetic algorithms.

Besides the generality and efficiency of the novel algorithm demonstrated through simulation results, this chapter also covers the convergence analysis of the algorithm to define its optimum working conditions. It is found that the rank-based selection scheme has the fastest convergence speed among the selection schemes discussed in this work. Furthermore, the algorithm works best when the number of parents chosen to fill the mating pool equals 10 regardless the population size. Generational replacement schemes outperform overlapping schemes where the number of elite parents that are passed to the next generation equals 0.05

of the population size. It is noted that the proposed methodology works best with high crossover and mutation probabilities, where the best individual crossover and mutation probabilities are unity, while the best joint crossover and mutation probabilities are 0.9. Regarding the population size, it is observed that small population sizes suffer from larger number of generations required for convergence and the probability of being trapped in local minima, while large population sizes suffer from larger execution time. An acceptable figure is chosen in this work, which sets the population size to five times the number of knots in the problem. Finally, it is found that L_1 norm is preferred over L_2 norm.

Chapter 6 presents an investigation on the trajectory control of a robot using a new type of recurrent neural network. A three-layered recurrent neural network is employed to estimate the forward dynamics model of the robot. Standard Backpropagation (BP) algorithm is used as a learning algorithm for this network to minimise the difference between the robot actual response and that predicted by the neural network. This algorithm is employed to update the connection weights of the neural network controller with three layers using a gradient function. Simulation results show that the proposed neural network controllers have superior performance for controlling the trajectory of robots.

The singularities of a special parallel kinematic manipulator, known as the $6\text{-}6^P$ Stewart platform, are studied in Chapter 7. A closed form solution for the forward kinematics is developed and used for analyzing the singularity. The present study uses quaternions to define the orientations of the platform in order to eliminate a fallacious type of singularities, also known as the formulation singularity, which is caused by using the Euler angles. Because of its characteristics, the singularity of the platform considered can be classified into the architecture and the configuration singularity. The architecture singularity is global and results from improper solutions in its forward kinematics, and thus should be avoided when the manipulator is designed. On the other hand, the configuration singularity is local and is further divided into one position singularity and six orientation singularities. The geometric equivalences of these singularities based on the Euler angle expressions are presented to further characterize and clarify the singularities found. Since the entire singularity is algebraically expressed, the constraints to avoid the undesired effects of singularities can be implemented straightforwardly in the design of the manipulator or in the planning of workspace and trajectories.

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