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Abstract

DESIGN, ANALYSIS, AND CONTROL OF PARALLEL ROBOTS WITH DIFFERENT APPLICATIONS

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A parallel robot typically consists of a mobile platform that is connected to a fixed base by several limbs or legs in parallel. With a considerate design, parallel robots can exhibit several attractive advantages over their serial counterparts in terms of high stiffness, high accuracy, high load-carrying capability and low inertia, etc., thus they have been the subject of a great number of researches over the past two decades. This dissertation is concentrated on novel design, analysis and control of translational parallel robots dedicated to several different applications. According to major research objectives, the thesis contents are classified into the following three categories.

First, by considering that most of existing translational parallel manipulators (TPMs) possess a complicated structure, two new classes of TPMs, namely, 3-PRC and 3-PCR TPMs are designed, which own relatively simple architectures since they are constructed solely with low pairs of prismatic (P) joints, revolute (R) joints, and cylindrical (C) joints. By resorting to screw theory, it is shown that the proposed TPMs can provide pure translational motion with specific geometric conditions satisfied. For a 3-PRC TPM with intersecting guide ways, a comprehensive kinematics and dynamics analysis procedure covering the issues of kinematic modeling, singularity identification and avoidance, isotropy analysis, workspace determination, overconstraint elimination, accuracy evaluation, dexterity analysis, stiffness modeling and assessment, architecture optimization, dynamic modeling and validation, and robust dynamics control are conducted. During the process, the stiffness model is ėstablished via the screw theoretical approach. A new mixed error amplification index is introduced as a performance measure to characterize the TPM accuracy property. The TPM dimensions are optimized via the particle swarm optimization (PSO) approach, which represents the first attempt to introduce PSO into robot structure optimization field. A mass distribution factor is proposed to simply the dynamics modeling process. Moreover, it is shown that a 3-PRC TPM with orthogonal structure possesses a cubic shape workspace and a partially decoupled motion. Besides, the 3-PCR TPMs have identical mobility and kinematics properties to those of 3-PRC TPMs, while they own a more compact architecture which makes them more suitable for such applications as pick-and-place operation, and so on.

Next, the application of parallel robots is turned to micro/nano scale manipulation. By taking into account that most of existing compliant parallel micromanipulators (CPMs) possess a coupled motion, three novel CPMs with fully or partially decoupled translational motion are designed for the application. All of the CPMs are featured with flexure hinge-based joints and piezoelectric actuation. Concerning the first 2-DOF XY CPM, the performances in terms of kinematics, statics, stiffness, and dynamics are evaluated based on pseudo-rigid-body model simplification approach and verified through finite element analysis (FEA), and the dimensions are optimized via the PSO. A prototype is developed and experiments on kinematic calibration and visual servo control are conducted to improve the accuracy. Then, the concept of totally decoupling is proposed to design a class of new XY CPM with both input and output decoupling properties. The stage is modeled based on the matrix method and optimized via PSO. The decoupling property is tested by both FEA and experiments on a fabricated prototype. Additionally, the plant model of the system is identified and a lag-lead controller is designed and then employed to realize a zero phase error tracking controller to evaluate the CPM positioning and contouring performances. As for the 3-DOF XYZ CPM, it is converted from an orthogonal 3-PRC or 3-PCR TPM. The creative structure evolution processes are presented for the sake of eliminating stiffening and buckling phenomena, reducing parasitic motions, and enlarging workspace of the CPM. The mathematical models describing the CPM statics, stiffness, and dynamics are established and validated as well. Moreover, an optimum CPM architecture is obtained with the goal of minimizing the CPM parasitic motions subjected to stiffness and natural frequency requirements and other performance constraints.

Then, the research is focused on the exploration of new application fields of parallel robots. By considering the problems existed in cardiopulmonary resuscitation (CPR) operation, a conceptual design of a medical parallel robot system is proposed to satisfy the requirements. A 3-PUU TPM is selected, analyzed, and developed as a case study to demonstrate the concept. The designed CPR medical robot is expected to reduce the risk and workload of doctors in rescuing patients significantly. Besides, to increase the effective workspace of parallel robots while maintaining their inherent advantages, a conceptual design of a mobile parallel manipulator (MPM) is proposed by adding a wheeled mobile platform to a parallel robot. A 4-DOF MPM is presented and analyzed in terms of kinematics, dynamics and control issues to reveal the new concept, which is constructed by combining a mobile cart with a 3-RRPaR parallel robot. Such kind of manipulator is expected to be applied in environments where high accuracy operation, high rigidity and payload capacity are required, for instance, an autonomous guidance vehicle, service robots and personal robots, underwater robots, and space robots, etc.