2． 項目簡介

(*項目所屬科學技術領域、主要研究內容、發現點、科學價值、同行引用及評價等內容。*)
This project belongs to parallel manipulator design, compliant parallel mechanism design and control field.

1. RESEARCH SIGNIFICANCE

In the field of robotics, parallel manipulators have received extensive attentions over the past two decades. A parallel manipulator typically consists of a mobile platform that is connected to a fixed base by several limbs or legs in parallel. The rigidity and payload carrying capacity of this kind of manipulator are better than those of a conventional serial manipulator; therefore it is more suitable for applications where high precision, stiffness, velocity, and heavy loads are required. Most six-degrees-of-freedom (6DOF) parallel manipulators are based on the Stewart platform architecture because of the aforementioned advantages. However, six DOF is not always needed in many practical applications. Therefore, in recent years, manipulators with fewer than six DOF called limited DOF manipulators which maintain the inherent advantages of parallel mechanisms and possess several other advantages such as reduction in total cost of the device. As the increasing of activities around the research and development in micro- and nano-scales technology, micro/nano manipulators play more and more important roles in such applications as biological cell manipulation, optical fibers alignment, micro component assembly, and scanning probe microscope or atomic force microscope, etc. As a key technique in the domain of micro/nano manipulation, micro/nano manipulators have attracted extensive attentions from both academia and industry in recent years. The structures and mechanical systems should be designed to enable better performance under different types of loading, particularly dynamic and transient loads. Moreover, to meet stringent accuracy and performance requirements, the nonlinearities and disturbances resident in a flexible parallel structure have to be overcome.

2. MAIN RESEARCH CONTENTS

2.1.In view that most of existing Translational parallel manipulators (TPMs) possess a complicated structure with high pairs (e.g., spherical joints), a new 3-PRC TPM is designed, which owns relatively simple architectures since they are constructed solely with low pairs. By resorting to screw theory, the proposed TPM is proved to provide pure translational motion with specific geometric conditions satisfied. Being an overconstrained mechanism, the proposed 3-PRC TPM is constructed using fewer links and joints than it is expected, that leads to an extensive reduction in cost and complexity of the device. For the 3-PRC TPM, a comprehensive analytical 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 established 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 simplify the dynamics modeling process.

2.2.By considering the problems existed in cardiopulmonary resuscitation (CPR) operation, a novel conceptual design of a medical parallel robot system is proposed to satisfy the requirements. In view of the requirements from medical aspects, 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.

2.3. A 3-PRS parallel manipulator with varying actuating angle is investigated, which can adapt to different workspace and payload requirement.

2.4.In view of the cooperative contribution of parallel mechanism and compliant mechanism to an ultrahigh precision with compact size, three major classes of novel XY/XYZ compliant micro/nanomanipulators are designed and developed. Besides, the stages employ piezoelectric actuators (PZTs) for the actuation since the PZT is capable of linear positioning with subnanometer resolution, large blocking force, high stiffness, and rapid response characteristics. However, most of the previously proposed manipulators have a coupled motion and stress stiffening effect. Stress stiffening means the stiffening of a structure due to its stress state, which usually arises from overconstraint, and augments the transverse stiffness in the presence of axial stresses. This phenomenon should be avoided since it brings amplified forces and reduced strokes to the structure, and accordingly causes nonlinearities to actuation. Moreover, in the situations where the stage is underactuated or the sensory feedback of the stage's output platform positions is not allowed, a decoupled XY stage with proper calibrations is preferred. The ideas of integrated design and totally decoupling for the compliant parallel micro-/nanomanipulator design are proposed, and several novel decoupled XY and XYZ stages are created. By input decoupling, the PZTs are isolated and protected. With output decoupling, the parallel stage behaviors like a serial one, which enables the adoption of single-input-single-output (SISO) controller for each axis. The design of a TDPS is a challenging work even for an XY stage. They perform better in both input decoupling and output decoupling than existing works. Moreover, the decoupling properties can tolerate a large misalignment angle of the actuation axes of PZT actuators. Experimental results demonstrate the potential of proposed manipulators in micro-/nanomanipulation fields.

2.5.PZT introduces nonlinearity into the system due to the inherent hysteresis and creep effects, and the system usually has a low damping attributed to the flexible compliant mechanism.Three new adaptive and robust controllers have been proposed to suppress the piezoelectric hysteresis and external disturbances while without modeling the complicated hysteresis effect. The three novel controllers are named adaptive sliding mode control with perturbation estimation and PID sliding surface, model predictive discrete-time sliding mode control, and model predictive output integral discrete-time sliding mode control. The stability of the controllers is proved based on Lyapunov stability analysis. Moreover, their superiority over existing controllers has been validated by extensive comparative experimental studies.

3. MAIN DISCOVERIES

3.1. A new 3-PRC parallel manipulator has been proposed, designed, and analyzed.

3.2. A 3-PUU parallel manipulator has been designed and fabricated, which can be applied in a new medical field for cardiopulmonary resuscitation operation.

3.3. A general type of 3-PRS parallel manipulator is discovered.

3.4. Some new XY or XYZ compliant parallel micromanipulators have been discovered. The new concept of totally decoupled parallel stage (TDPS) is introduced to describe a compliant parallel positioning stage with both input and output decoupling.

3.5. Various sliding mode controllers and PID controllers have been designed and validated by experiments.

4. SCIENTIFIC VALUES

TPMs have potential applications in the scenarios demanding a pure translational motion.The developed parallel manipulators can be applied in the field of fast pick and place food industry, electronic parts assembly line and medical field, which can elevate productivity. The micro/nano manipulation system theory has been developed, the developed micro-/nanomanipulators can be applied in micro/nano manipulation, assembly, cell injection fileds, which has significant values in macro/micro industry field.

5.CITATIONS AND COMMENTS BY PEERS

This project has 17 representative papers which have been published in high standard SCI journals. The SCI citation times for these papers are 198 by other authors' SCI papers. Our research results have been commented positively and exploited by peers around the world, Prof. Yangmin Li was selected as highly cited researcher by ISI Thomson Reuters in the preliminary version of engineering subject in December 2012 , which further certify that the research works are significant and have great influences.