Research Statement

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I am interested in mechatronics and robotics field. My long-term goal is to bring medical robots into the real world. Throughout my Ph.D. degree, I implemented a novel surgical manipulator based on the parallel mechanism. Problems of the system kinematics, singularities, control, teleoperation, workspace mapping, hardware, and software are investigated and solved.

Previous Research

For Minimally Invasive Surgery (MIS), the provision of parallel manipulators becomes necessary to substitute serial manipulators that use wires for motion transmission. These serial manipulators have various defects such as the possibility of wires cutting during surgery and the difficulty of sterilization process. A 4-DOF parallel manipulator (2-PUU 2-PUS) was previously proposed where the feasibility of the design was proved by computer simulation. It was found during the experimental work that the movable platform of the proposed parallel manipulator could not resist forces in some configurations. Hence, a thorough singularity analysis was needed to discover the source of the above problem.

New geometrical/analytical approach for reciprocal screw-based singularity analysis was proposed, during my Ph.D. work, to facilitate the singularity analysis of parallel manipulators with h-pitch wrench systems. This proposed algorithm was used to find all singular configurations inside the workspace of the previously developed 2-PUU 2-PUS manipulator, which has h-pitch reciprocal screws. The discovered singularity configurations of the 2-PUU_2-PUS manipulator occur when the center of the movable platform lies on two orthogonal planes. These planes are parallel to the axes of the prismatic joints, and each plane contains the axes of two opposite prismatic joints and passes through the center of the fixed base. These orthogonal planes divide the workspace into four equal parts. Thus, the singularity-free workspace is one-fourth the original workspace. ADAMS software and experiments have verified the results of the new approach.

During my Ph.D. work, we proposed a novel 3-DOF (2 rotational and 1 translational DOF) endoscopic parallel manipulator. It consists of three limbs having a unique joints arrangement connecting the fixed platform with the movable one. This unique arrangement of the manipulator's joints enables unprecedented large bending angles, more than ±90^{o} in all directions, and almost free-interior-singularity workspace. Hence, the proposed manipulator can be applied perfectly as an endoscopic manipulator for MIS.

The virtual prototype was constructed using ADAMS software in order to validate the proposed manipulator and its bending capability. The results indicated the ability of the proposed manipulator (3-PUU) to bend in any direction with a large bending angle that can exceed ±90°.

Closed form solution for the inverse kinematics was obtained analytically. The forward kinematics solution was obtained numerically. Singularity analysis of the new parallel manipulator was investigated using the proposed geometrical/analytical approach which showed almost free-singularity workspace. The reachable singularity-free workspace of the proposed manipulator was determined by the use of MATLAB software. Evaluation of the workspace was achieved using motion/force transmissibility indices. The results showed that all workspace points with low transmissibility indices are located near the boundary of the workspace. Therefore, the proposed 3-PUU PM has a workspace with perfect motion/force transmission.

A communication between ADAMS and MATLAB/Simulink software was accomplished in order to design a controller for the proposed manipulator. PID controller was designed to control the motion of the 3-PUU parallel manipulator. The results show that the error in each active prismatic joint was less than 0.56 mm. FMRLC algorithm was designed in order to improve the response and to decrease the error in each active prismatic joint. The results proved that the proposed FMRLC controller reduced the error to be less than 0.15 mm. So, the FMRLC algorithm can perform high trajectory tracking.

An annealed stainless-steel prototype of the proposed manipulator was manufactured and tested successfully. The complete experimental setup of a teleoperated surgical system has been built using the 3-PUU parallel manipulator as the slave robot and PHANTOM-Omni haptic device as the master robot. PID controller was utilized to control the motion of the slave robot. The obtained experimental results confirmed the feasibility of the surgical manipulator that has bending angles more than ±90° in all directions. Finally, the results ensured the efficiency of the designed controller in spanning the slave workspace with similar tracking accuracy that obtained during simulation study.

Current & Future Research

Currently, I am working towards finding a dynamic model for the novel surgical manipulator 3-PUU. This model will be used to predict the behavior of the system and to improve the controller's performance. Moreover, my current interests focus on modeling and manipulation of deformable objects. To successfully perform manipulating tasks, we need a model of deformation/flexibility. The model implies being able to accurately represent the geometry, as well as the mechanical behavior of involved parts. Deformable Linear Objects (DLOs) are involved in medical surgery (especially suturing). A suture is a flexible wire that typically needs to go from a straight configuration to a knot. Limited visibility and limited tactile feedback can make this a challenging task for a surgeon. The main motivation is to define a strategy to enable a robotic manipulator to predict in real-time the shape a DLO will achieve during the execution of a manipulation action. Finally, deformable objects (like tissues) are involved deeply in medical surgery and needed to be investigated intensely.

Following are some of the problems for future research work:

1. The FMRLC algorithm will be applied experimentally to improve the performance and decrease the error in each prismatic joint.

2. A gripper with force sensor will be attached to the surgical manipulator. The addition of force feedback will enhance the operation of the system.

3. Experiments will be performed with animals to evaluate the performance of the system and get feedback about the device.

4. The whole teleoperated surgical system will be constructed in which the master and slave robots are not existed in the same place. This will help in investing the experiences of expert surgeons around the world without asking them to travel.