Abstract

This thesis presents the design, development, and kinematic exploration of the spring compliant tendon- driven three-segment continuum robot. A four tendon per segment driven continuum robot-based architecture has been proposed, taking into account clinical demands and the shortcomings noticed in literature, to enhance the dexterity and flexibility of the robot for surgical applications. At the outset, the robot design-specific kinematics is derived, and a geometric modelling of the robot is carried out. Based on the kinematic model, novel performance metrics for dexterity based on data density have been proposed. We perform the computation of these metrics with forward kinematics using the Monte Carlo method, and showing its computational efficiency. We compare the dexterity distribution property index across the workspace with existing approaches. These measures are utilised to optimise the design of such multi-segment continuum robots. A path planning and motion control framework is proposed to control the task space manipulation of a three-segment continuum robot. Differential Jacobian base inverse kinematics with unit quaternion is employed for tool centre point motion control of a tendon-driven three-segment continuum robot. Further, a follow-the-leader-based path-following method is proposed that aims to determine the ideal robot configuration that minimises the robot's backbone's deviation from the path and tip position and orientation to avoid colliding with any obstacles in a highly constrained environment has been proposed. The effect of the change of curvature and the twist of the 3D curved paths on robot deviation in such constrained environments have been analysed during the simulation of a path-following trajectory. The gradient-based optimization method (fmincon) used in the study is compared with the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO)-based optimization approach for path-following motion. Simulation results show that the present approach effectively optimizes the configuration of the three-segment continuum robot for complex path-following motion and navigation. Overall, this study highlights the importance of configuration optimization and robot design (allowable curvature) in path planning for three-segment continuum robots. This framework is useful for robot selection and path-following motion of such robots in various applications. The robot's 3D manipulation discussed in this work includes insertion, point-to-point motion, and tool- centre point motion. The follow-the-leader motion approach was employed for the robot insertion. The point-to-point motion trajectory is generated in configuration space and differential Jacobian based inverse kinematics with unit quaternion is employed for tool centre point motion control of a tendon-driven three-segment continuum robot. The simulation results indicate that the obtained input parameters in joint space ensures smooth robot manipulation. Finally, in this thesis a spring compliant, tendon driven continuum robot using a helical compressive spring has been designed and considered. It utilises the bending compliance of a helical spring as the backbone of the continuum segment. A kinetostatic model of a spring-compliant continuum robot by utilising the flexural stiffness of a spring element has been derived. This has been experimentally validated the bending of the segment and estimated the transverse tip force in relation to tendon tension. Based on the experimental observation from the kinetostatic analysis and by considering the optimal design, a prototype of the spring compliant three-segment tendon-driven continuum robot is developed and a task space manipulation has been demonstrated.

Keywords: continuum robot; surgical robot; dexterity; path planning; spring compliant; kinetostatic.