

Abstract

Robotic manipulators constitute multi DOF (Degree-Of-Freedom) mechanisms. Contrary to single DOF mechanisms that perform a single task, robotic manipulators are designed to perform a variety of tasks from simple pick and place operations to complex assembly tasks - all of which demand different specifications from the robot in terms of its stiffness and accuracy.

For any given task there are several associated performance demands from the robot in terms of its stiffness, accuracy, speed, and workspace. These demands guide the synthesis of an optimal robot for a task. However, in performing any given task, a non-redundant robot performs within its limitations, i.e., it constitutes a compromise in terms of its performance measures that are determined by its architecture and inverse kinematics rather than task demands.

This work addresses this limitation of parallel robots. It considers the methods for improving parallel robots' capabilities to suit their characteristics for a given task. The work introduces the term *variable geometry parallel robots*. These robots are capable of changing their geometry for improving their performance per a given task.

Parallel robots feature various advantages over serial robots in terms of their accuracy, stiffness, structural rigidity, dynamic agility, and compactness. However, they suffer from several crucial shortcomings that preclude their use for many tasks where their advantages are required. Since the stiffness of these robots is a crucial performance index for various applications, e.g., assembly tasks and for indicating presence of singularities, this work chooses it as a driving criterion for the geometry change of *variable geometry parallel robots*.

The work considers two modes for stiffness modification of variable geometry parallel robots by incorporating actuation and kinematic redundancies in their kinematic chains. These two modes are termed *stiffness modulation* and *stiffness synthesis*.

In stiffness modulation, the work considers fully-parallel robots with actuation redundancies. Previously reported "higher-order singularities" in which the stiffness control problem is singular are investigated. The work connects the stiffness modulation singularities with derivatives of the inverse kinematics Jacobian and shows that to these derivatives there are 36 associated lines in space. Consequently, the applicability of line

geometry methods for analyzing these stiffness modulation singularities is shown. This geometric interpretation constitutes the first known line-based interpretation to these stiffness modulation singularities.

In stiffness synthesis, the work investigates variable geometry parallel robots with kinematic redundancy in their branches. Contrary to other previous works on stiffness synthesis, the work focuses on stiffness synthesis using a limited set of free geometric parameters – as is the case for a physical robot. Using Gröbner basis computations it is shown how the solvability of these stiffness synthesis problems can be characterized and solved. The stiffness synthesis problems are transformed from a polynomial form to an associated eigenvalue problem using multiplication tables based on quotient ring algebra. The proposed method is implemented on a planar three DOF and double planar six DOF variable geometry robots.

All the subjects addressed in this work constitute the knowledge base for the design and synthesis of variable geometry parallel robots with stiffness modification capabilities.