Abstract

The thesis presents a holistic approach to the problem of shape-synthesis of manipulator workspaces. The problem of workspace synthesis involves determination of the kinematic dimensions of the manipulator such that its workspace approximates a given taskspace. The manipulators under consideration are general planar mechanisms, that is, the mechanisms may be kinematically simple or complex, simple jointed or multiple jointed, and may have any number of links and degrees-of-freedom (dof). Most often, dimensional synthesis is an intermediate but critical step in the total process of design. For better designs, it is, therefore, necessary to develop fast but accurate and robust synthesis procedure that solves all the intermediate subproblems automatically. To achieve this objective, the thesis has made the following contributions:

(a) The problem of workspace synthesis is formalized by examining the sub-problems involved and determining the hierarchical relationship among these sub-problems. This decomposition is independent of the particular methods used for solving the problems. However, it is established that, for workspace synthesis to be a feasible proposal, extremely fast methods of kinematic and workspace analysis are necessary with complete control on the branch of solution.

(b) Complex mechanisms are believed to generate wider variety of workspaces. An algorithm has been developed for synthesis of highly complex kinematic chains of given minimax loop-size and dof. A number of counter-examples to a well-established theorem on possible complexity in kinematic chains are synthesized.

(c) Conventional iterative methods of solving mechanisms with general topology is shown to be prone to chaotic behaviour and, therefore, unreliable. A method, based on the concept of modular kinematics has been developed for easy modeling and closed-form solution of position, velocity and acceleration kinematics of any revolute jointed mechanism with full control over branches. For position...
analysis of complex mechanisms, a highly efficient iterative method has been developed. It is shown that, for such mechanisms, only four types of modules—rotary, dyadic, transformation and constraint modules—are sufficient. The strength of the present approach lies in the following facets:

1. Automatic determination of module sequence, the plan of solving the mechanism from connectivity information alone. Metric information of the links is utilized during execution of this plan.

2. Automatic block-decomposition and sub-block resequencing for partitioning of complex mechanisms into simple and complex sub-chains and making constraint modules mutually independent.

3. Execution of only relevant portion of module sequence during kinematic analysis.

With the above features, kinematics of any planar mechanism is solved orders of magnitude faster than the conventional methods.

(d) A centro-based method for characterization and classification of all possible types of singularities in a planar dyadic manipulator is developed. The method has been used for mapping both internal and boundary singularities in the workspace of different manipulators by employing input-space scanning.

(e) Since the above method is slow, and since workspace synthesis needs only external boundary of the workspace, a computational geometry based method is developed for that purpose which acts on a set of points representing the workspace of a manipulator and determines the shape-hull of the set of points which approximates the workspace boundary. The method is fast, accurate and robust. Workspace boundaries of simple and complex mechanisms are determined.

(f) It is shown that using the concept of shape normalization, a linear transformation can be determined that takes both the desired and the present workspace in a configuration where their shapes can be easily compared. Global properties (GP) of the normalized curves are their shape attributes. The thesis uses shape comparison independent of location, orientation, size and reflection.
(g) The GP vector and Fourier descriptor for shape representation, and steepest descent and simulated annealing methods of optimization are applied in the process of synthesis for a comparative evaluation of performance. It is found that, by and large, simulated annealing and GP representation give accurate results faster. A wide variety of workspaces are synthesized.

(h) A mechanism cannot have a full kinematic range of motion in the presence of obstacles in the environment. The problem of obstacle analysis has been carried out for a five-bar manipulator. For synthesis of obstacle tolerant link geometry for any manipulator, the concept of discretized inverse motion is proposed for determination of the infeasible zones whose removal from the lamina of a link allows unobstructed motion of the link.

The theory presented in the thesis is implemented in a computer program written in C and is supported with a user-friendly graphical interface. With this software, modeling, kinematic analysis, on-line animation and workspace synthesis can be performed for a mechanism and its inversions very easily and the user need not worry about the structural complexity of the linkage. A typical synthesis process takes about twenty to thirty minutes on a 486 processor. The implementation establishes the feasibility of the concepts in the thesis and the versatility of the holistic approach to the problem of shape-synthesis of workspaces of planar manipulators with arbitrary topology.