Chapter 17
Parametric Dimension Synthesis and Optimizations of Planar 5R Parallel Robots

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ABSTRACT

The dimension synthesis problem for parallel robots in general is much more complex than their serial counterparts, due to the strong dependence of geometric parameters and their performances. In dimension synthesis for robots, typical performance characteristics that may be considered to evaluate the fitness of a design include workspace, manipulability, velocity, stiffness, and payload. A case study on optimal design for both workspace and manipulability had been presented previously for a class of planar parallel robots with 5R joints. This paper extends the design optimization study to include stiffness, velocity, and payload characteristics for the same class of 2-dof robots. A simple and effective parameter-variation-based, constrained optimization method will be demonstrated to obtain various optimal design solutions corresponding to those characteristics respectively. The optimal design solutions, obtained in scalable dimensionless forms, are global in nature and relative to a workspace constraint.

1. INTRODUCTION

In robot design, there is no doubt that workspace and singularity characteristics are important geometric properties that should be considered. And many researchers have indeed addressed the topics of workspace and singularity of parallel manipulators (Merlet, 1989; Pennock & Kassner, 1993; Merlet, Gosselin, & Mouly, 1998; Gao, Liu, & Chen, 2001; Simaan, & Shoham, 2001; Huang, & Thebert, 2010) Being able to avoid the singularities is more critical in practice for parallel manipulators than their serial counterparts due to potential control uncertainty associated with the unwanted mobility, albeit instantaneous, even with all actuators locked. Such uncertainty also manifests itself in poor force transmission performance, in that the manipulator cannot effectively resist or apply forces or torques at the end-effector in certain direction (Notash, 1988).

DOI: 10.4018/978-1-7998-1754-3.ch017

Ideally a robot should have as large a workspace and as small of density in singularity as possible, both being functions of robot geometries. Attaining such a kinematic property requires a dimension synthesis process through some optimization. Both the workspace and the singularity properties have been used, individually or together, as primary objectives in many optimal design studies for parallel robots (Lou, Zhang, & Li, 2005; Miller, 2004; Liu, Wang, & Pritschow, 2006; Liu, 2006; Hao, & Merlet, 2005; Stan, Maties, Balan et al., 2008).

Besides considering the workspace and the singularity, there are also other performance characteristics such as velocity, stiffness, and payload that may need to be considered depending on the primary task requirements. For example, if a robot is intended to have good precision under loads, then stiffness may be the primary performance objective to consider in its design. In a previous paper by the author, a case study on optimal design for both workspace and manipulability had been presented for a class of planar parallel robots with 5R joints (Huang & Thebert, 2010). Such parallel robots may be better suited for 2D positioning applications where high speed and/or payload are required, as alternatives to serial devices such as x-y linear stages. An optimal set of dimension parameters were obtained based on a custom dexterity measure, a composite index defined as a ratio of areas of workspace and singularity. In this paper we extend the design optimization study to include the additional performance characteristics; i.e., stiffness, velocity and payload, for the same class of robots.

This paper is organized as follows. Section 2 gives a description of the system model being studied. Characteristics of its workspace and singularity are then illustrated in Section 3. Analyses of individual performance characteristics relative to the velocity, stiffness, and payload properties are presented in Sections 4-6. A simple and yet effective parameter-variation-based method will be used to obtain various optimal design solutions corresponding to each characteristics respectively. Section 7 then concludes the paper.

2. SYSTEM MODEL

The robot being considered is a two-degree-of-freedom five-bar planar parallel robot (see Figure 1) for positioning applications. The robotic mechanism consists of a wrist (point P) supported by two articulated arms. Each arm is composed of two links forming a closed chain connected through five revolute (R) joints between the links (at points A and B, P) and to the ground (points O_1 and O_2). The link lengths of each two-link arm are L and m, respectively. Point Q is the tool center point of end effector which is located at βm from the wrist point P along the upper right arm.

Detailed derivations of governing kinematic equations, both position and velocity, for the planar 5R robot have been given in (Huang & Thebert, 2010). However, these system equations are included in the appendix for convenience and completeness.

3. WORKSPACE AND SINGULARITY

Workspace and singularity are the two basic properties that are of concern in geometric design of robot. In the case for the planar robot being considered, workspace is the collection of all the points reachable by the tool points and singularity corresponds to the configurations in which the robot gains a transitory degree of freedom at uncertainty configuration.