

**MULTICRITERIA INVERSE KINEMATICS  
FOR GENERAL SERIAL  
ROBOTS**

**by**

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**DISSERTATION**

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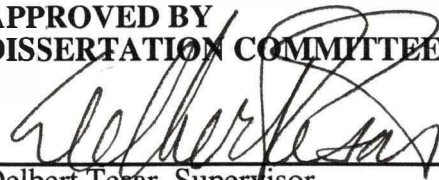
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Delbert Tesar, Supervisor



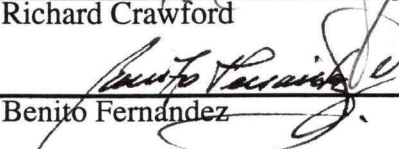
Ronald Barr



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Richard Crawford



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## Preface

Understanding the inverse kinematics problem is seductively easy, yet the problem is older than I am. Over the last five decades this problem has attracted the attention of a number of dedicated and gifted researchers. Kinematicians studying spatial mechanisms laid the foundation. Dimentberg in the 1950's and Freudenstein in the 1960's and 1970's were seminal authors. With the realization in the late 1960's that a serial robot could be modeled as a spatial mechanism, the disciplined and analytical theory of mechanisms was applied to the exciting new field of robotics. This work dominated inverse kinematics research during the 1970's as the search for a general closed-form solution became the "Mount Everest" of kinematics problems. Duffy, Pieper, and Roth were at the forefront of inverse kinematics research during this time. In the mid-1980's, the focus began to shift towards redundant robots and optimization methods. The robots of the 1990's, and into the future, will almost certainly have more redundancy, more sensors, and be controlled by ever more powerful computers. We must now solve the inverse kinematics problem while simultaneously making decisions in the face of multiple, possibly conflicting, performance measures derived from mathematical models and sensor feedback.

*Rich Hooper*

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This work applies to all serial robots and allows for the incorporation of an unlimited number of performance criteria. This work includes:

- a formal statement of the multicriteria inverse kinematics problem,
- the development of a general multicriteria inverse kinematics method,
- experimental and simulation results.

Essentially, the inverse kinematics problem for a serial robot is to find the displacements of the robot's joints given position and orientation constraints on the placement of the robot's terminal link. Current industrial robots typically have six independent joints since six constraints completely specify the position and orientation of a rigid body in space. This gives current robots spatial tool placement capabilities.

Modern research robots often have more than six joints. For these robots the inverse kinematics problem is also a type of optimization problem. Current inverse kinematics efforts for these robots focus on solutions that minimize joint speeds, system kinetic energy, joint accelerations, or joint torques. The main problem with these formulations is that they only optimize a single performance criterion at a time. This is not enough to address the complexity of a modern robot.

The development of a multicriteria inverse kinematics method is one of the principal contributions of this work. This method uses a series of joint-level perturbations to generate a set feasible options for the robot's motion. A sophisticated decision making strategy evaluates these options based on multiple performance criteria and chooses one option as the next motion command for the robot's controller. This inverse kinematics method:

- applies to all serial robots,
- may incorporate an unlimited number of performance criteria,
- is effective throughout the robot's work space.

Experimentation and simulation validated the effectiveness of this inverse kinematics method for a number of different robots. Each of the robots in these examples has especially interesting or difficult geometries. The robots cover a spectrum, from an industrial robot with six joints to a conceptual robot with twenty-one joints. The results include the computational speed and accuracy of the solution for each of the example robots.