Development of the Carpal Wrist; a Symmetric, Parallel-Architecture Robotic Wrist

Stephen Lee Canfield

Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Mechanical Engineering

Charles F. Reinholtz, Chair
Scott L. Hendricks
Larry D. Mitchell
Michael J. Panza
Robert J. Salerno

May 21, 1997
Blacksburg, Virginia

Keywords: Robotics, Parallel Architecture, Manipulator Kinematics, Manipulator Dynamics
Development of the Carpal Wrist; a Symmetric, Parallel-Architecture Robotic Wrist

by

Stephen Lee Canfield

Committee Chairman: Charles F. Reinholtz
Virginia Polytechnic Institute and State University
Department of Mechanical Engineering
May 1997

Abstract

This dissertation summarizes the research effort to develop a novel, three degree-of-freedom device that is ideally suited as a robotic wrist or platform manipulator. Because of its similarity to the human wrist, this invention has been named the “Carpal Wrist.” Much like its natural counterpart, the Carpal Wrist has eight primary links, corresponding to the eight carpal bones of the human wrist, a parallel actuation scheme, similar to the flexor and extensor carpi muscles along the forearm, and an open interior passage, which forms a protected tunnel for routing hoses and electrical cables, much like the well-known carpal tunnel. The Carpal Wrist also has the significant advantages of possessing closed-form forward and inverse kinematic solutions and a large, dexterous workspace that is free of interior singularities (either considered separately or as part of a manipulator arm). As a result of its symmetric parallel architecture, the Wrist can handle a large payload capacity and can easily be adapted to a variety of actuation schemes.

While parallel-architecture manipulators have long been recognized for their high-rigidity and large payload-to-weight capacity, few have been developed for application, primarily because of complications in kinematic and dynamic modeling. The mathematical model of any manipulator must be developed in order to allow the necessary motion control of the device. The mathematical model provides a mapping from the input space (called joint space) to the output space (called tool space) of the manipulator. Given a desired task in terms of motion of the robot tool, the mathematical model determines the required motor input parameters. Advanced manipulator performance through automatic control becomes possible when the model includes inertial or dynamic effects of the manipulator and tool. The research leading to the development of the Carpal Wrist is significant because it presents a complete kinematic and dynamic model of a parallel-architecture manipulator, and thus will provide significant improvement over current serial robot technology.

This research was funded in part by TRIAD Investors Corporation (University Partners), Baltimore MD.
Carpal Wrist Prototype Video
Acknowledgments

Many people have contributed to this work. I gratefully thank all of them.

My advisor, Charles Reinholtz, has been the strongest influence on my development during my graduate work. Of course, he provided the tireless support and constant encouragement necessary to guarantee the success of my graduate research. However, he has also provided a role model for all aspects of my future career as an educator and a researcher. His devotion to all students, empowering them to do good things, is exemplary. His skill and enthusiasm toward applied research has been contagious. Finally, the deep respect he shows to others and is shown to him in the research community demonstrates the admiration others have in the work he is doing. In a career where new-comers are categorized by who they work under, I am thankful to be begin mine with such a big head start. I look forward to continue my relationship with him for many years to come.

Naturally, with an advisor like Dr. Reinholtz, his graduate students, the Robotics and Mechanisms Group, were the best team to be associated with at Virginia Tech. The group provided support, encouragement, and camaraderie making graduate school a great experience. I appreciate the motivation and mentoring of the “old” crowd, including Bob Salerno, Paul Tidwell, Steve Shooter, Ravi Voruganti, Barry Fallon, and John Stulce, as well as the “younger” crowd, Randy Soper, Tony Ganino, Joe Calkins, Greg Saccoccio, Matt Doyle, and T.J. Hayes. I particularly thank Tony Ganino for his devoted involvement to the project and to Randy Soper, my “partner in publications”.

I appreciate the monetary support of Triad Investors, making prototype development possible, as well as their continued support, providing future application of this work.

Finally, the support and encouragement of my parents and grandparents has been invaluable throughout my college career. They have always made sure to tell me they are proud, particularly my grandmother who loves me even though I am not a “real doctor”.