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OPTIMAL PATH PLANNING OF REDUNDANT COOPERATIVE ROBOTS UNDER EQUALITY AND INEQUALITY CONSTRAINTS

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ABSTRACT

Using kinematic resolution, the optimal path planning for two redundant cooperative manipulators carrying a solid object on a desired trajectory is studied. The optimization problem is first solved with no constraint. Consequently, the nonlinear inequality constraints, which model obstacles, are added to the problem. The formulation has been derived using Pontryagin Minimum Principle and results in a Two Point Boundary Value Problem (TPBVP). The problem is solved for a cooperative manipulator system consisting of two 3-DOF serial robots jointly carrying an object and the results are compared with those obtained from a search algorithm. Defining the obstacles in workspace as functions of joint space coordinates, the inequality constrained optimization problem is solved for the cooperative manipulators.

Keywords: *Redundant Cooperative Robots, Path Planning, Two Point Boundary Value Problem, Equality and Inequalities*

1. INTRODUCTION

Cooperation among robots to perform a common task has increasingly developed and created a new field of study in Robotics. The capability of cooperative robot systems to perform complicated, accurate and high performance functions, not expected of single robots, has attracted a lot of attention by researchers. When two (or more) robots are cooperating, they create a closed kinematic chain. Regarding the kind of object grasping, the closed chain is usually redundant.

In addition to a basic motion task, redundant manipulators can achieve additional tasks by utilizing their degrees of redundancy. However, as a result of kinematic redundancy, path planning for redundant manipulators is a complicated job. There are two main aspects of path planning: motion planning, which deals with the existence of a feasible path; and redundancy resolution, which deals with selecting a single configuration among all possible ones. The common idea in redundancy resolution is that redundancy should be resolved in such a way that the mechanism optimizes a performance measure of system while carrying out its given task.

Two possible approaches to resolving the redundancy are the local optimization methods and the global optimization methods. Numerous studies on redundant manipulators have involved instantaneous redundancy resolution at velocity level using pseudo inverse of Jacobian matrix [1-3]. It has been shown that pure pseudo inverse control to most manipulator geometries is not conservative in that a closed trajectory in the Cartesian space may not necessarily result in a closed joint space trajectory [4]. A Jacobian pseudo inverse approach, modified to include the null space solution, could make the control of a kinematically redundant robot conservative [4,5]. A lot of effort has been put into finding the null space solution including the approaches of least square joint velocities. All the methods developed can only rely on local information. They are not capable of sacrificing local interests so that the trajectories are globally optimized. However, they are adequate for real time implementation. An alternative method involves the optimization of an integral performance index with the forward kinematics as constraints. The integral is over the length of the path. Therefore, the history of cost function is taken into account, which yields a global optimal. The chosen cost function can be a kinematic or kinetic index. The former is a function of kinematic parameters and the kinematic equations are, therefore, considered as constraints of optimization problem; the latter is a function of kinematic parameters such as joint torques or consumed energy and power; hence, the motion equations are used as constraints.

This global method is based on calculus of variation and leads to a set of ODEs with split boundary conditions (BCs). Accordingly, to obtain the optimal solution, one should solve a boundary value problem [6-7]. The price one pays in order to

