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Control of Mobile Manipulators with Hyper Degrees of Freedom

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Abstract

The term of “Hyper Degrees of Freedom”(HDOF) is an emblematic word to express strong necessity of much more kinematic degrees of freedom for a manipulator nowadays. By using much more kinematic degrees of freedom, a mobile manipulator with HDOF is expected to move in a highly constrained environment, especially to go into a very narrow space like a tube with obstacles deep inside that could not be observed from outside. Previous investigations about HDOF manipulators are described in the following.

If a proposed obstacle avoidance scheme for moving the upper part of an hyper degrees of freedom manipulator along a curve will never collide with any obstacle, then it is useful for the obstacle avoidance. Mochiyama shows a concrete control law based on shape tracking control to achieve the objective of this scheme for a given desired curve. Mochiyama says that it is important to note that the motion along manipulator's length is essential to go into a narrow space. The lower part of a HDOF manipulator can achieve additional mobility for the motion along this length. But, its mobility is still limited within volume of the workspace. If a HDOF manipulator is combined with a mobile robot, its workspace is extended. Further more, we can control the operation of a HDOF manipulator and a mobile robot at same time; its operation is more efficient. E.g., a mobile manipulator with HDOF is expected to move in a highly constrained environment, especially to go into a very narrow

space like a tube with obstacles deep inside that could not be observed from outside. For this reason, we hope that HDOF manipulators combined with mobile robots are superior to fixed-base HDOF manipulators, because of their larger workspace.

On the other hand, previous investigations about mobile manipulators are described below: The trajectory planning method proposed by Kurisu consists of generating a trajectory for the platform from a given trajectory of the arm tip. The main concept of this trajectory planning method is to determine the redundant degrees of freedom of the mobile manipulator in order to minimize the value of a performance index defined as a function of traveling distance, driving force, variation of joint velocity, and manipulability. But, it is difficult to control mobile manipulators with HDOF by using these methods for mobile manipulators.

For proposing a new control law, we expect to raise control performance by investigating the dynamic model and not only the kinematic model. To attain this objective, we investigate the dynamic model of mobile manipulators with HDOF. Therefore, we consider the following two kinds of shape tracking control. The first one is called "part shape tracking control " It ensures that the upper part of joint points of a HDOF manipulator and virtual mobile base point to desired curve and point. The other one is called "look-ahead shape tracking control" which considers not only the tip of a HDOF manipulator, but also its whole shape and the virtual mobile base point such that it desired curve and points.

As an object model in this study, we consider a mobile robot driven by two independent wheels with a HDOF manipulator. We investigate the dynamic models of the system in the following way :
First, we investigate the dynamic model of a HDOF manipulator and a mobile robot.
Next, we take dynamic interaction between the manipulator with HDOF and the mobile robot under account.
Finally, the equation of motion of the HDOF manipulator and the mobile robot is derived with respect to the dynamic interaction the mobile manipulator with HDOF.

When we develop a control law for mobile manipulators with HDOF, a problem arises because wheeled mobile robots are subject of non-integrable kinematic constraints, known as non-holonomic constraints. Such constraints are generally caused by one or several rolling contacts between rigid bodies, and reflect the fact that the mobile robots must move in the direction of its main axis of symmetry. It can attain any position in the plane motion with any position in the plane of motion with any orientation; hence the configuration space is three-dimensional. However, the velocity of motion must always satisfy a non-holonomic constraint; thus the space of achievable velocities is two-dimensional.

In this thesis, to solve this problem, we investigate part shape tracking control and look-ahead shape tracking control for mobile manipulators with HDOF. When we develop a control law, it is difficult to calculate desired curve parameters. Therefore, we introduce the shape of the mobile manipulator with HDOF to control by estimating the desired curve parameters.

First, we propose a part shape tracking control law using an inverse dynamics control. In part shape tracking control, a mobile manipulator with HDOF has redundant degrees of freedom referring to a given desired curve. The part shape tracking control law solve this problem by using redundant degrees of freedom, and attains tracking control for mobile manipulators with HDOF.

Second, we propose look-ahead shape tracking control law using an inverse dynamics control. When we consider to control not only the tip of a manipulator, but also its whole shape and base point, it is known that the mobile robot cannot be controlled by using a static feedback because of mobile robot have non-holonomic constraints. To solve this problem, Sarkar proposes a look-ahead control for wheel mobile robot. Using this method, we control a reference point instead of a center point of mobile robot. e.g., when driving a car, a driver looks at a point or an area in front of the car. For this reason, we combine look-ahead control with shape tracking control and call it "look-ahead shape tracking control". This new control law is able to that can control to not only the tip of a manipulator, but also its whole shape and the reference base point.

As a result of this thesis, the part shape tracking control method and the look-ahead shape tracking control method are widened to mobile manipulator with HDOF. We solve two problems by those methods. Thus mobile manipulators with HDOF are expected to move in a highly constrained environment and to transport grasping objects of various sizes and shapes that can not never be attained before.