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Author(s)	望山，洋
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Shape Control of Manipulators with Hyper Degrees of Freedom

Hiromi Mochiyama
School of Information Science,
Japan Advanced Institute of Science and Technology

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Abstract

This thesis provides a theoretical framework to control a manipulator with hyper degrees of freedom. The term "Hyper Degrees Of Freedom" (HDOF in short) is an emblematic word to express strong necessity of much more kinematic degrees of freedom for a manipulator nowadays. An HDOF manipulator has ability to achieve various kind of tasks. In order to make full use of its ability, shape control is proposed here, that is, not only the tip of a manipulator, but also its whole shape is controlled positively.

Before discussing shape control, we define rigorously shape correspondence between an HDOF manipulator and a spatial curve used for prescribing the desired shape. It is defined by using the solution of some nonlinear optimization problems termed the shape inverse problem. We give not only the existence theorem of its solution, but also a theorem on the existence region which allows us to convert control problems appeared later into more tractable ones.

Shape regulation control is considered first to bring an HDOF manipulator onto a given time invariant curve. The idea of estimating the desired curve parameter enable us to find the shape regulation law with curve parameter estimation law by Lyapunov design.

This crucial idea of curve parameter estimation is also effective for the shape tracking, where a time-varying curve is given to prescribe the desired shape. Two shape tracking control laws are derived by utilizing familiar tracking control laws for conventional manipulator tracking.

Furthermore, it is shown that joint velocity signals are not essential to achieve shape tracking, that is, shape tracking using only joint angles is attained. Based on the idea of conceptual duality, we derive an observer that does not directly estimate the joint angle velocities, but estimate the velocity of the shape. After properly tuned, the modified shape tracking controller and shape velocity observer assure local asymptotic stability of the closed-loop system.

We also give an example to show that new tasks which have never done before can be accomplished by shape control. The useful motion control for sophisticated obstacle avoidance is achieved by shape control idea. That is the motion along a curve useful for going into a narrow space. Two controllers achieving this motion are shown as the counterparts of two shape tracking controllers derived before.

We also propose the way to find essentials of an HDOF manipulators by increase in DOF. Conditions of the kinematic structure are derived from a geometrically natural requirement that its direct kinematics tends to Frenet-Serret formula by increase in DOF.

The results in this thesis give a completely new vision for robotic manipulator control.

Key Words: **hyper degrees of freedom manipulators, spatial curves, dynamics-based shape control, Lyapunov stability theory, desired curve parameter estimation**