On the Robust Tracking Control of Kinematically Constrained Robot Manipulators

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Abstract— **This paper addresses the problem of robust controller design for holonomic constrained robotic systems which guarantees global asymptotic and exponential like stability of joints' position and velocity tracking error. It is well known that the presence of the constraints makes the controller design more complex as compared to the unconstrained robots such as serial manipulators. Control algorithms should be developed to satisfy both the system dynamics as well as kinematic constraints without explicit computation of the inverse kinematics. The paper develops a new robust control algorithm which can be applied in trajectory tracking control for both parallel and constrained serial manipulators. The method considers the constraint forces in the system dynamics to improve the system stability and tracking performance. The controller is designed through the direct Lyapunov approach and ensures asymptotic and exponential like stability in the position and velocity tracking errors. In order to verify the validity of the proposed control algorithm the algorithm is applied on two different illustrative examples.**

Keywords— **Robust systems, Motion control, Stability analysis, Lyapunov theorem, Constrained robotic systems.**

I. INTRODUCTION

Over the last decades, a lot of research efforts have been put into designing sophisticated control strategies for robotic systems especially constrained systems. For further information on recent reviews, refer to Fantoni and Lozano [1] and Abdallah et al [2].

Due to their ability to perform a wider class of tasks, constrained manipulators have been receiving more attention and a lot of research has been conducted to create an appropriate and effective controller design for these systems. The kinematic constraints usually are resulted in the generation of some sort of external or internal forces acting on the manipulator and modifying its dynamic behavior. Depending on the particular tasks performed by the robot, various constraints may occur resulting from a host of factors such as the robot environment geometry, optimization objectives or differential limitations. The kinematic constraints are divided into holonomic or non-holonomic constraints.

Control of constrained robot manipulators is a rather complicated problem because of two main reasons. First, in addition to system dynamics the constraint equations should be considered in the design process.

Second the controller design process involves the system inverse kinematics problem (I.K.P.) as the controller requires all the dependant and independent coordinates. A stable control algorithm which avoids the explicit calculation of the robot I.K.P. would be of clear advantage in terms of simplicity and accuracy.

An initial study in controlling a constrained robot is given in [3]. Recently, a general theoretical framework for the constrained motion control was rigorously developed in [4-5] where a mathematical model was provided for the system that explicitly incorporates the constraint equations. This model was then used to develop a modified computed torque controller that guarantees the global asymptotic stability for position and force tracking.

Since the method is computed torque, it suffers from the requirement of exact knowledge of robot dynamics. The robust [6-8] and adaptive controllers [9-14] were designed to overcome uncertainties and the presence of disturbance to the control of the manipulators' motion.

Concerning the constrained systems, one can refer to the works in [15-17]. In these researches either the accurate model is required or the constraint forces are not included in the controller design algorithm. In [18-19] a mathematical model is developed for the constrained robots which embody the constraint equations into the dynamic equations resulting in an affine nonlinear system without any constraints. [20-23] present different robust algorithms while [24-25] develop adaptive controllers to deal with the constrained systems.

A reduced model for a constrained manipulator was developed by Koivo and Arnautovic [27]. As an alternative to the common approaches, the method presented by [27] provides a new framework which can be considered as a basis to control the constrained manipulators. They have developed a control algorithm which does not require an explicit calculation of I.K.P.

The scheme developed by these authors, however, only considers one class of constraints and requires exact knowledge of robot dynamics.

In this paper, based on the model of the constrained robots developed in [27-28] and used in further works such as [15-26], a robust strategy without requiring the explicit solution of I.K.P. is proposed to achieve trajectory tracking purpose. Compared with the robust methods presented in [6-23], the proposed robust control approach in this paper has two main advantages.