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# Object Slippage Control in a Cooperating Manipulators System

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**Abstract**
Many Researchers have worked on grasping phenomena in cooperating systems in default of slipping condition. Although the control system is designed such that to keep the contact force inside friction cone and avoid slipping, however, slippage can occur due to many reasons. In this research dynamics analysis and control synthesis of a cooperating system, considering slipping condition is performed. Equality and inequality equations of frictional contact conditions are replaced by a single second order differential equation with switching coefficients in order to facilitate the dynamical modeling. Using this modeling of friction, a modified grasping design approach is presented to control end-effector slippage and object.
**Keywords:** sliding condition, cooperating systems, frictional point contact, grasping.

## Introduction

Grasping is an important issue in cooperating systems such as multi-fingered hands and multiple robots. A lot of papers can be found on grasp planning. Research on grasp planning focuses on two categories: grasp analysis and grasp synthesis. In grasp analysis, most of the researchers have been focused on finding appropriate conditions for force-closure grasps. Early, Reulaux introduced the notion of force-closure and form-closure [1]. Salisbury and Roth developed several different types of finger contacts and showed which finger configurations allow complete immobilization of the gripped object relative to the fingers, and also allow for the manipulation of the object by the fingers while maintaining the grasp, using screw theory [2]. With the linearization of the friction cone, Liu developed a ray-shooting based algorithm using the duality of polytopes [3]. Zheng and Qian enhanced the ray-shooting approach proposed by Liu to complete the exactness, increase the efficiency and extend the scope [4]. The general problem of determining if a grasp is force closure is considered to be completely solved.

Having sufficient conditions for force closure, grasp synthesis deals with optimal grasping. This synthesis consists of: 1) determination of the optimality criteria and 2) derivation of methods and algorithms for computing contact locations with respect to the optimality criteria and subject to accessibility constraints. Liu et al. introduced several candidate grasp quality functions and formulated grasp synthesis problem as a max-transfer, max-normal-grasping-force and a min-analytical-center problem [5]. Based on the geometric condition of the closure property, Zhu and Ding presented a numerical test to quantify how far a grasp is from losing form/force closure. They also developed an iterative algorithm for computing optimal force-closure grasps [6]. Morales et al. addressed the problem of designing a practical system able to grasp real objects with a three-fingered robot hand. They presented a general approach for synthesizing two and three-finger grasps on planar unknown objects using visual perception [7].

All of the above researches consider no slip in grasping, and control systems try to keep control forces lied in the friction cone. Slipping, however, can occur during the grasping maneuver due to many reasons, such as changes in the object geometry, mass, inertia and coefficient of friction or dealing with unknown object. As an example, one can assume the practical case when a cooperative system manipulate a dirty object or manipulate an object in a dirty environment. In such a case, coefficient of friction between end-effectors and object can change. None of the previous researches perform good analysis of slipping phenomena. In this research, dynamic analysis and control synthesis of a cooperating system consist of two robot arms manipulating an object with frictional contact points, considering slipping condition, have been performed.

## Dynamic Analysis

System under consideration is shown in Figure 1.

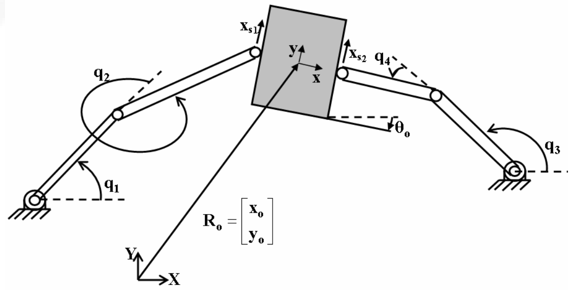


Figure 1 : Schematic of the system