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# DYNAMIC MODELING AND SLIPPAGE ANALYSIS IN OBJECT MANIPULATION BY SOFT FINGERS

**Amin Fakhari*** **and Mehdi Keshmiri**
Department of Mechanical Engineering
Isfahan University of Technology
Isfahan, Iran
a.fakhari@me.iut.ac.ir, mehdik@cc.iut.ac.ir

**Mohammad Keshmiri**
Department of Mechanical and Industrial Engineering
Concordia University
Montreal, Canada
m_keshm@encs.concordia.ca

## ABSTRACT

*In this paper, dynamic modeling and slippage analysis of a three-link soft finger manipulating a rigid object on a horizontal surface is studied. In order to integrate the dynamics of soft tip with the finger linkage, power-law model and a linear viscous damper are used to model the elastic behavior and damping effect of soft tip respectively. Because of the enlarged contact area in the soft contact, a frictional moment can be exerted at the contact interface along with the normal and tangential forces. Furthermore, because of planar motion of object, frictional forces and moment are applied in the contact of object and ground. Therefore, friction limit surface is used as a mapping between contact forces/moment and sliding motions in both contacts. Instead of using equality and inequality equations of frictional contact conditions, a method is proposed to describe different states of the contact forces and moment by a single second-order differential equation with variable coefficients. This kind of formulation of the system dynamics facilitates the design of a controller to cancel the undesired slippage occurs between the soft tip and object during the manipulation.*

## INTRODUCTION

Human hands are able to grasp and manipulate the different kinds of objects without having knowledge about their weight and friction coefficient. This ability makes hands one of the most complex organs of human body. Hence, considering the different aspects of human hands have been one of the interesting subjects for many researchers in different fields specially robotics in order to design the dexterous and anthropomorphic robotic hands.

Selecting an appropriate contact model is the first step in object grasping and manipulation analysis. Contact models can be categorized into two main groups; *rigid-body contact*, which also known as point contact or hard contact, and *soft contact*. Many of the previous researches on grasping and manipulation are based on the rigid-body contact model. In this model, deformation in the contact is neglected and Coulomb's law is commonly used to model the contact frictional force. An extensive literature review on analysis of grasping and manipulation with rigid-body contact assumption is available in [1]. However, this model is not applicable when the deformation in the contact interface is not negligible.

In the soft contact, the contact area enlarges; therefore, similar to planar motion of a rigid body, a frictional moment is exerted at the contact interface along with the normal and tangential frictional forces. In these cases, limit surface is used to model the contact frictional forces and moment. Limit surface is a mapping between contact forces/moment and sliding motions and can determine when planar slippage in contact interface of two bodies occurs. Goyal *et al.* [2] presented a description of the net frictional force and moment between a rigid body and a planar surface on which it slides. Howe and Cutkosky [3] focused of developing simple and practical methods of computing the force-motion relationship. They theoretically and experimentally showed that an ellipsoid is a proper approximation of limit surface in most cases. Xydas and Kao [4] proposed a soft contact model for a wide range of soft materials and numerically

*Address all correspondence to this author.