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FULL PAPER

Slippage control in soft finger grasping and manipulation

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Handling objects with robotic soft fingers without considering the odds of slippage are not realistic. Grasping and manipulation algorithms have to be tested under such conditions for evaluating their robustness. In this paper, a dynamic analysis of rigid object manipulation with slippage control is studied using a two-link finger with soft hemispherical tip. Dependency on contact forces applied by a soft finger while grasping a rigid object is examined experimentally. A power-law model combined with a linear viscous damper is used to model the elastic behavior and damping effect of the soft tip, respectively. In order to obtain precise dynamic equations governing the system, two second-order differential equations with variable coefficients have been designed to describe the different possible states of the contact forces accordingly. A controller is designed based on the rigid fingertip model using the concept of feedback linearization for each phase of the system dynamics. Numerical simulations are used to evaluate the performance of the controller. The results reveal that the designed controller shows acceptable performance for both soft and rigid finger manipulation in reducing and canceling slippage. Furthermore, simulations indicate that the applied force in the soft finger manipulation is considerably less than the rigid one.

Keywords: soft finger; contact modeling; contact forces; slippage control; grasping and manipulation

1. Introduction

AQ1 The dexterity of human hands is recognized as unbeatable with regard to the ability to explore, grasp, and manipulate different kinds of objects. The process involved in such functionality is so complex that even with multidisciplinary efforts combined, advances in replicating the simplest processes is still in its infancy.

The first step toward a factual analysis of object grasping and manipulation using robotic hands is the determination of an appropriate contact model. Selection of the contact model depends highly on the material properties of the finger and object, range of the contact forces and rate of application. In general, the contact models can be classified into two main groups; *rigid contact* and *soft contact*. Most of the previous research on grasping and manipulation are based on the rigid contact model.[1] Although straightforward to use, it is not reliable when the deformation in the contact interface is not negligible. Thus, the use of soft contact models in many analyses is inevitable. Because of the enlarged contact area in the soft contact, a frictional moment will be exerted at the contact interface along with the normal and frictional tangential forces. This requires fewer contacts to guarantee robust and stable object grasping and manipulation using soft fingers compared to rigid fingers. Moreover, the enlarged contact area of the soft fingers enhances stability and robustness of the grasp. However, soft fingers suffer from drawbacks such as increased complexity from modeling their viscoelastic behavior and the need for more considerable control effort for precise manipulation of the grasped object in sensitive applications.

The research on the soft robotic hands can be categorized into three main subgroups. The first group includes research that focuses on designing artificial soft fingers [2,3] and tactile and incipient slip sensors.[4–6] The second group consists of the research focuses on developing an explicit soft contact model for human and soft artificial fingers, some of which are described in detail in Section 3.1. The third research group is mainly focused on robust grasping and dexterous manipulation using soft fingers. Kim [7] analyzed the manipulation of an object using a pair of soft fingers, assuming a linear spring/damper system in each contact interface to model the soft contact behavior. Inoue and Hirai studied dynamic and posture control of an object during grasping and manipulation using soft fingers in a 2D model [8] and extended it to a 3D model.[9] They assumed a parallel distributed model for the soft contact model of their study. Arimoto et al. [10,11] analyzed object grasping and manipulation using soft fingers with softness illustrated by

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