Active and Passive Reaction in Grasp Stability Analysis of Underactuated Hands

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Stability analysis is one of the foundational problems for multi-fingered robotic manipulation. It is often formalized as the problem of answering the following questions: can the hand exert contact forces on the object either without a net resultant wrench (thus loading the contacts while creating purely internal forces) or in order to counterbalance an external disturbance (by applying an equal and opposite wrench). However, most commonly used methods for performing this analysis assume full controllability of joint torques and hand configurations. The kinematics of underactuated and compliant hands, that allow adapting to the grasped object and even the external disturbance, are disregarded. Hence, these methods are of limited applicability to underactuated and compliant robotic hands.

We concern ourselves with grasps, where some level of *preload* has been established by selecting a set of actuator commands maintained throughout the task. This is a common approach to grasp creation, due to the difficulty of measuring the applied wrench without tactile sensors and controlling joint torques accurately in response. A key factor that allows this approach to succeed is *the ability of a grasp to absorb resultant forces that would otherwise unbalance the system without requiring active change of the motor commands.* Therefore, we argue it is important to make the distinction between *active force generation*, directly resulting from forces applied by an actuator, and *passive force resistance*, arising in response to forces external to the contact or joint.

Thus, it is important to not only consider the wrenches the hand can apply actively by means of its actuators, but also the reactions that arise passively. This is of particular importance for underactuated hands, as joint torques cannot be explicitly controlled but are determined by the specific kinematic constraints of the hand. Wrench resistance is highly reliant on passive compliance and contact forces in the nullspace of the transposed grasp Jacobian are common due to the underactuated nature of the hand. These contact forces will have no effect on the actuator but cause a purely passive reaction. The existing grasp stability analysis tools are not designed to account for such phenomena.

We introduce an analysis framework constructed to capture the passive behavior of some of the most commonly used underactuated hand mechanisms. We have developed a quasi-static grasp stability analysis framework to determine the passive response of the hand-object system to applied joint torques and externally applied forces. To capture the passive behavior of the system in response to external disturbance, we (as others before) rely on a compliance model utilizing virtual object movements. Unlike previous work however, we attempt to also capture effects that are non-linear w.r.t. virtual object movement. We achieve this by casting the kinematic constraints of the underactuated hand mechanism as a mixed integer optimization problem, which can be readily solved.

We have used this framework to analyze the stability of underactuated grasps from an inverse perspective: given a set of actuator commands and an external disturbance to be applied to the grasped objects, what is the net effect expected on the grasped object, accounting for passive effects? Thus, we hope to answer what we believe to be not only a meaningful theoretical question, but also one with important practical applications: *once a given joint preload has been achieved, can a grasp resist a given wrench passively, i.e. without any change in commanded joint torques?*
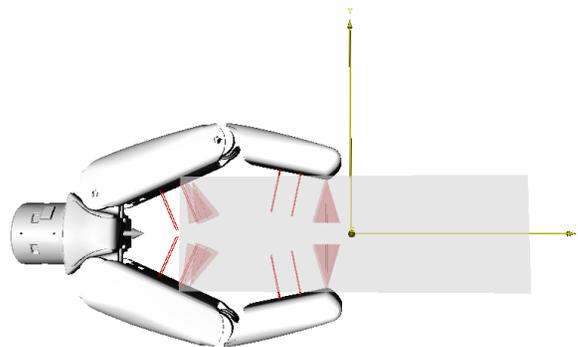

Fig. 1. An example of a test case analyzed within our framework. Analysis of passive stability reveals interesting phenomena due to coupling of proximal and distal joints.

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