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.

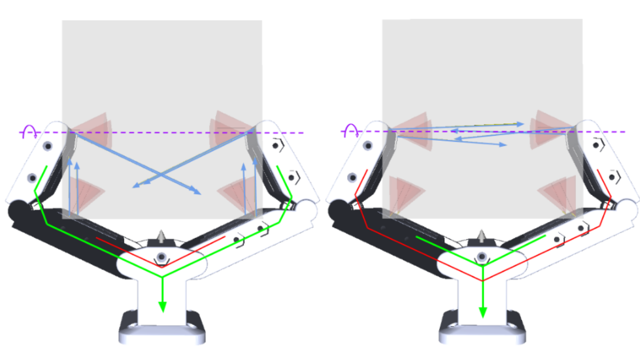
We concern ourselves with grasps, where some level of *preload* has been established by selecting a set of actuator commands maintained throughout the task. This is a common approach to grasp creation, due to the difficulty of measuring the applied wrench without tactile sensors and controlling joint 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.* We argue it is important to not only consider the wrenches the hand can apply through *active force generation* by an actuator, but also consider the effects of *passive force resistance*, arising in response to forces external to the actuator. 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.

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 actuation 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?

Consider the grasp shown in the figures below. The hand has two independently actuated tendons; a proximal tendon only applying torque to the proximal joint and a distal tendon extending through both links and applying a torque to both proximal and distal joints. A tendon can be loaded actively by commanding the corresponding actuator to apply force. As the tendons are not allowed to elongate and the actuators are non-backdrivable, a tendon can also be loaded passively due to an external wrench applied to the object or actively loading the other tendon. Thus, consider the two cases that arise, when only one tendon is actively loaded. These two cases are shown in the figure, where an actively loaded tendon is shown in green, a passively loaded tendon is shown in red and the resulting contact forces are shown in blue.

There appear to be large differences in contact force distribution depending on which tendon has been actively loaded. This has consequences on the set of external wrenches a grasp established as such is able to resist. For example, loading the distal tendon actively leads to much larger resistance to torques about the axis marked in violet than a grasp in which solely the proximal tendon has been loaded actively. The reason for this behavior lies in the kinematics of the hand. When loading only the proximal tendon actively any closing motion of the proximal joints allows the distal joints to open accordingly. The result is that the object is slightly pushed upwards and the contacts at the proximal link are weakened or broken entirely.

The conclusion we draw from this result is that different tendon loads produce dramatically different results for kinematically identical grasps. Traditional GWS-based methods cannot capture this difference. Our proposed method predicts the correct result.



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