Robust, Cheap and Dexterous Manipulation : Applications of a passivity-based approach for dynamic grasping

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We often do what we did not intend when we loosely focus on a task. However, we merely fail to do a task itself. In contrast, a robot can appropriately select a task but it often fail to do a selected task, e.g., a robot easily drops an object during grasp. We need appropriate controllers or planning to reliably execute a task.

Force/torque closure is a powerful index for evaluating a static equilibrium for grasping and it is widely used for determining grasp points. However, it does not provide any control method. We need to design controllers to dynamically grasp and manipulate an object and to increase the robustness to disturbance and modeling errors. A robotic hand has highly nonlinear dynamics and indirectly controls the force acting on an object through the constraints between the fingertips and the object. It has been generally believed that the force sensors at the fingertips are indispensable because the fingertip forces must be controlled to accomplish dynamic object manipulation. However, it is not true. We can design a controller that recovers a disturbed object to the equilibrium point where the force and torque acting on the object is closed without force sensors by utilizing kinematic and dynamic features of the hand-object system.

A passivity-based controller for grasping is one of the solutions to this problem [1]. This method has progressed to grasp varieties of objects and manipulate them in several ways [2]. The features of this method are given as follows:

1) Precision grasping controllers inspired by thumb-index-finger opposition enable a robotic hand to stably grasp an object using the fingertips without force sensor, object sensing and object models. Therefore, we can save the computational and the hardware costs and do not suffer noises of the force sensors.
2) The grasping controllers can apply to a robotic hand with soft and stiff fingertips without any modification.
3) The position and orientation of a grasped object can be controlled through the rolling constraints between the object and the fingers. The position and orientation controllers are simply superimposed to the grasping controller, although the robotic system has nonlinear dynamics. We need the position and orientation sensing of the object for precise control but do not need them for approximate control. This approximate control method is useful in the application of teleoperation.
4) In the case of the soft fingertips, the robotic hand can control the rotation around the gripping force axis using the potential energy stored in the fingertips. This is an example of dexterous manipulation that is difficult for humans to do (Fig. 1) [3].

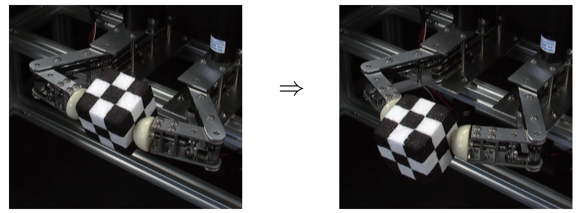

Fig. 1. Torsional fingertip manipulation. The object rolled around the grip force axis, from the left to the right states.

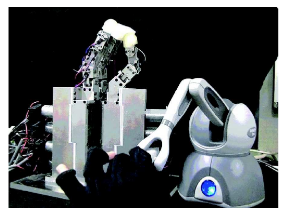

Fig. 2. A teleoperation system.

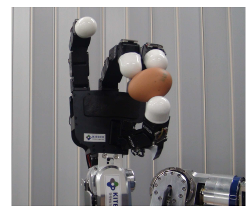

Fig. 3. A hand-arm system.

To implement such a robust, cheap and dexterous manipulation is indispensable for realizing dynamic manipulation systems and is useful in assigning the computational resources efficiently to higher level planning.

In this paper, we explain about features of the stability of the dynamic grasping comparing to the force/torque closure. We introduce controllers for grasping, positioning and orienting and explain why the force sensors are not needed to stabilize the grasping. We demonstrate grasps and manipulations using robotic hands, hand-arm systems and introduce a teleoperation system using the controllers (Fig. 2) [4] and a commercially available robotic hand system implemented the proposed controllers (Fig. 3) [5].

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