Applied Force-Based Multi-Fingered Grasping and Manipulation Control

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Abstract— **This work presents experimental results on a recently developed manipulation controller applied to a multi-fingered robotic hand to execute both grasping and manipulation tasks. The active control strategy was applied to a three-fingered, seven degree of freedom robotic hand with impedance-based tactile sensing at the fingertips. The controller, designed with Lyapunov nonlinear control techniques, extensively uses sensory feedback to robustly perform hand-object interactions. Tests were conducted on spherical and prismatic objects with tripod and precision lateral pre-grasp configurations. The hand was commanded to hold the object (grasping) as well as perform translations and rotations (manipulation). Results indicate that the strategy is a viable solution path towards enabling more intelligent and purposeful, hand-object interactions.**

Keywords: manipulation, grasping, nonlinear control

I. Background

Multi-fingered robotic grasping and manipulation is an active area of research with many different approaches. Regardless of the strategy or task under consideration, any grasping and manipulation operation can be reduced to a mathematically approachable problem by seeking to control the states (position and velocity) of an object in the environment. Solution paths to this problem fall roughly under one of two main categories - kinematics (position) [1], [2] or kinetics (force) [3], [4]. This work presents experimental results on a force-based controller that was recently developed using Lyapunov nonlinear control techniques [5]. The strategy imparts many beneficial properties such as finger-object slip minimization, smooth force saturation, and robust tracking control.

II. Implementation and Results

A. Sensing and Control

The control architecture was successfully implemented on a three-fingered, 7 degree-of-freedom robotic hand as shown in Fig. 2. By design, the control scheme is cascaded through the use of a high-level manipulation controller and lower-level force controllers (see Fig. 1). The manipulation controller receives the desired Cartesian trajectory of the object as inputs, and outputs appropriate forces for each finger in contact with the object. These desired forces are then issued to an underlying, admittance force controller for each finger. Measured object states and contact forces are relayed back to the manipulation and force controllers. These feedback signals were obtained by the impedance fingertip sensors which were calibrated to resolve three-dimensional contact force directions, contact normal force directions, and contact center of pressure. Touch-based object tracking was generated by using three, time-varying finger-object points of contact. All sensing and control rates were set to a nominal 100 Hz operation.

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B. Artifacts and Test Method

Grasping and manipulation tasks were conducted on objects with different characteristics, including a plastic sphere of diameter 12 cm with a mass of 0.204 kg, and a plastic prismatic shape with dimensions 9 cm by 9 cm by 7.5 cm with a mass of 0.163 kg. Furthermore, a tripod pre-grasp configuration was used to interact with the sphere, while a lateral precision pre-grasp configuration was used to interact with the prismatic part. Each test was initiated by commanding the hand to lightly touch the object (based on fingertip sensor feedback). Once a three-fingered touch was acquired, the manipulation controller was tasked to complete the following three maneuvers, contiguously: 1) hold the object in place for 15.7 s, 2) translate the object in the Z-axis along a sinusoidal position profile of magnitude 1.5 cm and frequency 0.08 Hz over 28.27 s, and 3) rotate the object about the X-axis along a sinusoidal position profile of magnitude 0.126 rad at a frequency of 0.08 Hz for 25.1 seconds.

C. Results

The desired, $[X_d, Y_d, Z_d, R_{xd}, R_{yd}, R_{zd}]^T$, and measured, $[X, Y, Z, R_x, R_y, R_z]^T$, object poses in Cartesian space during manipulation operations for the spherical object are shown in Fig. 3. Meanwhile, the desired fingertip force magnitudes as issued by the manipulation controller when interacting with the sphere are shown in Fig. 4. As seen, the contact forces are time-varying, bounded, and appropriately determined by the manipulation controller in order to carry out the manipulation task. The Root Mean Squared Error (RMSE) calculated from the tracking error for both the spherical and prismatic part tests are shown in Table I. Slightly better tracking was achieved with the sphere across all dimensions except for R_z (interestingly enough, the sphere had more mass than the prismatic part). RMSE values in the linear dimensions were mostly within 2 mm, while those in the rotational dimensions remained mostly within 0.01 rad. These results are encouraging, and point to active, force-based control schemes as a viable solution path to achieving grasping and manipulation with dexterous robotic hands.

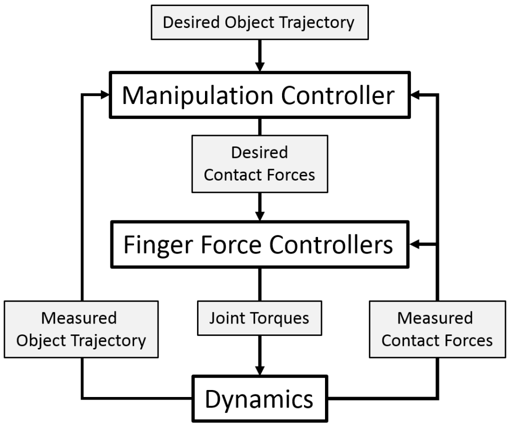

Fig. 1. Control and sensing hierarchy enabling grasping and manipulation.

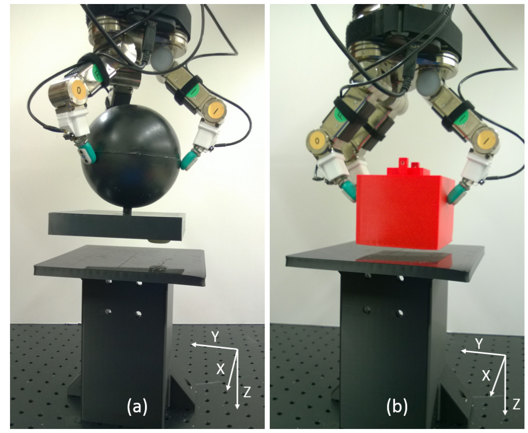

Fig. 2. Three-fingered hand manipulating a (a) spherical object with a tripod pre-grasp configuration, and (b) prismatic object under a precision lateral pre-grasp configuration.

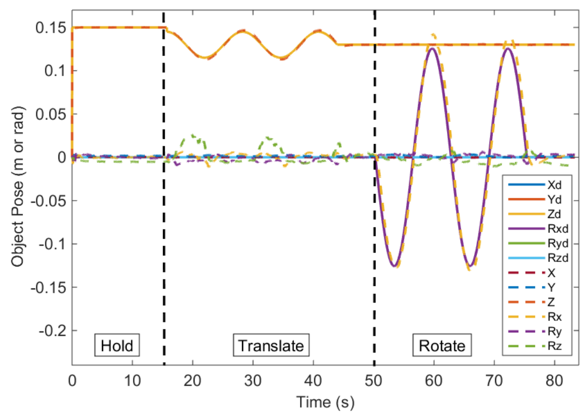

Fig. 3. Desired and measured spherical object pose during the hold, translation, and rotation tasks.

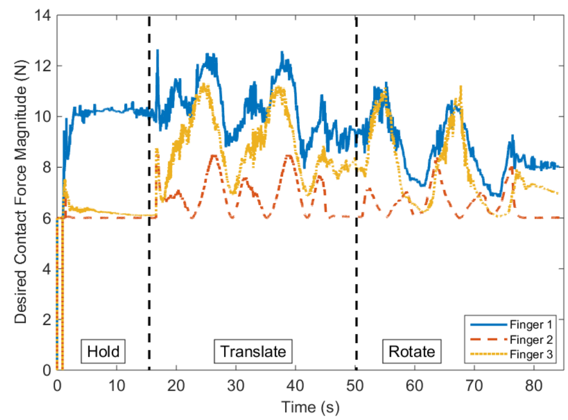

Fig. 4. Desired contact force magnitude for each finger on the spherical object during the hold, translation, and rotation tasks.

III. Future Work

Future efforts include testing the control strategy across a more diversified set of objects, and implementing an external object pose tracking system as a reference to measure the accuracy of the touch-based object tracking scheme. Force control responses will also be further improved.

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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TABLE I

RMSE of object pose for both spherical and prismatic parts.

Dimension	Sphere RMSE (mm or rad)	Prismatic RMSE (mm or rad)
X	0.2385	0.3134
Y	1.6789	2.1636
Z	0.9103	1.0057
R_x	0.0069	0.0102
R_y	0.0034	0.012
R_z	0.0081	0.0078