2014 IEEE International Conference on Robotics & Automation (ICRA)
Hong Kong Convention and Exhibition Center
May 31 - June 7, 2014. Hong Kong, China

Regrasping Objects Using Extrinsic Dexterity

Nikhil Chavan Dafle[1], Alberto Rodriguez[1], Robert Paolini[2], Bowei Tang[2], Siddhartha S. Srinivasa[2]
Michael Erdmann[2], Matthew T. Mason[2], Ivan Lundberg[3], Harald Staab[3] and Thomas Fuhlbrigge[3]
[1] Department of Mechanical Engineering, Massachusetts Institute of Technology,
[2] The Robotics Institute, Carnegie Mellon University, [3] ABB Corporate Research Center
(nikhilcd, albertor)@mit.edu, (rpaolini, boweit)@cmu.edu, (siddh, me, matt.mason)@cs.cmu.edu,
ivan.lundberg@se.abb.com, (harald.staab,thomas.a.fuhlbrigge)@us.abb.com

I. Introduction

This video presents the application of *Extrinsic Dexterity* to change the pose of an object in the hand, i.e., to regrasp the object.

Gravity, inertia, arm motions and external contacts can all be exploited to manipulate an object in the hand. As such dexterity does not depend solely on the intrinsic capability of the hand, but rather is derived from external resources, we call it as *"Extrinsic Dexterity"*.

The video showcases a repertoire of regrasps developed for a simple gripper and presents one of the sequences of regrasps designed to explore border manipulation capability by connecting different regrasps.

II. Related Work

Robotics researchers have studied regrasp for a long time. Place and pick as seen in [1] was one of the earliest approaches used to regrasp an object and is still being used in industry. Dexterous manipulation is another approach, originally formulated by Salisbury [2], which relies on finely controlled motions of fingers to manipulate the object.

Contrary to these two approaches which rely only on intrinsic capability of a gripper, extrinsic dexterity exploits all possible resources for manipulation. A more general use of external resources such as gravity, constraints from external contacts and dynamic motions of a manipulator for object manipulation was noted by Lynch and Mason in [3]. Brock's work on controlled slip [4], Erdmann's research on two palm manipulation [5] and Lynch and Mason's work on dynamic manipulation [6] are few of the examples that fit this approach which we refer as extrinsic dexterity.

III. Regrasp Actions

We developed twelve regrasp actions for three different objects. One of the regrasps, squeezing, is an *intrinsic* regrasp, as it does not depend on any external resources. It squeezes an object in an enveloping grasp to move it to a more stable pose. All other regrasp actions harness external resources and are divided into three categories.

A. Quasistatic regrasps using external contacts

Regrasps grouped in this category take advantage of the constraints from external contacts to reorient the objects in the hand. Manipulator motions are planned such that a wrench required at every instant to move an object is generated as a result of arm motions and external constraints.

B. Passive dynamic regrasps

The outcome of these regrasps is entirely governed by the dynamics of the object rolling on the phalanges under the influence of gravity. The initial pose of an object determines the effective reorientation of the object after it is released.

C. Active dynamic regrasps

These are more challenging regrasps in which the opening and closing of the hand need to be coordinated with the dynamic motions of the manipulator.

All these regrasp actions are hand-scripted and are tuned manually for particular objects. The robustness of the regrasp actions is evaluated from over 1200 experiments; 50 trials of each regrasp, 600 trials of one of the regrasps by changing the initial pose of the object and 90 trials of sequences of regrasps.

IV. Grasp Graph and Sequences

We introduce a *grasp graph* as a directed graph having grasp types as nodes and regrasp actions as edges. A strongly connected grasp graphs allow us to plan sequences of regrasps to transfer the objects from any grasp pose to any another. Using grasp graphs we developed three sequences of regrasps, one of which appears in this video.

V. Discussion

The video demonstrates that dexterity is not a property of a robotic hand alone, but that of the entire system. Dexterous manipulation is possible with a hand dramatically simpler than typical dexterous hands; the key is to use the motions of the arm, object inertia, gravity, and external contacts: extrinsic dexterity.

References

[1] R. Paul, K. Pingle, J. Feldman, and A. Kay, "Instant insanity," film, 1971.

[2] J. K. Salisbury Jr., "Kinematic and Force Analysis of Articulated Hands," PhD Dissertation, Stanford University, 1982.

[3] K. M. Lynch and M. T. Mason, "Stable pushing: Mechanics, controllability, and planning," *Int J Robot Res*, vol. 15, no. 6, pp. 533–556, 1996.

[4] D. Brock, "Enhancing the dexterity of a robot hand using controlled slip," in *IEEE Int Conf. on Robotics and Automation*, vol. 1, 1988, pp. 249–251.

[5] M. A. Erdmann, "An exploration of nonprehensile two-palm manipulation," *Int J Robot Res*, vol. 17, no. 5, pp. 485–503, 1998.

[6] K. M. Lynch and M. T. Mason, "Dynamic nonprehensile manipulation: Controllability, planning and experiments," *Int J Robot Res*, vol. 18, no. 1, pp. 64–92, 1999.