Robust dexterous grasping
through virtual hand-object interconnection

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Introduction

Dexterous grasping in unstructured environment remains an open problem. In such settings, the central challenge is to achieve a general methodology for grasping across diverse objects while maintaining robustness to high levels of perceptual noise. Relying on detailed object knowledge reduces flexibility and limits applications, as sensor-based reconstruction is often unreliable due to noise, occlusions, and incomplete observations. A promising approach to avoid these limitations is to abstract the object representation, capturing only its stable and invariant aspects while absorbing perceptual uncertainty. We hypothesize that representing objects using simple shape primitives [1] (spheres, cylinders, or boxes) embeds sufficient information to enable adaptive grasping, and we propose a grasping policy built upon this representation.

Approach

Our idea for achieving adaptive grasping under such coarse modeling is to frame the grasp action as a dynamic interconnection between the robot and the object, following the philosophy of Virtual Model Control (VMC) [2, 3]. Conceptually, virtual mechanical components such as springs and dampers are structured in a suitable geometry related to the shape primitive of the object and virtually attached to the robot and to the real object. The controller is then implemented to emulate the forces these elements would exert. To enable the motion to be adaptive to any object dimension, the springs attach points are not fixed but rather free to slide all along the object surface, as illustrated in Fig. 1. The key idea is that the grasp motion should emerge from this coupled dynamics rather than being imposed through explicit motion commands.

Experiments

Experimental validation is performed using a Shadow Dexterous Hand (see Fig. 2). Robustness is evaluated through grasping experiments on 3D-printed shape primitives of different sizes, under progressively increasing levels of controlled noise. This noise affects both the estimated object dimensions and its pose, including position and orientation. Generalization performance is then assessed by applying the same policy to a broad set of everyday objects. The results show that the proposed approach exhibits strong robustness to uncertainty while generalizing effectively beyond the primitive shapes.
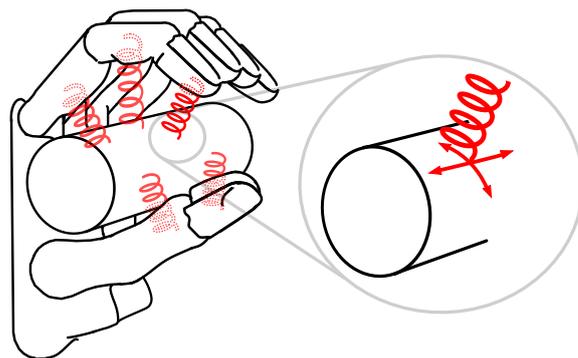

Figure 1: Contact is established by interconnecting the hand and the object while adaptive grasping is achieved by allowing contact points to slide along the object surface

Figure 2: Experimental setup: an anthropomorphic ShadowHand robot grasping various 3D-printed shape primitives

References

[1] A. T. Miller, S. Knoop, H. I. Christensen, and P. K. Allen, "Automatic grasp planning using shape primitives", in *2003 IEEE International Conference on Robotics and Automation (ICRA)*, Sep. 2003, pp. 1824–1829.

[2] J. E. Pratt, "Virtual model control of a biped walking robot", Master thesis, Massachusetts Institute of Technology, 1995.

[3] D. Larby and F. Forni, "Optimal virtual model control for robotics: Design and tuning of passivity-based controllers", *IEEE Transactions on Robotics*, vol. 42, pp. 439–454, 2026.