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Multi-Metric Comparison of Optimal 2D Grasp Planning Algorithms

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Abstract

The planning of optimal grasps is an important problem in robotics which has been investigated by many researchers. The large number of available methods has made it difficult to discern those which plan a grasp with good overall performance, i.e. one with high strength, insensitivity to positioning errors, and ease of computation. In this paper, a new grasp planning method is introduced and compared to three existing planning methods using three such metrics. A new metric for measuring the sensitivity of a grasp to positioning errors is also introduced. Since grasp planning is much simpler in 2D, and 2D grasps are applicable to many 3D objects, the four methods involve only 2D analysis. The methods are applied to a set of six polygonal objects, ranging from 3 sided to 74 sided, and their overall performance is compared. The benchmarking procedure is readily applicable to other grasp planning methods.

1. Introduction

The planning of optimal 2D and 3D grasps is an important problem in robotics which has been the focus of many previous researchers. As in the majority of past work, our focus here is on fingertip or "precision" grasps. In 1999, Smith et al. [9] presented an algorithm for planning two finger, parallel-jaw grips of 3D objects. They analyze a horizontal slice of the object through its center of mass, which reduces the problem to planning for a 2D polygon. Five criteria are used to determine the best grip. Work by Borst et al. [1] and Miller and Allen [4] focussed on obtaining "good" but not optimal grasps using 3D analysis. In [4] an interactive approach is taken. Their grasp simulator, when given a object model, hand model, and hand configuration, determines the quality of the resulting grasp. It can also locally optimize the grasp, although this required 98 minutes of computation in one instance. Their approach benefits from the operator's understanding of grasping, but cannot be employed in an automated system. In [1] heuristics are first used to generate candidate grasps. A grasp quality measure is calculated for each, and the highest quality candidate grasp is selected. They recognized that a grasp planner must plan robust, high quality grasps quickly in order to be practical. Interestingly, the high quality grasps they planned for the mug and banana objects both appear to be nearly 2D grasps, in that the contact points are located near a 2D plane. This demonstrates that 2D grasps are applicable to 3D objects, and indeed may be of high quality under 3D analysis. Please see Shimoga [8] for an excellent review of earlier grasp planning research.

In the majority of the prior work, each approach tends to focus on one aspect of the problem, e.g. minimizing the contact forces required to resist an external wrench. They are also applied to different objects and computational times are reported for different computers. These facts, along with the large number of approaches, has made it difficult to discern those which plan a grasp with good overall performance, i.e. one with high strength, robustness, and ease of computation. The objective of this paper is to perform a multi-metric comparison of four (one new and three existing) optimal grasp planning algorithms. To our knowledge, this is the first time an objective, side-by-side comparison has been reported in the literature.

Since grasp planning is much simpler in 2D, and 2D grasps are applicable to many 3D objects (as observed above and previously observed in [5]), we will examine 2D planning methods only. Six test objects and three quality metrics, including a new metric for measuring the sensitivity of the grasp to positioning errors, will be employed.

2. Problem Definition

It is assumed that a three fingered dexterous hand, or similar device, capable of independently controlling the finger forces is available. The finger to object contacts are modeled as hard contacts with Coulomb friction. The perimeter of the object is modeled as a polygon. The origin of the coordinate system is located at its center of mass. It is assumed that the finger forces are applied