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Kinematic enveloping grasp planning method for robotic dexterous hands and three-dimensional objects

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SUMMARY
Three-dimensional (3D) enveloping grasps for dexterous robotic hands possess several advantages over other types of grasps. This paper describes a new method for kinematic 3D enveloping grasp planning. A new idea for grading the 3D grasp search domain for a given object is proposed. The grading method analyzes the curvature pattern and effective diameter of the object, and grades object regions according to their suitability for grasping. A new approach is also proposed for modeling the fingers of the dexterous hand. The grasp planning method is demonstrated for a three-fingered, six degrees-of-freedom, dexterous hand and several 3D objects containing both convex and concave surface patches. Human-like high-quality grasps are generated in less than 20 s per object.

KEYWORDS: Robotic hands; Enveloping grasp; Grasp planning; Grasping quality.

1. Introduction

Grasp planning is a difficult problem in robotics that has occupied researchers since the 1980s. In general, identifying suitable contact locations, hand pose (both position and orientation), and force-exertion strategies require satisfying three main sets of constraints: (1) constraints due to limited capabilities of the gripper or the dexterous hand, (2) constraints due to object geometry and material characteristics, and (3) constraints due to the task requirements. In analyzing a grasp, it is hard to separate these constraints from each other. A successful grasp is typically accomplished by reasonably satisfying all of these constraints together, which is not always possible. Most of the grasping systems (i.e., planning software plus robotic hardware) are task based and are focused on the range and type of the objects the robot should grasp. To overcome some of these limitations, the researchers introduced dexterous robotic hands. The design of these hands is usually a compromise between the simplicity of single degrees-of-freedom (DOF) grippers and the many DOF of human hands. For an excellent review of the robotic hand design and control, see the work of Pons *et al.*[1] Two common types of grasps implemented with dexterous hands are fingertip grasps (also termed precision grasps) and enveloping grasps. Between these two types, from a dexterous manipulation perspective, a fingertip grasp is preferable. However, from a grasping perspective, an enveloping grasp is preferable for the following reasons: it is more robust to errors in positioning of the fingers on the object; it is more robust to force control errors; it relies less on friction to constrain the object; and it is compatible with simple robotic hands. The robotic hands designed by Ceccarelli *et al.*[2] and by Figliolini and Rea[3] are examples of simple and effective mechanisms designed to perform such enveloping grasps. However, enveloping grasps are particularly difficult to plan for 3D objects for the following reasons.

- Locating the palm and fingers of an N DOF hand for an enveloping grasp requires searching a $6 + N$ dimensional space.
- The physical limits such as the length of the finger phalanges, or the ranges of motion for the joints, add complex constraints to the search.
- The contact between the object surface and the surfaces of the palm and fingers is much more complex to model and analyze than a fingertip contact.

This paper is focused on the kinematic aspects of enveloping grasp planning for 3D objects with dexterous hands, and presents an algorithm for finding a feasible and human-like high-quality grasp.

2. Related Work on Enveloping Grasp Planning

In this section, we will focus on the recent enveloping grasp planning literature, with a particular emphasis on the kinematic aspects. For more extensive reviews of the grasp planning literature, see the works of Bicchi and Kumar[4] and Shimoga.[5] Based on the human enveloping grasping routine, Kaneto *et al.*[6] divided the procedure of grasping into three phases: approach, lifting, and grasping. The routine they proposed can be very helpful in estimating the relative placement of the hand and object before hand closure. However, it models the grasping as lifting a cylinder. This assumption can make the results quite inaccurate for noncylindrical objects. Hwang *et al.*[7] solved the kinematic contact problem between a robot hand and an object as a contact between a B-spline surfaced object and a finger modeled by cylinders and a half ellipsoid. They solve for all contact locations using a complex recursive numerical calculation. Their algorithm is not truly a grasp planner since it requires the location of the palm to be specified *a priori*. This algorithm could be quite useful in handling delicate

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