Optimization-based Robot Grasp Synthesis and Motion Control

av

Robert Krug

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Opponent: Prof. Dr.-Ing. Sami Haddadin
Institute for Control Theory, University of Hannover
Hannover, Tyskland

Örebro universitet
Institutionen för Naturvetenskap och Teknik
Fakultetsgatan 1
701 82 ÖREBRO

Abstract

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This thesis investigates the questions of where to grasp and how to grasp a given object with an articulated robotic grasping device. To this end, aspects of grasp synthesis and hand motion planning and control are investigated. Grasp synthesis is the process of determining a palm pose with respect to the target object, as well as a hand joint configuration and/or grasp contact points such that a successful grasp execution is allowed. Existing methods tackling the grasp synthesis problem can be categorized in analytical and empirical approaches. Analytical approaches are based on geometric, kinematic and/or dynamic formulations, whereas empirical methods aim at mimicking human strategies.

An overarching idea throughout this thesis is to circumvent the curse of dimensionality, which is inherent in high-dimensional planning problems, by incorporating empirical data in analytical approaches. To this end, tools from the field of constrained optimization are used (i) to synthesize grasp families based on available prototype grasps, (ii) to incorporate heuristics capturing human grasp strategies in the grasp synthesis process and (iii) to encode demonstrated grasp motions in primitive motion controllers.

The first contribution is related to the computation and analysis of grasp families which are represented as Independent Contact Regions (ICR) on a target object's surface. To this end, the well-known concept of the Grasp Wrench Space for a single grasp is extended to be applicable for a set of grasps. Applications of ICR include grasp qualification by capturing the robustness of a grasp to position inaccuracies and the visual guidance of a demonstrator in a teleoperating scenario. In the second main contribution of this thesis, it is shown how to reduce the grasp solution space during the synthesis process by accounting for human approach strategies. This is achieved by imposing appropriate constraints to a corresponding optimization problem. A third contribution in this dissertation is made to reactive motion planning. Here, primitive controllers are synthesized by estimating the free parameters of corresponding dynamical systems from multiple demonstrated trajectories. The approach is evaluated on an anthropomorphic robot hand/arm platform. Also, an extension to a Model Predictive Control (MPC) scheme is presented which allows to incorporate state constraints for auxiliary tasks such as obstacle avoidance.

Keywords: Robot Grasping, Grasp Synthesis, Grasp Planning, Motion Control, Model Predictive Control, Independent Contact Regions, Obstacle Avoidance, Motion Planning.

Robert Krug, School of Science and Technology
Örebro University, SE-701 82 Örebro, Sweden, robert.krug@oru.se