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On Using Optimization-based Control instead of Path-Planning for Robot Grasp Motion Generation

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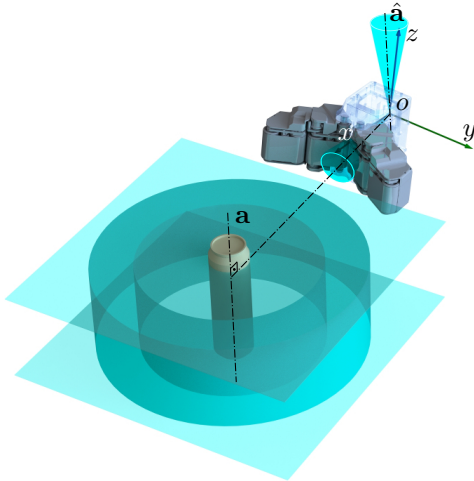


Fig. 1. *Grasp interval*: The shaded cyan regions illustrate the side grasp interval constraints for a cylindrical object. For a successful grasp, the palm frame origin o needs to lie inside the depicted cylindrical shell which is aligned with object axis a . The cylinders height is limited by two planes which are normal to a . Additionally, the gripper's vertical axis (z) is constrained to lie in a cone whose axis \hat{a} is parallel to the object axis a . Furthermore, the gripper's approach axis (x) has to lie inside a cone centered on the normal which connects axis a and point o .

Keywords: Grasping, Motion Control, Motion Planning

In current autonomous grasping systems [1], [2], [3], motions are frequently generated by planning paths with sampling-based motion planners [4]. Here, to circumvent the curse of dimensionality, grasp planning and manipulator motion planning are usually seen as independent sub-problems. A database storing object models together with sets of pre-computed grasps is used to find suitable gripper poses and joint configurations [5]. In the online stage, sampling based planners attempt to generate valid trajectories for the pre-planned grasps, which are executed in a feasible-first manner [1]. During the execution phase, such approaches necessitate many futile motion planning attempts, which often incurs significant time delays. While being able to solve complicated planning problems if given enough time, sampling-based planners do not scale well to geometrically simple scenarios and they are ill suited to incorporate contact events with the environment which is a prerequisite for any grasping/manipulation application. Also, there is no straightforward way to qualitatively influence the resulting

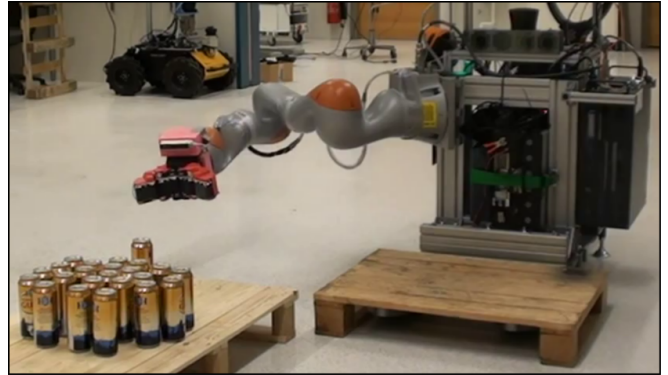


Fig. 2. *The APPLE platform*: Shown is the mobile research platform for Autonomous Picking & Palletizing (APPLE) developed at the AASS Research Center, Örebro University [9]. A KUKA LBR iiwa arm is mounted on a retrofitted Linde CitiTruck forklift AGV. The robot can autonomously pick up and load EUR-pallets. The depicted grasping device is a further developed and smaller version of the underactuated Velvet Fingers gripper described in [10]. Each of its two fingers has a planar manipulator structure with two rotary joints and active surfaces which are implemented by conveyor belts on the inside of the two phalanges. These belts are used to assist in robust grasp acquisition as outlined in [11]. Object detection is done with a Structure IO device which is mounted on the gripper's palm.

motions which frequently are unnatural. With respect to the considered grasping applications, planning paths for pre-defined grasp poses means to fully constrain all Degrees of Freedom (DoF) of the manipulator during movement.

On the other hand, using control to exploit manipulator redundancy with respect to a set of given tasks has long been in the focus of research [6]. In this line of thought, generating motions by online inversion of the manipulator kinematics/dynamics has become a popular method. Approaches in this mold form a hierarchical Stack of Tasks (SoT) [7] and solve lower-ranked equality tasks in the null-space of tasks with higher priority. The expressiveness of these methods was significantly increased by Kanoun et al. [8], who allowed to incorporate inequality tasks by solving a sequence of hierarchical quadratic programming problems at each time-step. Embedded optimization allows to generate reactive motions with additional constraints for, *e. g.*, obstacle avoidance or end-effector orientation.

To leverage the redundancy obtained by a control-based motion generation framework, a different grasp representation than fully constrained pre-planned grasp poses/configurations is necessary. In this work, we present a redundant grasp representation as a set of constraints (see Fig. 1) and use the aforementioned SoT-based prioritized kinematic control framework presented in [8] to generate manipulator motions for the platform depicted in Fig. 2.

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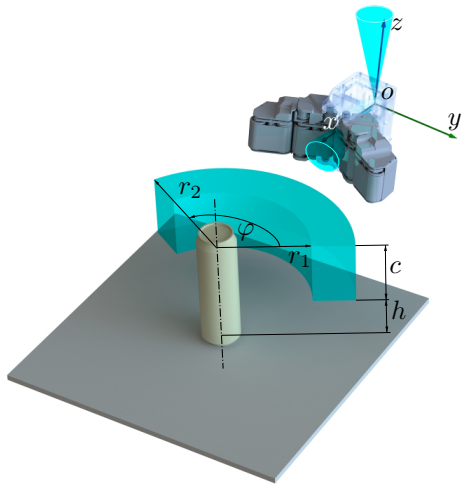


Fig. 3. *Truncated grasp interval*: During the online stage, the corresponding grasp interval shown in Fig. 1 needs to be truncated (*i. e.*, parameters for r_1 , r_2 , c , h and φ need to be determined) to accommodate the specific target object dimensions and to account for the fact that some regions of the grasp interval might not be feasible due to obstruction by the environment.

Conceptually similar to the task space regions in [12], the suggested grasp interval representation bounds the grasping devices position and orientation, but does not fully constrain its pose. For simplicity, we limit ourselves to the illustrated grasp interval defined for cylindrical shapes here. Corresponding intervals can be defined for other shape categories such as spheres and parallelepipeds as well. These grasp intervals are deliberately designed to incorporate additional desiderata about robust grasp poses. It has been shown that human grasps are roughly aligned with the target objects principal component directions to achieve robust grasping behavior [13]. This property is achieved by the cone constraints for the case depicted in Fig. 1.

Currently, the parameters of the grasp intervals such as the distance range between gripper and object have to be evaluated experimentally for each primitive shape category. To ease this non-trivial requirement, in the presented work we rely on a gripper which offers a low pre-grasp pose sensitivity combined with a compliant and robust grasp execution routine (see [11], [9] for more details). During operation, after the target object pose is detected, the grasp interval needs to be adapted to the specific scene and target object dimensions as illustrated in Fig. 3. For an early evaluation we pre-defined the corresponding parameters and gripper pre-grasp joint configurations, an appropriate programmatic approach is under development.

We conducted successful test runs where the APPLE platform was able to autonomously pick cans from a pallet as reported in [9]. While optimization-based control approaches become increasingly popular for robotic motion generation, real-world employments (especially for the considered grasping application) are so far scarce [14]. To the best of our knowledge, our work is the first to experiment with prioritized control in fully autonomous grasping scenarios. Compared to path-planning, the biggest disadvantage of the chosen motion generation framework is, that it is local in the sense that future state evolutions are not taken into

account. For the considered relatively simple pick & place tasks however, this did not pose significant problems. While it is possible to form control policies online via optimizing trajectories over their corresponding state evolutions [15], approaches in this mold are computationally costly and currently only exist in simulation.

For future work, we plan to exploit another benefit of online control-based motion generation: the ability to take sensory feedback into account. The utilized framework [8] allows to specify desired task dynamics and it should be straightforward to modulate these with feedback from, *e. g.*, wrist force sensors to adjust grasp motions on-the-fly.

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