Improving Grasp Robustness via In-Hand Manipulation with Active Surfaces

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Fig. 1. *Parcelrobot and Velvet Fingers Gripper:* The Parcelrobot platform is located at the Bremer Institut für Produktion und Logistik GmbH (BIBA) in Bremen, Germany. Its kinematic structure comprises linear and rotary axes that cover a cylindrical workspace. Equipped with the Velvet Fingers Gripper it comprises an autonomous system for unloading shipment containers filled with randomly packed goods.

In this article, we discuss a strategy to employ and exploit the active surfaces of an articulated robotic grasping device for in-hand manipulation in order to achieve a robust enveloping grasp starting from an initially acquired dexterous fingertip grasp. The presented work was carried out within the scope of the EU-FP7 project RobLog (`http://www.roblog.eu/`), which is aimed at using the Parcelrobot platform shown in Fig. 1 for the autonomous unloading of shipment containers filled with geometrically simple objects (such as boxes, barrels or coffee sacks). Here, the underlying idea is to simplify the design and control of the necessary articulated grasping device and to tailor it to preserve specific desired features. To this end, the Velvet Fingers gripper [1], [2] was developed during the course of the RobLog project. Each of the gripper's two fingers has a planar manipulator structure with two joints and active surfaces which are implemented by coupled conveyor belts on the inside of the two phalanges. The mechanical structure is underactuated and comprises only one actuated Degree of Freedom (DoF) for opening and closing and two DoF for the belt movements. If, during grasping, the proximal phalanges are blocked by an object, the gripper's distal phalanges continue to "wrap around" and envelope it in a firm grasp.

The experiments reported in [3] showed, that in cluttered scenes fingertip grasps are more likely to be feasible than robust enveloping grasps, because the latter necessitate large opening angles resulting in bulky gripper silhouettes for which no collision free approach trajectories can be found. Therefore, we employ the "pull-in" strategy which is illustrated in Fig. 2. Here, the underactuated nature and the conveyor belts on the grasping device are exploited to embrace the object in a firm envelope grasp by simultaneously squeezing it while actuating the belts inwards. This is achieved by compliant low-level position controllers which saturate on experimentally evaluated current thresholds. We use a simple grasping routine which is triggered after an initial fingertip grasp is achieved (see Figure 3). This routine consists of issuing commands to fully close the gripper while moving the belts a pre-defined offset towards the palm. Three thresholds on the current absorption of the opening motor are used: a low threshold (LT) signifies contact between the gripper and the object and a mid threshold (MT) indicates a large enough contact force to stop the closing movement. Finally, an upper threshold (UT) prevents damage to the grasping device. Once the pull-in sequence is completed, the controllers maintain the final torques to ensure a stable grasp.

Fig. 2. *Pull-in grasping strategy:* Depicted is a sequence of intermediate grasp states where the belts of the gripper are used to pull the object towards its palm which results in a transition from a fingertip to an enveloping grasp.

To autonomously grasp an object, the grasp planning problem ($i.e.$, finding an appropriate grasp configuration and corresponding joint trajectories) needs to be solved. For RobLog, a data-driven solution (see [4] for a recent review) was adopted where the central tenet is to simplify planning and to rely on the inherent capabilities of the grasping device to ensure robustness during grasp execution. Here, in order to deal with the curse of dimensionality, the grasp synthesis problem ($i.e.$, finding a suitable palm pose and gripper joint configuration) is separated from the problem of planning collision free motions for the gripper-manipulator chain. In an offline stage, a database is populated with target object models and associated grasps. These grasps are synthesized in an approach similar to [5] by minimizing an energy function depending on distance and alignment of the object and pre-defined desired contact locations on the gripper. Additionally, grasping principles observed in humans (approach along an object surface normal and orientation of the hand's lateral axis normal to one of the object's principal compo-

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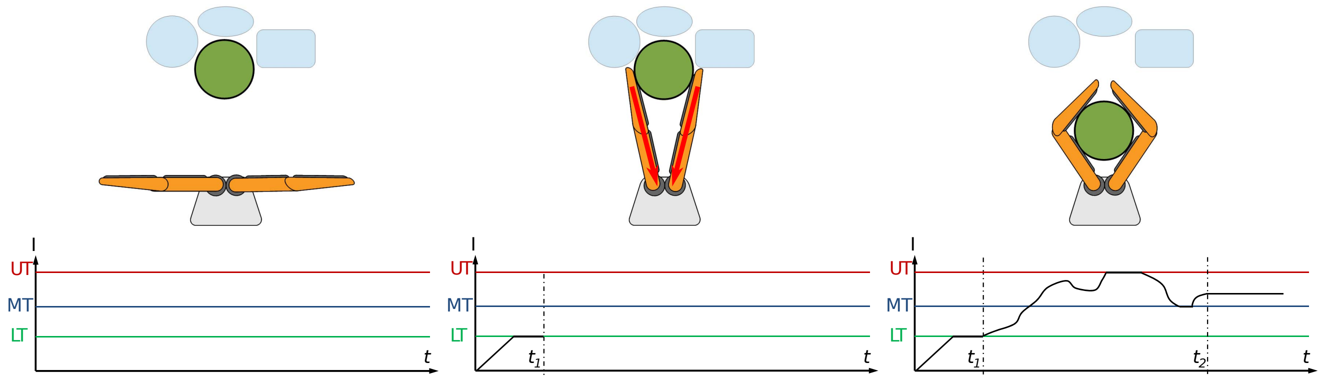

(a) (b) (c)

Fig. 3. *Grasp Execution Control:* As the open griper closes in on the object (Left), the current through the opening motor is monitored. When contact is made (Middle), the actuated belts are switched on to pull in the object. The controller then strives to maintain the current in between two target thresholds by opening or closing the gripper during in-hand manipulation (Right).

Fig. 4. *Grasp Execution:* The Velvet Fingers gripper on the Parcelrobot platform retrieves a box autonomously by employing the pull-in strategy.

nents) are incorporated by imposing appropriate constraints to the underlying optimization problem [3]. In the online phase, objects in the database are matched to the observed scene and grasps associated to detected objects are ranked according to a scoring function following the idea in [6]. Subsequently, motion planning and execution attempts are made for the highest scored grasps in a feasible-first manner. In the presented work, the grasp score is a function of the value of the grasp energy function obtained during grasp synthesis, the alignment between final and current palm pose and the number of points in independent contact regions [7], which capture the robustness of a grasp to modeling and positioning uncertainties. Once a valid grasp candidate is found, joint motion trajectories are generated and passed on to the controller to execute the movement. In our experiments, inverse kinematics, collision checking and motion planning were carried out with the MoveIt! framework [8]. The approach was evaluated on the platform depicted in Fig. 1, an example of using the described grasping pipeline together with the developed strategy for grasp execution is illustrated in Fig. 4 and in the video attachment.

For future iterations of the Velvet Fingers gripper, it is planned to augment the device with tactile sensors which will allow to estimate contact locations, forces and torques. This will allow for more sophisticated post-grasp manipulation schemes based on analytic grasp stability criteria in the wrench space as, $e.g.$, proposed by Platt et al. [9].

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