The Autonomous Picking & Palletizing (APPLE) Robot: A Research Platform for Intralogistics Applications

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***Abstract*— Todo ...**

I. Introduction

The increasing need for fast and flexible commissioning (i. e., order picking and collection of unstructured goods from storage compartments in warehouses) in logistic scenarios has created substantial interest for autonomous robotic solutions. This was also evidenced by a recent BBC investigation into a UK-based Amazon warehouse, which highlighted that the dull and strenuous nature of commissioning could cause mental and physical illness in human workers. Amazon themselves took action by organizing their first Picking Challenge at ICRA 2015.

The key obstacle for many application scenarios is the autonomous grasping in uncer- tain real-world environments. Currently, despite of a large research effort, no commercially viable solution is available for this problem. State of the art autonomous grasping systems [1], [2], [3] commonly employ sampling based planners [4] to generate online reach-to-grasp motion plans for offline planned grasps which are stored in a database. During the execution phase, such approaches necessitate many futile motion planning attempts which often incurs significant time delays mainly due to the frequent colli- sion checks which are necessary to avoid the robot coming in contact with itself or the environment. For APPLE, we adopted a real-time reactive control approach for manipulator mo- tion generation which allows to exploit redundancy, opposed to the commonly used sense-plan-act architectures which constrain all manipulator DoF. The main idea is to formulate a hierarchical set of tasks [5] such as move end-effector on this plane or avoid joint limits and to compute controls such that tasks of lower priorities are executed in the null-space of higher ranked tasks [6], [7], [8].

II. System Architecture

A. AGV Naviagation

This module ensures that the AGV is capable to move autonomously and safely through the workspace environment. In order to achieve this task, we use components of a navigation system previously developed in the context of our KKS-funded Safe Autonomous Vehicles (SAUNA) project. We construct a 3D map of the static parts of the environment (using [9]) and use it to localize the vehicle in the presence of dynamic entities (using [10]). For motion planning and control of the non-holonomic AGV, we will our lattice planner [11] and a model-predictive tracking controller. The complete navigation system has been implemented, extensively tested and successfully integrated on the APPLE demonstrator, a detailed description can be found in [12].

B. People Detection

As the envisioned mobile manipulation system will operate in environments shared with human workers, people detection and human safety are important issues. In APPLE we address the problem by using the RefleX system we recently developed [13]. RefleX is a camera-based on-board safety system for industrial vehicles and machinery for detection of human workers wearing reflective vests worn as per safety regulations. The system was designed with industrial safety standards in mind and is currently being tested as an industrial prototype.

C. Object Perception and Grasp Planning

In order to detect target objects, we use an Asus Xtion Pro RGB-D camera, mounted on the wrist of the KUKA LBR iiwa. Pallet detection and picking is adopted from our previous work on the KKS SAUNA project, standard processing algorithms from the Point Cloud Library [14] are employed for target object detection. Instead of representing grasps as discrete gripper wrist poses and joint configurations, we use grasp interval regions as depicted in Fig. **??**. These grasp intervals can easily be transcribed as target tasks for the manipulator motion control and allow for redundancy in the manipulator wrist positioning which eases reach-to-grasp acquisition. Grasp interval formulation depends on the specific target object and has to be verified experimentally. For now, we constrain ourselves to cylindrical objects as shown in Fig. **??**. We then rely on the inherent capabilities of the grasping device and the compliance of the system for successful grasp execution as stated below.

D. Manipulator Motion Generation

For reactive on-the-fly motion generation we formulate a stack of hierarchical tasks and use the recently developed method by Kanoun et al. [15], which allows to account for inequality tasks and solves a sequence of convex optimization problems at each time step to obtain appropriate joint velocity commands (the method also can be used to directly

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generate torque commands while accounting for the robot dynamics [16]).

Obstacle avoidance is also achieved on a control-level, by formulating tasks which maintain minimum distances between simple geometric primitives such as spheres, planes, points and capsules. We argue that for the considered application strict collision avoidance is neither necessary nor desired, since picking and manipulation inherently necessitates contact events between the robot and the environment. Also, in real-world applications where knowledge about the environment is available only in form of noisy sensor data, it might not be possible to avoid contacting the environment without being overly conservative. This makes the KUKA LBR iiwa with its compliant low-level control schemes and contact detection abilities an ideal platform for the tackled purpose and motion generation scheme. The relatively simple picking task in APPLE provides an ideal testbed in a real-world scenario.

E. Robust Grasp Execution

For this component, we adopted the approach we developed in RobLog and leverage the capabilities of the Velvet Gripper, namely underactuation and conveyor belts on the finger pads in order to achieve robust grasping behavior. Especially in cluttered scenes, a "pull-in" strategy has been shown to be especially effective to achieve stable grasps while starting from a relatively wide range of initial gripper poses with respect to the target object [3]. Here, the features of the grasping device are exploited to embrace the object in a firm envelope grasp by simultaneously squeezing it in a compliant fashion while actuating the belts inwards.

III. Evaluation

IV. Discussion and Outlook

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