Object exploration by visuo-tactile servoing

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I. Introduction

As an important interdisciplinary concept, body schemas attract more and more attention in the field of robotics. Originating from developmental psychology and computational neuroscience, body schemas comprise many developmental and adaptive mechanisms, that have inspired and extended traditional robotics research approaches. Important questions include: How to develop adaptive kinematics representations that facilitate robot motion planning? How the body schema can be exploited to interact with unknown environments? In this paper, we will focus on the latter question and propose a controller framework integrating multi-modal feedback for unknown object exploration.

II. Method

Based on the assumption, that the body representation of the robot is known, we developed a control framework to enable vision-guided tactile exploration of unknown objects as well as tactile-driven grasping and in-hand manipulation. Common to all these tasks is to establish and maintain object contact at visually provided locations, or to slide individual fingers across the object's surface – either for exploration or to optimize grasp stability.

Instead of hardcoding each of these action primitives, we provide a set of generic control primitives that can be flexibly combined and sequenced within the proposed control framework to realize many complex actions. The framework is divided into three control layers. At the lowest level it allows for classical robot motion control, i.e. controlling arbitrarily chosen effector frames in Cartesian space using proprioceptive feedback only. At the second layer, we add tactile feedback to provide several basic tactile servoing controllers that map errors in tactile features directly to correcting Cartesian velocity twists of the sensor frame. Subsequently, the low-level control primitives are employed to implement the desired sensor frame movement. Tactile servoing control primitives include (1) tracking the contact point location, (2) adjusting the contact force, (3) increasing contact area by rolling, and (4) aligning the tactile sensor array with an object edge. Combining these primitive controllers and superimposing an external motion component we are able to track an unknown one-dimensional object edge or to explore an unknown two-dimensional object surface.

At the third layer, we propose a visual servoing controller to provide a high-level motion command that is superimposed with the tactile servoing commands. In this manner we can realize high-level servoing tasks – e.g. tracking an object – while exploiting the mid-level tactile servoing controllers to maintain proper object contact. Combining the controllers at all levels, we have realized manipulation of unknown objects in 3D space (world frame centered or object frame centered). Furthermore it is possible to acquire a tactile point cloud that approximates the shape of an unknown, palpated object as can be seen in Fig. 1. This skill can in future be used to autonomously explore the robot's own body and thus incrementally improve the body schema. The proposed control framework is highly modular and can be easily extended when new learning and cognition components become available.

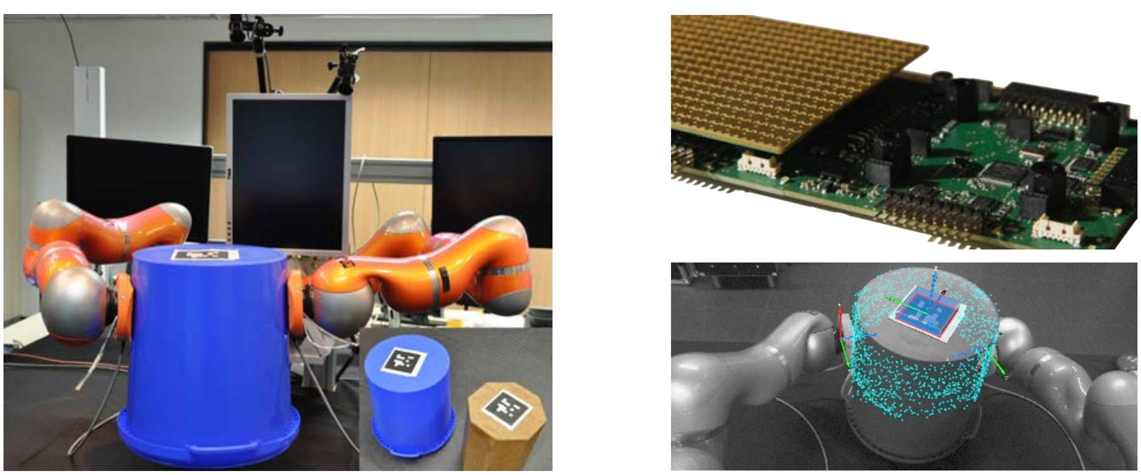

Fig. 1. Bimanual robot setup (left) with tactile sensor arrays (right top) mounted as large fingertips at the end-effectors of two Kuka LWR arms. Tactile object exploration acquires a point cloud of an unknown object surface (right bottom). The object pose is tracked using the visual marker.