Haptic Exploration for Navigation Tasks using a Visuo-Haptic Sensor

Nicolas Alt, Qing Rao, Eckehard Steinbach
Institute for Media Technology, Technische Universität München, 80333 München, Germany

***Abstract*—A system is presented for the haptic exploration of objects in a household environment. Haptic properties are acquired using a passive, deformable sensor tip mounted on a platform. The sensor deformation is measured visually, allowing for a flexible and low-cost design. Navigation of simple robots, such as vacuum cleaners, is improved by active manipulation.**

Simple service robots for households, such as the vacuum cleaner Roomba, see [1], currently rely on rather simple sensors for navigation. Some models navigate randomly, changing direction when an obstacle is hit, some build a map with static obstacles using a camera or a laser scanner. Currently, these platforms do not actively interact with objects – they rather try to avoid anything they encounter.

The performance of such robots may be improved by allowing simple controlled interaction with objects. For instance, if obstacles block access to a region of the map, one of them could be pushed out of the way. In this work, we propose a sensor and method to acquire haptic properties of obstacles and use them for interactive navigation. We refer to these properties as "haptic tags" associated to a certain object. This level of modeling detail is reliable and sufficient for the required manipulation tasks. The sensor is low-cost as it only relies on mechanical parts and a standard camera. Using a camera instead of a dedicated electronic force sensor offers a number of advantages: Both the applied force and the reaction of the object are read from the same sensor, making sensor readings naturally coherent and synchronized. A single camera observes a large number of interaction points simultaneously, and there is great flexibility concerning the shape of the sensor.

Visuo-Haptic Sensor — The proposed system consists of a passive, mechanic and deformable end-effector – such as a single-point tip mounted on a spring, see Fig. 1. Deformable sensors allow for save interaction with objects, avoiding destruction in case of collisions. Furthermore, the applied force can be measured visually from the observed deformation without an additional electronic force sensor. A camera is mounted on top of the robot, looking at the end-effector as well as onto the object. The pose of the sensor tip is determined by searching and tracking an arbitrary template close to the tip. Template tracking [2] is a robust, fast and accurate approach which relies on existing texture, such as the robot surface, and does not require specific markers. Using Hooke's law, the axial force is determined from the measured distances of the sensor tip T and a point R on the robot (Fig. 1 left), projected onto the main axis of the sensor. Point R is either fixed or determined from a texture on the robot platform itself.

In addition, the camera tracks a point G on the ground as a reference and to detect slip of the robot wheels. The line or point C which shows the position of the object on the ground is obtained from point cloud segmentation and subsequent edge tracking. A change of $C-G$ indicates that the object started to slip, allowing to determine friction and adhesion force. Once the sensor tip touches the object on point S, the distance $S-T$ remains constant. In case of a deformable object, $S-G$ increases with increasing force. Some objects may also fall or be destroyed by exploration, which is considered a "fatal event". This case is determined by sudden movements of patches on the object surface which are tracked using template tracking.

Exploration and Navigation — During exploration, a 2D map is generated with GMapping [3] using depth data from a Kinect sensor.

This work has been supported, in part, within the DFG excellence initiative research cluster Cognition for Technical Systems – see http://www.cotesys.org

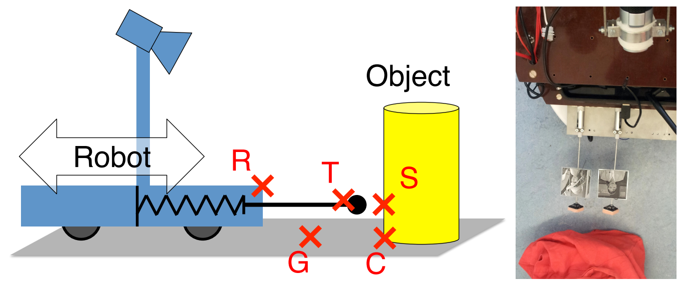

Fig. 1. For exploration, the robot pushes the sensor tip T onto an object. A camera tracks points on the robot and the scene (red, see text) to measure applied forces and the reaction of the object. Right: The pose of two sensor tips is obtained by tracking arbitrary templates (e.g. the Lenna image).

Individual objects are segmented by ground plane removal and filtering of large, narrow or isolated areas in the point cloud. The robot drives close to an object to explore it and then pushes it with the sensor for a certain time period, until a maximum force is achieved or until a fatal event occurs. Afterwards, objects in the visual scene map are augmented by haptic tags which comprise of friction and adhesion force, object deformation and fatal events. In addition, haptic tags may also be added to an object database which is used to re-detect previously seen objects.

Navigation is performed using a simple local planner which evaluates local path candidates based on their agreement with the global goal and a costmap showing obstacles extended by a buffer zone. A global path is obtained by consecutively running the local planner. Costs of obstacles are based on the associated haptic tag, namely the measured adhesion force and, to a small extent, deformability. An obstacle has infinite costs if the adhesion force could not be determined, a fatal event occurred or the object was not explored. Like that, paths are planned to locally reduce the required manipulation effort. In case the global path has finite costs but collides with an obstacle, the robot needs to move this object out of the way. Similar to exploration mode, the object is approached and pushed towards the closest wall of the room. Once this task is completed, path planning is repeated with the updated costmap. A video showing a test run of the system is available online[1].

Outlook — In future work, the concept of visual acquisition of interaction forces will be extended to sensing along lines and surfaces. This allows for a more accurate representation of obstacles and increased flexibility for sensor shapes. Additionally, an existing navigation framework will be integrated to obtain a globally optimized path with minimized manipulation effort.

References

[1] J. Forlizzi and C. DiSalvo, "Service robots in the domestic environment: a study of the roomba vacuum in the home," in *Proc. 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, 2006.

[2] C. Mei, S. Benhimane, E. Malis, and P. Rives, "Efficient homography-based tracking and 3-d reconstruction for single-viewpoint sensors," *IEEE Transactions on Robotics*, vol. 24, no. 6, pp. 1352–1364, 2008.

[3] G. Grisetti, C. Stachniss, and W. Burgard, "Improved techniques for grid mapping with rao-blackwellized particle filters," *IEEE Transactions on Robotics*, vol. 23, no. 1, pp. 34–46, 2007.

[1] Demo video available online: http://www.lmt.ei.tum.de/?id=1013