NimbRo@Home 2014 Team Description

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Abstract. This document describes the RoboCup@Home league team NimbRo@Home of Rheinische Friedrich-Wilhelms-Universität Bonn, Germany, for the competition to be held in João Pessoa, Brazil, in July 2014. Our team uses self-constructed humanoid robots for mobile manipulation and intuitive multimodal communication with humans. The paper describes the mechanical and electrical design of our robots Cosero and Dynamaid. It also covers our approaches to object and environment perception, manipulation and navigation control, and human-robot interaction.

1 Introduction

Our team NimbRo competes with great success in the @Home league since 2009, winning the last three international RoboCup@Home competitions (2011 Istanbul [1], 2012 Mexico City [2], 2013 Eindhoven [3]). We also participate successfully in European competitions, winning RoboCup German Open for the last four years in a row (2011–2014).

Our robots, Dynamaid and Cosero, have been designed to balance requirements of indoor navigation, mobile manipulation, and intuitive human-robot interaction. We equipped the robots with omnidirectional drives for robust navigation, two anthropomorphic arms for object manipulation, and a communication head. In contrast to many other service robot systems, our robots are lightweight, relatively inexpensive, and easy to interface.

We developed methods for real-time environment, person, and object perception using 3D sensors such as laser scanners and RGB-D cameras. Based on these percepts, we developed efficient planning methods for navigation and object manipulation. Furthermore, the robots are equipped with a multimodal dialogue system.

In the next section, we detail the mechanical and electrical design of our cognitive service robots. Sections 3 and 4 cover perception and behavior control, respectively.

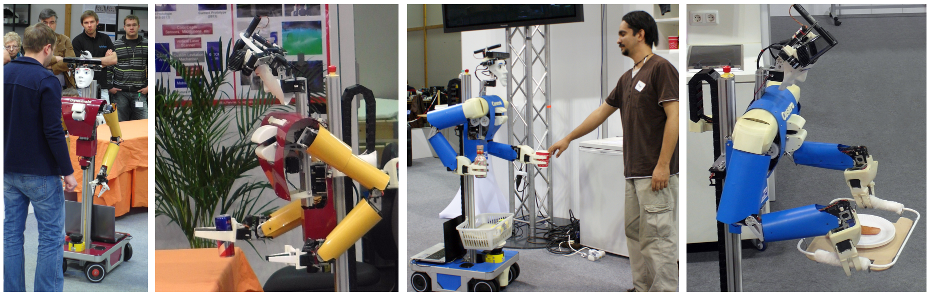

Fig. 1. Cognitive service robots Dynamaid (left) and Cosero (right).

2 Mechanical and Electrical Design

We equipped our robots Cosero and Dynamaid (see Fig. 1) with omnidirectional drives for flexible locomotion in restricted spaces. Four pairs of directly driven, steerable wheels are mounted on the corners of the rectangular base.

The robots have an anthropomorphic upper body with two 7 DoF arms that have a human-like work space. The upper body can be twisted about the vertical axis and linearly moved along the vertical to further extend the work space.

The lightweight robot structure is made from aluminum. All joints are driven by Robotis Dynamixel actuators. Because Cosero has stronger motors and additional gears, it can lift heavier objects (up to 1.5 kg with a single hand) than Dynamaid. Both robots are equipped with 1 DoF grippers ending in Festo FinGripper fingers.

The robots perceive their environment with a variety of sensors. A horizontally scanning SICK S300 laser range finder (LRF) is mainly used for 2D mapping and localization. For detection of small obstacles on the floor, a Hokuyo URG-04LX LRF is mounted between the front wheels. For 3D perception, a tilting Hokuyo UTM-30LX LRF is mounted in the chest. For measuring the height and distance of support surfaces, e.g. table tops, and detecting objects on these, a URG-04LX LRF is mounted on a roll joint on the hip. The head contains a RGB-D camera (MS Kinect) and a directed microphone. Both can be directed at objects or persons by a pan-tilt mechanism in the neck. To detect the presence of objects, the grippers are equipped with IR distance sensors. Recently, Cosero has been equipped with an additional camera in the belly.

The robots are controlled by a notebook with Intel QuadCore CPU and powered by Lithium-polymer rechargeable batteries.

3 Perception

3.1 Perception of Human Interaction Partners

For person detection and tracking, we combine complementary information from LRFs and the head camera. We also detect gestures like pointing and showing

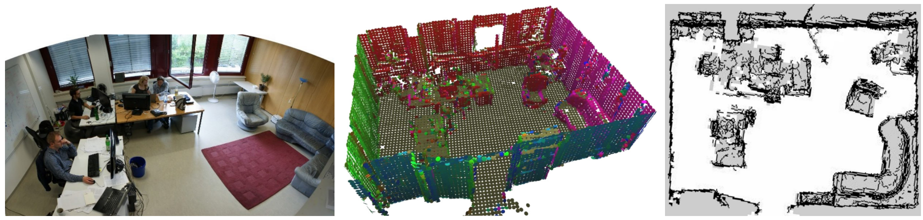

Fig. 2. 3D surfel map of office and and drivability assessment [5]. Note that the opened window is perceived as an obstacle.

in RGB-D images [4]. The robot can approach persons and enroll their faces for later recognition using the VeriLook SDK. For speech recognition and synthesis, we rely on Loquendo. When Loquendo recognizes a sentence, it provides a parse tree according to a grammar, which we define for each test. Our task execution module then interprets the resulting semantics and generates appropriate behavior.

3.2 Mapping and Localization

In addition to state-of-the-art methods for simultaneous localization and mapping (SLAM) in 2D, we developed mapping and localization in 3D using surfel grid maps [5]. As shown in Fig. 2, this allows for full 3D traversability analysis. It also makes localization more reliable, because upper parts of indoor environments tend to be less dynamic.

We also developed efficient RGB-D SLAM methods, based on Multi-resolution Surfel Maps (MRSMap) [6], which run in real time on a CPU. These can be used to model the environment and localize in these maps, or to obtain 3D object models from multiple views and track these in the camera images. Fig. 3 shows some examples. For difficult situations, we developed a particle filter-based method that detects and tracks MRSMap object models [7].

In addition to recognition of known object instances, which is based on SURF features and color histograms, we also developed methods for 3D semantic map-

Fig. 3. 3D Multi-resolution surfel models of objects generates by RGB-D SLAM [6].

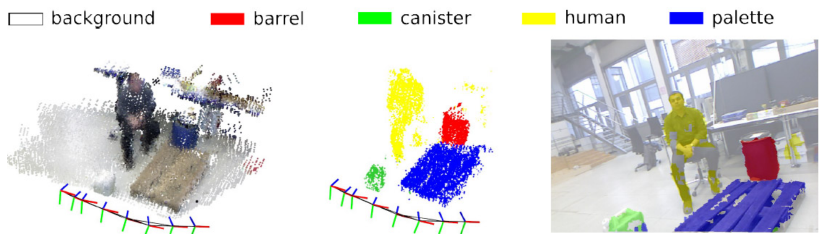

Fig. 4. Semantic mapping from a moving RGB-D camera [8].

ping, which are based on RGB-D SLAM and random forest object-class segmentation [8]. Fig. 4 shows an example.

4 Behavior Control

The autonomous behavior of our robots is generated in a ROS-based modular control architecture. Hierarchical finite state machines are employed for high-level control of test progress. These configure individual mid-level modules, such as the perception of objects and persons, navigation planning, or the grasping and placement of objects. The motions themselves are controlled on the lowest layer of the hierarchy.

4.1 Robust Indoor Navigation

We developed an omnidirectional driving controller that coordinates the steering and rotation of the eight wheels to realize arbitrary combinations of 2D linear and rotational velocities. For navigation, we implemented path planning in occupancy grid maps and 3D obstacle avoidance using measurements from the LRFs and the depth camera [9].

4.2 Manipulation with One and Two Arms

We control the 7 DoF arms using differential inverse kinematics with redundancy resolution. The arms also support compliant control in task-space [10].

Our robots can grasp objects on horizontal surfaces like tables and shelves efficiently using fast grasp planning [11]. We derive grasps from the top and the side directly from the raw object point clouds. The grasps are then executed using parametrized motion primitives, if the direct reach towards the object is not obstructed. In complex scenarios, such as in bin-picking, the robots plan collision-free grasps and reaching motions [12].

We also developed solutions to pour-out containers, to place objects on horizontal surfaces, to dispose objects in containers, to grasp objects from the floor. Based on compliant control, we also implemented mobile manipulation controllers to open and close doors, e.g. of fridges and closets. We also implemented

Fig. 5. Manipulation skill transfer demonstrated at RoboCup 2013 in Eindhoven: watering a plant with an unknown can based on non-rigid registration of a can model to the novel can [13].

task-specific motions, e.g. for switching on a cooking plate or for unscrewing the cap of a bottle.

Since our robots have two arms, they can grasp and manipulate larger objects. This has been used e.g. to push chairs to a specific location, to grasp a watering can and water a plant, or to carry a tray. In order to transfer manipulation skills from known object instances to novel ones, which differ in geometry and appearance, we developed efficient deformable registration methods [13]. As shown in Fig. 5, they determine a dense correspondence between the model and the novel object, which we use for transfer of grasp poses and end-effector frames to the novel object, which leads to adapted motion primitives. This has been demonstrated at RoboCup 2013 by the use of an unknown watering can.

We developed also a method for using tools, which have been equipped with a special handle that fits firmly into the gripper of our robot Cosero. Fig. 6 shows the opening of a bottle with a bottle opener and the use of a pair of tongs for picking a sausage from the BBQ. To correct for mechanical inaccuracies, the robot perceives the tip of the bottle opener and the cap of the bottle with its RGB-D camera before the final part of the bottle opening motion. For grasping sausages from a plate or a barbecue, we segment the sausages using plane segmentation and adapt the grasping motion to the position and orientation of the sausages. The opening of the gripper is directly transferred to the tool.

4.3 Intuitive Human-Robot Interaction

For natural interaction with its users, we developed a multimodal dialogue system, which is based on the experiences made with our communication robot Robotinho [14]. This includes recognition and generation of speech (using Loquendo) and gestures.

The robots also perform physical human-robot interaction, e.g. by handing over objects from robot to human or vice versa and by cooperative carrying large objects, like a table [15]. For these functions, the compliant arm motion [10] is crucial.

For immobile users, it is important to have a possibility to remotely interact with the robot. To this end, we implemented a handheld teleoperation interface,

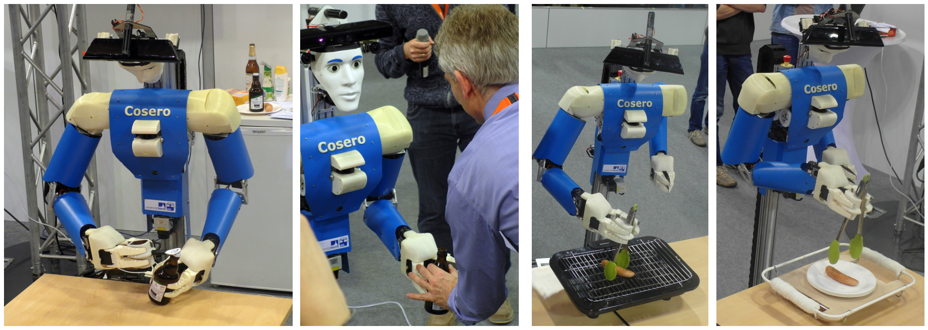

Fig. 6. Tool use demonstrated in the RoboCup German Open 2014 final: Opening a bottle and picking a sausage from the BBQ.

based on a tablet [16], see Fig. 7. Based on displayed camera images, maps, localization, and object detections, the user can control the robot on three levels of autonomy, from task level, where the user only specifies the goal of a complex task, over skill-level, where individual skills like grasping an object are triggered by the user, to body level, where the user direct controls base and arm motion. For German Open 2014, we developed an object localization system, based on Bluetooth LE tags attached to objects and receivers distributed in the environment. This allowed for keeping track of object positions in the teleoperation interface, such that the user could send the robot to fetch objects which had been placed at unknown positions in the arena (Fig. 7 right).

5 Conclusion

Our @Home system covers the basic functionalities required for the standard tests well. It is also very modular and contains some advanced functions, which can be combined to design novel demonstrations for the open tests with limited effort. The system performed very well, winning the last seven competitions we participated in (German Open and international RoboCup since 2011).

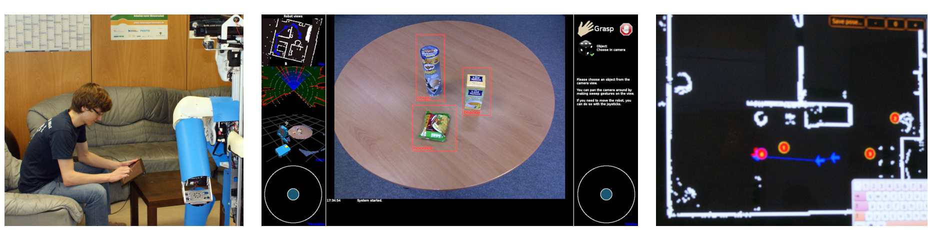

Fig. 7. Handheld teleoperation interface based on a tablet [16] (left). The user can e.g. select the object to grasp (center). Estimated locations of tagged objects (right).

We will continue to improve our system for RoboCup 2014 and to integrate new capabilities. The most recent information about our team (including videos) can be found on our web pages www.NimbRo.net/@Home.

Team Members

Currently, the NimbRo@Home team has the following members:

- Team leader: Max Schwarz, Jörg Stückler
- Staff: David Droeschel, Kathrin Gräve, Dirk Holz, and Michael Schreiber
- Students: Nikita Araslanov, David Schwarz, and Angeliki Topalidou-Kyniazopoulou

Fig. 8. Team NimbRo@Home at RoboCup German Open 2014.

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