Mobile Teleoperation Interfaces for Domestic Service Robots

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***Abstract*— Domestic service robots are envisioned to provide assistance to persons in need of help with their activities of daily living. These tasks require a comprehensive set of perception, control, and planning skills—beyond the state of the art of autonomous robots. On the other hand, direct control of complex robots requires special equipment and the full attention of the operator. Hence, it is necessary to combine state-of-the-art autonomous capabilities with the intelligence of users in a complementary way. We report on handheld user interfaces for domestic service robots that allow for teleoperating the robot on three levels of autonomy: body, skill, and task control. On the higher levels, autonomous behavior of the robot relieves the user from significant workload. If autonomous execution fails, or autonomous functionality is not provided by the robot system, the user can select a lower level of autonomy to solve a task. The benefits of providing adjustable autonomy in teleoperation have been successfully demonstrated at RoboCup@Home competitions.**

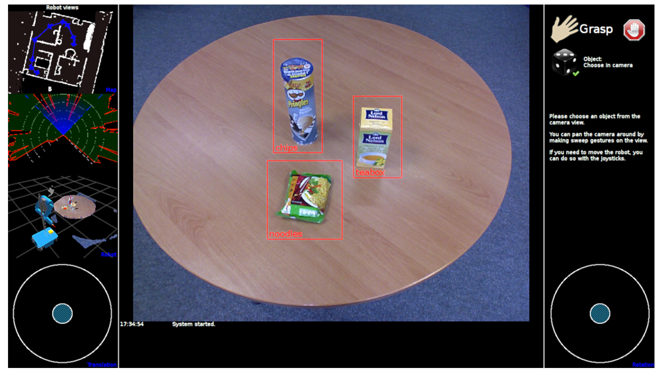

Fig. 1. Skill and body-level GUI with a view selection column on the left, a main view in the center, a configuration column on the right, and a log message window on the bottom center. Motion is controlled directly with two joystick control UIs.

I. Introduction

Domestic service robots that shall assist persons in their activities of daily living (ADL) not only require versatile autonomous skills, but also intuitive user interfaces. While natural interaction modes such as speech, facial expressions, and gestures work well when the robot is in direct vicinity of the user, many application scenarios require that robot and user are at different places in a home. For example, the mobile robot could fetch objects requested by a user with mobility restrictions. Hence, there is a need for controlling the robot from a distance. While complex teleoperation interfaces, such as exoskeletons, have been developed for the direct control of robots, they are quite impractical to use for persons in need of assistance, because they are stationary, bulky, and require the full attention of the operator. Lightweight mobile computers with touch screens are already used for many applications and have been shown to provide intuitive interfaces for teleoperation of mobile robots.

Many high-level tasks that are difficult to achieve autonomously can already be tackled when the intelligence of the user is combined with robot skills. In this way, both sides contribute their strengths and complement each other. When the robot performs mosts tasks autonomously, it relieves the user from tedious and time-consuming low-level control. Only in difficult situations, in which no autonomous solution exists yet, the user should need to take over control of the robot on the most convenient, i.e. most autonomous, level.

We propose handheld user interfaces that allow persons to teleoperate a complex anthropomorphic service robot on three levels of autonomy. The user adjusts the autonomy level according to the complexity of the task and available robot capabilities. The notion of adjustable autonomy has been coined by Goodrich et al. [1]. Leeper et al. [2] evaluate body-level teleoperation GUIs for mobile manipulation. We identified *body*, *skill*, and *task* level autonomy [3], [4] and develop teleoperation interfaces for our domestic service robots Dynamaid and Coseros [5] on these levels. Our robots have mobile manipulation and human-robot interaction capabilities to perform tasks autonomously in everyday environments. This involves grasping and placing of objects and safe omnidirectional locomotion.

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II. Handheld User Interfaces

Handheld computers such as smart phones, tablets and slates provide a touch-sensitive display suitable for the implementation of teleoperation interfaces which visualize robot sensor data and estimated state for situation awareness and allow for finger-based control. The GUI can be designed to mediate what the robot actually can do, which improves common ground. For instance, the user may only be given the choice between possible actions and involved objects and locations. We investigate teleoperation with a handheld computer on three levels of autonomy. On the body level, the operator directly controls robot body parts such as the end-effectors, the gaze direction, or the omnidirectional drive. On the skill level, the operator controls robot skills, e.g. by setting navigation goals or commanding objects to be grasped. Finally, the operator configures autonomous high-level behaviors that sequence skills on the task level.

Body-Level Teleoperation: The body-level controls allow the user to execute actions with the robot that are not covered by autonomous skills and therefore are not supported on

Fig. 2. Illustration of our task-level teleoperation interface. Top left: A user composes a task. Bottom/top middle: The robot grasps an object. Top right: The robot delivers the object.

higher levels of the teleoperation interface. The user gains situational awareness through the visualization of live camera images, external robot views, and 2D laser scans (see Fig. 1). To prevent the robot from being damaged, these modes include obstacle avoidance.

Skill-Level Teleoperation: The skill-level user interfaces configure robot skills that require the execution of a sequence of body motions. The robot controls these body motions autonomously. By that, the workload on the user is reduced. While the robot executes the skill, the user can supervise its progress. Compared to body-level control, the skill-level UI does require less communication bandwidth, since images and control commands have to be transmitted with less frequency. Hence, this mode is less affected by high latency or low bandwidth communication. The user has access to several autonomous robot skills such as navigation to goal poses in a map, grasping objects in the view of the robot, and handing objects over to a user.

Task-Level Teleoperation: The task-level teleoperation UI is intended to provide the high-level behavior capabilities of the robot (Fig. 2). The user can compose actions, objects, and locations similar to our implementation for the parsing of complex speech commands. Our user interfaces allow for composing a sequence of skills in two stages. On the primary UI, the user adds and removes skills from the sequence. Once a skill is selected, the user specifies location and object for the skill on a secondary UI. A monitoring UI lets the user keep track of the task execution status.

III. Results

At RoboCup 2012 and German Open 2013, we demonstrated concepts of mobile teleoperation with Cosero. In the Demo Challenge at RoboCup 2012, we showed an elderly-care scenario in which a user commanded the robot to fetch a drink from another room. At first, the person let the robot fetch a specific beverage. The robot drove to the assumed location of the drink, but since it was not available, the user had to take a different choice. The user switched to the skill-level control UI and selected one of the other beverages that were perceived by the robot on the table and displayed in live images on the UI. Finally, the robot grasped the selected drink, brought it to the user and handed it over. The demonstration was well received by the jury consisting of the league's technical and executive committee members. At German Open 2013, we extended the Demo Challenge with receiving objects from users and putting the object in a waste bin. Our team received best score in this test. At RoboCup 2013 in Eindhoven, Netherlands, we presented the teleoperation UI with task specification to the jury in the Demo Challenge. For German Open 2014, we extended our system by displaying locations of easy-to-displace objects tagged with Bluetooth Low Energy senders [6], which allowed for fetching them without search. At RoboCup 2014 in Joao Pessoa, Brasil, we demonstrated another extension of the user interface, which allowed the user to send the robot to the apartment door in order to receive a delivery. This involved signing the delivery sheet on behalf of the user.

IV. Conclusions

We proposed mobile teleoperation interfaces with adjustable autonomy for domestic service robots. We identified three levels of autonomy and designed various user interfaces on these levels for handheld computers. On the body level, the user can control body motions such as omnidirectional driving and gaze direction. The next higher level allows the execution of robot skills. These skills require a sequence of body motions and perception capabilities which are executed autonomously by the robot. The task-level UI is designed to configure high-level behavior similar to complex speech commands. Failures are detected on the skill- and task-level automatically and reported to the user. The user then decides for the appropriate lower-level UIs to resolve the situation. We demonstrated our mobile teleoperation interfaces successfully at multiple RoboCup competitions. Overall, our team NimbRo won the @Home League at RoboCup German Open 2011-2014 and RoboCup 2011-2013.

References

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