Enhancing Supervised Autonomy for Extraterrestrial Applications by Sharing Knowledge between Humans and Robots

Daniel Leidner, Peter Birkenkampf, Neal Y. Lii, and Christoph Borst

***Abstract*— As the human race continue its exploration farther into the solar system, extraterrestrial habitats can be placed on asteroids, moons, and planets, such as Mars. These habitats would require on continuous monitoring and maintenance in order to remain safe and functional. However, permanent astronaut on-site may not be available for this task. A possible alternative to direct inspection is remote inspection with a teleoperated robot. In order to cope with long communication round-trip time and possible data package loss, we propose to utilize a knowledge-driven supervised-autonomy approach to control a robot. The information to interact with the environment is thereby shared between the robot and the operator. With this concept, an intuitive human-robot interface can be designed to solve even complex manipulation tasks. The proposed framework will be utilized as a part of the SUPVIS-JUSTIN experiment within the ESA METERON project.**

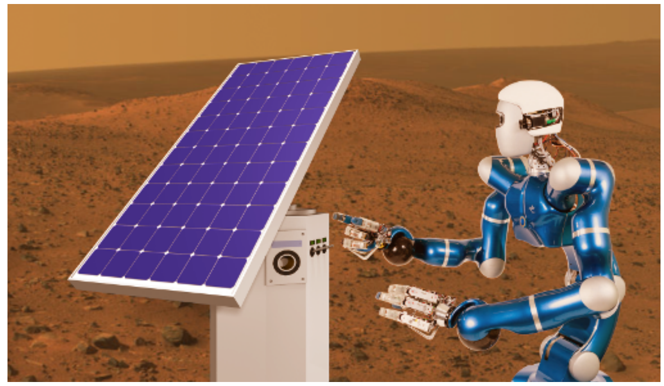

Fig. 1. Conceptual illustration of the humanoid robot Rollin' Justin of DLR maintaining a solar panel on Mars[1].

I. Introduction

An *intuitive human-robot interface (HRI)* with a high task abstraction level, can reduce the cognitive load for the operator (astronaut) for highly complex tasks, such as remote commanding a robot in a distant extraterrestrial environment (see Fig. 1). This requires a method to communicate the commanded tasks *to the robot*, as well as the visualization of the information feedback *to the operator*. One option to achieve this is through the sharing of the required task knowledge between the human and the robot.

II. Knowledge for the Robot

Typically, HRIs follow a robot-centric approach where expert knowledge about the capabilities of the robot is required in order to execute a specific task. However, any type of required expert knowledge can increase the cognitive load of the operator. To avoid this, Suzuki *et al.* proposed to apply an object-centered task specification to teach a robot [1]. We combine this approach with our previous work where we arranged knowledge within an object-centered context to solve everyday manipulation tasks [2]. Based on this knowledge, a robot can autonomously reason the task execution as follows:

A shared knowledge base provides object information to the robot, and likewise to the HRI of the operator, to create a knowledge common ground. As part of this knowledge base, *action templates* store the symbolic and geometric descriptions for the manipulation instructions. Based on these instructions, hybrid reasoning is utilized in a two step approach: First, the symbolic *Planning Domain Definition Language (PDDL)* [3] header of the action template is parsed to solve a given task symbolically. The resulting action sequence is then processed and carried out next. In step two, the geometric description of each action template is evaluated according to the actual state of the environment by the use of robot-specific geometric reasoning modules including motion planning, navigation and controller parameterization. In case of failure possible alternative geometric solutions are considered. If all alternatives fail, geometric backtracking may be initiated to re-evaluate the previous action to find a different solution. A detailed description of this procedure is available in [2].

The resulting level of autonomy allows an operator to command the robot from a high level of abstraction, instead of sending low level commands such as joint values or Cartesian trajectories. As a result, the cognitive load of the operator can be significantly decreased while at the same time bandwidth of the communication channel is saved. However, in order to cope with the wide variety of planetary exploration tasks an intuitive user interface is required. We approach this issue by converting the internal world state of the robot into a graphical user interface (GUI). Given the set of available objects, we can compute the actual executable list of actions by the robot w. r. t. the current state of the environment. In this sense, we share the knowledge of the robot to create an intuitive interface for the operator as described in the following section.

III. Knowledge for the Operator

The same knowledge base used by the robot to plan the task execution is used on the operator side to create

All authors are affiliated with the Institute of Robotics and Mechatronics, German Aerospace Center (DLR), Wessling, Germany. Contact: daniel.leidner@dlr.de

[1]Mars image by NASA/JPL-Caltech/Cornell Univ./Arizona State Univ.

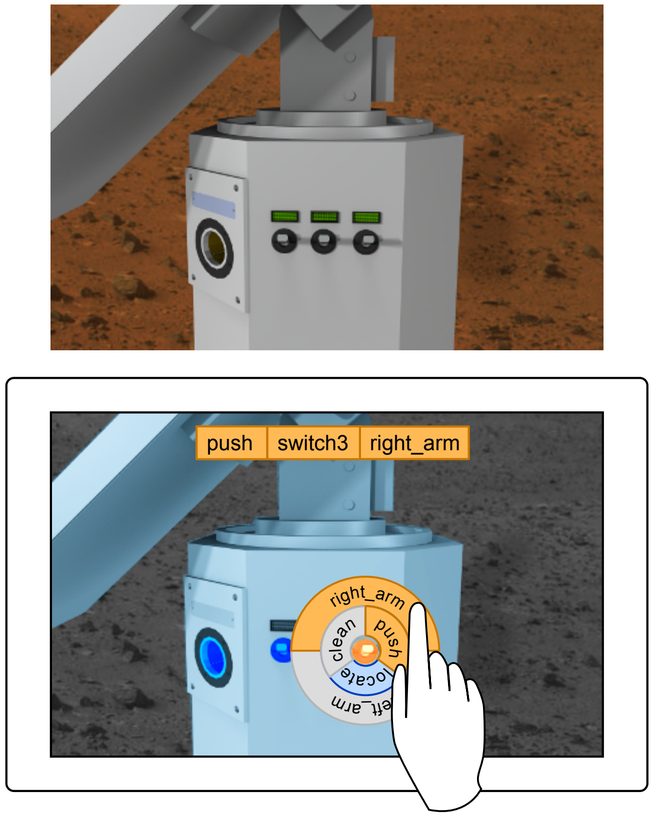

Fig. 2. The view on the solar panel of Fig. 1 as seen from the robot (top). The operator receives an augmented version of this scene where the detected objects are highlighted (bottom). A ring menu is used to select the desired action to be executed by the robot.

an intuitive HRI. As ground truth, a video stream of the cameras of the robot is presented to the operator via a tablet computer. The size and structure of a humanoid robot helps to maximize the immersion of the HRI supporting a higher situational awareness. In addition to the video stream we augment CAD models of the objects the robot recognized. Rouanet *et al.* [4] confirm the advantages of touchscreen devices for commanding robots as they provide information and interaction possibilities in a combined manner. Similarly, our implemented features enable an intuitive sharing of knowledge between the robot and the operator.

By applying the well known point-and-click user input, the operator can select the augmented objects as entry-point for telemanipulation. The operator will be informed about the actual possible actions available for the selected object. It is also possible to select several objects and receive a list of combining actions. A ring menu is used to guide the operator step-wise through the task parameterization (see Fig. 2). After the operator selects one action, the robot may autonomously reason the symbolic action sequence and the required geometric parameters to solve the task according to Sec. II. This procedure demands minimal communication bandwidth and is robust to long signal routing times.

A preliminary version of the proposed HRI has already beend developed to command a cleanup task in a domestic environment [5]. Furthermore, we have evaluated our reasoning framework for more complex manipulation tasks such as window wiping [6]. In the next step we are going to evaluate our concept in the SUPVIS-JUSTIN experiment under real space conditions.

IV. The SUPVIS-JUSTIN Experiment

The SUPVIS-JUSTIN experiment within the ESA METERON project addresses the scenario of planetary exploration. The experiment aims to demonstrate the possibilities of commanding a robot to carry out complex dexterous tasks with significant communication round-trip time. SUPVIS-JUSTIN will address the local intelligence of the robot required to interpret and execute an astronaut's command. The UI concept proposed in this work forms the basis for providing the astronaut with sufficient flexibility to tailor task sequences, while maintaining simplicity and intuitiveness.

SUPVIS-JUSTIN will take place in a mock-up environment. In particular the humanoid robot Rollin' Justin [7], stationed on earth at the German Aerospace Center (DLR) in Oberpfaffenhofen, Germany, will be commanded from the International Space Station (ISS). A fully functional Mars solar farm environment consisting of an array of solar panel units will be constructed at DLR for the mission's experiment. The robot will not solve the entire task autonomously. Instead, it will be semi-autonomously guided by an astronaut. High-level commands are therefore commanded to the robot via the human-robot interface described in Sec. III. As a result, the robot reasons on symbolic combinations of possible actions to solve the task, proceeded by the concrete task execution on the geometric level. By realizing this concept, the robot on the planetary surface acts like a coworker of the on-orbit astronaut.

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