Report Summary

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Periodic Reporting for period 1 - CENTAURO (Robust Mobility and Dexterous Manipulation in Disaster Response by Fullbody Telepresence in a Centaur-like Robot)

Reporting period: 2015-04-01 to 2016-09-30

Summary of the context and overall objectives of the project

Disaster scenarios, like the Fukushima nuclear accident, clearly show that the capabilities of today’s disaster response robots are not sufficient for providing the needed support to rescue workers for resolving the situation. The CENTAURO project aims at the development of a human-robot symbiotic system where a human operator is whole-body telepresent in a Centaur-like robot, which is capable of robust locomotion and dexterous manipulation in the rough terrain and austere conditions characteristic of disasters. The CENTAURO robot will consist of a four-legged basis and an anthropomorphic upper body and will be driven by lightweight, compliant actuators. It will be able to navigate in affected man-made environments, including the inside of buildings and stairs, which are cluttered with debris and partially collapsed. The CENTAURO system will be capable of using unmodified human tools for solving complex bimanual manipulation tasks, such as connecting a hose or opening a valve, in order to relieve the situation. A human operator will control the robot intuitively using a full-body telepresence suit that provides visual, auditory, and upper-body haptic feedback. A rich suit of multimodal environment perception sensors will provide the necessary situation awareness. Robot percepts and suggested actions will be displayed to the operator with augmented reality techniques. The main operator will be supported by at least one additional operator with a 3rd person perspective. For routine manipulation and navigation tasks, autonomous robot skills will be developed. This will allow for taking the operator partially out of the control loop, which will be necessary to cope with communication latencies and bandwidth limitations and to reduce the operator workload. A series of increasingly complex tests with corresponding evaluation criteria will be devised from end-user requirements to systematically benchmark the capabilities of the developed disaster response system.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

Together with end-users, requirements for the CENTAURO disaster-response system have been defined. Evaluation tasks and their associated performance metrics have been specified. From this, specifications for the CENTAURO system components have been derived and concepts for robot design, operator interfaces, modelling and simulation, autonomous navigation and manipulation have been derived.

The major part of the work performed in the first reporting period was devoted to the development of core components.

The CENTAURO robot upper body has been designed and manufactured. It has an anthropomorphic body configuration plan with two arms having seven joints each that are driven by high-performance torque-controlled series-elastic actuators.
A bi-manual exoskeleton has been designed and manufactured, to capture the arm motion of the main operator and to provide force-feedback during teleoperation of the robot. The exoskeleton has four joints per arm in the shoulder and the elbow. In addition, three joints for wrist actuation and a hand exoskeleton for finger motion capture and force feedback have also been developed. Bilateral teleoperation control over delayed communication has been developed. Further, a head-mounted display providing live immersive visualization of the robot environment has been integrated.

A simulatable model of disaster-response robots and their environment has been developed as virtual testbed. This serves as central integration tool to test software modules before hardware components are available.

Efficient software for 3D mapping of the environment based on the robot sensors and for 6D robot localization has been developed. Based on camera images, semantic terrain classification is performed. Combined with geometric analysis of terrain traversability, this is used to assess locomotion costs. An efficient method for planning cost-optimal hybrid driving-stepping locomotion has been developed.

Perception software for reconstruction the 3D structure of the robot manipulation work space, object detection, semantic segmentation, and 6D pose estimation of objects has been developed. Based on the perceived object poses, manipulation actions have been planned. An efficient method for optimization of robot manipulator trajectories according to multiple criteria has been developed.

A wireless data-link has been integrated, providing low-latency communication for force-feedback, high-bandwidth communication for mass sensor data, and a high-availability link to always maintain control of the robot.

The developed core components have been evaluated according to the identified requirements and performance measures. Initial integration of subsets of the components has been performed to demonstrate their joint functionality. The developed core components form a solid basis for further development and integration in the remainder of the project.

**Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)**

Many of the developed core components advance the state-of-the art, e.g. the highly integrated torque-controlled compliant robot actuators, the real-time robot communication system, the dual-arm exoskeleton, the hand exoskeleton, teleoperation under latency, efficient 3D environment mapping, semantic terrain classification, hybrid locomotion planning, object detection, semantic segmentation, object pose estimation, and arm trajectory optimization.

The final disaster-response system will have a new level of capabilities. It perceives its environment in 3D and recognizes terrain types and objects. It will be capable of omnidirectional driving, adaptation to terrain, climbing over obstacles, and stair climbing. Autonomous manipulation skills, like the use of unmodified tools and two-armed handling of objects will be developed. Interfaces for full-body telepresence of a human operator in the robot and operator assistance functions will enable efficient performance of complex disaster-response tasks.

The project devised systematic benchmark scenarios and performance measures based on input of end-users. System tests will be performed in realistic rescue training facilities. The project results are expected to enable a breakthrough in the introduction of robots for disaster-response applications.