JPL SPACE ROBOTICS: PRESENT ACCOMPLISHMENTS AND FUTURE THRUSTS

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Space Telerobotics, Surface Inspection Rover Technology, Microsurgery, Emergency Response Robotics, Remote Control.

TELEROBOTIC SERVICING

Remote Surface Inspection

Complex missions require routine and unscheduled inspection for safe operation [1]. The purpose of research in this task is to facilitate structural inspection of the planned Space Station while mitigating the need for extravehicular activity (EVA), and giving the operator supervisory control over detailed and somewhat mundane, but important tasks. The telerobotic system enables inspection relative to a given reference (e.g., the status of the facility at the time of the last inspection) and alerts the operator to potential anomalies for verification and action [2]. One example might be the inspection of truss struts for micrometeoroid damage and visible cracks on the thermal radiator surface. Simulation of realistic dynamic lighting is included. In addition, configuration control of manipulators with redundant degrees of freedom has been developed and implemented to assure dexterous manipulation near complex structures [3]. To assure safe operation, collision detection and avoidance algorithms monitor the arm motion.

A multi-sensor end-effector [4] includes a gas sensor for detection of gas leaks and a pyrometer to measure surface temperatures, in addition to CCD cameras. This end-effector also houses two proximity sensors to provide collision avoidance and a force/torque sensor for safe contact with the environment. Algorithms for flaw detection based on real-time image differencing with appropriate registration to account for variable lighting and manipulator/camera position have been developed and validated. A serpentine robot with 12 degrees-of-freedom (external diameter 3.31 cm, 91.44 cm extended length, and less than 2.73 kg) has been developed for use as a tool for inspecting regions with small openings [5]. This tool is to be picked up by the larger robotic arm and placed near small openings for inspection. The serpentine robot carries a fiber optic light/camera system and is self-contained. Several of the developed technologies within this task have successfully been transferred to the Johnson Space Center (JSC) for realistic tests in a high-fidelity robotics laboratory with evaluation by astronauts.

Ground Operator Environment

There are two primary objectives of this project: To develop technologies that enable well-integrated NASA ground-to-orbit telerobotics operations, and to develop a prototype common architecture workstation which implements these capabilities for other NASA technology projects and planned NASA flight applications.

This task develops and supports three telerobot control modes which are applicable to time delay operation: Preview teleoperation [6], teleprogramming [7], and supervised autonomy [8]. Preview teleoperation provides a graphical robot simulation which moves in real time according to the operator's motion input to a hand controller. This same teleoperation motion is sent to the real robotic system for execution. In teleprogramming, the operator's manual interaction with a 3-D virtual environment (physically identical to preview teleoperation) is symbolically interpreted by computer software (e.g. for a grasping operation) to a low-bandwidth, low-level sequence of autonomous commands that are synchronously transmitted to the remote site, which has a simple sensorreferenced behavioral control capability. The best features of dexterous teleoperation are preserved, while providing greatly increased operational robustness against extended (2-10 s) and possibly intermittent time delay. The operator's graphical workstation environment can be automatically updated based upon modeled sensor data feedback from the remote site, and robot sensor data is used instantaneously at the remote site to behaviorally compensate for operator motion errors and positioning uncertainties. Finally, supervised autonomy provides capability to generate high-level autonomous command sequences via either a graphically programmed operator interaction with the modeled environment, or using conventional menus.

Distributed Space Telerobotics

This effort is a cooperative research and development activity between NASA-JPL (Jet Propulsion Laboratory) and the Ministry of International Trade and Industry (MITI)-Electrotechnical Laboratory (ETL) of Tsukuba, Japan. The main technical thrust of the project is safe ground control of orbital robots under operational uncertainties caused by impaired remote viewing, communication time delay, and tasking contingencies. Each of these technological areas manifests itself in respective application interests; the main Japanese application interest is in space assembly, while the U.S. focus is in space servicing.

There are two key research areas currently under development. Intelligent Viewing Control (IVC) involves computerized planning and sequencing of multi-camera views which are fused with calibrated 3-D virtual workspace presentations. This capability includes software facilities for interactive modeling, i.e., the capture of new workspace features, their rendering/presentation, and calibration, intended to improve workspace perception and facilitate camera management. Intelligent Motion Control (IMC) or teleprogramming has already been mentioned in the previous section. The teleprogrammed mode is intended to extend time-delay teleoperation to useful low-Earth-orbit (LEO) applications, and provides a mission resource for contingency tasking in partially structured environments (having geometric uncertainties).

Initial interface specifications have already been developed resulting in successful remote operation of robots in the collaborating country.

Exoskeleton and Telepresence

The focus of this task involves the augmentation to telemanipulation capabilities through the development of human-equivalent dexterity of remotely operated hands, with emphasis on minimal training and use of human rated tools. The technical objective is to prototype a force-reflecting master-slave arm-hand system in exoskeleton form with a 7-DOF (degree-of-freedom) arm and 16-DOF four-fingered hand [9]. This includes integration with a visual telepresence system. The programmatic objective is to determine how far an exoskeleton alternative can perform EVA-glove rated manipulative activities without changing EVA tools or adding new ones to the existing repertoire.

PLANETARY EXPLORATION

Rover Technology Program

Rover technology is enabling for extensive robotic exploration of selected areas of Mars. The rover technology base emerging from this activity has enabled the MESUR/Pathfinder project microrover currently planned for launch in 1996. An active research and development program aimed at significant capabilities beyond Pathfinder microrover is in place at JPL [10-12]. This technology base will greatly expand the current MESUR/ Pathfinder microrover performance in the areas of goal identification, increased vehicle mobility, intelligent terrain navigation with in situ resource management, and manipulation of science instruments. The goal is to combine both research and system demonstrations to advance the state of rover technologies while maintaining flight program relevance. Specific goals over the next four years are: (1) autonomously traverse 100 m of rough terrain within sight of a lander; (2) autonomously traverse 100 m of rough terrain over the horizon with return to lander; (3) autonomously traverse 1 km of rough terrain with execution of select manipulation tasks; (4) complete science/sample acquisition and return to lander with over the horizon navigation. A series of rover vehicles is being used to conduct these tests.

The rover technology program at JPL is being implemented with extensive university and industrial involvement in such areas as: Sensor suites for long-distance navigation on planetary surfaces; legged vs. wheeled mobility; virtual environment operator interfaces; robotic grasping devices; and behavior based obstacle avoidance and fault tolerance.

NASA TERRESTRIAL APPLICATIONS AND COMMERCIALIZATION

Robot-Assisted Microsurgery

Through a cooperative NASA-Industry effort, the Robot-Assisted Microsurgery (RAMS) task develops a dexterity-enhanced master-slave telemanipulator enabling both breakthrough procedures in micro/minimally invasive surgery [13]. The applicable medical practice includes eye, ear, nose, throat, face, hand, and cranial surgeries. As part of planned task activities, the resulting NASA robot technologies will be benchmarked in actual operating room procedures for vitreous retinal surgery.

The primary objective of this task is to provide an integrated robotic platform for master-slave dual-arm manipulation operational in a one-cubic-inch work volume at features in the 100-micron range (our goal is to extend these capabilities to features in the 20-micron range). The research is a natural evolution of our extensive experience in force-reflecting teleoperation with dissimilar master/slave. Capabilities will include force-reflection and textural tactile feedback, and in situ multiple-imaging modalities for improved surgical visualization and tissue discrimination. Potential NASA applications may include EVA/IVA (intravehicular activity) telescience, bioprocessing, materials process and micromechanical assembly, small-instrument servicing, and terrestrial environmental testing in vacuum.

Emergency Response Robotics

Following four years of effort, this project has prototyped a teleoperated mobile robot enabling the JPL HAZMAT (hazardous material) response team to remotely explore sites where hazardous materials have been accidentally spilled or released rather than risk entry team personnel [14]. JPL robotic researchers, engineers, Fire Department and Safety personnel have worked in close cooperation to develop the system. The primary mission of the robot, called HAZBOT, is first entry and reconnaissance of an incident site; the most dangerous part of a response since the type of materials involved and the magnitude of the spill may not be fully known. During such missions HAZBOT must first gain entry into the incident site. This may involve climbing stairs, unlocking and opening doors, and maneuvering in tight spaces. Once the spill is located, an onboard chemical gas sensor is used for material identification. The robot can also be used to aid in remediation or containment of the incident by, for instance, closing a leaking valve, deploying absorbent material, or placing a broken container in secondary containment. HAZBOT has been specially designed to enclose all electrical components and provide internal pressurization, enabling operation in atmospheres that contain combustible vapors. Other system features include a track drive base with front and rear articulating sections for obstacle/stair climbing, a six-DOF manipulator with five-foot reach and 40-pound payload capacity, custom tools for unlocking and opening doors, and 2-color CCD cameras. To date, the robot has been used by the JPL HAZMAT team in three simulated response missions to test and demonstrate system capability. HAZBOT is currently being prepared for actual field use, responding to HAZMAT incidents at JPL. Future work includes the integration of onboard sensors, as well as improvement to the operator control station.

Satellite Test Assistant Robot (STAR)

STAR is a remote inspection robot which has been developed to assist engineers in the ground testing of spacecraft in simulated space environments. STAR is designed to operate inside JPL's 10-ft and 25-ft thermal/vacuum test chambers where temperatures range from –190° C to +100° C and extremely high vacuums can be achieved. STAR consists of a 25-ft vertical axis and an azimuthal axis which provides mobility around the inside diameter of the chamber. A 2-axis scanning platform is instrumented with two high-resolution video cameras, controlled lighting and an Infrared Imaging Camera.

At an Operator Control Station engineers remotely control the position and orientation of STAR's lighting and camera instrumentation allowing close-up real-time visual inspection and infrared thermal mapping of a spacecraft under test in the simulated space environment inside the chamber. STAR will help engineers by improving test reliability and reducing overall test costs.

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REFERENCES

A comprehensive list of references, not included here due to length considerations, can be found in SPACE TELEROBOTICS and ROVER RESEARCH AT JPL, C. Weisbin, S. Hayati, G. Rodriguez, ANS 6th Topical Meeting on Robotics and Remote Systems, February 5–10, 1995, Monterey, CA.

A U.S.-Japan Collaborative Robotics Research Program

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INTRODUCTION

The Jet Propulsion Laboratory (JPL) and the

such as the Space Station will otherwise be delayed.

COMMON TRADITIONS, COMPLEMENTARY STRENGTHS AT ETL AND JPL

JPL and ETL share a long-standing interest