The Space Congress® Proceedings

1994 (31st) Space Exploration and Utilization for the Good of the World

Apr 28th, 2:00 PM - 5:00 PM

Paper Session III-C - Earth Dividends From the Development of Space Vehicle Robotics: Technologies and Techniques

Margaret M. Clarke
Rockwell Space Systems Division, Downey, CA

David L. Gerhardt
Rockwell Space Systems Division, Downey, CA

Joseph M. Hansen
Rockwell Space Systems Division, Downey, CA

Thomas S. Lindsey
Rockwell Space Systems Division, Downey, CA

Suzanne M. Hodge
Rockwell Space Systems Division, Downey, CA

See next page for additional authors

Presenter Information
Margaret M. Clarke, David L. Gerhardt, Joseph M. Hansen, Thomas S. Lindsey, Suzanne M. Hodge, and David Manouchehri

EARTH DIVIDENDS FROM THE DEVELOPMENT OF SPACE VEHICLE ROBOTICS: TECHNOLOGIES AND TECHNIQUES

Margaret M. Clarke, Ph.D.
David L. Gerhardt
Joseph M. Hansen
Thomas S. Lindsay, Ph.D.
Davoud Manouchehri

Rockwell International
Space Systems Division
12214 Lakewood Boulevard
Downey, California 90241
Phone: 310-922-0785
Fax: 310-922-0537

Suzanne M. Hodge
Rockwell International
Space Systems Division, Florida Operations
8600 Astronaut Boulevard
Cape Canaveral, Florida 32920
Phone: 407-799-5505
Fax: 407-799-5515

This paper identifies and describes advanced robotics technologies and novel applications of state-of-the-art techniques which presently focus on space-related missions but which could result in other dividends on Earth.

The paper has three sections. The first section focuses on the development of technology to help NASA automate the reprocessing of low-Earth-orbit vehicles. These advanced technologies include vibration isolation for robot arms and end-effectors, automated handling of fuels and other hazardous materials, and automated safety systems for process control. The second section describes the use of state-of-the-art solid modeling techniques to assist in the design of a robot arm, camera systems, sensors, and platforms for characterizing and exploring a planetary terrain. The third section discusses the use of these advanced technologies and novel applications to provide dividends on Earth in both space- and nonspace-related applications. Vibration isolation could improve the performance of long manipulator arms used for vehicle processing and cleaning Department of Energy waste tanks. Automated handling of hazardous fluids could help automate the fueling of commercial and passenger vehicles. The advanced safety circuit could enhance many chemical process control operations. Modeling techniques for designing terrain exploration systems could assist the design of vehicles for exploring the many sites on Earth where human entry may be unsafe or inefficient, such as nuclear waste sites, military sites with unexploded ordnance, and widespread geological and agricultural surveys.

Advanced Technologies

Vibration Isolation

The Shuttle remote manipulator system (RMS) has long, flexible links that tend to vibrate when the arm is moved. This vibration has a long settling time. Many techniques have been presented to reduce or eliminate this vibration, but most involve a redesign of the RMS controller, which is an unacceptable solution. Rockwell is developing a hardware interface, to be located between the RMS and its payload, which can dynamically isolate vibrations between the RMS and payload. The hardware interface, called the end point control unit (EPCU), does not require modification of the RMS controller. In operation, the RMS will grab the EPCU as if it were another end-effector or payload. Another grapple fixture on the EPCU will attach to the payload. With the EPCU between the RMS and the payload, the motion of the arm, especially starts and stops, will not induce as much vibration in the system. This will reduce the duration of many RMS tasks. Operations such as payload capture and berthing, where the RMS payload will also have initial vibration modes, will also be simplified.

The current version of the EPCU, shown in Figure 1, is actuated in one dimension only. The next-generation EPCU will be actuated in three dimensions. Forces detected by a force/torque sensor mounted on the EPCU are fed back into the EPCU controller, which controls the extension of the actuator. The controller must also adapt to changing conditions, such as a change in payload mass. Several control algorithms are being currently tested with the existing EPCU hardware.

Automated Fueling of Launch Vehicles

Fueling launch vehicles and space assets involves handling toxic and highly flammable fuels. Spills or leaks during cryogenic or hyperbolic fueling operations therefore constitute a serious hazard. To prevent these spills and leaks, highly reliable systems are needed to transfer fuel and to couple and decouple the fuel lines. Currently, human operators handle all the line connections manually. Rockwell has performed an in-depth study to look at automating this operation for the Space Shuttle at the launch pad.

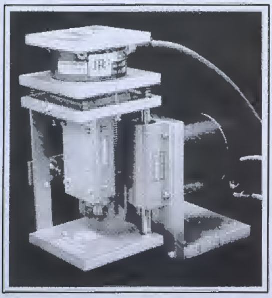

Figure 1. Photograph of EPCU

The concept shown in Figure 2 is based on minimizing the impact to the launch pad while ensuring system functionality and removing the human operators from the coupling and decoupling operations completely. This concept consists of a gross positioning system, micro positioning system, self-mating connector system, and fuel line management system. The gross positioning system brings the fuel line and connector half to less than 1 inch from the other connector half while the micro positioning system positions the self-mating connector to about 0.01 inch of the Shuttle connector in all three axes. A camera system and target are used to provide feedback sensor data for both the gross positioning and micro positioning systems. All the fuel lines, power lines, and data lines are managed through an E-chain/track system.

Automated Safety Systems for Process Control

In any automated process there should be a number of safeguards and built-in capabilities for ensuring safety and error-free operation. Among the issues of most concern are the following:

- Computer malfunction or failure (hardware/software)
- Erroneous sensor data
- System or component failure
- Quick response to a failure

These issues are conventionally resolved by using redundant computer systems and specialized hardware, which is very costly and involved. Rockwell has developed an inexpensive hardware-based fail-safe system that does not use redundant computers and software.

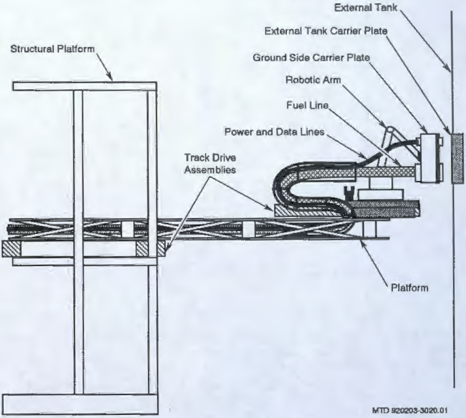

Figure 2. Concept for Automated Fueling

This safety system consists of a single board with analog and digital circuitry. The analog portion receives sensor feedback data and converts them into discrete signals based on operational limits. The digital portion has a programmable logic array (PLA) as the main logic device. It receives inputs from the analog portion as well as from the computer controller and any discrete-output sensors. It sends output signals to the hardware based on the state of all its inputs. In the event of a failure, the PLA determines which outputs should be shut off (if not all) in order to safe the system. Since there is no software involved, the response time to a failure becomes almost instantaneous. Any output shut off remains in that state until the safety system is reset from the computer controller, thus preventing an on/off switching situation. Figure 3 shows a block diagram of the safety system.

Solid Modeling Techniques

A state-of-the-art graphical solid modeling software package is being used for various space programs at Rockwell. Depending upon the application, various levels of complexity can be achieved using the IGRIP system developed by Deneb Robotics. For one project, visualization of a space deployment operation from the Shuttle cargo bay was the ultimate goal. Even in this simple project though, the utility of the software led to a second deployment sequence concept. Another program project, terrain characterization and exploration, used more of the software capability. The initial probe design was imported into IGRIP from the CATIA CAD system. The kinematic pieces of the probe were separated and animated to present a visualization of a concept for the probe deployment. At this point, the dynamics of the

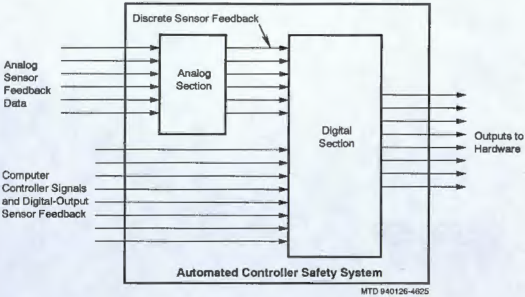

Figure 3. PLA-Based Safety Circuit

probe were entered, and based upon the kinematic motion of the separate parts, the energy of deployment was studied. A more energy-efficient deployment sequence for opening the probe's solar panels was easily demonstrated, requiring only a short amount of time and effort to restructure the sequence and examine the dynamic simulation data. Another area where the software's utility was observed was in the design of the robot manipulator arm. Manipulator requirements included the dexterity to perform identified tasks, weight savings, reduced complexity, and lower development costs. Modeling arms with fewer and greater degrees of freedom and comparing them with the original arm executing a simple task made the benefits and drawbacks of such arms apparent, enabling the arm best able to meet all requirements to be identified (see Figure 4).

Earth Dividends

Vibration isolation technology would improve the performance of long manipulator arms for space vehicle processing or the long arms planned by the Department of Energy for cleaning nuclear waste tanks. Operation time would be decreased and precision improved. Laser alignment operations in vibration-filled environments could be enhanced. Vibration isolation technology could also reduce machine tool chatter in manufacturing environments, which would lessen machine tool wear and tear and improve the quality of the product.

Automated handling of space vehicle fueling would minimize self-contained atmospheric protective ensemble (SCAPE) operations, which now require fully suited personnel. An additional advantage is that schedules would no longer be driven by SCAPE requirements. Task time would be reduced and dexterity could be increased since SCAPE operations are often cumbersome because of the restricted movement of suited personnel. If spillage could be reduced or eliminated, it would have obvious environmental benefits.

Installation of automated safety systems in any autonomous process control operation would convert the operation into a fail-safe process. These cost-effective hardware systems would replace the redundant computer normally used to meet fail-safe requirements. Possible applications include chemical processing, many robotic systems, and CNC machines.

Modeling techniques to design robotic terrain exploration systems would benefit the

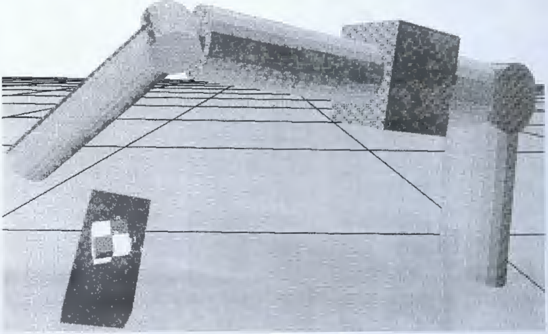

Figure 4. Kinematic Simulation of Robot Arm

design of automated vehicles used to explore many sites on Earth where human entry may be unsafe or inefficient. Characterizing the many thousands of acres of nuclear waste sites demands mobile robotic vehicles with integrated sensor suites that are able to negotiate varying terrain features at these waste sites. Designs for security systems for known buildings can be verified by simulating building parameters. The required dexterity, reach envelope, center of gravity, and stability can be identified by modeling task and environment features, with a reduction in redesign, retrofit, or even failed missions.