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Commercial Users Panel

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INTRODUCTION

The National Aeronautics and Space Administration (NASA) Office of Commercial Programs (OCP) has responsibility for insuring the transfer of NASA-developed and -sponsored technology to the public and private sectors. The OCP program of actively pursuing new projects for terrestrial application of NASA technology is assisted by 1) a Technology Applications Team (TATeam) at the Research Triangle Institute (RTI) and 2) a network of Technology Utilization officers at NASA Field Centers.

NASA technology transfer has been fostered by an original mandate in the Space Act of 1958 which created NASA. This provides for "...the widest practical and appropriate dissemination of information concerning NASA activities and the results thereof." More recent directives include 1) the Stevenson-Wydler Technology Innovation Act of 1980 (PL 96-480), 2) Report 98-867 of the Committee of Conference to Accompany Bill HR 5713, which authorized funding for the Space Station, directing NASA automation and robotics to be "...identified and developed not only to increase the efficiency of the Station itself but also to enhance the nation's technical and scientific base leading to more productive industries here on earth." and 3) the Technology Transfer Act of 1986 which further promotes industry interaction with Federal laboratories.

The Jet Propulsion Laboratory's Space Telerobotics Workshop afforded an opportunity for the non-aerospace community to review NASA-related projects and planning in automation and robotics (A&R), an area of emphasis by OCP. OCP selected a Commercial Users Panel to meet at the workshop. This group, Table 1, represents organizations and industry sectors with the potential for expanding commercial telerobotics.

In contrast to the aerospace and academic makeup of most of the Workshop, the panel primarily represents the commercial sector outside the NASA family. While such industries as automotive or electronics have lesser motivation for man-in-loop approaches, they do represent about 70% of the market for robots in the U. S. It was also kept in mind that single component spinoffs (e.g., sensors, system architecture, manipulators) from NASA telerobotics-related research could provide commercial improvements in any sector. Such representatives as the U.S. Army's Human Factors Laboratory do not directly represent commercial interests, but their decisions and efforts will have important future impacts on automated systems, especially in mobility and manipulation. Such applications of NASA telerobotics as satellite servicing were not represented on the panel since these are so closely linked to NASA programs as to assure natural technology transfers.

TABLE I. PANEL MEMBERS

Mr. Joseph S. Byrd
Savannah River Laboratories--
DuPont
Aiken, SC

Mr. Carl Flatau
Telerobotics, Inc.
Bohemia, NY

Dr. David C. Hodge
Human Factors Engineering
Laboratory
Aberdeen Proving Ground
Aberdeen, MD

Dr. Ralph Hollis
IBM Research
Yorktown Heights, NY

Mr. Eugene F. Leach
Caterpillar, Inc.
Peoria, IL

Mr. Ray Gilbert
NASA-Office of Commercial
Programs
Washington, DC

Dr. John Cleland
NASA Technology Applications Team
Research Triangle Park, NC
Electric Power Research Institute
Palo Alto, CA

Dr. Larry Leifer
Veterans Administration and
Stanford University
Stanford, CA

Dr. Joseph Naser
Nuclear Power Division
Electric Power Research Institute
Palo Alto, CA

Dr. Samson D. Schmuter
Manufacturing Development Center
Ford Motor Company
Detroit, MI

Dr. George Schnakenberg
U.S. Bureau of Mines
Pittsburgh, PA

Mr. Kenneth F. Sebok
Perry Offshore
Riviera Beach, FL

Dr. Thomas Walters
Technology Utilization
Jet Propulsion Laboratory
Pasadena, CA

Discussion by the panel was focused on telerobotics, first because NASA has the opportunity to remain at the leading edge of this science through Space Shuttle and Space Station activities and through other NASA R&D programs. Second, telerobotics represents a limited subset of the overall NASA automation and robotics activity which could be reasonably discussed within a limited timeframe. NASA has decided to utilize telerobotics as a foundation for its A&R activities and to move toward more autonomous systems from this foundation. This approach is also strongly influencing Strategic Defense Initiative (SDI) planning, especially as related to unmanned maintenance of orbiting platforms and satellites.

Commercial User Panel members examined NASA-related telerobotics programs and technology through materials supplied before the Workshop, and through plenary sessions, conversations and other presentations at the Workshop. The panel then met in closed session to discuss how, why, and where NASA developments might be applied.

MOTIVES

The NASA Technology Utilization program is predicated upon a demand side approach, i.e., problems and requirements are requested from companies, reviewed through the Technology Utilization network, and matched where possible with appropriate NASA technology. The approach relieves industry of having to sort out the myriad technology developments over NASA's history. Similarly, the CU Panel was asked to identify needs of industry possibly related to NASA telerobotics developments. On the earth, several motives for teleoperation arise. These can reasonably be grouped into the categories of Safety, Security, and Productivity.

Safety: The primary concept in promoting safety by telerobotics is that of allowing a remotely located person to manipulate, inspect, or perform some other action in a hostile environment. The nuclear industry has long implemented master-slave type operations to allow handling of radioactive materials. Related to this, the Savannah River Laboratory is currently supporting GCA to build a large telerobot to handle contaminated equipment and put it into storage. Both Dr. Naser and Mr. Byrd discussed how telerobotics are becoming an option to improve the safety of 1) nuclear power plant operations and maintenance and 2) response to emergency situations. The essential precept is to minimize possible human exposure to radiation. In emergency situations, a telerobot can move into a hostile environment much more quickly than a person who must wait for radiation levels to subside or at least be specially clothed against radiation and high temperatures (ice water circulation suits). The telerobot may be unable to completely solve a contingency problem, but may perform many simpler preparatory tasks. This allows a person to follow up and complete the more complex parts of a repair. An example is telerobot removal of bolts from a valve flange. The valve is then aligned and replaced by a human who leaves immediately, allowing the remotely controlled robot to complete retightening and initiate leak testing.

Handling of other hazardous materials such as toxic chemicals with teleoperated manipulators has received less attention. Laboratory robotics are becoming more important in the chemical processing industry. Safety motivations for utilizing telerobotics in field operations (for example, the handling of hazardous wastes, from sampling through drum removal) have not resulted in a market large enough to attract equipment manufacturers. Mr. Leach indicated that Caterpillar had discussed such systems with companies responsible for hazardous waste management, but could not redesign equipment for less than a dozen units.

Mr. Sebok of Perry Offshore and Dr. Schnakenberg of USBM said that their organizations' respective ultimate objectives were to remove people from the water and from underground. Oceanographic explorations and off-shore oil rig maintenance have more recently emphasized the utilization of unmanned submersibles, a trend that is aimed finally toward near-autonomous systems. This trend and the advances in undersea machines have been in evidence with the recent explorations of the R.M.S. Titanic by the Woods Hole Oceanographic Insitute's submersible, Alvin, and its tethered telerobotic "eyeball", Jason Jr. (National Geographic, Vol. 170, No. 6, December 1986).

In mining, not all hazards are associated with underground operations, Dr. Schnakenburg stated. For example, there is interest in automating high wall surface mining where the miner drives into a wall with a coal seam exposed and goes as far as possible, e.g., out to 1000 feet. Inexpensive but effective teleoperation is needed to optimize this process.

Robotics have as yet made little inroads into the health and medical field, but considerations for staff safety, said Dr. Leifer, may move teleoperated units into isolation wards. Also, patients who must avoid exposure to any contamination (from other people or through frequent access and egress to their isolation rooms) could be remotely treated and supported.

Dr. Hodge expressed the Army's concern for promoting safety through A&R as one of "soldier survivability". Here telerobots might be used in activities ranging from removing fuses from unexploded armaments to initial engagement of an enemy.

Safety was also considered in an aspect other than human protection. In the case discussed, Dr. Hollis indicated that the one possible application of telerobotics as a system in electronics/semiconductor manufacture would be in clean rooms. Contamination-free environments are preferred and sometimes essential for semiconductor work. Telerobot use would also reduce the size of these expensive enclosures, allow more flexibility than wire guided mobile units, and allow prompt emergency responce.

Security: This category relates to safety but with an important distinction. i.e., rather than a requirement to remove people from hostile environments (safety), there is sometimes a need to maintain a person in the control loop to provide confidence (security) that adequate intelligence and experience is available. This is again perhaps most obvious in the nuclear utility industry. As stated by panelists Naser and Byrd, people are simply not going to be replaced by autonomous machines in nuclear power plants.

NASA considerations in applying telerobotics follow much the same lines. A teleoperated manipulator in orbit is probably handling very expensive equipment in a critical environment under conditions which can be only partially simulated on the ground. Here a "mistake" by a more autonomous machine could mean a failed mission or even a threat to personnel in orbit. At the current stage of robotics development, the level of confidence is greater for the telemanipulator with human backup.

Another area where a high level of confidence is essential is in the health and medical field. Mr. Flatau described a proposed endocorpuscular teleoperator for endo surgery and other emerging options of teleoperator microsurgery were discussed. Stanford and the University of Southern California are pursuing such research, the latter utilizing X-ray tomograms for manipulator orientation in brain surgery. Dr. Hollis also briefly described a project that IBM is pursuing with the University of California--Davis in robotic machining of bone for prosthetic knee or hip joint implantation. More precise routing should promote improved bone ingrowth. In all cases, the surgical physician must constantly observe these operations and maintain ultimate control. A consideration here related to telerobotics is how to provide a capability for failure or fault prediction and to allow near-instantaneous interruption by the human controller.

The panel noted that NASA progress in telerobotics is important to the "security" category of motivation because NASA demonstration of technology can offer confidence to those in the commercial sector who must first minimize risk in applying automated systems. NASA applications should also help identify those parameters of teleoperation entailing higher risk than others.

Productivity: Safety and security considerations have been the most important motivations for the industries (i.e., nuclear and undersea) which have led the way in telerobotics. However, these motivations may be closely related to productivity, and it was interesting to find that the panel emphasized increased productivity in considering telerobotics for commercial applications. This agrees with the needs for automation in space described in the original report by the NASA Advanced Technology Advisory Committee, "Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy" (NASA Technical Memorandum 87566). Here productivity through A&R has been broken out to include -- lowering of operating costs, increasing flexibility (communications, computers, modularity) to support innovation, improving reliability, achieving station autonomy, and performing tasks unsuited to humans alone. "Reducing hazards" constitutes a final category.

As a first example by the panel, John Hodge said that, beside soldier survivability, their lab concentrates on 1) force multiplication, and 2) reducing military operation costs. Related to the first area, the Army operates on no-projected-growth of manpower. High tech is being relied upon to increase productivity or control more weapon systems. Of 24 current related Army projects, six deal with weapon delivery (vehicles, mobility), four with reconnaissance (mobility, sensors), and fourteen with services and support (manipulation and mobility about half and half). He stated that his shop was supporting development of 1) a field material handling robot (FMR), an autonomous robot with a twenty-five foot reach and 4,000 pound payload for handling ammunition, 2) a soldier robot interface project (SRIP), which is a small teleoperated platform with a manipulator having a six foot reach and 150 pound payload, used for ordinance disposal and refueling, and 3) a single manned station for controlling two semi-autonomous vehicles simultaneously. This project is called TEAM. The Army is forecasting AI and robotics developments as they relate to their own projects and training. There is also work underway on a robot sentry vehicle which could patrol nuclear weapon stockpiles.

Teaching robots efficiently requires addressing many of the same human interface problems found in telerobotics. Mr. Schmuter related one aspect of Ford's automated manufacturing to telerobotics developments. To improve efficiency, his group is building a generic robot controller for computer-aided path generation. The idea is to reduce by an order of magnitude the number of points to teach for 3-D complex trajectories. Most pendant buttons and the typical recourse to a special robot language would be eliminated. After thirty minutes of instruction, Ford employees are now teaching 3-D paths in about 15 percent of the time it may have taken before.

Caterpillar is also looking for better man-machine interfacing, said Gene Leach. They will accrue the same advantages as space based teleoperators from improvements in levers, knobs, linkages and such control strategies as going from joint-specific to end-point control. Heavy equipment vendors, both for surface excavation and underground mining, are increasingly seeking "expert system"-type diagnostics for maintenance and fault prediction of machines. The panel experts for both mining and excavation believe their industries will keep the man on the machine for some time to come. The first priority of new systems is to make the job easier for the man, automating more repetitive cycles, within the context of cost effectiveness. John Hodge mentioned that the enthusiastic response to Army solicitations for field materials handlers indicated a market potential.

George Schnakenberg explained that the underground mining environment is one of consistently structured geometry and that automation is most effective in the "long wall" mining prevalent in Europe while the "room-and-pillar" approach common in US underground coal mines introduces more complexities. Also, metals mining is so batch-process oriented as to be non-conducive to automation. Nevertheless, with 82 percent of US recoverable energy reserves being represented by our coal resources, more productive mining should be a national goal, and productivity is an important consideration in USBM automation planning.

Thin seam mining utilizing TV cameras and teleoperators is under study, as well as automation of simpler repetitive tasks on continuous mining machines. Canada is attempting to develop automated drills and load haul dumps (2-8 yard scoops that roll on rubber tires) and Germany is attempting to automate installation and removal of roof supports.

Nuclear and other utility power plants could operate more efficiently with properly designed surveillance, testing and preventative maintenance teleoperators. Such remote controlled duties as checking valves and sensors, looking for leaks and testing for radiation content of any leaks should also be accompanied by some on-board intelligence. As with any teleoperation involving routine tasks, operator strain from constant observation is too high, e.g., long hours using a stereo monitor. Surveillance and scrabbling telerobots have received well-publicized testing at the Three-Mile Island nuclear plant and remote operated cavity cleaners are being used. The three major nuclear power utility vendors have used robots in the steam generator area. Both Germany and France have a brigade of emergency telerobotic vehicles on exhibit. However, Carl Flatau believes this technology lags US potential technological capability. He cited a unit developed mutually with a Belgian company which can climb stairs, clear obstacles 16 inches high, has autonomous capability (backtrack to operator) if radio contact is lost, and has programmable navigation including some obstacle avoidance.

For undersea operation, telerobotic system ruggedness and reliability is especially essential, first because of the difficult logistics of maintenance and secondly, because standby costs at off-shore oil rigs range from $10,000-100,000 per day. Mr. Sebok described their teleoperations (which can be applied down to depths of 20,000 feet or more) by two methods, 1) for simple tasks, multiple degree of freedom manipulators operating off subsea vehicles and 2) for complex tasks, specially designed tool and manipulator work packages as complicated as the vehicles themselves. For example, a package for a large oil company installs 650 pound insert valves with 30,000 pound torque castellated nuts. The package also removes valves, tests seals integrity, and replaces a 3,000 pound, seven cubic foot control pod. Inspection and non-destructive testing are often applied.

Dr. Leifer's work with the Veterans Administration Rehabilitation Center has been concerned with applying telerobotics to increase the productivity and self-sufficiency of disabled persons. He indicated that for younger handicapped persons, investment in a $100,000 tool to get back into the work force is obviously attractive. Also, he emphasized that physical therapy and other patient care is growing rapidly in the face of demands to push health care costs down. Acute (versus chronic) care is only 30 percent of all medical care. The therapy and chronic care market can be addressed by telemanipulation on the low-cost, low-intelligence end. A robot using force feedback has been developed by Athtec Corp. for human performance evaluation and will be marketed for health care. Otherwise, the panel was not aware of any company marketing a telerobotic product to the $85 billion plus medical industry.

As enlightening as the described potential advantages for telerobots were, IBM offered just as informative reasons for not using them. Dr. Hollis pointed out that the electronics/computer/semiconductor industry requires high speeds (approaching 100 [!] motions per second), low tolerance precision and accuracy (microns or sub-microns), typical assembly intergrating 35-45 parts with different tools, and operation in a fairly large workplace. An automated, sensory-feedback error recovery capacity is necessary to deal with assembly process exceptions without informing an operator any more than every thirty minutes. One operator should be able to tend several robots. Within the industry, robots assemble while humans take things apart for maintenance and repair. While the automation trend has been somewhat slower than expected, IBM exemplifies the industry picture with its automation commitment. This includes design and execution in 2- and 3-D assembly, geometric modeling, queing and scheduling systems, 2- and 3-D machine vision support, new actuation developments, and evolving computer architecture for real-time control.

Of necessity, a number of possible application areas for telerobotics were not represented by the panel. For example, not included were firefighting and agriculture. A survey before the workshop turned up intelligent-machines-in-agriculture efforts going on at the Universities of Georgia, Florida, Purdue, California-Davis, and at Weyerhauser and Batelle-Northwest. Studies covered soil analysis, planting seeds, harvesting, nursery maintenance and pruning.

SPECIFIC NEEDS

Beyond the general interests and more specific activities described under Motives, the panel indicated some items that might head a NASA telerobotics technology transfer shopping list. Not surprisingly, new and improved software received considerable attention-- but not always specifically related to telerobotics. Some examples of these requirements include:

1. Expert systems to diagnose equipment condition for monitoring and predicting failures, combined with machine maintenance during off-shifts.

2. A CAD/CAM type simulation system for mining applications.

3. Methods to reduce the coding required for handling exceptions in electronic assembly.

4. Intelligence built into teleoperated machines so that they know when they need help and can decide on proper response.

5. More expert systems work on the design and planning end rather than on the analytic or diagnostics end. For example, a system searching through a large set of design alternatives, for associating them and arriving at a device synthesis.

6. Scheduler/planners, an area where NASA excels.

7. Data capture codes, to prevent production process decision information from being lost in host computers rather than being readily accessible to a localized plant requirement.

8. Emulators, which incorporate human factors simulation, as with cockpit or flight control simulation. The implications for telerobotics training and simulation are obvious. Recent examples are a Honeywell system for Army tank operators and a Mercedes automotive trainer.

Joe Naser and Ray Gilbert discussed a software technology transfer project on which EPRI and NASA are collaborating. The transfer derives from an expert system developed for the Space Shuttle at the NASA Kennedy Space Center. The original system was for liquid oxygen handling, which then evolved to a knowledge-based automatic test equipment system (KATE) for system monitoring, signal validation, fault location and diagnosis, automatic control and reconfiguration. EPRI is taking advantage of this "off-the-shelf" product to further develop it and apply it in simulators and eventually in a nuclear power plant production system. Joe Byrd added that such software is needed by their industry but must be begun in simple applications and gradually assimilated into the system. He also commented that it is often easier to incorporate new hardware than software for nuclear power.

On the low end of teleoperator hardware, Dr. Leifer reiterated that the medical field will first best incorporate "dumb" systems which serve to extend a patient's control a little beyond his reach. However, voice control is a more sophisticated requirement often added to such systems.

Mining, nuclear and undersea experts stated that sensors and additional software adding some autonomy to telerobots are important. A basic example is to allow a mobile system to take itself from point A to B without operator input and then to request instructions. USBM needs guidance systems. Lasers are a possibility but will not work in undulating seams. Inertial systems, even using ring-laser gyros, probably lack sufficient accuracy over long cuts. USBM has been assisted by the NASA Lewis Research Center with IR and ultrasonic systems and are now examining vibrations in the mining machines and mine strata to determine whether the machine is in the coal seam. A sensor for tracking a coal seam would be an invaluable tool. Control research requirements begin with closed-loop control, then task planning for simple or reflexive machine control in a well-defined open area, and finally developemnt of strategies for mining more than one area.

An important point that was emphasized for nuclear plant automation is that there will be only retrofit systems for some time to come. There are no current new orders for nuclear power plants, although EPRI would like to design automation into planned Advanced Lightwater Reactor systems. For this reason the Savannah River plant is emphasizing testing of such equipment as the Odetics walking machine which may be able to wend its way through a nuclear power plant maze.

One interesting need is for disposable robots (expendable, low-cost) or disposable modules. Both the Army and Savannah River laboratories would like these futher developed. The Army is also interested in NASA developments of 1) computer-aided driving of remote vehicles, applying 3-D displays and point-to-point navigation updated every 30 seconds, 2) 2- and 3-D vision, 3) manipulators, and 4) low data rate communications.

Few high tech improvements will be made soon to most earth handling equipment, said Mr. Leach, although they have simple remote operation packages and have announced a new unmanned electric forklift truck for warehousing. There are no plans to move toward camera-based type teleoperator systems. He also noted that with large equipment it is important to provide feedback other than such force feedback as that felt through the back pressure of hydraulic wheels. An example is audio feedback, which equipment operators have lost because of the evolution of, first, mufflers and then turbochargers and electronically controlled transmissions which eliminate the ability to calibrate the shifter with engine noise.

Ken Sebok asserted, on the other hand, that undersea operations are very similar to those in space and their problems may have mutual solutions. Vehicles operate in an essentially weightless environment without a source of ambient air and with sealing against pressure differentials required. Ocean activities must also consider problems of corrosion, high external pressures, ocean currents, low visibility and light attenuation. NASA could possibly assist with 1) sensors for acquiring a landing site, 2) sensors for alignment (e.g. valve replacement), 3) sensor monitors, 4) manipulators and end effectors, 5) methods for achieving soft failures, 6) non-destructive inspection and test methods, 7) remote welding, 8) vision systems to overcome lack of depth perception (stereo cameras and headsets are hard on operators), 9) inertial navigation, 10) stabilized platforms for better microwave uplinks from ocean surface to satellites, and 11) miniaturization of electrical and mechanical devices and systems.

Dr. Brian Wilcox, head of a telerobotic research group at the Jet Propulsion Laboratory, provided the panel with some additional "supply side" information for NASA technology transfer. Further discussion by the panel was prompted by Dr. Wilcox' descriptions of 1) light-weight manipulator arms for space applications whose construction and control paradigms could be of commercial interest, 2) the NASA commitment to force-synchronized dual arm control, to include handling of extended rigid objects, and 3) planning to include critical autonomous functions (such as on-board force sensing instead of force reflection) on space-based teleoperators controlled from the ground. This is essential to work around the 1 to 2 second time delay through the TDRSS satellite up- and down-links.

CONCLUSION

The discussions of motives and requirements for telerobotics application demonstrated that, in many cases, lack of progress was a result not of limited opportunities but of inadequate mechanisms and resources for promoting opportunities. Support for this conclusion came from Telerobotics, Inc., one of the few companies devoted primarily to telerobot systems. They have produced units for such diverse applications as nuclear fusion research, particle accelerators, cryogenics, firefighting, marine biology/undersea systems and nuclear mobile robotics. Mr. Flatau offered evidence that telerobotics research is only rarely supported by the private sector and that it often presents a difficult market.

Questions on the mechanisms contained within the NASA technology transfer process for promoting commercial opportunities were fielded by Ray Gilbert and Tom Walters. A few points deserve emphasis:

- NASA/industry technology transfer occurs in both directions and NASA recognizes the opportunity to learn a great deal from industry in the fields of automation and robotics

- Promotion of technology transfer projects takes a demand side approach, with requests to industry for specific problem identification. NASA then proposes possible solutions.

- Commitment of motivated and technically qualified people on each end of a technology transfer is essential.

- NASA assures protection of proprietary interests and provides incentives such as exclusive licensing of NASA patents as part of the technology transfer process.

- NASA often enlists the assistance of other agencies (e.g., Dr. Hodge mentioned the DoD Joint Technical Panel on Robotics), associations, or technical societies to recommend or participate in transfers with industry.

The Office of Commercial Programs and its agents for technology transfer solicit the interest of industry and seek their specification of problems or requirements with which NASA might assist. Prompt attention to any inquiries may be obtained by contacting the Technology Applications Team, Research Triangle Park, NC (919) 541-6156. OCP gratefully acknowledges the opportunity for the Commercial Users Panel afforded by the Jet Propulsion Laboratory and greatly appreciates the contributions of the panel experts.