EGG-M-89460
CONF-901131--1

ROBOTIC APPLICATIONS AT THE IDAHO NATIONAL ENGINEERING LABORATORY

EGG-M--89460

DE91 001926

Brad E. Griebenow, Donna J. Marts
Idaho National Engineering Laboratory *
Idaho Falls, Idaho 83415

The Idaho National Engineering Laboratory (INEL) has several programs and projected programs that involve work in hazardous environments. Robotics/remote handling technology is being considered for an active role in these programs. The most appealing aspect of using robotics is in the area of personnel safety. Any task requiring an individual to enter a hazardous or potentially hazardous environment can benefit substantially from robotics by removing the operator from the environment and having him conduct the work remotely. Several INEL programs were evaluated based on their applications for robotics and the results and some conclusions are discussed in this paper.

INTRODUCTION

Working in and around hazardous waste and hazardous environments is a reality today for many government and commercial contractors. This work is time consuming and expensive and is always somewhat of a risk for the personnel that have to enter and work in these areas. If, instead of manually obtaining data or performing a task, it is performed remotely with the operator safely removed from the environment, much of the risk would be eliminated. Providing for personnel safety is paramount at the Idaho National Engineering Laboratory (INEL) and the utilization of robotics and remote handling is a viable method of doing so. At the INEL we have several programs and anticipated programs that involve work in or around hazardous environments where robotics could prove beneficial. This paper discusses some of these projects, looks at the similarities of the applications, and draws some conclusions on how these applications could be met.

ROBOTIC APPLICATIONS

The INEL, a U.S. Department of Energy facility, is situated on 890 square miles in southeast Idaho. It contains the largest concentration of nuclear reactors in the world. Of the INEL's 52 reactors, 13 are still operable. The INEL is a leading center of nuclear safety research, defense programs, nuclear waste

* This work was supported by the U.S. Department of Energy, Idaho Operations Office, under DOE contract No. DE-A007-76ID01570.

technology, and advanced energy concepts. The majority of INEL projects are for the Department of Energy with some work being done for the Department of Defense as well. Several INEL programs have been evaluated based on their applications for robotics and a summary of these applications is discussed below.

1. Power Burst Facility/Boron Neutron Capture Therapy

The INEL's Power Burst Facility (PBF) has completed its initial design mission and is now available to conduct new missions. One identified application for the facility is in support of Boron Neutron Capture Therapy (BNCT). BNCT holds promise in the treatment of a specific brain tumor called Glioblastoma Multiforme, as well as Melanoma skin cancer and perhaps other forms of cancer. BNCT requires injection of a nontoxic, nonradioactive boron compound into the bloodstream which is assimilated into the tumor. The tumor is then subjected to a neutron beam to cause the boron to fission, resulting in destruction of the cancerous cells. PBF is the primary candidate to deliver a high concentration of neutrons at an energy level, epithermal, capable of penetrating the skull bone. These epithermal neutrons allow the patient to be treated without a dangerous surgical procedure to expose the brain tissue. The PBF facility can be modified to deliver epithermal neutrons in sufficient quantity to permit treatment in less than 10 minutes. These modifications will require approximately two years. Modifications for which robotics may be used are listed below.

A. Surveying. Cubicle #13 in PBF is near the designated area for the patient table. Manned entry into the cubicle has been determined hazardous due to the extremely high radiation levels. Decontamination of this cubicle is very desirable due to the additional space it would make available in the patient area. Present design, however, leaves the cubicle in its present state due to the hazards involved with decontamination. Modifications in this high radiation environment are further complicated due to shielded items with an unknown point source and large items that require disassembly. A small mobilized robot that can be remotely driven through PBF cubicle 13 will allow entry into this otherwise prohibitive environment. The contents of the cubicle, the geometry of items inside, and the radiation levels can be identified and evaluated for decontamination without any personnel entering. The robot will provide visual access to the cubicle and assist in planning the task by mapping the cubicle and identifying hot spots. The robot will need to provide video data, perform distance measurements, measure radiation fields, and take contamination swipes.

Cubicle #10 in PBF will also benefit from the remote survey capability. Although less contaminated and in a lower priority location than cubicle 13, it is still the goal of the project to decontaminate the majority of the facility.

B. Decontamination and Decommission. After cubicles 13 and 10 have been surveyed and evaluated, a plan must be devised for decontamination and dismantling of the area. This will include cutting of pipe sections, dismantling accumulation vessels, and scrabbling concrete floors and walls. All these activities are best done remotely due to the high radiation levels. A mobile device similar to the surveyor with specialized tooling will make these activities possible with minimal risk to personnel.

Once radiation levels have been reduced to allow safe manned entry, final decontamination and decommissioning can be performed. Regardless of which program is ultimately placed in PBF, the decontamination of cubicles 13 and 10 will need to be accomplished.

Decontamination efforts are also required in the reactor annulus between the reactor vessel and the concrete wall surrounding the vessel. The annulus, which is cluttered with piping, provides very little space for performing decontamination activities. High radiation levels and contamination levels make manned entry into this area undesirable. Some piping may be too radioactive to be approached by personnel. A mobile device is needed to evaluate and decontaminate the area to a point where manned entry is acceptable to continue modifications. This device would have capabilities similar to the surveyor, but would have to be operable on the vertical reactor vessel walls. Decontamination would be accomplished by remote tooling operated by the robot.

C. Welding and Inspection. A remote controlled cutter, welder, and weld inspector is needed to perform some difficult welds and weld inspections within the PBF reactor vessel. Once the reactor vessel is made ready for modifications, a "window" must be welded in place. This window will run from the vessel through the concrete wall surrounding the vessel to deliver epithermal neutrons to the target. Prior to this activity, a penetration must be cut in the vessel to accept the window flange. The slag generated from the cutting and welding operations should be contained during these operations to prevent the spread of contamination.

An indexing system is needed to accurately locate the correct positions on the vessel interior. Since there are no indicator markings inside the vessel, reference points should be used and translated to an in-vessel location.

Risk from exposure to high radiation levels, confined and unconventional work areas, and time consuming operations are the driving forces behind utilizing robotics for these tasks. The welder would need imagery devices, an accurate position indicator, a welding manipulator, a cutting manipulator, weld inspection sensors, and a mobile platform. A single platform with interchangeable end effectors would best accomplish this.

2. Buried Waste Program Retrieval Project

The mission of the Buried Waste Program (BWP) is to select, demonstrate, and implement remedial actions that will permanently protect people and the environment from the mixed (hazardous and radioactive) waste buried in the Subsurface Disposal

Area (SDA) of the Radioactive Waste Management Complex (RWMC). The purpose of the Retrieval Project, which is part of the BWP, is to demonstrate and/or develop strategy for removal, processing, and shipment of the buried waste to its final disposal. It must be a "cradle to grave" process, including all steps from site preparation through final disposition of the exhumed waste and clean soil. Due to the hazardous environment, the majority of the retrieval work must be performed remotely.

A. Surveying. Prior knowledge of the waste type in the area being exhumed will prove beneficial in the segregation process. This knowledge may be achieved by continuous surveying of the dig face at the area of excavation. A small mobile robot equipped with the appropriate sensors could provide this type of information. This vehicle would also provide a mobile camera, which would allow views of the work location from various desired angles. Of primary concern to the retrieval project team is alpha contamination and migration. The vehicle would not be susceptible to damage from alpha particles and would be equipped with a real-time alpha counter to measure the particulate concentration. This information can then be used for evaluation of manned entry.

B. Maintenance. The large earth moving equipment to be used in the retrieval project will require periodic maintenance. Present designs require this maintenance to be done manually. The policy of minimizing worker exposure levels, however, make manual maintenance undesirable. A remote maintenance system would minimize this concern. This system would perform routine maintenance and simple repair on all the specialized remote operated mining equipment. This would reduce personnel exposure and costly equipment decontamination. The system would use most of the features of the mobile surveyor, and would have additional manipulators and tool attachments to facilitate maintenance and repair. In this application, advanced sensory feedback would be necessary to allow the operator to have more knowledge about the forces applied to the robot.

C. Decontamination. Some manual equipment maintenance will be required in addition to remote maintenance. A remotely operated mobile vehicle would be beneficial to decontaminate equipment for manned maintenance when required. Remote decontamination to remove gross contamination prior to manned entry to the area will reduce personnel exposure levels.

3. Process Experimental Pilot Plant

The Process Experimental Pilot Plant (PREPP) will process selected radioactive wastes into a form acceptable for placement at federal repositories. PREPP has already demonstrated its capability to process solid classified and hazardous wastes and materials. Processing these types of materials provides operational and technological experience which is factored into radioactive waste processing.

The process consists primarily of material shredding, rotary kiln incineration, and product immobilization in a grout mixture. Waste is processed through a shredder then fed into the rotary kiln incinerator. Process solids and gases move into separate flow paths from the rotary kiln. Solid residue is moved to the rotating trommel to separate coarse solid material from fine ash. The fine ash is pneumatically conveyed to the fine ash hoppers and blenders for ultimate transfer to the grout mixer. The coarse material continues through the trommel into the drum fill enclosure where it is combined with the grout in product drums. After product drums have been inspected and determined to be acceptable, they are available for emplacement in the federal repositories.

A. Glovebox Manipulator. Present procedures require personnel to perform grouting operations using access windows in gloveboxes. The gloves in these gloveboxes wear out quickly due to the coarse nature of the grout mixture. A manipulator installed in the glovebox would allow the operator to be placed in a safer environment and would reduce maintenance required to replace the gloves. This manipulator would mix the grout with the coarse material and place the mixture in drums for storage. Robotic capabilities in the manipulator could be used to clean the glovebox interior periodically and to perform other repetitive tasks.

B. Shredder Manipulator. Some items placed in the shredder do not shred well and require removal. A manipulator is needed to remove these items from the shredder and lower them to a lower level of the plant for processing. This manipulator would also be used to clean out the small particles remaining in the shredder at the conclusion of the shredding process.

4. Advanced Test Reactor

The Advanced Test Reactor (ATR) is designed to study the effects of intense radiation on samples of reactor materials. ATR produces an extremely high neutron flux for testing the durability of reactor fuels and materials when bombarded with streams of neutrons and gamma rays in high pressure and high temperature conditions. The four-lobed core delivers a wide variation of power levels to nine main test spaces. Each main test space, or loop, has its own separate environment apart from the main core of the reactor. This allows nine individual experiments to be conducted simultaneously. Additional smaller test spaces surrounding the loops allow even more experiments to be conducted independently.

A. Surveying. Each loop at ATR has an associated primary cubicle which contains various high pressure and high temperature components. When the reactor is operating, entry into these cubicles is hazardous. A small, mobile robot that could be remotely driven through the cubicles to locate piping leaks would be beneficial. The robot would provide visual access to the cubicle without requiring human access and would be equipped to allow humidity measurements, temperature measurements, and radiation measurements. End effector tools could also provide the platform with the capability to repair valve packing leaks and perform other minor maintenance.

B. Welding. Maintenance and component change outs inside the reactor vessel are done periodically at ATR. Cutting out and welding of components are the most time consuming tasks and require personnel to be exposed to high radiation environments for extended periods of time. A remote cutter/welder would drastically reduce the exposure to personnel during the maintenance cycles. Equally important is remote inspection to certify the quality of the finished weld. Quality assurance inspectors receive accumulated doses as high as those of the welders. The remote platform would have to be able to operate on the rounded, vertical wall of the reactor vessel. Cutting, welding and inspection capabilities must be accommodated on this remote platform.

5. New Production Reactor

The DOE is pursuing the design, development, and construction of a New Production Reactor (NPR) to meet the tritium needs of the nations' defense program. The INEL is participating in a program proposing the use of the Modular High Temperature Gas-Cooled Reactor (MHTGR) to meet the DOE objectives. The proposed MHTGR design is based on the commercial standard MHTGR that is being developed under the DOE Advanced Reactor Program. The NPR is capable of producing predetermined quantities of tritium while assuring reactor safety through physical principles and the use of passive design features. The reactor core facilitates passive decay heat removal, a strong negative temperature coefficient of reactivity, and a maximum power rating of 350 MWt. This passive safety capability represents a significantly different design philosophy than that used in existing production reactors and current generation commercial reactors, all of which are dependent on active emergency safety features systems to mitigate the potential consequences of postulated accidents.

A. Refueling System. A maximum of 12 days has been allotted to reactor refueling in order to meet tritium production goals. Manipulators are needed to remove fuel elements, each weighing more than 300 pounds, from the reactor vessel in this short period of time. These manipulators will require extended reach to ensure access to all fuel elements contained in the vessel. Manipulator access to the vessel is limited to control rod penetrations in the top head of the vessel. The manipulator design is further complicated by the accuracy required; a gap of only .040 inches exists between adjacent fuel elements. A fail-safe grapple head is required as the manipulator end effector to ensure safe shutdown in the event of loss of power or other unplanned event. This grapple head would extend into a hole in the top of each fuel element, and expand once inserted to obtain the proper grip. Robotic operation of the manipulator is essential due to the short duration allowed for the refueling process.

B. Target Replacement. A system is needed to replace the targets contained in the fuel elements after the elements have been removed from the reactor. These targets have a slight interference fit with the fuel elements. Due to thermal expansions and contractions of both the fuel element and the target, the interference may be greater when removing the target than when inserting it. It is essential to determine the forces applied to remove a target to alleviate the possibility of destroying a target or fuel element in the process. An automated system is needed for target replacement due to radiation levels.

C. Surveying. A mobile surveyor could be used to access the reactor area while the reactor is operating. The main purpose of this surveyor would be to provide visual inspection capabilities without personnel exposure. The down time allowed for the NPR is minimal to ensure production rates of the facility. Unmanned entry to the reactor facility would assist in meeting the plant efficiency requirements.

6. Waste Calcining Facility / Rover Fuel Processing Facility

Both the Waste Calcining Facility and the Rover Facility, located at the Idaho Chemical Processing Plant (ICPP), are proposed for decommissioning and system disposition. The facilities are no longer active. Contamination levels and radiation levels within containment cells are high, precluding decontamination without high exposure to personnel.

A. Decontamination and Decommission. It is desirable to minimize personnel exposure by conducting operations using remote handling techniques. Robotic handling equipment needs to be fabricated to remove all vessels and piping. This handling equipment would include mobile units. A remote sampling technique is required to determine vessel and pipe contents for analysis and accountability. Primary and supplemental viewing systems also need to be developed to assist in the D&D effort. Methods to remotely package and transfer the hazardous waste components also need to be developed.

The diverse activities required for facility D&D may justify the use of several robots with differing abilities rather than a single "all-purpose" robot. Possible designs include a mobile surveyor to determine facility inspection capabilities for planning purposes, mobile vehicles with specialized end effectors to dismantle equipment, and mobile vehicles to remove the debris from the facility.

7. High Level Liquid Waste Tanks

Underground waste tanks provide interim storage of high level radioactive, hazardous, liquid waste at the Idaho Chemical Processing Plant. The current corrosion data for these tanks in incomplete. Because of this lack of critical information, the 26-35 year age of the tanks, and secondary containment requirements, more information is required for a complete tank corrosion analysis to ensure and verify the integrity of the tanks.

A. Inspection. By performing a high resolution, image-enhanced visual inspection of the inner surface of each tank, the condition of the tank structure and the extent of possible cracking, pitting, localized corrosion attack or metal deterioration may be determined. Due to the limited accessibility, the 8 to 10 inch layer of sludge that remains on the bottom after draining, and obstruction by interior cooling coils, a full inspection of the tank's interior wetted surface is not feasible or cost effective. An inspection of a percentage of the welds and base metal on the tank walls, bottom, and the critical knuckle region where the wall and base join would provide the needed data to determine whether these tanks should be abandoned. The inspection must be performed remotely with a teleoperated robotic system that can access the inside of the tank, prepare the interior tank surface for surveillance, and obtain a high resolution picture. The tank interior can only be accessed through 12 inch diameter, 15 foot long risers that extend into the dome of the tank. The robotic inspection system must include design of: a delivery device that lowers and vertically positions the inspection equipment within the tanks, an articulated arm at the end of the delivery system to manipulate the inspection equipment, a high resolution inspection system, and development of a tank bottom inspection system.

B. Decontamination and Decommissioning. This effort presents several major challenges that include the following: The tanks are drained with steam jets that leave an 8 to 10 inch heel of liquid and suspended solids, or sludge, on the bottom surface, the existing tank configuration does not provide a method of removing this heel, the tanks are lined on the interior walls and bottom surfaces with 1 1/2 and 2 inch cooling coils, and the tank interior can only be accessed through 12 inch diameter, 15 foot long risers that extend into the dome of the tank. Due to these obstructions and limitations, D&D must be performed remotely with some type of robotic system. This device would be deployed through the access risers and would be required to articulate to all surface areas within the tanks. It will be required to perform cleaning, decontamination, and sludge removal of all interior surfaces between and under the cooling coils. It must also cut these coils and the actual tank structure into handleable pieces and lift these pieces into waste storage containers.

INEL MOBILE ROBOT PROTOTYPE

The robotic applications described above have been evaluated to determine a course of action. Although each has merit, lack of resources precludes meeting each of the recommended project needs. With this in mind, it has been proposed that a robotic device which can meet a broad range of these demands be developed.The First-generation Remote Exploration Device (FRED) prototype has been proposed to obtain information pertaining to the radiological and logistical layout of a hazardous environment. A schematic representation of FRED is shown in figure one.

There is a hard wire communication connection between the mobile platform in the hazardous environment and the data storage and operator centers in the non-hazardous environment. The data acquisition and data storage area continuously obtains data associated with the conditions surrounding the robot such as temperature, radiological, and visual information. The operator station obtains the information necessary to maneuver the platform inside the hazardous area. This includes visual feedback, manipulator control, and collision information. Inside the hazardous area the hard wire communication link is equipped with an untethered communication capability. This allows for the mobile platform to "unplug" itself from its umbilical cord and maneuver in areas where there are too many obstacles that could damage the cabling or hinder the motion of the platform. The vehicle used for untethered communications cannot be a typical radio frequency since this could interfere with the facility and its plant protective systems.The platform itself would be self contained with respect to power supply and would be decontaminatable. It also would be equipped with cameras, a manipulator arm, and sensors. All of these attributes would have to be modular such that they could be added or deleted simply by plugging or unplugging them.

First-generation Remote Exploration Device "FRED"

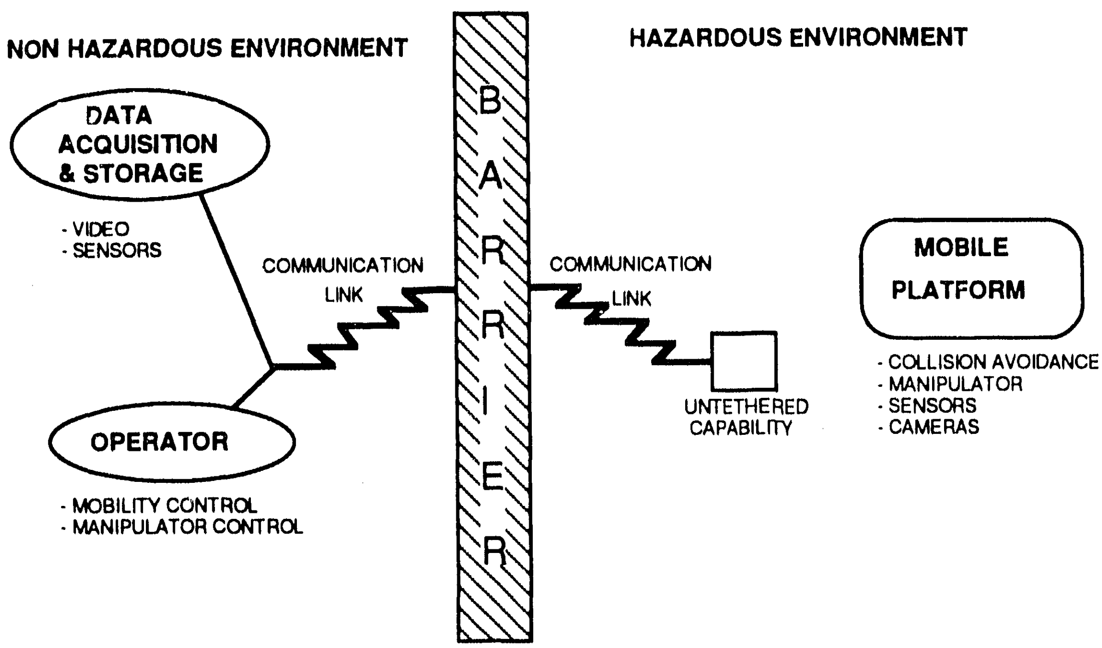

FIGURE 1

Mobile Platform

The mobile platform consists of the mobilizer base of the robot as well as all the attributes necessary to enable data to be obtained from inside the hazardous environment. All of these components must be packaged such that they are decontaminatable and can be reused in another environment. They must also be modular so that they can be removed and replaced by other modular components by simply plugging and unplugging them.The operation and control of these components must be performed and/or observed from a remote location. The overall desired envelope for the platform is thirty inches in diameter and forty two inches in height. This will allow it to navigate through most doorways and around tight corridors.

Mobilizer base
This is the mobile base which maneuvers inside the hazardous environment. It must be able to move slowly over non-uniform surfaces such as unfinished concrete, handle slight bumps such as door thresholds, and be stable on a 8% grade. It should pivot freely around its own geometric center to obtain a zero turning radius. The mobilizer is also the major framework of the entire mobile platform and must support all of the robot attributes. It also will need to network the various signals to and from the operator control center and the data collection center.

Visual input
The visual data from the platform will be obtained with a minimum of two cameras. Initially these cameras will obtain black and white pictures and have their own lighting. One camera will be dedicated to the operation of the platform. The camera will have standard pan, tilt, zoom, and focus features. A manual override for the iris and focus will allow the operator to adjust to difficult lighting areas. The camera will be mounted at the top of the platform and be able to telescope up an additional eighteen inches. The mounting fixture will be able to rotate 135^0 as well providing the telescoping action. The secondary camera will provide data for the data storage center at the discretion of the operator. It will be identical to the primary camera with respect to capabilities. In the event of a primary camera failure, the secondary camera will provide operator information and data collection will be limited to the operator's view.

Manipulator arm
To pick up and examine small items and to take radiological readings and contamination swipes, a manipulator arm will be placed on the platform. The arm will have six degrees of freedom with a reach of forty eight inches. The payload of the arm in its fully outreached position would ten pounds. The arm will be electrically driven instead of the more typical hydraulic. Electrical is the most compatible with contaminated environments.

The manipulator arm will also be equipped with end effector tools. These are tools that are easily attached to the manipulator by the manipulator itself and can perform specific tasks. Initially, three end effector tools will be used. A gripper with three fingers will be permanently mounted to the end of the arm. This provides gripping function for tasks such as picking up items and using small tools like a wrench. The second end effector would be a radiation detector. The type of detector would depend somewhat on the anticipated environment and more than one could be taken into the hazardous area. The final end effector would be a tool for taking contamination swipes. The tool must be able to take one swipe, store it such that it is identifiable, then take another swipe. The swipes will be "counted" outside the hazardous area.

Any power needed for the end effectors will be taken off the manipulator arm. Control and communications will also be directed through the arm so the design of these components must be closely related.

Sensors

The primary function for sensors will be to notify the operator of an abnormal condition with the platform. Collision avoidance sensors will alert the operator that there is an obstacle somewhere within the current path of the platform. This will allow the operator to use the camera(s) to find the obstacle and plan a course around it. Sensors will also indicate if the loading of the manipulator arm is excessive and if the mobilizer motors are operating abnormally. Power level will also be monitored and the operator will be notified when the reserve power system is activated. If temperature, humidity, or oxygen concentration information is needed, sensors can be added to provide this information.

Power

The power for the entire mobile platform is carried on the mobilizer. It will be a rechargeable system and completely contained in a common package. This facilitates its replacement when needed. There are two components to the power system, the primary and the reserve. The primary system can power the entire platform at 100% for a total of 60 minutes. If only a few systems are used at a time, the time will increase. A reserve system has power for the entire platform for 15 minutes. The reserve is intended to be used to maneuver the platform either to the recharging area or out of the hazardous environment. The reserve can be activated at any time so it can be used when the primary system is depleted or if there is a malfunction with the primary system.

Communication

There are two identical and separate communications systems. The primary communication system provides the operator with all of the information and control for the mobile platform. This includes the primary video, the maneuverability control, and the manipulator and end effector control. A secondary system provides the link to the data collection system for a continuous flow of input from the cameras and/or sensors as determined by the operator. In the event of a primary system failure, the secondary system can be transferred over to provide the primary link. This will be at a loss to the data collection system. The communication link will be, for the most part, a hard wire system. There will, however, be instances where a hard wire connection can either hinder the movement of the platform or get tangled in areas of numerous obstacles. For these instances, an untethered communication link is available.

This untethered system cannot jeopardize any protective systems in the hazardous area so typical radio frequencies cannot be used.

Man - Machine Interface

The operator of the remote system is dependant on the Man - Machine Interface (MMI) to provide accurate real-time visual data and sensor data to properly command the operations of the remote platform. The MMI will provide real-time visual data via a closed circuit system camera. The MMI display will be a high resolution display in which critical signal data would be superimposed on the screen to allow for human factors consideration of its effectiveness. Thus, both a camera view of the remote platforms progress and alarm/sensor data would be presented to the operator increasing the hysteretic coupling of the human to the machine. The MMI would allow for coupling of both remote manipulator actuation and simple voice command inputs. The control of the remote manipulator would be facilitated by the real-time data acquisition system's closely coupled input and output control system.

Data Acquisition Control Collection System

The Data Acquisition Control Collection System (DACCS) will provide real-time data gathering and operator command output. The data sensor system input devices and data output devices will reside on the remote platform. The sensor values will be converted and transmitted to the MMI location via the data link for further data processing and storage. The remote platform will have sufficient environmentally hardened processing capabilities to automatically sample critical input/output control functions such as collision avoidance. Sensitive electronics not required for these critical functions will be located with the control station outside the hazardous environment. The remote electronics would be designed to minimize power drain on the remote platform by using a sleep mode on equipment that is not in heavy use and use of CMOS electronics to further reduce power consumption. The high speed data link will allow for massive data transfer rates providing rapid closed loop control techniques to be used.

CONCLUSION

The Idaho National Engineering Laboratory, like most Department of Energy Laboratories, has numerous hazardous environments in which robotics could play a significant role. As worker exposure limits continue to be lowered and worker safety emphasized, robotics technology will be mandatory in many cases. This paper discusses just some of the many possible robotics applications at the INEL to foster information exchange. Through cooperation between the D.O.E. laboratories, government agencies, and the commercial industry, many of the applications identified as well as others can be met now. Future cooperation will result in significant advances in robotic capabilities for these and future applications.

DISCLAIMER

END

DATE FILMED

12 / 03 / 90