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GENERAL IMPACT OF ROBOTICS AND AUTOMATION IN RADIATION ENVIRONMENTS

A. Meghdari and M. Salehi

Nuclear Engineering Division
Department of Mechanical Engineering
Sharif University of Technology
Tehran, Islamic Republic of Iran

ABSTRACT

Robotics and automation systems in nuclear environments require special design considerations. This paper presents an overview of selected robotic systems already designed and developed for use in nuclear applications at some U.S. laboratories. It will further emphasize on tasks identification, operational constraints, special considerations in materials selection, and a general guideline for robotic systems design in radiation environments.

1. INTRODUCTION

Nuclear workstations challenge automated handling technology and equipment. Radiation, hazardous chemicals, and particulate contamination require many process areas to be inaccessible to humans and hostile to all but specialized tools and equipment. Hence, developing robotics and automation systems for nuclear applications should be the primary focus of any nuclear energy organization when speaking of ways to minimize personal exposures. Principal activities may include identification and development of error-free automation processes for hazardous and repetitive operations. Special design considerations and modifications are generally required to apply robotic systems in radiation environments (i.e. glove boxes). This is due to the fact that most robot manufacturers have developed their products for major markets such as automobile assembly, spot welding, or small appliance assembly and have not addressed the problems associated with the nuclear industry. Due to the interaction of atomic fission fragments with the almost unlimited array of solid materials, developing equipment for this type of environment involves a wide variety of factors. Some of these design considerations arise from the need for making robotic systems compatible with glove box environments, the necessity of repairing various equipment within glove boxes, selecting proper fabrication materials that are radiation and corrosion resistant and developing mechanical, electronic, and control systems that are operational within radioactive or corrosive atmospheres.

In 1945, at the dawn of the atomic Age, scientists at the Massachusetts Institute of Technology realized the need for high technology instruments to automate the emerging nuclear technology. Their realization pioneered early developments of safer methods for handling hazardous and toxic materials produced in nuclear industry. Early mechanisms developed for handling nuclear or contaminated materials started by applying awkward usually overhead-mounted devices, master/slave manipulators mounted through the vertical face of the containment wall, and ended up with electric-servo manipulators with the master remotely located from the slave. Figure 1 shows a clear picture of these mechanisms.

Today, the robotics systems technology in conjunction with other electro-mechanical equipments can be used to automate the safe handling of hazardous/nuclear materials in day to day operations. In support of the demands for reduced exposure to all forms of hazardous materials all nuclear organizations and laboratories should identify, develope, and implement automation processes for hostile operations.

2. TASK IDENTIFICATION FOR ROBCTIC SYSTEMS

Proper selection of a robotic remote handling system requires a basic knowledge of most types of manipulator systems. Figure 1 shows four types of commercially available manipulator devices suitable for nuclear operations. These are namely, mechanical master/slaves, power manipulators, servo master/slaves, and robots. Each of them has advantages in different applications. Master/slave manipulators are operated through the walls of shielded cells to perform dextrous tasks in line-of-sight applications. In large process areas, power manipulators have been mounted on large Cartesian gantry cranes. The manipulators are controlled unilaterally with switches which move each joint of the arm individually. These units are best suited for heavy materials handling and tasks where precision motions are not critical. Computerized servo master/slave manipulator have been developed to expand the capabilities of mechanical master/slave to remote process areas. Like mechanical master/slaves, they may be bilaterally controlled, meaning that position and velocity information is transmitted from the master arm to the slave arm and vice-versa. In general, servo master/slaves have light, low inertia linkages, and backdrivable gear trains and are intended for light duty applications. Thus, they are ideally suited for emergency response operation maintenance functions, and tasks where the operator must make motion responses based on tactile information.

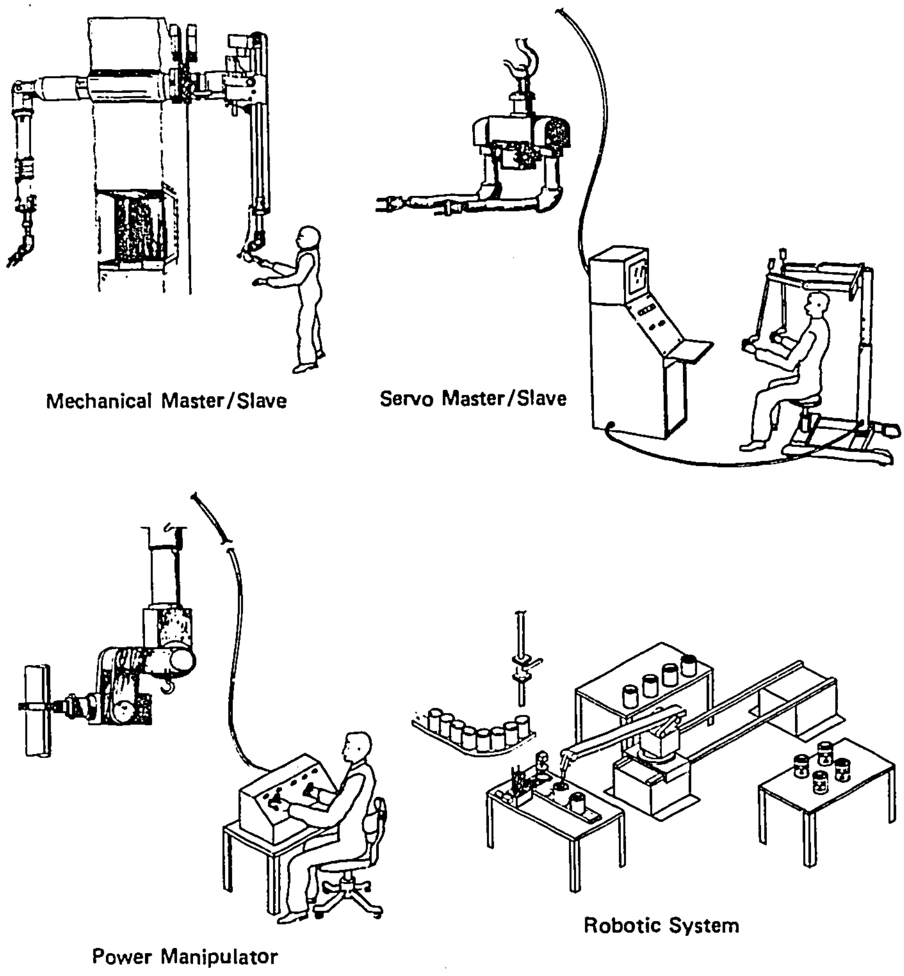

Fig. 1. Four types of manipulators.

Other special purpose computer controlled manipulator systems have been developed for selected nuclear operations. Asano (1) describes a 17 degree-of-freedom, snake-like manipulator developed by Toshiba, Inc. which can pass through a small port hole to perform remote inspections. The Westinghouse Energy System Service Division has developed a remotely operated service arm

(ROSA) that has been successfully used to perform eddy current inspections and manual tube plugging operations in steam generators. It has also been used to insert plugs into a reactor core barrel.

In general, three types of remote handling operations can be solved by a robotic system. In nuclear applications which contain repeated structured tasks, automation can be considered. Note that automated tasks are those which can be performed in a completely preprogrammed mode. They require a structured work environment. A second type of application contains specific tasks which can be performed automatically. These, however, require operating personnel to monitor and sequence their execution. A robot can perform these tasks through a manually supervised control system instead of a fully automatic one. The last type of application requires manual (teleoperated) control of the robot's motions in addition to programmed motions. This type of application requires the arm to function in a tele-robotic control mode.

3. AUTOMATION

Industrial robots can be used to automate routine and nonroutine tasks, which are repeated in structured nuclear applications. Routine processes are mainly production tasks which include fuel slugs, performing radiation assays on parts, and preparing samples. These nuclear operations share many similarities with standard industrial robot applications, and a dedicated robot work cell may provide a successful automation alternative. Other tasks suitable for robots, but not as easily recognized, are nonroutine but repeatable jobs which are awkward or potentially dangerous to perform. Examples of these tasks include: handling radioactive waste containers, changing filters, and performing selected or planned maintenance functions.

Complicated or multiple step operations may also be candidates for automation. Robotic systems are not generally limited by the complexity of particular tasks since arms can be adapted with multiple tools and end effectors. Furthermore, the number of steps required in an operation is also not a limiting factor since robots can be adapted with virtually unlimited memory for stored routines. A successful strategy in a particular automation process requires the designer to be fully aware of various robot capabilities. In addition, a general awareness of robotic systems cost and performance is essential for most applications. Furthermore, successful and efficient implementation of a robotic system in an automation process necessitates a thorough knowledge of the process that is to be automated. On the whole, the following guidelines should be addressed in a particular automation process:

1. Fully understand the process that is to be automated

and present a process profile outlining the details of the process, the number of steps involved, the level of skills required, etc.

2. Find out whether a robotic device can be mounted in the process area or adapted to an overhead gantry system, floor conveyer, or mobile platform to access the parts and machines in the process?
3. Find out when and how often the operations are modified with special procedures? Can these instances be recognized and alternate procedures be implemented automatically?
4. Study the possibility of alternate approaches to perform the operations in a simpler manner.
5. Find out whether any of the parts that are to be handled/assembled are sensitive to scratches, dents, etc. And if any of these materials are hazardous, corrosive, or radioactive.
6. Estimate the work space that is required to perform the whole process.
7. Study the sizes, shapes and weights of the parts that are to be handled/assembled by the robotic system.
8. Evaluate the minimum degree of precision required to perform the predefined tasks.
9. Study the load carrying capacity of various commercially available robotic systems and determine the ones satisfying the requirements.
10. Carefully study the workspace of these robots and see if any are compatible with the required workspace for the predefined tasks. Furthermore, study the number of degrees of freedom required to access all the parts and perform all the operations within the required work space. Six degrees-of-freedom generally provide the sufficient dexterity to perform a very large variety of tasks and operations.
11. Study the claimed accuracy and repeatability of the selected robotic systems and determine those which best suit the requirements.
12. Study the possible requirements of special tooling, such as end effectors, conveyors, and other supplemental fixtures. All designs must incorporate fail-safe operational modes in the event of a power interruption.
13. Study the number of sensor interrupt channels required for part orientation sensing, gripper sensors, safety sensors, etc. Determine whether it is required for the robot to have force sensing capability.
14. Determine the required memory capacity for a large number of program points in the application program, and the robot control configuration for such memory requirement.

4. CHOICE OF EQUIPMENT: RADIATION CONSIDERATIONS

Industrial robot controllers and sensory devices rely heavily on digital integrated circuit (IC) technology (i.e.

bipolar and metal oxide semiconductor). The IC's in a robot or sensors are usually the limiting factor in the radiation hardness of the device. The Gamma and neutron radiation cause extensive and unpredictable damage to semiconductor devices and the packaging they come in. Consequently, a analysis of the expected radiation fields is required to determine if standard off-the-shelf robotic components are usable or if specially designed or selected devices are required. For a complete data on radiation hardness of various semiconductor (IC's), the reader should refer to Long (2). In addition to the above, the reliability and maintainability factors of the industrial robots are very important in a radiation environment. Industrial robots have shown to be reliable in many commercial applications (average time is over 5000 hours for some units). However,when these systems fail, repairs may be complicated and labor intensive. Consequently, special maintenance considerations must be addressed before a system is installed in an area with high radiation fields or potentially harmful levels of nuclear contamination.

In high radiation applications, the robotic system and components should be installed so they can be easily transported to a "cool" regulated area. This greatly simplifies installation and maintenance operations and may also extend equipment life since radiation-sensitive components can be removed from the radiation zone when they are not in use. One design approach is to mount the robot on a sliding platform. The slide mounting provides a stable base for the robot and an easy means to transport the system. An alternate approach uses and overhead bridge crane to transfer the robot and system components. Lifting bails, alignment pins and fixtures must be integrated into the workcell to allow the robot to be removed and subsequently remounted.

Contaminated nuclear workcells present special problems to system maintenance. In many existing nuclear processes, hands on repairs, using maintenance personnel in plastic suits, are required. This practice, however, is avoided whenever possible to reduce radiation exposure and the possibility of nuclear material assimilations. A maintenance method preferred to operating through plastic suits is to remotely decontaminate components to a suitable level; then to transfer them to a "cool" regulated area for repairs. Decontamination chemicals used in nuclear processes include: nitric acid, caustic solutions, and "Freon". Unfortunately, very few commercial robot arms and components can be cleaned with these chemicals without damaging their internal components and wiring. Protective covers, boots and gauntlets, however, can accomplish the same function as mechanical sealing. Covers should be designed for easy removal and replacement so they can be changed in a glove box. Air purging is also desired to keep contaminated process air from entering the cover as it expands.

An alternative to decontamination is to employ a modular system design. System components such as end effectors, sensor devices, and arm sections can be removed remotely and replaced remotely via master/slaves, remote cranes, or through glove ports. Many times this approach is after, easier, and more economical than attempting to clean a contaminated piece of process equipment. Depending on the accessibility of the equipment in a process, modularity may be an important design requirement. Few commercial robots use modular designs, but several manufacturers will quote modular designs as special options.

5. SAMPLE AUTOMATION PROCESSES

5.1. Direct Oxide Reduction

Plutonium metal is produced from plutonium oxide by the direct oxide reduction (DOR) process. The procedure calls for introducing three reagents: PuO_2, calcium metal, powdered calcium chloride, and a pressed calcium chloride cylinder into a magnesia crucible inside of a glove box. The reagents and the $CaCl_2$ cylinder are placed in the crucible which is then inserted into a stainless steel can and into a reduction furnace. At about 800 °C, the reduction reaction starts and stirring of the molten mixture begins. After the exothermic reaction is complete, the components are disassembled and the plutonium metal button is broken away from the bottom of the crucible. The product metal and salt residues are then transferred out of the glove box.

At Los Alamos National Laboratory (LANL), this process is successfully automated by an IBM 7565 rectangular robot in the following four phases:

1. Measure reagents and assemble components.
2. Control furnace cycle and mixture stirring.
3. Disassemble components.
4. Separate product and residues, and assay.

5.2. Milliwatt Generator Calibration Line

$^{238}PuO_2$ heat sources are routinely produced at some nuclear laboratories around the world. These sources generate heat by the alpha decay of $^{238}PuO_2$ which is converted to electricity by the use of a thermopile. The electricity generated is used to power remote systems such as satellites, and arctic and subsea installations. The thermal calibration of these heat sources is generally carried out manually and is very routine in nature. A typical measurement currently takes about two hours. At Los Alamos National Laboratory, a robotic system based on the cylindrical Zymark robot is developed to perform this operation automatically. The robot has been interfaced to a

HP 9825 desktop computer that operates the two calorimeters and maintains the data base for the results. Figure 2 shows a radiation-resistant modified version of the Zymark robot.

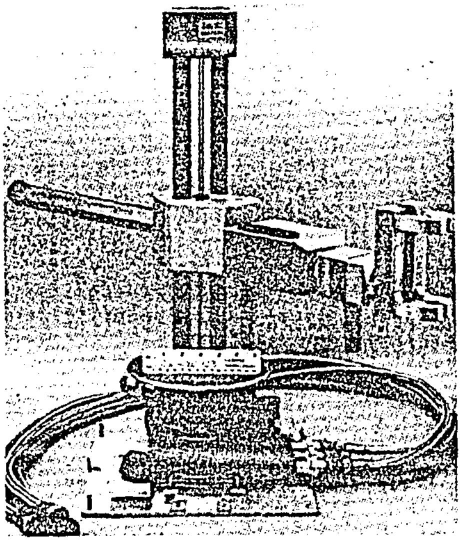

Fig. 2. The Zymark Laboratory Robot.

5.3. Automated Bagout Operation

Most of the waste generated inside of glove box trains is extracted in one gallon cans. Removal of these cans from the glove box is called a "bagout operation". This operation involves removing a can from the glove box through a special port into a plastic bag without breaching the atmosphere of the box. Robotic systems have been developed and installed to remotely perform the bagout operation at both Los Alamos and Savannah River National Laboratories in the United States. As the can is extracted by the robot, a plastic bag collapses around it. A gathering and clipping mechanism necks down the bag between the extracted can and the glove box port. Four metal clips are applied at this point, isolating the waste can from the glove box. A penumatically driven knife severs the bag between the two inner clips with two clips each sealing the newly formed ends of the bag. Figure 3 shows a clear picture of this operation.

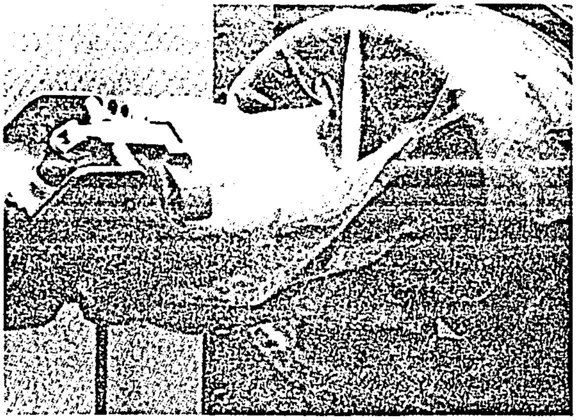

Fig. 3. The fail-safe gripper removing a waste can from a Glove Box.

5.4. Environmental Gamma Spectrometers

The Health, Safety and Environment Division of the Los Alamos National Laboratory is in charge of monitoring the environment around the Los Alamos County to insure that radioactive contamination is not being released due to many activities of the laboratory. To discharge this role, the division operates a gamma spectroscopy laboratory where environmental samples (i.e. soils, rocks, grasses, etc.) are counted for activity. Due to the extremely low activity of these samples, long counting periods (10000 seconds) are commonly used. Hence, in an eight hour day, no more than three samples can be measured on any of the six counters in the laboratory. To make more efficient use of the counting equipment and to use the evening and weekend hours more productively, a robotic system is developed to automatically change samples in each counter at the conclusion of each counting period. Due to the extremely low levels of radioactivity encountered with these environmental samples, no modification were required for the PRI 2000 robot used.

5.5. Isotope Detector Fabrication Process

Detectors are fabricated from a family of isotopes that include up to six or seven different elements. The radioactive oxides, in the form of low density powders are received at the Los Alamos in a wide variety of shipping containers. In this process, which takes place in a controlled atmosphere glove box, highly radioactive oxides are subdivided, weighed and placed into target capsules which are then welded shut. This process is automated by a

PRI-1000 robotic system and a number of automated devices such as a capsule cutter installed within the glove box. Figure 4 and 5 show pictures of the PRI robot installed in a glove box for the IDF process.

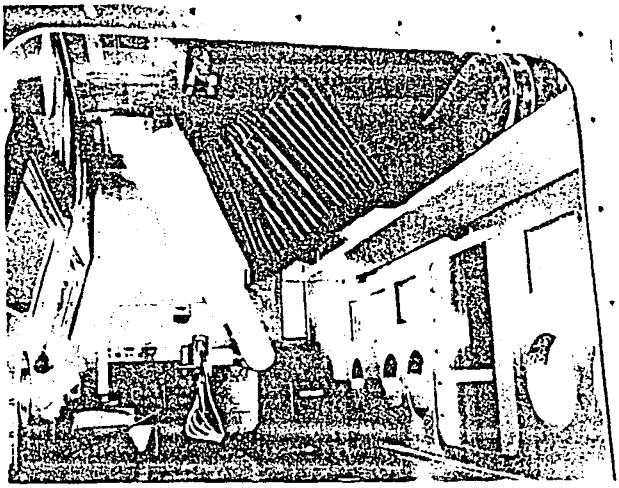

Fig. 4. The PRI-1000 robot in a glove box.

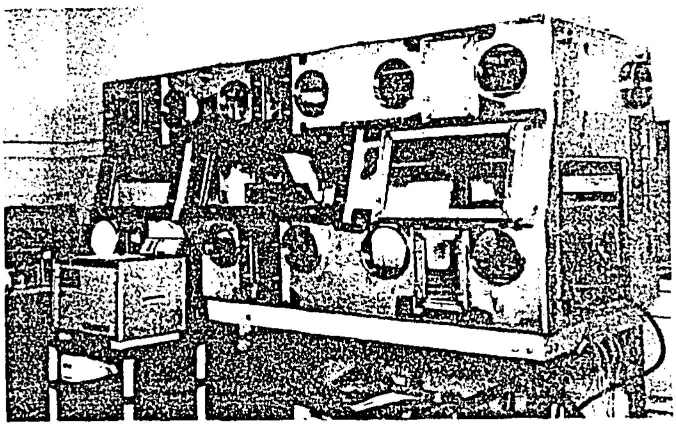

Fig. 5. The glove box used for isotope detector fabrication.

6. CONCLUSIONS

General issues for implementing robotic systems in radiation environments have been addressed. Samples of successful automation systems were briefly explained. It can be concluded that automation is currently playing a major role in nuclear industries around the world.

REFERENCES

1. K. Asano, "Control System for a Multi-Joint Inspection Robot", ANS Conf. on Robotics and Remote Handling in Hostile Environments, Gatlinburg, TN, April 23-27 (1984).
2. D.M. Long, "Radiation Hardness of Semiconductors", IEEE Trans. on Nuclear Science, NS-27 (16): 1974, (1980).
3. T.J. Beugelsdijk and D.W. Knobeloch, "Robots in Radiation Environments", Journal of Liquid Chromatography, 9(14), 3093-3131 (1986).
4. A. Meghdari, C.P. Keddy, T.J. Beugelsdijk and R.F. Ford, "A Systematic Approach to Robotic Testing and Evaluation", Procs. ISMM Int. Conf. in Computer Applications in Design, Simulation and Analysis, Honolulu, Hawaii, 161-167, February 1-3 (1988).
5. H.L. Martin, "Joining Teleoperation with Robotics for Remote Manipulation in Hostile Environments", RI/SME Robotics 8 Conf., 9-1 (17), Detroit, MI, June 4-7 (1984).