Robotics Applications at the Savannah River Site

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Abstract

Robots were first developed in the early 1960s with large, hydraulic-powered units and unique, proprietary, control systems. Electric robots controlled by personal computers were introduced in the mid 1970s. By the mid 1980s, robotics technology matured to where nuclear applications could be considered. Personnel at the Savannah River Site (SRS) recognized this opportunity and have applied robotics to many different tasks at SRS since the mid 1980s. These applications significantly reduced personnel radiation exposure and accomplished tasks beyond human capability. This paper provides an overview of five robotics technology applications implemented at SRS, including mobile robots, a pipe crawler, special manipulators, and custom-designed tooling.

Introduction

Robots were first developed in the early 1960s for the automotive industry. These robots were large, hydraulic-powered units with unique, proprietary, electro-mechanical control systems programmed to autonomously perform different tasks. Electric robots with personal computer controls were introduced in the mid 1970s, making them more reliable and less expensive, and popular. By the mid 1980s, robotics technology matured to where nuclear applications could be considered. Also, in the mid 1980s, remotely controlled vehicles with manipulators were developed for bomb disposal in response to bomb threats throughout the world. Though these units are not programmable like a true robot and a human controls all motions, they are typically referred to as mobile robots. Savannah River Site personnel have applied robotics technology to different tasks since the mid 1980s.

SRS was one of the first DOE sites to apply robotics in actual nuclear applications. The driving force was and continues to be reducing personnel radiation exposure, the goal for all mobile robot applications at SRS. However, some tasks such as reactor tank inspection and pipe crawling could be not be accomplished by humans, so this technology was imperative in those cases.

In many applications, robotic systems, such as mobile robots, could be integrated with special tooling and sensors. For instance, to remove a junction box in the H Hot Gang Valve Corridor, a bomb disposal robot was modified and a special cutting tool was added to remove this radioactive junction box with minimal exposure to personnel. The Remote Overhead Video Extendable Robot (ROVER) (see Figure 2), used many years to monitor remote operations in the F- and H-Tank Farms, was created by modifying a standard man-lift for remote operation and adding cameras and lights that can be manipulated. This system saved personnel from radiation exposure with each operation.

In other applications, the lack of commercially available equipment suitable for the task forced the design and integration of commercial components into a unique system. All equipment for reactor tank inspection had to fit through the relatively small penetrations in the reactor tank top, requiring custom design and the capability to endure extremely high radiation exposure during operation. In another

Figure 1. Mobile teleoperator used to remove a wall-mounted junction box

application, the tooling designed at SRS to install pour spout inserts was used with a unique manipulator from a nuclear equipment vendor to maintain the Defense Waste Processing Facility (DWPF) melter. These pour spout inserts have extended the life of the melter to obtain years of additional operation. Although commercial pipe crawlers are available, none could climb about 230 feet through pipes 3 feet in diameter, including vertical sections, or cut off a pipe section after arriving at the remote destination. A unique pipe crawler was designed at SRS to carry a plasma torch to cut a pipe section from a canyon exhaust duct, successfully completing the cut with minimal exposure.

Removing a Contaminated Junction Box

In the late 1980s, a radioactive liquid leak from the F Canyon contaminated the inside of an obsolete junction box in the adjacent Hot Gang Valve Corridor to a level of 200 R per hour. The contamination radiation level was high enough to prevent repairing and maintaining equipment in that section of the corridor. Since the contamination was inside, the box would have to be removed so that normal operations in the corridor could resume. An estimated total exposure of 8 R to personnel would be required to remove the box manually, even using tools mounted on long poles and with the operators behind temporary shielding.

A bomb disposal robot (see Figure 1) was modified by installing a new upper arm assembly and a tool-mounted camera, and by adding two degrees of dexterity in the wrist required to cut the supports and conduits for the junction box. A hydraulic cutter, designed to extract victims from severely damaged cars, was attached to the wrist in three different orientations to make the cuts. Three remote cameras were set up in the corridor for views from different perspectives to monitor the vehicle and manipulator movement.

The junction box was mounted on the wall 7 feet above the floor and was obstructed by several air lines, pipes, conduits, and junction boxes. The mobile robot design was tested and refined by removing a junction box four times in a cold mockup of that section of the corridor. It was also tested by removing an uncontaminated junction box in that section of the corridor and removing a similar, uncontaminated junction box in a different section of the actual corridor. In June 1987, from a control station in the Hot Gang Valve Corridor about 150 feet away from the contaminated junction box, the modified bomb disposal robot made 13 cuts and removed the contaminated junction box in one week with less than 1 R of total personnel exposure.

Remote Observation of Diversion Pits

Radioactive waste produced at SRS is held in large, double-walled, steel storage tanks in F- and H-Area Tank Farms. Operating the tank farms requires manipulating piping and vessels with an overhead crane within below-ground pump diversion pits. Historically, personnel have been required to peek over the side of the pits and give hand signals to the crane operators, who in turn, replaced equipment or moved flow control jumpers. This direct viewing exposes workers to radiation from the pits. When placed on fixed tripods to perform remote viewing, cameras were quite often incorrectly positioned for the views required for the entire operation. As a result, the Remote Overhead Video Extendable Robot (ROVER) was developed and provides multiple overhead video views a considerable distance above the pits. Each camera and light can be remotely repositioned to effectively view the entire operation. ROVER is based on a commercially available, electric, battery-powered man-lift selected because it can position the cameras at an elevation just above portable shielding, as much as 30 feet beyond the shielding, or up to 45 feet above the pits. ROVER deploys two cameras on booms that extend 20 feet horizontally from each other with left and right views. Each camera can remotely pan, tilt, and zoom and is enclosed in a transparent bubble for outdoor use. A third camera, on its own mast, provides an overall view and can be placed up to 10 feet above the other cameras. Two high-intensity lights were installed on the mast for night operations, and all controls and video signals are multiplexed over three coaxial cables. These cables are routed to a van containing the remote equipment; the control console, video monitors, camera controls, lighting switches, two camera boom controls, a single camera mast control, and the man-lift booms, steering, and locomotion.

The ROVER mast and cameras can be collapsed to fit within the vehicle footprint for transport to and between F and H Areas. The three camera systems, large distance between cameras, high camera elevations, and repositioning capability have been versatile for remotely viewing the diversion pit operations for many years and reduced or eliminated radiation exposure during diversion pit activities.

Figure 2. The Remote Overhead Extendable Robot (ROVER) used for

Reactor Tank Inspection

In 1989, a program to restart three SRS reactors began, and ultrasonic inspection of the reactor vessel wall welds was a prerequisite to the restart. The reactor vessels were rolled and welded into 1/2 inch thick, 304L stainless steel cylinders 16 feet in diameter. To access the welds, the equipment had to pass through tank top openings 4-3/8 inches in diameter and as much as 21 feet below the tank top, position the sensors with an accuracy of ± 0.030 inches, operate underwater, and endure radiation levels exceeding 1,000 R per hour for days during the inspection operation.

The SRS-designed system (see Figure 3) included an inspection system, the remote inspection robot, three camera positioners, a calibration mast, and a control center designed to be transported from reactor to reactor. The control center was in a 48-foot trailer that housed the robot control, camera control, audiovisual system, and the ultrasonic and eddy current inspection system. A 5-ton crane was designed to be installed, operated, and removed on existing crane rails in the reactor building. Since all components entering the reactor vessel were long with relatively small diameters, strongbacks were designed to transport the components and be placed to the vertical position without damage by a custom-designed erector.

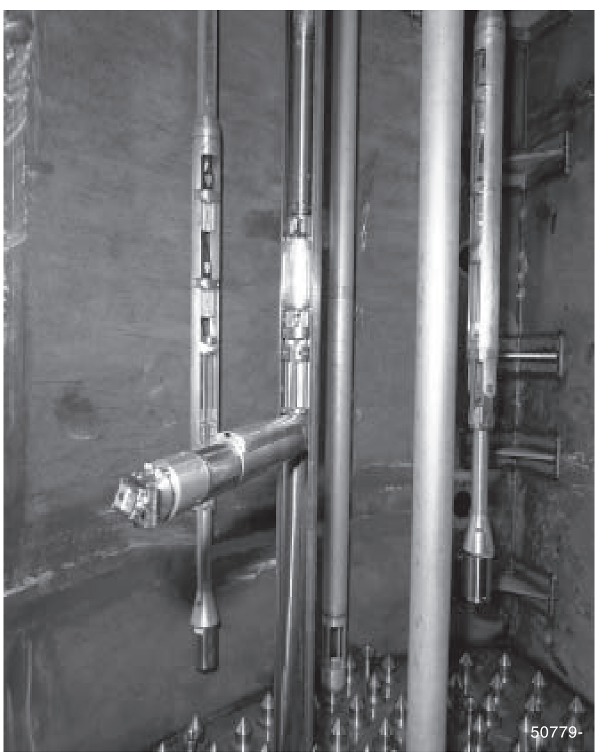

Figure 3. Reactor Tank Inspection Robot used to inspect welds in reactor vessels in

A full-scale mockup of 1/4 of a reactor tank was constructed to develop, test, and qualify the system. The mockup qualified the system in accordance with accepted practices in the nuclear industry and ASME codes. System qualification was achieved using blind samples from an outside agency. During actual operation, a calibration standard on a calibration mast was used before and after data acquisition to assure data quality.

The robotic positioning tool was a five-degree-of-freedom manipulator. The axes included a vertical lift, a rotation about the vertical, an elbow, extension, and a wrist roll. The end effector consisted of two transducers mounted in a gimbal on a spring-loaded, compliant member. A sensor monitored the amount of compliance produced to maintain sensor contact with the wall. Operation of the positioning tool was monitored by three camera and light systems. Each system had a three-degree-of-freedom mast, a radiation-hardened camera, and two lights.

The Reactor Tank Inspection System was successfully deployed in P, K, and L Reactors. It met all performance, cost, and schedule goals.

Pour Spout Insert Installation

Since radioactive start-up, the Defense Waste Processing Facility (DWPF) has experienced glass melter difficulties. The melter, intended to pour vitrified glass mixed with high-level waste long term, was not providing a clean, steady pour. Prolonged glass canister filling caused wicking when the glass stream went over the internal knife-edges of the pour spout. The wicking interfered with glass flow and changing the canisters. These problems were identified during non-radioactive melter testing. Conventional, mechanical master/slave manipulators in the melter cell could not lift the tools and could not reach the melter pour spout. To correct this situation, a custom-designed, electric manipulator with robotic capabilities was installed in existing through-the-wall openings in the melt cell before radioactive start-up. Cleaning tools, a high-temperature inspection device, a removable pour spout insert, and installation and removal tools were developed to use with the electric manipulator to modify the pour spout and reduce wicking caused by pour stream deflections.

SRS personnel designed a high-temperature inspection device to be used by the electric manipulator to inspect the pour spout interior at temperatures beyond 1050 degrees Celsius. Inspection of this device revealed that the upper knife edge that detached the pour stream from the spout was severely corroded. SRS personnel designed and tested a mockup of the pour spout insert at the DWPF operating temperature. The insert provided a new knife edge, closer to the canister opening, for an acceptable pour stream without wicking. The insert was constructed from Inconel 690 to match the pour spout material. The robot uses the insertion tool to place the insert into position and to slide a slotted ring with three horizontal pins up a tapered surface to gain initial contact of the pins against the pour spout. After contact, the thermal expansion drives the pins into the wall, locking the assembly in place. These pins can be pulled, and the insert can be removed after the insert knife edge erodes to the point where a new insert is needed. A chipping tool and scraping tools were designed and used to clean the entire pour spout area between removing and installing inserts.

These pour spout inserts and the tools have been combined with other improvements to increase production and extend the melter life. The increased production exceeded goals set by the Department of Energy and resulted in significant award fees for Westinghouse Savannah River Company. The melter extended life saved millions of dollars associated with changing to a new melter.

Elbow Cutting Pipe Crawler

Because of safety and environmental concerns, an elbow section of pipeline that carried exhaust from F Canyon had to be removed. The elbow was in an underground concrete tunnel that led to a sand filter. By removing the elbow, the air would be redirected from the pipeline's stack to the sand filter. The pipeline was 36 inches in diameter and made of 1/4-inch-thick stainless steel. The section to be removed was 265 feet from the pipeline's entrance. Because part of the building's ventilation system would be affected during the elbow removal process, work had to be timed to prevent a radiological impact on the facility.

A number of metal-cutting technologies were investigated, but plasma arc cutting (PAC) was chosen because of cost, no requirement to introducing liquid, and ease of remote operation.

An internal pipe crawling system was developed to transport the torch through the pipe because the elbow could not be removed externally. The pipe crawler moved in an inchworm motion using pneumatic cylinders. Before this task, SRTC personnel had built units that could operate in pipes up to 12 inches, so this task required a significant scale-up of this technology. A suspension system was added for flexibility to negotiate the elbows and "gooseneck" sections of the pipeline. The resulting crawler was nearly 7 feet long and weighed nearly 125 pounds (see Figure 4).

Six miniature, low-light level, CCD cameras were installed on the crawler to help navigate and locate the elbow section. The plasma arc cutting torch, three cameras, and two lights were mounted to a powered rotator on the front of the crawler. Springs were added to improve compliance in the deployment tool and to compensate for pipe wall irregularities such as weld seams. A tether bundle 300 feet long extended from the rear of the crawler to the control console. The bundle included tubing for the pneumatic cylinders, a torch cable, video coaxial cables, a rotator power cable, a crawler control cable, and cable for emergency retrieval.

After two successful elbow removals in a mockup, the system was moved to a radiological hut that was set up at the pipeline's entrance. The travel time to the elbow section was 2.5 hours. With the aid of the on-board cameras, the first cut was located and made. The crawler was then driven backwards and made the second cut, which successfully dropped the elbow to the bottom of the air tunnel. An insignificant dose was received during the task even though rates of up to 1 R per hour were detected by sensors on the crawler.

Figure 4. The Elbow Cutting Pipe Crawler was used to cut piping located 265 feet

Biography

Clyde R. Ward graduated from Tufts University with a Bachelor of Science degree in mechanical engineering in 1996. After working for Du Pont Company in 1966, Mr. Ward transferred to the Savannah River Plant in 1977. Currently, Mr. Ward works in the remote specialty equipment in the Savannah River Technology Center, where he has developed robots, teleoperators, and mobile teleoperators for the Robotics Group.