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# IMPLEMENTING ROBOTICS IN THE DEPARTMENT OF ENERGY DISMANTLEMENT PROGRAM



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# DISCLAIMER

# IMPLEMENTING ROBOTICS IN THE DEPARTMENT OF ENERGY DISMANTLEMENT PROGRAM

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## ABSTRACT

Since the end of the cold war, as our nuclear stockpile has decreased, the Department of Energy (DOE) has been working rapidly to safely dismantle weapons returned by the military. In order to be retired, weapons must be returned to the Pantex Plant in Amarillo, Texas. There they are reduced to their component parts. Although many of these parts are not hazardous, some, including certain explosive assemblies and radioactive materials, are sufficiently hazardous so that special handling systems are necessary. This paper will describe several of these systems developed by Sandia for Pantex and their technical basis.

**KEYWORDS**: robotics, dismantlement, safety

## INTRODUCTION

Since the end of the cold war, as our nuclear stockpile has decreased, the Department of Energy (DOE) has been working rapidly to safely dismantle weapons returned by the military. In order to be retired, weapons must be returned to the Pantex Plant in Amarillo, Texas. There they are reduced to their component parts. Although many of these parts are not hazardous, some, including certain explosive assemblies and radioactive materials, are sufficiently hazardous so that special handling systems are necessary.

We have built intelligent systems using commercial robots to perform some of these dismantlement tasks. The rationale is to lessen exposure to radiation or to sensitive explosives, and at the same time increase repeatability and throughput. These workcells are one-of-a-kind, using robots in areas where they have never been employed before. In most cases the workcells must have a coherent safety theme that not only protects people and the environment, but weapon parts as well. This theme must pass the rigors of several formal analyses.

Sandia has delivered three systems to the Pantex Plant and is readying another for delivery to Los Alamos National Laboratory. These systems are developed as turnkey installations in our laboratories, then delivered to the sites for staff training, review and approval. Our systems do not handle any weapon components which are capable of a nuclear explosion when processed. However, they do handle other nuclear materials and explosive components, so the levels of safety and reliability required are very high.

## IMPLEMENTATION GROUND RULES

Our systems are designed using some basic themes. At the beginning of each project we form a team consisting of mechanical, electrical, controls and software engineers. These

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are supplemented by technologists in machine vision, data acquisition, electronics, optics or whatever specialties are required. The team stays intact through development and delivery. Our customer provides a complementary team. Formal documentation of the design and development process is delivered with the system. In-depth interaction of the actual plant operators is required, and their suggestions taken very seriously.

We use as much commercial equipment as possible and strongly recommend that the systems use commercial robot manipulators. Manipulators should have a proven track record in high volume manufacturing operations such as automobile plants. Robot controllers should be from the manipulator manufacturer. Most of our systems use Fanuc S-700 manipulators and RJ controller. This philosophy solves many reliability and safety issues. Supervisory control is normally provided by a Sun or other Unix-based workstation, which displays the user interface and provides top level instructions to a VME-based control computer. A CPU on the VME bus runs VxWorks as a real-time operating system. The CPU communicates with the robot controller, safety or peripheral I/O systems and the supervisory control software. On some of the systems we have used a PC-based approach to reduce complexity.

We use software quality processes to produce requirements, design documents and documented code. The code for safety critical applications is peer reviewed and then subjected to in-house testing at both the procedure and systems level. The software is kept under configuration control at Sandia, and after delivery at the implementation site.

Safety is designed into our systems from the beginning relying on a robot safety theme. We do not, in general, use any safety approaches which require dual CPUs, dual sensors or similar devices. Early on it was decided that these would be too expensive and complex for our systems. Use of factory floor robots also precludes such use. However we have added themes which increase safety without added complexity. First, for our most complex workcell, we have done a Failure Modes and Effects Analysis and developed fault tree/event tree system descriptions. Since we use a similar robot, controller and design theme, these analyses are applicable in large part to all of our applications. Designs are modified based on these analyses. We have had one of our robots UL certified which involved the severing of encoder lines and power cables to examine for erratic robot behavior and found none.

Our systems are tested for between 1000 and 2000 hours prior to implementation, and we have not observed any erratic robot behavior therefore we have elected not to implement any intrinsic safety systems beyond those already in the controller (which meet ANSI r15/06-1992 safety standards for robot operation).

For our tooling, grippers, etc., we have employed a mechanical interlock system making it impossible to release tool changers and open grippers except when the interlocks are activated at the correct location. We also have incorporated a force torque sensor in the load train which will stop the robot if preset range values are exceeded. We have investigated the use of state machines to independently generate range values as the robot moves, but concluded that this level of detail and independence is not necessary for our present applications.

An additional safety/quality related "discovery" was that the systems in general are much more gentle than humans, even for delicate operations. Using the force torque sensor with compliant move software has resulted in much lower impact during mating and demating of the workpiece with tooling.

As is usual, the custom produced tooling has proven to be the most unreliable part of the design. For this reason, all of our tooling is engineered and configuration controlled, and analyses are performed on all mechanical and electrical hardware. Records of purchasing and manufacturers material certifications are necessary to pass our quality reviews.

Prior to actual operation, the systems are given a very thorough and demanding final review. The review usually encompasses design processes, quality, safety theme, documentation, training and operation. Upon resolution of findings, the workcell can go into operation. Sandia support for the system is normally provided for a year after first operation with the goal to develop capability to handle most problems by site personnel. For complex difficulties, we provide continuing support.

## APPLICATIONS

The dismantlement process is the first large scale application of robotics and intelligent systems within the DOE. We have developed systems for this area for several reasons. First, the disassembly process is more straightforward than assembly. Second, thousands of components must be handled which increases hazard exposure and the possibility of mistakes. Robotics can alleviate these concerns. Third, some of the storage and monitoring tasks will be done over periods of several to tens of years. The capital investment in the workcells can be paid back during the projected long term use.

Described below are three systems which have been implemented in the production complex, all at the DOE Pantex Plant.

### *AUTOMATIC GAS GENERATOR DISASSEMBLY*

During weapon dismantlement explosive components called gas generators must be opened and the explosive removed. These components often are old and the explosive (similar to gunpowder) has become more sensitive, so the preference is to not use humans for the operation. The manual disassembly begins by unscrewing a spanner type threaded cap, removing a closure disc and pouring out the explosive. The empty shell must be cleansed of remaining powder, and an igniter assembly removed and palletized. At this point the process is complete. We duplicate the manual process with a 6DoF Fanuc S-700 robot (see Figure 1 and Reference 1). The robot is controlled by a Fanuc RJ controller with a PC running Windows and a PLC to handle real time I/O and control. The workcell is operated remotely from a console. Observation of the process is maintained via remote zoom, pan and tilt video at the console. A graphical user interface (GUI) is provided to control the robot.

Several types of user control are available. First, in the normal mode, the robot can process the item autonomously, with minimal interaction from the operator. Second, if there is difficulty with the process like a stuck closure disc or a jammed thread, the component can be put aside for manual intervention. In some cases an operation can be executed again if the operator so designates. For example, if video inspection reveals that the cleaning was not successful, a retry can be directed. If the vision system used to orient the wrenches to unscrew the cap and igniter fails to locate the wrench properly the process will stop and a try can be made by operator motion of the robot.

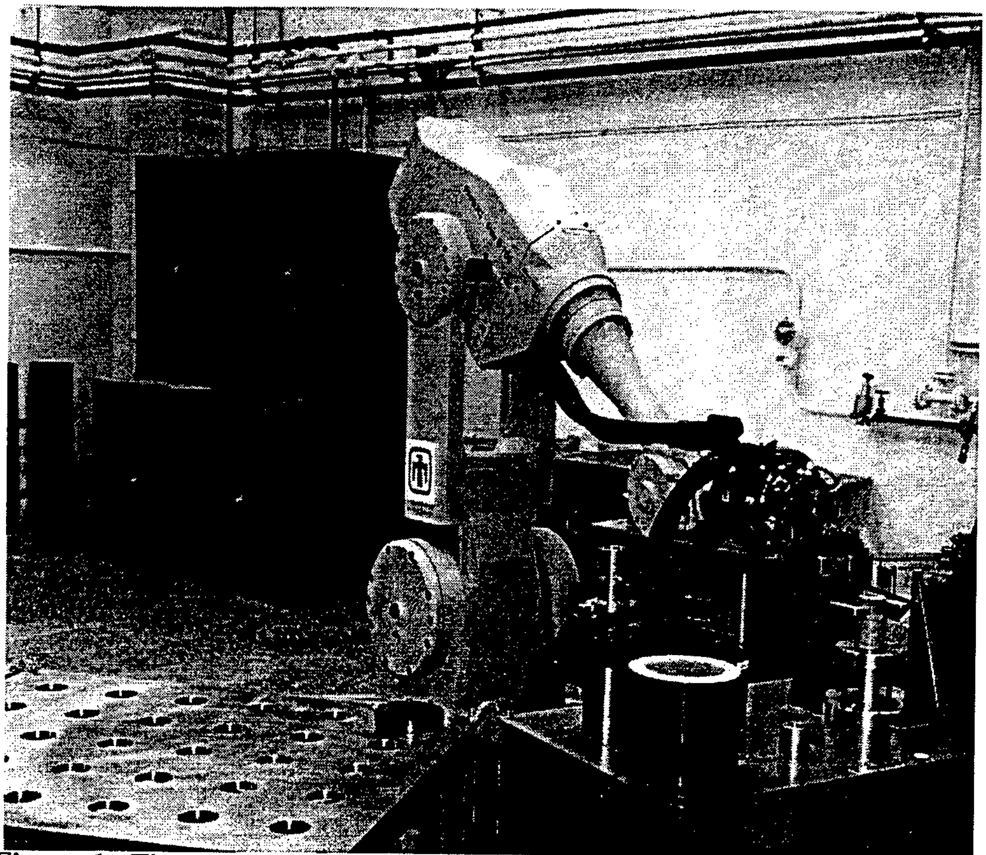

**Figure 1**. The gas generator workcell. The generator is a soft drink can sized object in the robot's grasp.

The system performed very well in pre-production testing. When we moved to the production floor, some fine tuning had to be made including reteaching points in spite of our built in calibration system, adjusting the vision system for the actual images of the explosive shell (we could not test on explosive components at Sandia) and several programming improvements. Once these were made the system disassembled over 500 units in roughly 6 months. This is a pace between 5 to 10 times the manual rate. There have been few manual interventions, occurring mainly when a component is not as expected--e.g., stuck together, blackened, etc. The system is going to be modified for the second type of generator in early CY98 after it completes about 2000 units.

*STAGE RIGHT*

Project Stage Right is a joint project with another Sandia group and the Pantex Plant to provide increased storage capacity for nuclear bomb cores, or "pits." In this process Pantex dismantles a weapon and renders it incapable of nuclear yield, but the pit remains as a radioactive component that must be stored in a high security area. Since the closure of the Rocky Flats Plant pits have been stored at Pantex pending startup of another plant to dismantle them. However storage space is limited, and any increase in density in the storage bunkers increases radiation levels to a point where human exposure is precluded, except for short intervals. Pantex and Sandia designed and implemented a storage and retrieval system based on a commercial Automated Guided Vehicle (AGV). The vehicle was procured with the vendor providing structural modifications and "hooks" into control software for us to implement our top level control scheme. The vehicle is captured between floor rails which contain encoder notches for position information. These rails run the length of the bunker with pits stored in pallets on either side. A turret boom is attached to the mast to allow side to side lifting. The pits are contained in drums which are packaged into 4 or 6 pack pallets. The vehicle stores and retrieves the pallets, and using a special monitoring instrumentation rack, can monitor a pit in situ.


**Figure 2.** The Stage Right AGV entering a magazine. Note the guide rails and computer controller on the rear.

The vehicle is controlled from a small control station in a trailer that is placed outside the bunker. An RF ethernet connection is established between the AGV and trailer. The vehicle is programmed with a task then autonomously performs it with no operator assistance. Video monitoring is available to make sure there are no surprises. In this case we had to circumvent some of the built in ANSI safety features that require an AGV to stop whenever it detects and obstacle and to require an operator to reset the system prior to restart. Here a "smart" response to off normal conditions in a magazine is required because of the desire to keep humans out of the magazines. The vehicle also can be teleoperated to attempt to clear any error conditions, and if the fault cannot be cleared, the vehicle has manual assists to use in extraction of the vehicle from the magazine.

This system has been in use for about three years with virtually no problems. We are modifying the concept for work in a much larger and more complex warehouse. The Savannah River site has implemented a similar system, and the IAEA is evaluating the concept as a baseline for international storage and monitoring.

*THE WEIGH AND LEAK CHECK SYSTEM (WALS)*

For pits which are removed from weapons or in long term storage, routine surveillance of their physical condition must be done. This normally involves removing them from their storage drum, doing a visual inspection, weighing and checking them for leaks using an evacuated bell jar. Even though the individual pit does not create a high radiation dose when handled, the great number of pits to be inspected does create a large cumulative dose in the plant workforce. For reasons of radiation safety and quality of surveillance operations, the WALS system was developed to perform these steps automatically (reference 2, 3).

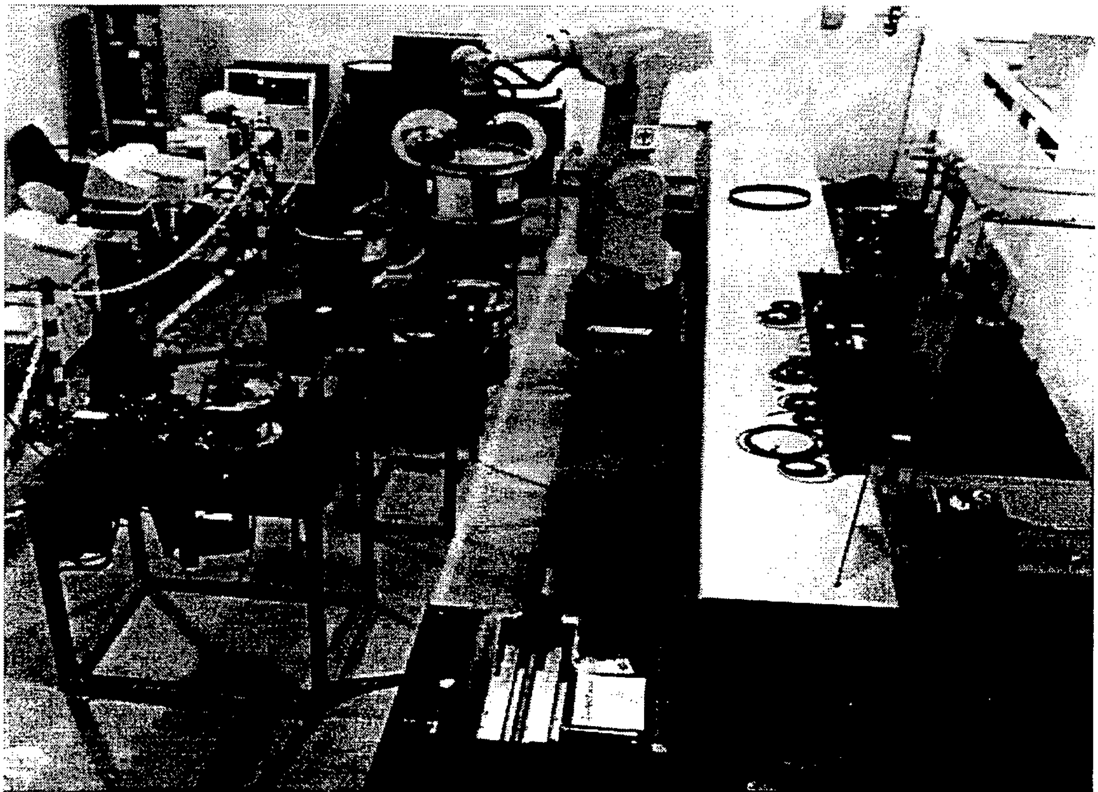

**Figure 3.** Panoramic view of the WALS workcell.

The system performs the operations listed above autonomously. It must deal with up to 7 different pit types and internal supporting assemblies, 4 different pit containers (drums) and the various processes particular to each pit type. The pit information is entered from a barcode and database. Two operators must be present to use the system for security reasons. One of the operators reads the barcodes, does a visual inspection (using a remote video system) and cleans off the pit surface if needed. The other operator runs the system via the GUI. Since the leak check can take a long time, 3 pits of different types can be in process at one time to increase throughput. This system performs these multiple operation using an S-700 robot and a track to expand the workspace.

The system incorporates all of the themes mentioned under groundrules. However, because of the sensitivity of handling pits directly outside of a drum, the safety and security measures are extraordinary. Instrumented mockups were used in system testing to assure acceleration and shock levels were within limits during emergency stops, off normal conditions and normal operations.

One very difficult operation is removal of the pits from their support fixture. The fixture is removed from the drum robotically. The robot then take the fixture to a manual disassembly station. This station is designed to assist the robot in disassembling the fixture, and to keep the various parts in position for reassembly, or to build up a new fixture. The real challenge was in automating a process that could not be fundamentally changed and was difficult for even humans to do. The fixtures vary significantly among themselves, as they were built to nominal dimensions only. Using sensor based control and real time changes in the robot path we have been able to reliably perform this operation on a variety of fixtures, but final confirmation on a production stream is pending.

Because of the danger of damaging the pits, very few error recovery procedures are automated. The preferred response is to lock the system up and call for an engineering supervisor in case of a problem. The robot can, then, under human supervision be brought to a resting position and restarted if appropriate.

The system has been installed at Pantex and is anticipated to begin hot operation sometime in FY98.

## CONCLUSION

We have implemented robotic systems doing hazardous materials handling at the Pantex plant. These systems have been subject to extraordinary scrutiny regarding safety and reliability. We have successfully utilized commercial equipment, and indeed, capitalized on its proven characteristics to construct systems that are safe and reliable for use within the DOE.

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