Robotically Deployed Laser Imaging for Facility Characterization—9096

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ABSTRACT

The generation of facility 'as built' engineering drawings can be a significant problem in planning D&D projects. This is particularly the case when the facility has been abandoned for some time, undocumented changes in configurations have occurred, or the facility has been used to store excess material from another facility. These conditions are further compounded when the facility is known, or suspected, to contain hazardous conditions that could endanger personnel.

The Savannah River Site conducted a project to address these issues through the robotic deployment of a scanning system that produces volumetric representations of facility spaces and contents. High resolution laser imaging of complex structural and equipment configurations was conducted using a robotically deployed system at the P Reactor. The test objective was to demonstrate the capability for generating high quality volumetric data using a remote controlled deployment and data acquisition system that would be capable of entering spaces deemed too hazardous for initial human entry. A commercially available sensor and robotic platform were paired to conduct characterization of a complex configuration of piping and equipment in a subgrade portion of the reactor building. Laser image data sets produced point cloud images that were processed and loaded into a CAD package for further analysis. Such automated systems are capable of providing engineering quality drawings of facility 'as found' conditions that support the planning of D&D projects, as well as provide accurate representations of 'as left' conditions when facilities are closed.

INTRODUCTION

The Department of Energy has numerous facilities destined for Deactivation and Decommissioning (D&D) that require characterization to support adequate planning and development of work packages. Many of the facilities represent difficult challenges for adequate characterization because:

- High levels of contamination preclude prolonged human presence,
- Structural deterioration precludes human entrance, or
- As-built engineering drawings do not exist or are unreliable.

The Department identified this issue in the Environmental Management Engineering and Technology Roadmap [1] as the following challenge element:

> *Develop and deploy advanced remote and robotic methods to rapidly access and assay facilities to determine optimal D&D approach*

To the extent that characterization activities in hazardous facilities can be carried out using robotic deployment systems, personnel risk resulting from structural hazards or contaminant exposure can be reduced significantly. Furthermore, if appropriate data are collected, the D&D work planning can be carried out based on known, rather than assumed worst-case conditions. The products of many advanced data acquisition systems could allow substantial elements of the work planning to be accomplished with minimal worker entry, further reducing risk and the costs associated with mitigating that risk.

Initial entry into a facility with unknown hazards represents a significant risk to personnel. Additional risk is encountered during the structural characterization, particularly in complex facilities where accurate estimates of material take-off volumes are required. This latter task requires a substantial time commitment for D&D engineering staff to create 'as found' drawings, or verify and correct available drawings. To the extent that these tasks can be automated and conducted remotely, substantial worker risk can be avoided. If the deployed technology is sufficiently reliable and accurate, then time advantages can be achieved, even in non-hazardous facilities.

Savannah River National Laboratory (SRNL) and the Savannah River Nuclear Solutions Area Closure Project (ACP) undertook a task to test the ability to generate reliable as built drawings of a facility that was undergoing closure using a robotically deployed laser imaging system.

OBJECTIVES

In planning for this study, ACP personnel were requested to identify a facility that was

- Actively involved in D&D planning,
- Had structurally complex elements, and
- Was not so heavily contaminated to jeopardize subcontractor equipment release.

ACP personnel also supported this demonstration project by providing safety planning, radiological control support, facility access and operational oversight. Those personnel also provided reviews of the project results and critiqued the overall effort, identifying potential issues that may limit the applicability of this strategy.

The primary objective of the demonstration was to confirm the ability to deploy complex instrumentation into a complex environment using a relatively simple deployment platform. The characterization technology (three dimensional laser imaging) was selected because it had the potential to provide high resolution, volumetric information on facility equipment and conditions that could be used for developing engineering 'take-off' estimates for work packages and waste estimates.

DEPLOYMENT

SRNL researched laser scanning technologies and found three potential scanning systems that would meet project criteria: remote control, millimeter accuracy, and high scan speeds. GKS Inspection Services was chosen for this demonstration project. GKS deployed the FARO LS 880 for the project. This sensor has the following characteristics:

Scan Speed	120,000 points per second
Linear error	+/- 3 mm @ 25 m distance
Vertical scan area	320 degrees
Horizontal scan area	360 degrees
Laser power	20 mW (Class 3R)

FARO LS 880 also has onboard data storage and is capable of wireless data transmission. Other 3D scanning systems characteristically had reduced scanning areas and slower scan speeds, but the other systems that were reviewed would likely have produced comparable results.

The deployment platform for the 3D scanner was developed in house by SRNL. Working closely with GKS personnel SRNL's robotics group identified a minimum feature platform to transport the scanning system. The robotic vehicle platform was designed using commercially available drive motors, cameras, and lights. Two Inuktun drive tracks were mounted underneath and on the left and right sides of an aluminum plate whose approximate dimensions were 38 cm by 43 cm. The drive motor tracks are 43 cm long, made out of brass, operate at 24 VDC, and can each pull up to 23 kg. The black and white pan/tilt camera device was mounted on the front of the plate with room for the laser in the center and an LED type light located to either side. An L-bracket supporting the cabling between the robot and the operator console was mounted on the rear of the chassis plate. The cabling included controls for the left and right drive motors, camera pan/tilt/zoom functions, camera video, and lights. Power to, and communications with, the robot were through a tether, although onboard power and wireless communications could have been incorporated.

Video monitoring of robot movements were deemed essential for navigation in the facility and for post processing of the 3D data, although the laser system can also be deployed with it's own video system. Both the robot and the laser imaging system provided real time data feed for monitoring outside of the area being characterized. The laser scan post processing would also utilize video recordings for orientation and identification of features in the generation of the 3D CAD layers.

The demonstration project was conducted in the former Purification room at the -14 level in the P Reactor at the SRS. The reactor building and complex is currently undergoing deactivation and closure under the SRS Area Closure Project. The Purification room is a moderate sized facility (21mL x 6mW x 3.7mH) containing complex piping and valving systems that represents a significant, and realistic, challenge for the imaging system. Portions of the room perimeter were excluded as contamination areas. Additionally, numerous pieces of equipment (e.g. mobile stairways, scaffolds) were in the room and represented obstacles around which the robot platform must navigate, but would also be important for entry planning purposes in an unknown facility.

The study was conducted September 24, 2008 with participation by SRNL, GKS and SRNS-ACP operations personnel. After initial set-up, approximately five hours of data acquisition time from 20 locations within the facility were required for scanning. Included in the set-up was the positioning of Styrofoam spheres throughout the room to facilitate merging the multiple images that would be acquired for the characterization. In addition to the quarter resolution (standard) acquisition protocol by GKS, an additional scan was conducted at half maximum resolution to determine whether useful additional information could be obtained at the higher resolution.

Figure 1 shows the robot/sensor configuration that was deployed for this project during a test run to ensure that all systems were performing properly.

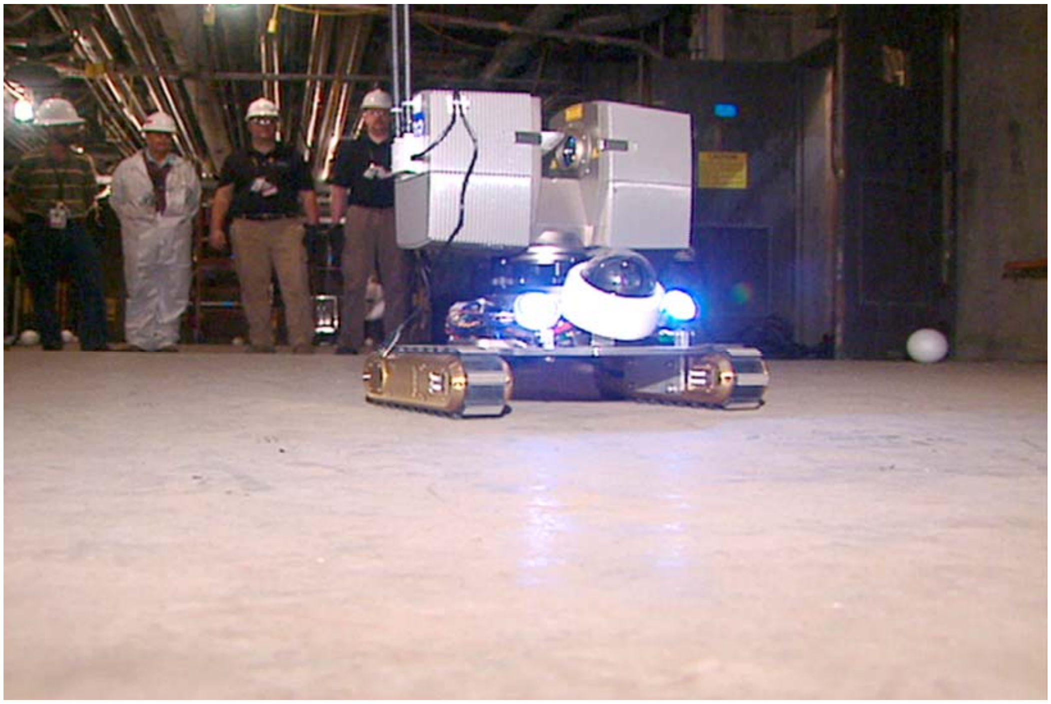

Figure 1. Mobility test of robot and imaging system. Lights and hemispherical camera provide precise navigation capability for optimal image system positioning.

As noted, approximately five hours of acquisition time were required to complete characterization of the purification room using 20 set points in a zig-zag pattern. This pattern was required to capture the complexity of the piping systems in the room. In one area, pipe runs were stacked 4 deep below the ceiling.

Personnel monitored the video feed from both the robot and the laser system throughout the acquisition from a location approximately 15 m from the entrance to the Purification room.

Figure 2 is an image of the room acquired in real time during the acquisition. The image presents the full view as captured at one set location by the laser system with the characteristic spherical distortion. Note the white orientation spheres scattered through the image. Figure 2 also contains an enlargement of a portion of the image demonstrating the level of resolution that can be obtained with this system at the time of acquisition.

Figure 2. Raw image of a portion of the 105-P Purification Room at SRS. Image has characteristic spherical distortion including the robot on-board camera and robot tracks at the bottom of the image. Insert is a blow-up of one device in the facility.

The high resolution of this scanner system allows the user to acquire additional information from the imaging system other than just structural data. Linear measurements can be obtained from the initial images obtained during acquisition. Similarly, the high resolution of the laser system showed labels on many piping systems. This information is obtained from the raw data feed using common image processing applications.

The processed point cloud is a data set suitable for loading into a standard 3-D CAD system. Figure 3 is an overview of the entire facility as a CAD image. This 'wire-frame' image shows all of the measured features detected in the facility. In addition to the critical piping and duct systems, various pieces of equipment being used by workers in the facility are clearly depicted.

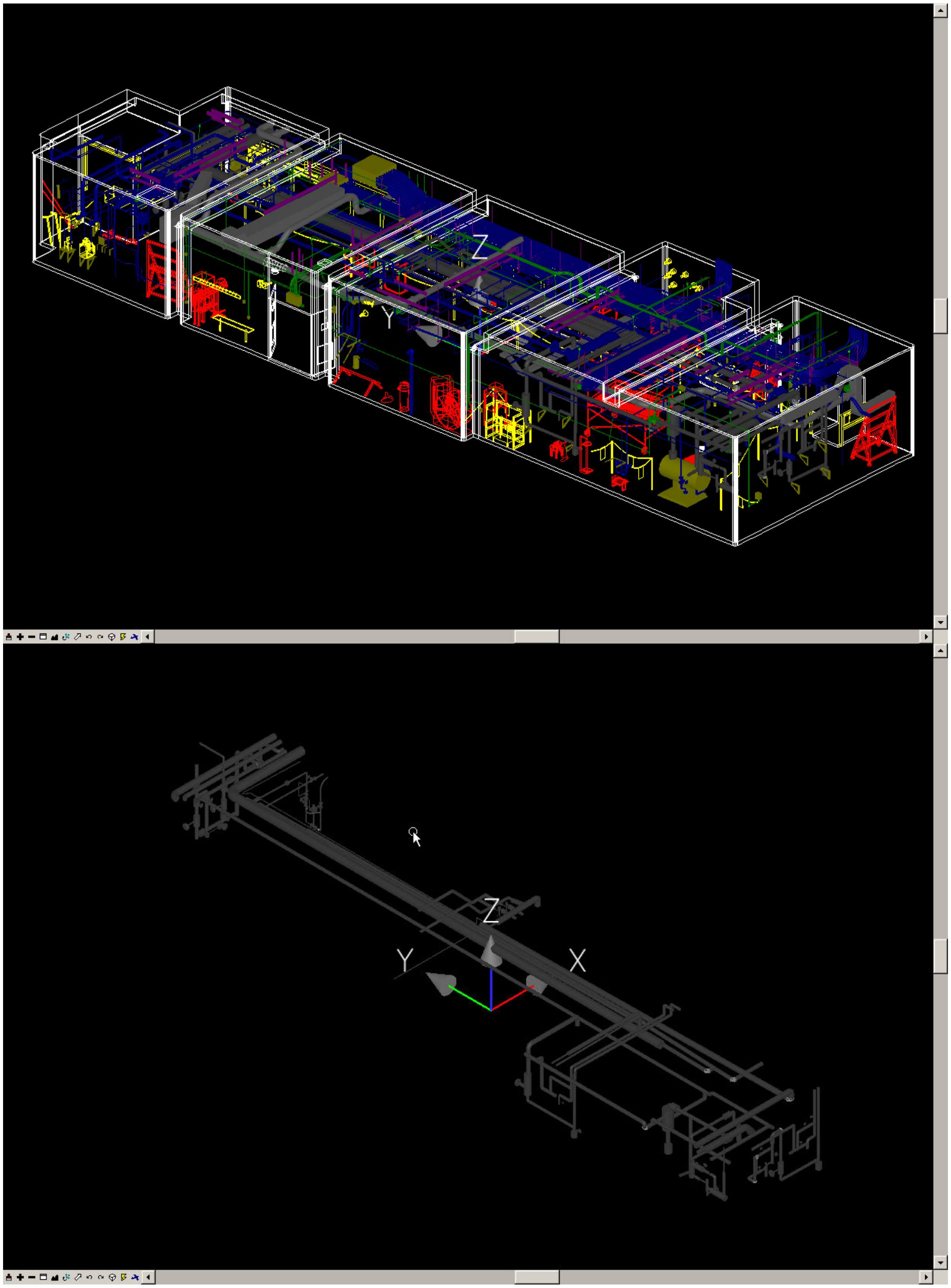

Figure 3. Rendering of the -14 Purification facility as an 'as-found' CAD drawing. The upper panel shows the entire facility, while the lower panel has all components except insulated piping digitally hidden.

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This level of resolution is more clearly depicted in Figure 4 where the view has been repositioned to the inside of the facility. Detailed features of the model are clearly visible, such as the individual piping and duct systems, sliding doors providing access to cells within the reactor facility, barricade chains and a workers toolbox. As part of the post processing, various features are classified to facilitate subsequent analysis and interpretation of the model features. In this representation, the various piping, duct and conduit systems are color coded. This differentiation is particularly useful to expedite the removal of specific layers of facility complexity to view specific features.

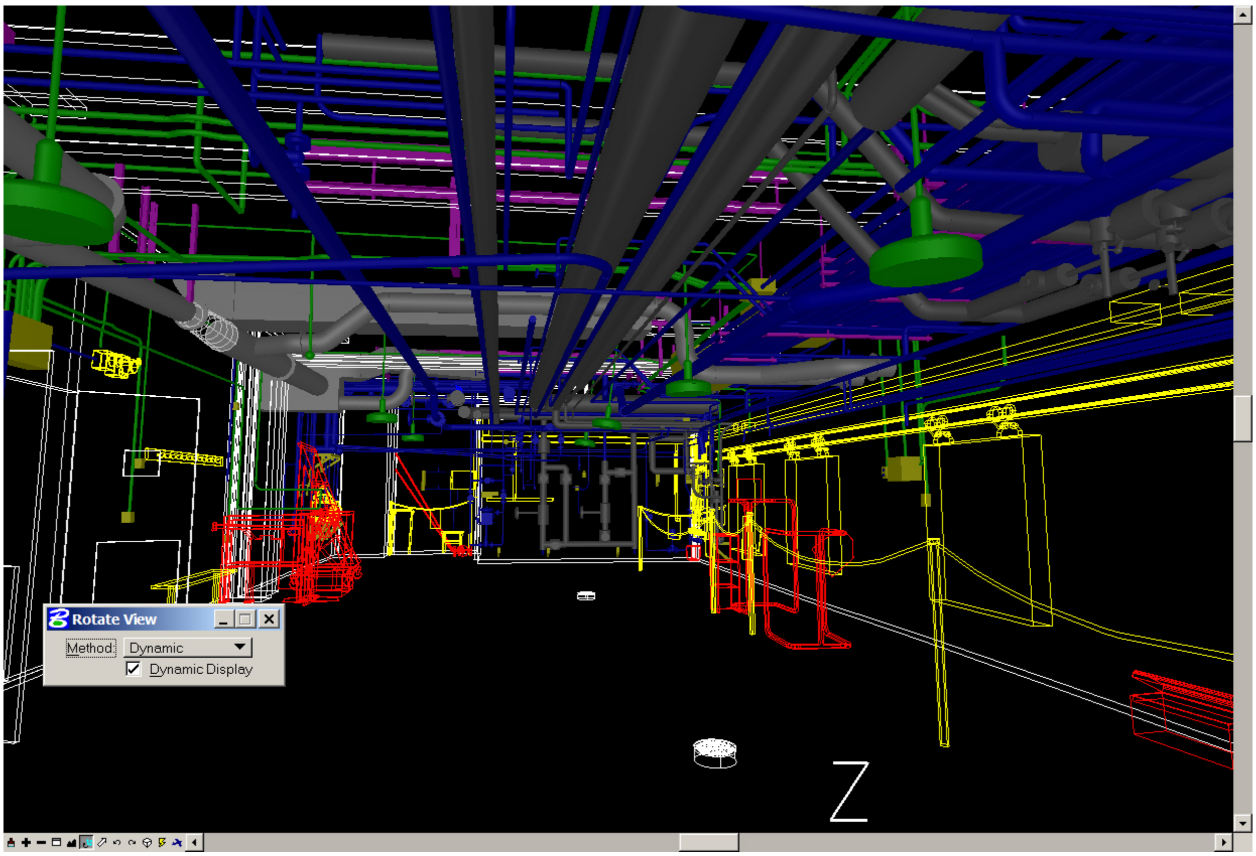

Figure 4. View of interior of the -14 Purification facility showing details of structures and equipment.

The preceding analysis was conducted using relatively simple CAD tools provided in the Bentleyview software package. This package, although not a full CAD package, can extract dimensional data from the model. Specific components of the model can be highlighted to obtain length, surface area and volume estimates that are needed for planning. More sophisticated and comprehensive analyses can be obtained with higher end CAD systems, but a significant amount of useful information can be extracted from the model at this level.

CONCLUSIONS

The demonstration of the robotically deployed laser imaging system was successful relative to the objectives of the study. The system was easily deployed on a robotic platform that was simple and provided all of the required functionality. For this demonstration, the wireless data transfer was not utilized, but both the robot and the laser system are capable of wireless control and data transfer. Of potential concern is the power system for the robot given the requirements for both navigation and data transfer, but this problem is likely easily resolved if it becomes a functional requirement for the facility. The FARO LS system carried its own power supply and experienced no power issues over the five hour deployment. A greater potential issue with data transfer is the construction methods for some of the facilities to be examined. Thick concrete walls and extensive use of rebar in construction may pose a greater challenge for wireless data transfer. The primary concern with tethered systems is potential entanglement of the power/communications tether in obstructions in the facility.

The real time imagery acquired during the project would be of great value for project planning by itself without the laser system, and robotic video deployment in deteriorated facilities should be considered in all cases. Between the on-board video and the real time laser acquisition, numerous potential obstacles and suspicious materials could be identified in the facility. Ladders, work equipment, various meters and gauges and facility barricades were identified at the time of data acquisition, as was the overall layout and complexity of the facility. These data alone would allow refinement of the initial worker entry strategy.

The resolution of the structural data was exceptional. All piping systems were reasonably identified, including those in stacked/bundled configurations. Multiple valves and control meters/panels were identified and located in a dimensionally and spatially correct fashion. Even with a low-functionality CAD system, the images could be manipulated to generate differing views of the room. Components could be selectively removed to provide better views of key structures. Dimensional data (length, surface area, volume) could be obtained for components that were individually selected in real time using the screen display. This capability would allow generation of take-off volumes even without more sophisticated CAD applications. Utilization of full CAD capabilities would speed this process considerably and provide products of higher value.

In conducting this study, one objective was to identify the potential limitations of the technology and to address modifications the strategy that might be appropriate. ACP personnel were invaluable in contributing to this analysis. Key limitations in the approach utilized included the following:

- D&D project managers frequently want the answer to important issues the next week, if not the next day. The two week turn-around for data processing was identified as a limitation.
- The project 'community' frequently tends to be well integrated among the engineers and operations personnel. This technology is not in common use and could be viewed as an extra, unnecessary addition to a well functioning program. Incorporation of CAD professionals into the project team may be a limitation and it is not reasonable to expect project personnel to be CAD capable.
- Some facilities that require such characterization include classified areas and/or components. The availability of cleared personnel to perform data post-processing is likely to be a significant limitation.
- Deployment of expensive equipment (e.g. laser imaging) into structurally or radiologically contaminated areas presents the potential that the equipment will be unrecoverable. Staged deployment of progressively more sophisticated equipment should be considered to meet project needs. It may also be possible to encase expensive components to prevent contamination.

Generally, the robotic deployment of characterization equipment should have wider utilization than appears to currently be the case. There are believed to be multiple causes of this limitation. One cause may be the expectation that involvement of robotic professionals will be expensive and delay the project.

While this can be a problem, numerous inexpensive and easily deployable robots are available that can accomplish simple tasks. In working with robot equipment developers, it is important to clearly define what the requirements are—and what they're not. For this class of applications, the robot is simply a 'mule' and does not require capabilities to manipulate. However, capabilities to navigate around and over obstacles may be essential. For initial facility characterization, good quality video is inexpensive and highly valuable for initial entry planning. This approach was useful at the Hanford Cribs [2] and will be of use here. As needs become better defined, robotic deployments of more sophisticated measurement equipment, while more expensive, must be weighed against the risk to personnel and the cost of mitigation against the personnel hazards.

ACKNOWLEDGEMENTS
This work was funded through the DOE Office of Deactivation and Decommissioning/Facility Engineering and conducted under DOE Contract DEAC-09-08SR22470 to Savannah River Nuclear Solutions, LLC.

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