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An Intelligent Inspection and Survey Robot

Authors:

Joseph S. Byrd

Contractor:

South Carolina Universities Research
and Education Foundation (SCUREF)
Strom Thurmond Institute
Clemson, South Carolina 29634-5701

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DISCLAIMER

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Joseph S. Byrd (jsbyrd@ece.sc.edu; 803-777-9569)
Department of Electrical and Computer Engineering
3A38 Swearingen Engineering Center
University of South Carolina
301 South Main Street
Columbia, SC 29208

Introduction

Large quantities of mixed and low-level radioactive waste contained in 55-, 85-, and 110-gallon steel drums are stored at Department of Energy (DOE) warehouses located throughout the United States. The steel drums are placed on pallets and stacked on top of one another, forming a column of drums ranging in heights of one to four drums and up to 16 feet high. The columns of drums are aligned in rows forming an aisle approximately three feet wide between the rows of drums. Tens of thousands of drums are stored in these warehouses throughout the DOE complex.

ARIES (*A*utonomous *R*obotic *I*nspection *E*xperimental *S*ystem) [Ref. 1], is under development for the DOE* to survey and inspect these drums. The robot will navigate through the aisles and perform an inspection operation, typically performed by a human operator, making decisions about the condition of the drums and maintaining a database of pertinent information about each drum.

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Objectives

The overall objective is to replace a weekly human inspection of drums using modern mobile robot, computer, and mechanical technology.

The integrity of each drum in storage is visually inspected weekly, according to regulations under the Resource Conservation and Recovery Act [Ref. 2], to determine if a drum has degraded to the condition that it should have its contents repacked into a new drum container. Currently, inspectors periodically roam the warehouses noting and reporting drum degradation. Typically the inspectors look for rust areas, streaks indicating leaks, dents, bulges, and tilting of the drums. These indicators identify *suspect* drums. The drums are stacked such that the side seam of the drum is in full view of the inspector. Empirical data has shown that a drum shows its first signs of degradation along this welded bead. A bar-code label is used to identify each drum. The bar-code is located to either side of the seam, in full view of the inspector. If the drum has degraded to the point that it warrants attention, the inspector identifies the drum using a

bar-code reader so that the drum can be retrieved by a fork lift and transported to the re-packing area.

Approach

The first phase of this three-phase project was a task-oriented, proof-of-principle phase in which demonstrations and reports were provided as the deliverables. The second phase was a technology integration effort to develop a single, commercializable prototype mobile robot capable of meeting many of the demands of the mission of environmental compliance and clean-up of DOE sites. During the third phase the prototype will demonstrated and evaluated in a DOE warehouse storage facility then productized for commercial availability.

An industrial partner, Cybermotion,[1] manufacturer of the Navmaster line of mobile robots was selected to join the university research and development team. This selection was based on the fact that the Cybermotion system is robust and has proven records in the areas of autonomous monitoring and security systems. Also, these systems are currently in use in other DOE and DOD applications.

Project Description

The Vehicle. Cybermotion, Inc. has developed a new 6-wheeled version of their Navmaster series of mobile robots that is the base mobile vehicle for ARIES. This new version consists of an improved and enhanced mobile platform (Model K3A)[Ref. 3] and a new subturret (Figure 1) that will permit turning around in a three-foot aisle. It has a capable ultrasonic imaging system used in navigation and collision avoidance and an automatic docking/charging system. Enhancements to the robot sonar system and a new lidar system have improved its ability to navigate in the drum aisles. Drum-

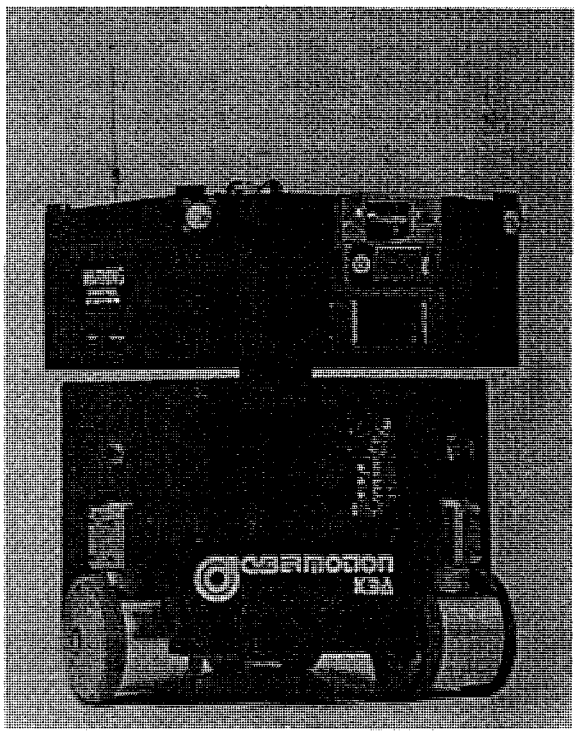

Figure 1
New Robot Base and Subturret

referencing algorithms and camera-positioning algorithms have been included in the primitive instruction set for the new robot.

Computers and Control: Computer systems and control enhancements have been made at the University of South Carolina (USC). The computer systems (Figure 2) consist of an onboard system and an off-board supervisory system. The onboard computer system, housed in the robot sub-turret, provides control of the inspection processes and manages other onboard activities. The onboard computer is a VMEbus system using a MIPS R3000 proc-

[1] Cybermotion, Inc., 115 Sheraton Dr., Salem, WV. (703) 562-7626.

essor board running the VxWorks[2] real-time operating system. The drum navigational algorithms, developed earlier in the project by USC and Cybermotion [Ref. 4], have been enhanced to accommodate the new robot.

Standard UNIX workstations are used for the offboard supervisory computers. The software is written to be portable across most UNIX systems and currently runs on Silicon Graphics, DEC, HP, and Sun workstations. Silicon Graphics systems are used for development purposes and some three-dimensional features require this system for acceptable performance. Provisions have been made for alternative representations in other systems. The offboard system provides three primary functions: *(i)* functional compatibility with the PC-based software provided by Cybermotion for control and programming of the basic robot, *(ii)* programming tools for creating the mission program, and *(iii)* the ability to monitor and control the robot during the inspection process. An assembler for the path language of the robot has been provided. This assembler operates in the DOS and UNIX environments.

Offboard computers networked via wireless Ethernet with onboard computers provide the high-level planning, monitoring, reporting, and general supervision of ARIES. Multiple control and monitoring stations may be employed. Planning the inspection task (the *mission*) begins with the implementation of a world representation of the robot's environment. A path planner automatically generates robot path programs for user-specified paths, based on the site description contained in the robot world. The mission program, used to control the inspection process, is down-loaded from the offboard system to the onboard computer where it is executed. The offboard systems may be used to monitor and control the system during the inspection process.

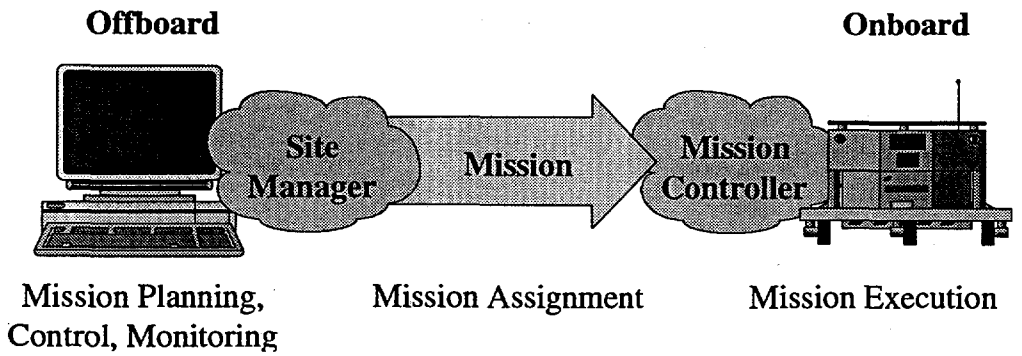

Figure 2.
Computer Systems for ARIES

Mechanical Systems: A camera positioning system (CPS), designed by USC and Cybermotion, capable of performing survey and inspection of drums in the warehouse has been fabricated by Cybermotion. The CPS consists of four separate inspection modules, one for each drum in a four-high stack. Each module includes a camera, bar-code scanner, and strobe lighting. For the

[2] Wind River Systems, 1010 Atlantic Ave., Alameda, CA 94501.

drum inspection process, at each stack of drums the CPS extends up and folds out to deploy the four inspection modules at various heights on the drums required by the vision system. Two "photo" positions are required for each drum. These positions are determined by requirements of the computer vision inspection system and are programmed as a table in the primitive instruction set. The CPS is retracted to its more compact position (Figure 3) for traveling in the warehouse en route to inspection

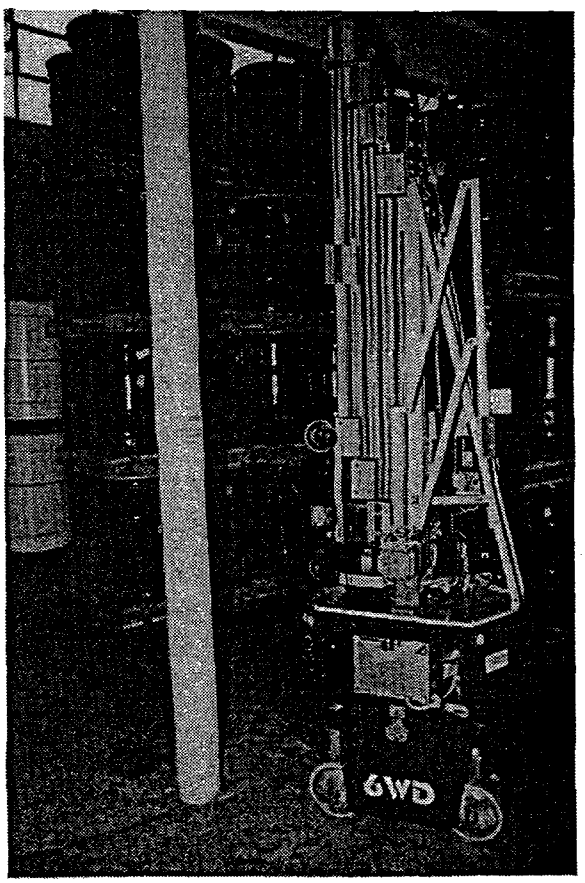

Figure 3
ARIES in Lowest Position

assignments and between drum aisles. It has an overall height of approximately eight feet in this collapsed position.

During inspection assignments in the various aisles of the warehouse, ARIES will encounter drums of three different sizes (55-

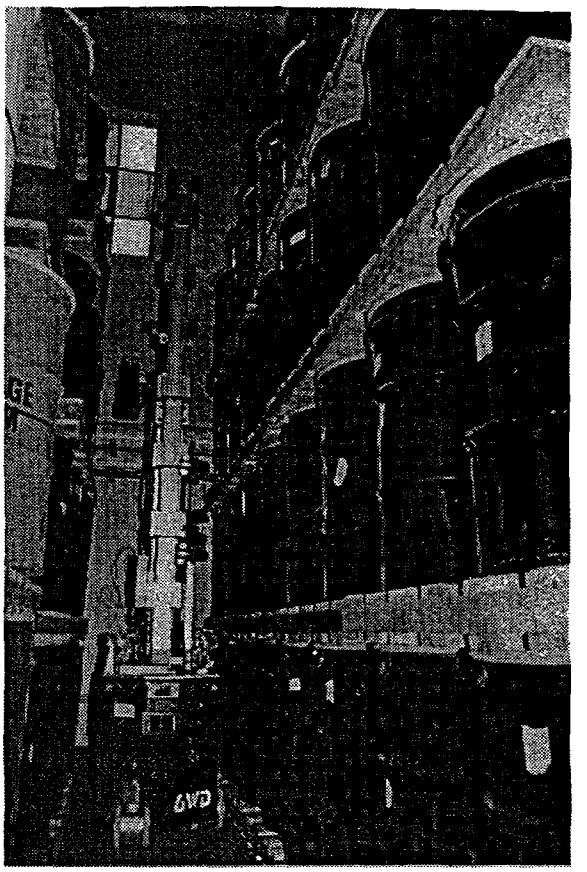

Figure 4
ARIES in 55-Gallon Drum Position

, 85-, and 110-gallon capacities) stacked up to four high. The system will determine the size of each drum stack and position the CPS accordingly to the required two positions per drum. The upper position for 55-gallon drums is shown in Figure 4.

Vision System. The application payload of the CPS includes computer vision and bar-code scanner modules developed at Clemson University (CU). The vision system [Ref. 5] is used to analyze the drums' external and visible conditions and to determine their structural integrity. The overall function of the vision module is to locate *suspect* drums and to report these conditions. Once drums have been located by the robot's navigation system, visual assessment of drum condition is primarily an

autonomous assessment of visible and quantifiable surface characteristics.

The visible surface blemishes which indicate probably drum failure are rust patches of approximately 0.5 x 0.5 inch size and paint blisters indicating internal surface rust. Basic sensor requirements for image delivery and image acquisition led to the specification of a color camera. Lighting for image acquisition has been carefully considered. The variability in site ambient lighting and power limitations of the mobile robot requires the use of a strobe-based image acquisition system. This ensures the on-robot illumination dominates ambient lighting and allows a reduced camera aperture and consequently increases imaging depth of field. A modular vision acquisition and analysis system is used. A learning algorithm is provided which adjusts the algorithm parameters according to information given by a human tutor.

Detail Survey & Inspection: A supplemental prototype dexterity package has been developed at CU to provide more sophisticated manipulations for more detailed inspection of the waste containers. A camera mounted on the end of a six degree-of-freedom revolute manipulator can be used in a telerobotic mode for close detailed inspection of the drum surface. The bar-code can be located and read using an integral camera and scanner. An additional sampling tool can be used to obtain surface samples of suspect areas and returned for operator analysis. This module will be demonstrated as a separate component during the Phase 2 demonstration at USC, but there are no plans for further development or testing at a DOE warehouse site since this is not a requirement in the current inspection process.

Radiation Hardening Study: A study has been conducted to determine the requirements for fabricating a radiation-hardened version of the mobile inspector [Ref. 6]. Requirements for the low-level warehouse drum inspections do not dictate radiation hardening, since the radiation levels of the inspection environment are low. However, future uses of such a mobile system in other applications may require a radiation-hardened system.

Accomplishments

Current mobile robot, computers, and mechanical technologies have been integrated to produce a practical commercial mobile robot system to be employed in a complex environment as a proposed solution to a vital National problem. The current ARIES prototype will be tested and evaluated at a DOE warehouse storage site and a commercial mobile system will be delivered to the DOE. Additional systems will be available from Cybermotion, Inc.

At the conclusion of Phase 2 a report will be available that includes plans and costs associated with the development of a radiation-hardened version of ARIES for applications that require high radiation considerations, such as decontamination and decommissioning operations.

Benefits

The mobile robot inspector, ARIES, is designed to relieve the warehouse inspector of the tedious and mundane task of inspecting warehouse-stored drums. Cost savings, reduced worker radiation exposure, improved documentation, improved quality with inspection consistency, as well as minimized disruptions to daily warehouse

operations, are some of the anticipated benefits from an autonomous inspection.

A commercial mobile system will be available to the DOE's environmental management program for use in drum storage inspection. It is anticipated that the system will be applicable to other DOE applications such as decontamination and decommissioning the nuclear sites.

Future Activities

A prototype demonstration will be conducted at USC on November 30, 1995. During 2QFY96 testing and demonstrations will be scheduled at a drum storage warehouse at the DOE Fernald site. Other test sites are under consideration.

Acknowledgments

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ARIES is a collaborative effort between Clemson University (CU), University of South Carolina (USC), and Cybermotion, Inc. The team members are: Joe Byrd (Principal Investigator and Project Manger), Jerry Hudgins, Bob Pettus, and Dave Rocheleau of USC; Darren Dawson, Fred Sias, and Bob Schalkoff of CU; Ed Hamilton and Angela Harrington of SCUREF; and, John Holland and Ken Kennedy, and staff of Cybermotion, Inc. Also, 10 graduate students at USC and CU have been invaluable team members. Cybermotion is under subcontract.

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