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An Intelligent Inspection and Survey Robot

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An Intelligent Inspection and Survey Robot

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Introduction

Very 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 five drums and up to 16 feet. The columns of drums are aligned in rows forming aisles approximately three feet wide between the rows of drums. Many tens of thousands of drums are stored in these warehouses throughout the DOE complex.

ARIES (Autonomous Robotic Inspection Experimental System) [Ref. 1], is under development for the DOE to survey and inspect these drums. The mobile robot will autonomously navigate through the warehouse and 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.

Objectives

The overall objective of this project is to autonomously inspect stored waste drums using modern mobile robotic, computer, and mechanical technologies. Since the robot operates more consistantly than human inspectors, the inspection process should significantly improve in quality. Collection of the drum database autonomously will provide a variety of computer generated reports.

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 walk through 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 on one side of the seam, in full view of the inspector. If the drum has degraded to the point that it

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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. Studies have revealed that significant improvements can be realized using robotic inspection techniques [Ref. 3].

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 developed and demonstrated a 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 was demonstrated as a drum inspection system at the Fernald TS-4 warehouse. Enhancements are underway based on lessons learned at Fernald. Two systems will be delivered to DOE.

An industrial partner, Cybermotion,[1] manufacturer of of security mobile robots, is a member of the university research and development team. This partner was selected based on the fact that the

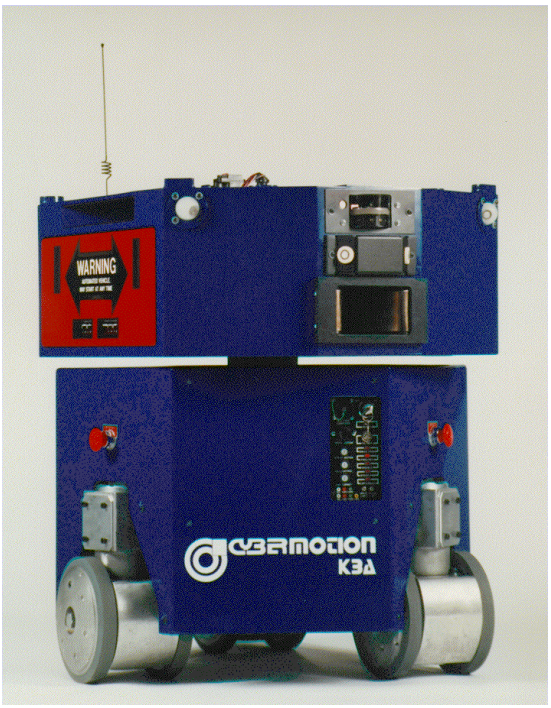

Figure 1
K3A Robot Base and Subturret

Cybermotion robots are robust and have proven performance records in numerous autonomous monitoring and security applications. Also, Cybermotion mobile robots are currently in use in other DOE and DOD applications. Including Cybermotion as a project partner insures that ARIES will be commercially available to DOE at the conclusion of the contract.

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

Project Description

The Vehicle. Cybermotion, Inc. developed a new 6-wheeled version of their previous Navmaster series of mobile robots that is the base mobile vehicle for ARIES (Figure 1). This new version consists of an improved and enhanced Model K3A mobile platform [Ref. 4] and a new subturret 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 large warehouses and in the drum aisles. Drum-referencing algorithms and camera-positioning algorithms have been included in the primitive instruction set for the new robot. The ARIES base vehicle is compatible with other standard security payload turrets available from Cybermotion.

Computers and Control: Computer systems and control enhancements have been made at the University of South Carolina (USC). The computer systems consist of an onboard system and an offboard supervisory system. The onboard computer system, housed in the robot subturret, provides control of the inspection processes and manages other onboard activities [Ref. 5]. The current onboard computer is a VMEbus system using a MIPS R3000 processor board running the VxWorks[2] real-time operating system. The drum navigational algorithms, developed by USC and Cybermotion during Phase 1 [Ref. 6], have been enhanced to accommodate the new K3A robot. Enhancements during the remainder of Phase 3 will include changing to the NT operating system for improved reliability and reduced cost.

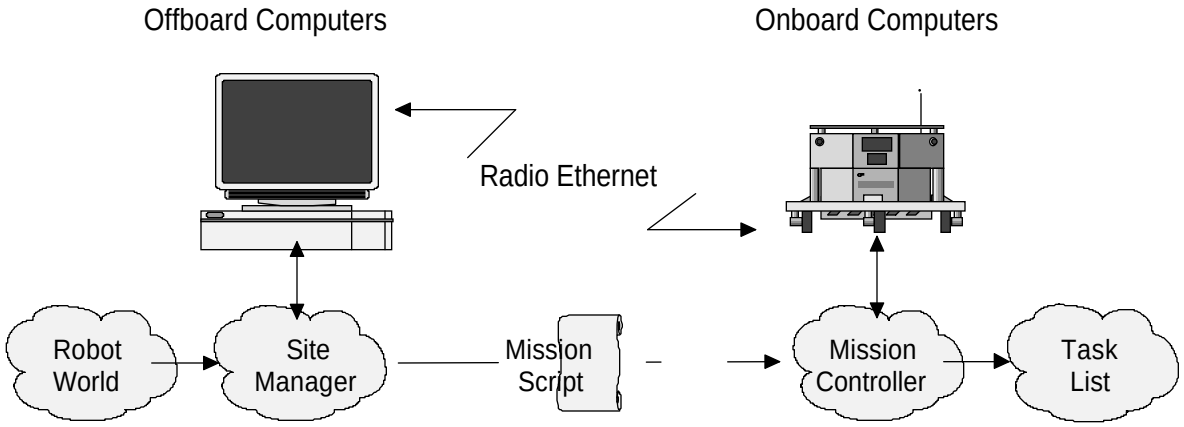

Figure 2.
Computer Systems for ARIES

Standard UNIX workstations are used for the offboard supervisory computers. The software is written to be portable across most UNIX systems. Silicon Graphics systems were used for development purposes and some three-dimensional features require this system for the desired 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

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

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.

Figure 3
ARIES in Stowed Position

Offboard computers networked via wireless Ethernet with onboard computers provide the high-level planning, monitoring, reporting, and general supervision of ARIES (Figure 2). 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 using the Site Manager software. A path planner automatically generates robot path programs (Mission Scripts) for user-specified paths, based on specifications from Site Manager. The mission program, used to control the inspection process, is down-loaded from the offboard system to the onboard computer Mission Handler where it is executed. The offboard systems may be used to monitor and control the system during the inspection process.

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 a single inspection module capable of inspecting columns of 55-gallon drums stacked up to five high and 85- and 110-gallon drums stacked up to four high. The inspection payload includes a camera, bar-code scanner, and strobe lighting. For the drum inspection process, at each stack of drums the CPS extends to the desired heights required by the vision system. Two "photo" positions are currently used at each drum position. These positions are

Figure 4
ARIES Navigating in Three-Foot Drum Aisle

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 stowed position (Figure 3) for traveling in the warehouse en route to inspection assignments and between drum aisles. This keeps the center of gravity at its lowest position. It has an overall height of approximately eight feet in this stowed position [Ref. 7 and 8].

During inspection assignments in the various aisles of the warehouse, ARIES will encounter drums

of three different sizes (55-, 85-, and 110-gallon capacities) stacked up to four high (five high for 55-gallon drums). The system will determine the size of each drum stack and position the CPS accordingly to the required two positions per drum. ARIES is shown during navigation in a three-foot aisle 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. 9] 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, paint blisters indicating internal surface rust, streaks indicating leaks, and dents. 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.

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 has been tested and evaluated at Fernald TS-4 warehouse (Figure 5). It will be enhanced and two commercial mobile system will be delivered to the DOE. Additional systems will be available from Cybermotion, Inc.

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 using specialized payload turrets will be applicable to other DOE applications such as decontamination and decommissioning the nuclear sites.

Based on discussions with various user site personnel it is apparent that many components of drum

storage and the inspection process are site-specific. It is anticipated that each autonomous inspection system will have customization based on the various standards and requirements. ARIES has been developed to accomodate for site-specific variations.

Figure 5
ARIES at Fernald TS-4

Current and Future Activities

Enhancements based on lessons learned during the Fernald TS-4 demonstration and evaluation are underway at the Cybermotion facility. The enhancements will include improvements in inspection throughput and system reliability. System production costs will be reduced wherever possible. USC and CU are supporting Cybermotion with the enhancements.

Discussions are underway with Los Alamos National Laboratory for evaluating ARIES at the LANL warehouse facilities during Spring 1997. The DOE Mixed Waste Focus Area is supporting these tests and evaluations.

Acknowledgments

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