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A ROBOTIC INSPECTOR FOR LOW-LEVEL RADIOACTIVE WASTE

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A Robotic Inspector for Low-Level Radioactive Waste

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Abstract

The Department of Energy has low-level radioactive waste stored in warehouses at several facilities. Weekly visual inspections are required. A mobile robot inspection system, ARIES (Autonomous Robotic Inspection Experimental System), has been developed to survey and inspect the stored drums. The robot will travel through the three-foot wide aisles of drums stacked four high and perform a visual inspection, normally performed by a human operator, making decisions about the condition of the drums and maintaining a database of pertinent information about each drum. This mobile robot system will improve the quality of inspection, generate required reports, and relieve human operators from low-level radioactive exposure.

The Problem

Waste generated at the Department of Energy's (DOE's) nuclear production facilities has been stored in 55-, 85-, and 110-gallon drums. Tens of thousands of these drums are located at DOE facilities, such as Fernald (OH), Oak Ridge (TN), Hanford (WA), and Idaho (ID). 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. Although the radiation level around the drums is considered to be relatively low and a non-hazardous environment for humans, continued exposure at this dose rate is undesirable.

Weekly visual inspections of the drum surfaces are required to determine if a drum has degraded to the condition that it should have its contents repacked into a

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new drum container. Currently, inspectors periodically patrol through the warehouses noting and reporting drum degradation. The drums are stacked such that the side seam of the drum is in full view of the inspector, since it has been found by experience that a drum shows its first signs of degradation along this welded bead. Typically the inspectors look for rust areas, streaks indicating leaks, dents, bulges, and tilting of the drums. These indicators identify drums that require special attention. A bar-code identification label is located to either side of the drum's 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.

Robotic Inspection

The new mobile robot inspector, ARIES, is designed to assist the warehouse inspectors who currently work in the low-level radioactive environment. The task of visual inspection is tedious, mundane, and potentially hazardous. 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 autonomous inspection.

An enhanced commercial mobile robot is used as the mobile platform for ARIES. Additional onboard and offboard computing facilities have been added. The application payload includes a computer vision module to perform a visual inspection of the waste drums. The robot system will locate and identify each drum, characterize relevant surface features (such as paint blisters, dents, rusted areas, etc.), and update a database containing the inspection information. Color image processing, using specialized algorithms, incorporates supplemental multi-strobe lighting and differential strobe-based structured lighting. An adaptive algorithm and learning concept, designed for unskilled computer operators, will train (calibrate) the vision system prior to the actual autonomous inspection process. A camera positioning system (CPS) positions the vision camera and any other required instrumentation packages (bar-code reader, etc.) to perform the inspection process for each drum. This is a power-efficient system designed to complement the features of the enhanced Navmaster[1] mobile robot system. A study was conducted to determine the requirements for manufacturing a radiation hardened version of ARIES for operation in higher radiation environments that require special equipment [4].

The Mobile Robot

Cybermotion, Inc., an industrial partner of the project team, developed a new version of their Navmaster Series of robotic systems that is the base vehicle for ARIES (Figure 1). The new robot consists of a new K3A [1] mobile platform, a new, more compact subturret that will permit turning around in narrow aisles, an enhanced and improved sonar (sound navigation and ranging) imaging system, a lidar (light

[1] Cybermotion, Inc., 115 Sheraton Dr., Salem, VA 24153, Tel. (703)-562-7626.

detection and ranging) navigation beacon system, and a camera positioning system (CPS) capable of performing the survey and inspection of drums stacked in the warehouse.

The Cybermotion system is robust and has proven records in the areas of autonomous monitoring and security systems. It has capable navigation and sonar collision avoidance systems, an autonomous re-charging system and an autonomous docking system to provide precise referencing of the robot in its environment. Drum-referencing algorithms and camera-positioning algorithms have been included in the instruction set primitives for the new robot. Enhancements to the robot sonar system and a new lidar system have provided the ability to navigate in the narrow drum aisles as well as the large open areas of the warehouse.

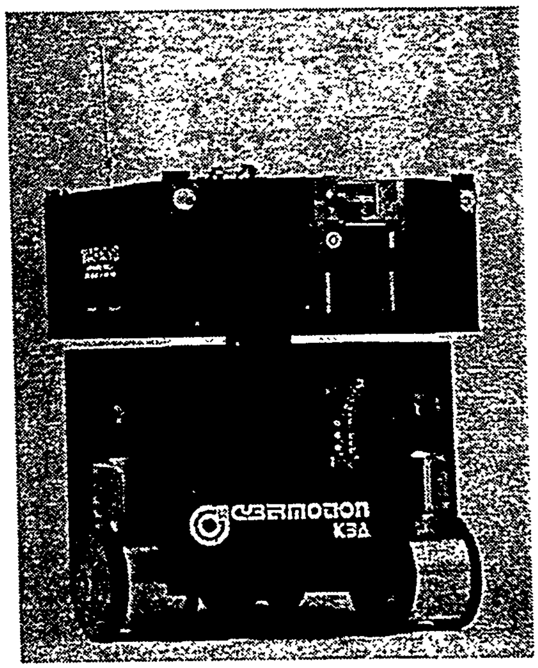

Figure 1. Cybermotion K3A Base and New Subturret

Computers and Controls

The computers and controls system (Figure 2) consists 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. The onboard computer is a VMEbus system using a MIPS R3000 processor board running the VxWorks real-time operating system. Low-level instructions used by the drum navigation algorithms onboard have been added to the basic instruction set of the K3A control computer. This was done to add the basic capability to the robot itself and to enhance the manner in which the algorithms utilize the sonar sensors of the robot.

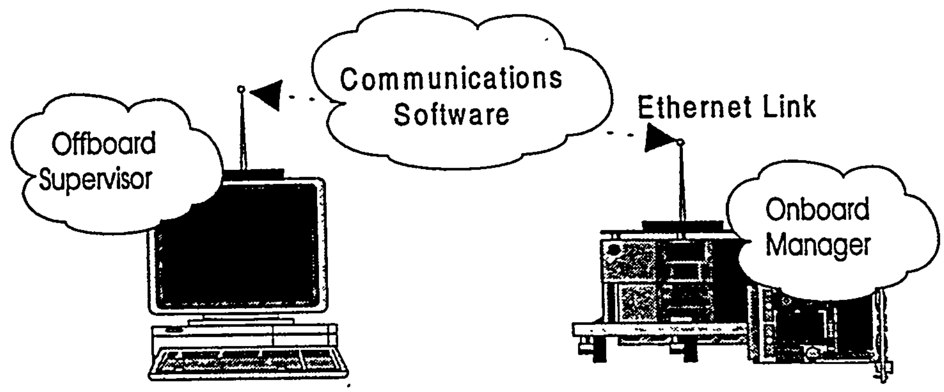

Figure 2. Computer Systems

Standard UNIX workstations are used for the offboard supervisory computers. 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 (PASM) for the programming language of the robot has been provided. This assembler operates in both 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 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 off-board 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.

Inspection Payloads

Mechanical Deployment. The mobile platform will transport an application payload that includes a mechanical deployment system designed specifically for this project [2]. The mechanical system, called the Camera Positioning System (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 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. Inspection modules for the three top drums are positioned by two linear actuators, a cabling system, and an interlocking five-rail mechanism. The inspection module for the bottom drum at floor level is positioned with a parallelogram special-case four-bar linkage. 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 for traveling in the warehouse en route to inspection assignments and between drum aisles. It has an overall height of approximately eight feet in this collapsed position (Figure 3).

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. The system will determine the size of each drum stack and position the CPS accordingly to the required two positions per drum.

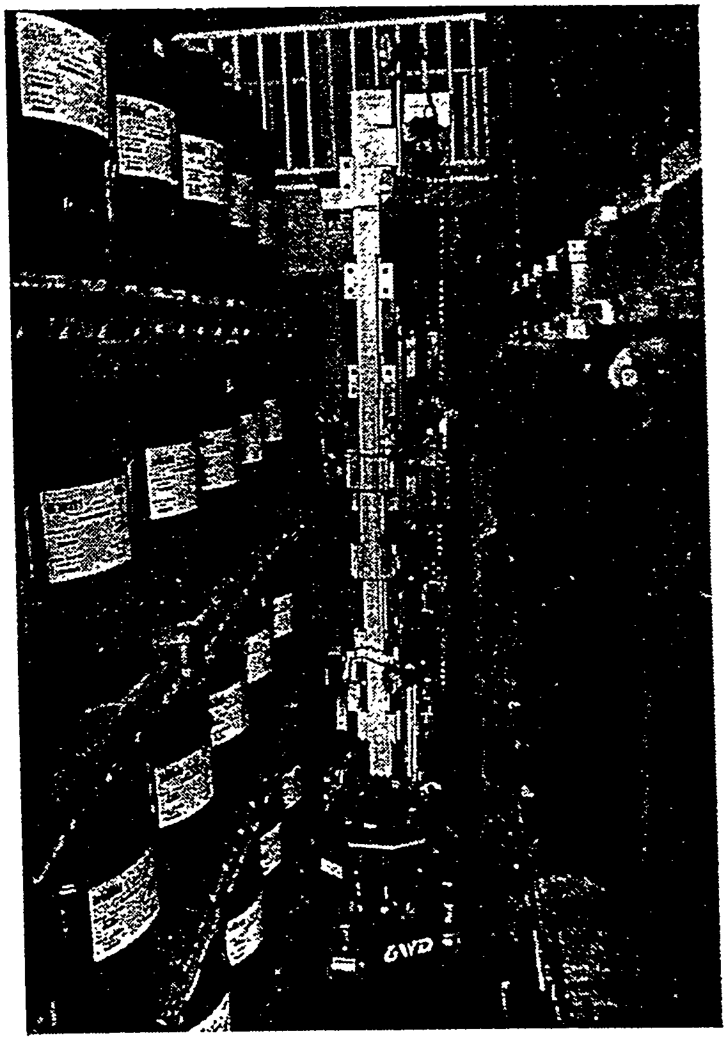

Figure 3. ARIES Inspecting Drum Aisle

Vision System. A major component of the inspection module is the vision system [3]. It 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 defective drum surfaces and to report these conditions. 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. The visual assessment of the drum's condition is an autonomous assessment of visible and quantifiable surface characteristics based upon acquired and segmented image data. Classifying a drum is implemented in four steps: segmenting the drum from the imaged scene, segmenting rust regions, segmenting paint blisters, and overall classification. Classification of a drum as *suspect* is done if the number of pixels in rusty regions or in paint blisters exceeds a specific threshold. A learning algorithm is provided which adjusts the algorithm parameters according to information given by a human tutor. The Nelder-Mead algorithm (Downhill Simplex Method) is the optimization procedure used.

Radiation Hardening Study

A radiation hardening study was performed on the system to determine the requirements and costs for fabricating a radiation-hardened version of the mobile inspector [4]. Requirements for the low-level 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, such as decontamination and decommissioning operations, may require a radiation-hardened vehicle.

Conclusions

Current mobile robot technology and computer technology have been integrated with mechanical enhancements 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 prototype will be tested and evaluated at a DOE warehouse storage site and a commercial mobile system will be delivered to DOE. Additional systems will be available from Cybermotion, Inc. The system and its components will be evaluated for potential use for other applications.

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