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by

E. Dudar, G. Teese, and D. Wagner

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

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E.M. DUDAR
G.D. TEESE
D.G. WAGNER

WESTINGHOUSE SAVANNAH RIVER COMPANY
SAVANNAH RIVER SITE
BLDG 773-A
AIKEN, SC 29808
803-725-2244

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E.M.DUDAR
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D.G. WAGNER

WESTINGHOUSE SAVANNAH RIVER COMPANY
SAVANNAH RIVER SITE
BLDG. 773-A
AIKEN, SC 29808
803-725-2294

ABSTRACT

The Robotics Development group at the Savannah River Site is developing an autonomous robot to perform radiological surveys of potentially contaminated floors. The robot scans floors at a speed of one-inch/second and stops, sounds an alarm, and flashes lights when contamination in a certain area is detected. The contamination of interest here is primarily alpha and beta-gamma. The contamination levels are low to moderate.

The robot, a Cybermotion K2A, is radio controlled, uses dead reckoning to determine vehicle position, and docks with a charging station to replenish its batteries and calibrate its position. It has an ultrasonic collision avoidance system as well as two safety bumpers that will stop the robot's motion when they are depressed. Paths for the robot are preprogrammed and the robot's motion can be monitored on a remote screen which shows a graphical map of the environment.

The radiation instrument being used is an Eberline RM22A monitor. This monitor is micro-computer based with a serial I/O interface for remote operation. Up to 30 detectors may be configured with the RM22A. For our purposes, two downward-facing gas proportional detectors are used to scan floors, and one upward-facing detector is used for radiation background compensation. SIMON is interfaced with the RM22A in such a way that it scans the floor surface at one-inch/second, and if contamination is detected, the vehicle stops, alarms, and activates a voice synthesizer. Future development includes using the contamination data collected to provide a graphical contour map of a contaminated area.

BACKGROUND

The Savannah River Site (SRS) is an isotope production facility operated by the Westinghouse Savannah River Company (WSRC) for the United States Department of Energy (DOE) and was established in the early 1950s to produce nuclear materials for defense purposes. The 777 km^2 (300 mi^2) complex is located in South Carolina and is composed of many separate plant operations, including fuel and target fabrication, nuclear reactors, chemical separations, and numerous waste handling facilities.

The Savannah River Laboratory (SRL) is also operated by WSRC, and its purpose is to provide technical research and support for site operations. The Robotics Development group (RD) is part of SRL, and its mission is to develop, apply, and support robotics and remote technology to improve safety, reduce personnel radiation exposure and contamination potential, increase productivity, and reduce manpower costs. Recent applications have centered upon the use of autonomous, mobile robots to perform surveys of floors which could possibly be contaminated.

The main building in SRL contains areas which are designated as RCAs (Radiologically Controlled Areas). In an RCA, radioactive materials are frequently handled to perform laboratory tests and to calibrate various instruments. Thus the potential for contamination is present and employees are required to exit the main building through portal monitors, which are capable of detecting alpha and beta-gamma contaminations on personnel. In January 1991, an employee detected both alpha and beta-gamma contamination on his shoes. The activity levels were about 30,000 disintegrations per minute (DPM) alpha and 20,000 DPM beta-gamma. Employees were required to wear plastic shoe covers in the building until the source of the contamination was found. Clearly, this scenario was undesirable, since it reduced employee effectiveness and the shoe covers contributed to waste handling problems.

The Health Protection group (HP) of SRL conducts floor surveys in the hallways of the SRL main building on a periodic basis. Typically, personnel manually scan floors at one-inch/second using hand-held portable monitors, or they smear a random location on the floor with a paper disk and analyze that disk for contamination. The problem with manual scanning is that it is labor intensive, cumbersome and inefficient to have humans walk at one-inch/second with an instrument in their hands, while the problem with smearing is that it is only conducted at random locations, i.e., it is virtually impossible to smear every square inch of floor surface.

Thus the idea of using a mobile, autonomous robot to perform floor surveys was conceived. This robot could perform the scanning much more reliably than the human counterpart. It can maintain its one-inch/second speed and can perform around the clock, thus covering more floor surface area. Furthermore, the mobile robot could be outfitted with memory boards for radiation data collection. This data could later be processed to provide a radiation contour map of a contaminated area. Since the environment that the mobile robot will be operating is made up of well-defined, unobstructed smooth surfaces, programming the paths that the robot will follow would be a rather straightforward task. Finally, with its collision avoidance system, the mobile robot would have no difficulty operating in the presence of humans or inanimate objects.

ROBOT DESCRIPTION

The mobile robot chosen to perform the floor survey missions is the K2A Navmaster. This mobile robot is a commercially available platform from Cybermotion in Roanoke, Virginia. Nicknamed

SIMON (Semi-Intelligent Mobile Observing Navigator), it is a three-wheeled vehicle, weighs about 300 lbs., and runs off a 24V battery (Figure 1). All three wheels on SIMON are locked together in steer and drive, a concept known as synchro-drive. Thus, when the vehicle turns, all three wheels turn in unison and trace parallel paths to each other. This synchro-drive technique provides excellent maneuverability, zero radius turns, and large tractive forces, since all three wheels are powered and always pull in the same direction.

SIMON is controlled over a UHF radio link and has two modes of operation, manual and automatic. In manual mode, an operator directs SIMON's motion via a joystick. While in automatic mode, SIMON executes a predefined path downloaded from a host computer to its navigation computer. Thus the actual path planning is done by the host computer, not onboard the vehicle. In either mode of operation, the host computer provides a map of SIMON's position, orientation and other robot parameters, such as battery voltage, motor currents, and obstacle range.

SIMON navigates autonomously by counting its wheel revolutions and translating them into linear distances. This navigation technique is known as dead reckoning and enables SIMON to sense position to 0.01' with an accuracy of 0.5%. SIMON calibrates its position and heading by docking with an optical docking beacon (Figure 2). The docking station has charging prongs with which SIMON mates to recharge the batteries. The docking station also includes an optical head that provides a structural infrared light beam to which SIMON aligns itself by the use of four infrared receivers. A narrow beam ultrasonic transducer on the dock provides the range information of SIMON with respect to the dock. SIMON docks with the beacon whenever the dead reckoning error is deemed significant enough to warrant it. This dead reckoning error is primarily due to the wheel slippages encountered when SIMON executes turns, as well as other factors.

SIMON could also calibrate its position and heading by using a sonic marker. A marker is a small corner reflector that returns a strong ultrasonic reflection. They are inexpensive passive devices made of sheet metal. If necessary, they will be located at different locations in the hallways of the SRL main building.

SIMON employs a collision avoidance system consisting of six wide-beam piezoelectric ultrasonic transducers. Two transducers are in the front, two in the rear, and one on each side of SIMON. These transducers operate at 75 KHz, thus permitting the detection of smaller objects and avoiding interference from noise sources. The transducers in the front and rear can detect an object 0.25" in diameter from 4" off the floor to 5' high. The rear transducers are active only when SIMON backs up.

The side transducers are used to protect SIMON's sides and also to implement advanced navigation techniques such as wall following and circumnavigation. Although dead reckoning is quite adequate in providing information on linear distance traveled, its position estimation accuracy is very sensitive to heading error. Wall following is thus the most powerful navigation aid in SIMON. The vehicle, using its side sonar, uses the position of the wall to correct its heading and position estimates on an axis normal to the wall. Circumnavigation is a technique whereby SIMON autonomously alters its path to go around an obstacle. However, in this state, the vehicle is acting on its own and this may not be desirable.

SIMON also has highly compliant front and rear bumpers. These bumpers serve as an additional safety system should the collision avoidance system fail. When contacted, the bumpers have limit switches which stop the vehicle. Vehicle motion may not resume until the limit switches go back to their normal position.

SIMON'S COMPUTER ARCHITECTURE

SIMON as a commercially available vehicle comes with three on-board computers. The device is flexible enough to allow end-users to put their own computers on board to meet their application needs. The computers on board use Z-80 CPUs and consist of the navigation computer (K2A), collision avoidance computer (CA2), and the vehicle docking beacon computer (VDB2). The CA2 interfaces to the headcards of the six ultrasonic transducers. Among other things, it processes the raw data coming from the transducers and provides information on obstacle ranges. The VDB2 is used primarily when SIMON attempts to dock with a docking beacon. It is through the VDB2 that SIMON calibrates its position and heading. The Robotics Development group added a STD-based Z-80 computer on board and named it SRL11. One advantage of using a Z-80 computer is that SRL11 would be able to use essentially the same communication software as used by the other Cybermotion computers. The SRL11's main function is to provide an interface with the radiation monitor and to collect data from it.

COMMUNICATIONS AND CONTROL

The vehicle has two internal communication links called the supervisory link and the control link (Figure 3). All the computers on board SIMON reside on the supervisory link and each computer has its own unique number. Typically, the host acts as the master computer. All other computers act as slaves on this link. A master computer differs from that of a slave in that a master can interrogate any other slave on its link for data; a slave, meanwhile, can only talk when interrogated. Thus the host uses the supervisory link to download programs, monitor robot performance, and control the modes of operation of slave computers.

A master computer uses two types of commands to communicate with slaves: a write of data and a request of data. Both are issued in a modified Intel hex data format. This data format contains a read/write byte, a computer number, starting memory address, and the number of bytes. The write command also contains the data to be written into memory, followed by a checksum. Through these commands, memory can be examined or altered for easy debugging. The writing and requesting of data into memory is handled as a background interrupt task in the software.

It is important to note that a slave computer cannot "talk" unless it is interrogated. Otherwise, bus contention problems could arise in the hardware. However, a slave computer with high enough priority can assert a "port request" line on the bus. If that slave has the highest priority, it immediately becomes bus master. SRL11 does this to issue a halt message to SIMON's navigation computer if its interface detects an alarm condition on the radiation monitor. After issuing the halt message, SRL11 releases the port request line to allow the host or other computers to become the bus master. Priority is determined by computer card position in the Turret Interface Panel (TIP), which is essentially SIMON's backplane.

The control link synchronizes events concerning navigation during autonomous operation of SIMON. The navigation computer (K2A) is the master on this link. The CA2 and the VDB2 computer reside on this link and act as slaves. When an autonomous mission is sent to SIMON, it is stored in the navigation computer. As the K2A steps through the program, it continuously reads the collision range calculation estimates from the CA2 and modifies the vehicle's speed accordingly. During docking, the K2A communicates with both the CA2 and VDB2 computers. Although the K2A is the default master on this link, jumper options on the TIP allows other computers to become the master.

SIMON'S HOST

The host computer serves as an integral part of SIMON. The host communicates with SIMON via the radio link. The software which runs on the host is called Dispatcher, and it is a Cybermotion product. Dispatcher is SIMON's path planning algorithm. It runs on an IBM PC-AT. To program SIMON using Dispatcher, the user must first define valid points in the workspace which SIMON could visit. Point-to-point path programs must then be written and assembled. These programs are called action files and they consist of simple commands and parameters pertinent to navigation. A cost is also attached to each action file. That cost could be related to distance or any other performance parameter. Thus, if it is desirable to go from point A to point E, and there is no straight path between them, Dispatcher will sort through its database of paths and merge together several action files in an attempt to find a valid path. If multiple paths exist, Dispatcher will download to SIMON the path with the least cost. A Dispatcher menu also provides the operator with an Autocad map of the workspace, and an icon provides a graphical picture of the vehicle's position and orientation relative to the workspace.

To monitor the activity of user-installed subsystems, a second host (IBM-PC compatible) must be used. Both hosts can communicate with SIMON through the Joy-Stick/Link Arbitrator (Figure 4). This unit contains a joy-stick for teleoperation and an arbitrator for dual hosts. The "A" host normally has the link, but host "B" may request it. When "B" is done, it must relinquish the link. In our setup, Dispatcher is host "A", while a program to monitor the activity of the contamination monitor runs on host "B". It is important to note that once a program has been downloaded, SIMON can still run if Dispatcher is discommunicated from it. Dispatcher's main usefulness during navigation is to display SIMON's positional coordinates as well as other parameters.

CONTAMINATION INSTRUMENT

The instrument chosen to monitor the contamination is the RM22A, a product of Eberline in Sante Fe, NM. The RM22A is a microcomputer-based radioactive contamination monitor which can operate with up to 30 different detectors, including gas flow proportional, scintillation, and Geiger-Mueller detectors. It uses the signals from these detectors to measure the radiation levels of objects being monitored. Furthermore, it performs pulse height analysis and is thus capable of discriminating between alpha and beta-gamma contaminations. The RM22A also features automatic subtraction of radiation background. Two serial I/O ports allow for remote computer control (via SRL11) and for a printer hookup. Individual detector alarm outputs, in the form of relays, open-collector transistors, and audible annunciators, allow for quick isolation of the contamination's presence.

SIMON'S CONFIGURATION

SIMON is configured with three gas proportional detectors, two facing downward to detect contamination and one facing upward to detect changes in the radiation background. P-10 gas cylinders mounted in SIMON's middle turret provide a constant purge of 30 cc/min of gas into the three detectors. P-10 is 90% argon and 10% methane, and is needed because radioactive contamination ionizes the gas more readily than it does free air. The two downward-facing detectors are arranged side by side, providing a scanning width of approximately 26". To attain reasonable alpha sensitivity, the detectors are positioned 1/2" off the floor surface. (The mean path of an alpha particle is about 1" in free air.)

The upward-facing detector is mounted on top of the downward-facing detectors, but it is shielded from them. This detector is dedicated to sensing high gamma radiation backgrounds, and its alarm threshold is set close to the nominal background. When the RM22A is initially activated, it goes into a "Background Update" mode whereby it updates the area's radiation background as a weighted average. After being placed into a "Counting" mode, the RM22A obtains a radiation count while automatically subtracting the background level from that particular count. For our application, the only time that the upward-facing detector alarms is if the background radiation changes significantly. Shielding between the floor surface and the upward-facing detector prevents floor contamination from being detected by this detector. Thus if the alarm on this detector triggers, SIMON will stop and update the background level before resuming its survey mission.

SRL11 is the interface between SIMON and the RM22A. It communicates with the RM22A through a serial port and constantly monitors the RM22A's open-collector outputs that signal high radiation levels. If SRL11 senses an alarm condition on the downward-facing detectors, it immediately sends a halt message to SIMON's navigation computer. It does this by asserting its "port request" line and becoming the master of the supervisory link. Thus the vehicle stops, sounds a loud audible tone, and flashes a red strobe light. If the vehicle is within radio range, a "Contamination Present" message is flashed across the screen of host "B" along with SIMON's coordinates. A real-time clock onboard the RM22A is used to time-stamp the alarm.

Once contamination is detected, the vehicle remains stopped until an operator walks up to it and pushes an "Alarm Acknowledge" pushbutton. Once this is done, a voice synthesizer onboard SIMON is activated. The voice synthesizer outputs a message indicating the type of contamination detected (alpha or beta-gamma) and its location (left or right detector). HP personnel could then be summoned to the area so as to conduct a more thorough investigation with more sensitive contamination equipment. Should the alarm be determined as bogus, the operator may then resume the vehicle's mission by pushing the "Alarm Acknowledge" pushbutton once again. This simply prompts SRL11 to send a resume message to SIMON's navigation computer. The advantage of this is that no path replanning and downloading is needed from Dispatcher, and mission resumption is initiated from onboard SIMON, not from a host which could be a considerable distance away.

An alarm condition occurring on the upward-facing detector prompts SRL11 to stop SIMON and place RM22A in a "Background Update" mode for approximately 25 seconds. SRL11 then issues a resume message to SIMON's navigation computer. This is all accomplished autonomously, and no human intervention is required.

SRL11 is also used for data collection purposes. After each counting interval, SRL11 reads all three detectors' counts over the serial link. The data is then compressed and stored in nonvolatile RAM memory. Up to 1 megabytes of RAM memory is dedicated to storing contamination data. This translates approximately into 48 hours of continuous, uninterruptable contamination survey time. After SIMON finishes a survey mission, the entire data is downloaded all at once over the radio link and is stored on the IBM PC-AT running on host "B". The data must be decompressed before it could be processed. Processing could be in the form of statistical analyses or graphical mapping techniques.

FUTURE

As of the writing of this paper, testing of the robot has been limited to a small area in the robotics laboratory. Eventually, the robot will be tested in the hallways of the main building in SRL and its performance evaluated by HP personnel. The testing will probably be conducted at night to reduce pedestrian interference with the vehicle.

One observation made during the initial testing is that of false alarm frequency. False alarms are inherent to most radiation monitors, and the parameters programmed into the RM22A yield a false alarm rate of about one per hour. This is clearly a nuisance, and work is underway to reduce the false alarm rate. One idea being considered is to have SIMON back up a detector's length (6 inches), reduce its speed to 1/2 inch/sec, and scan again the area where it had just encountered an alarm. It should be noted that reducing SIMON's scanning speed improves the sensitivity of the RM22A. If another alarm takes place over that area, then it is probable that contamination is present there and that the first alarm was a legitimate one. Otherwise, the first alarm will be assumed to be bogus and SIMON will continue its survey mission.

Another idea being considered is to construct graphical radiation contour maps of the areas surveyed by SIMON. Autocad maps of SIMON's environment already exist in Dispatcher's database, and superimposing contamination levels on these maps could provide valuable contamination versus position information. Finally, SIMON's survey capabilities need not be restricted to hallways and buildings. It could be taken to nuclear storage or spill sites to perform radiation survey missions.

ACKNOWLEDGEMENTS

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3. RM22A User's Manual, Eberline, Sante Fe, NM.

FIGURE 1. The SIMON Vehicle

FIGURE 2. SIMON with Docking Station

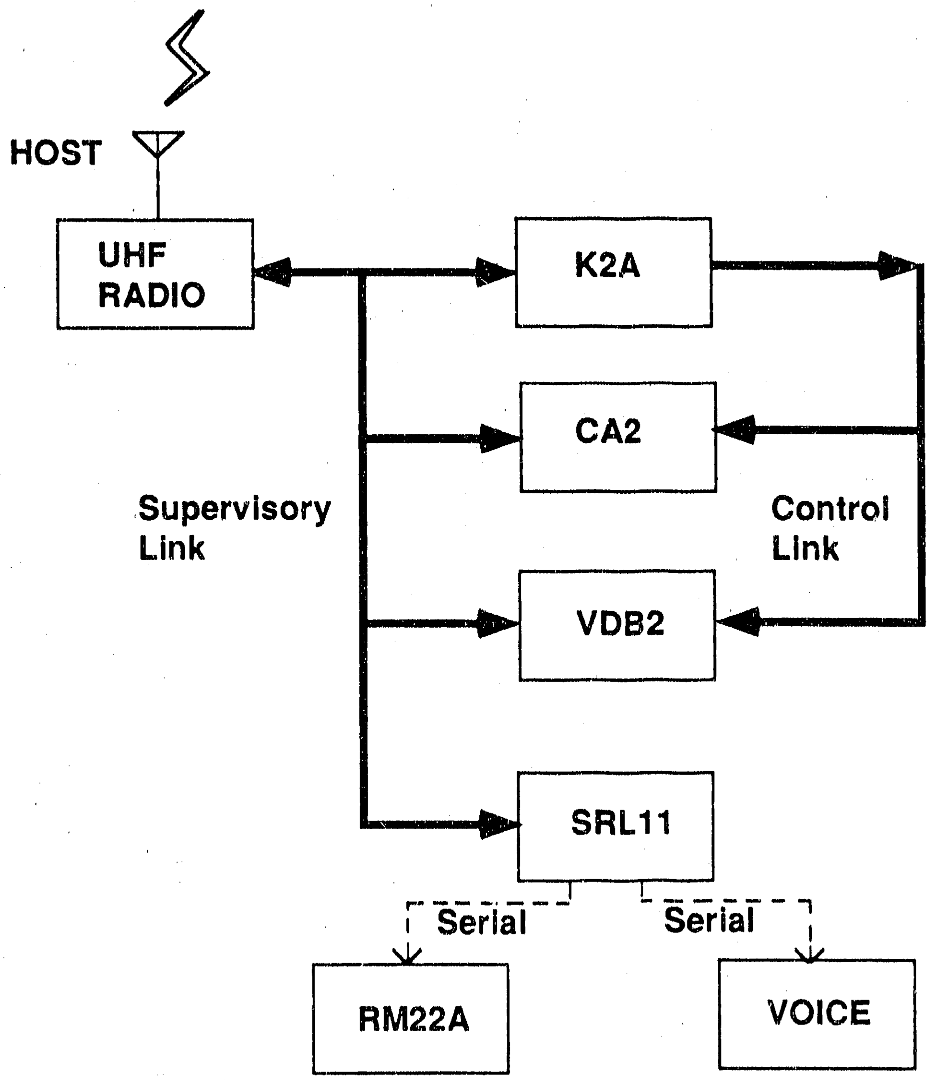

FIGURE 3. SIMON's Communication Links

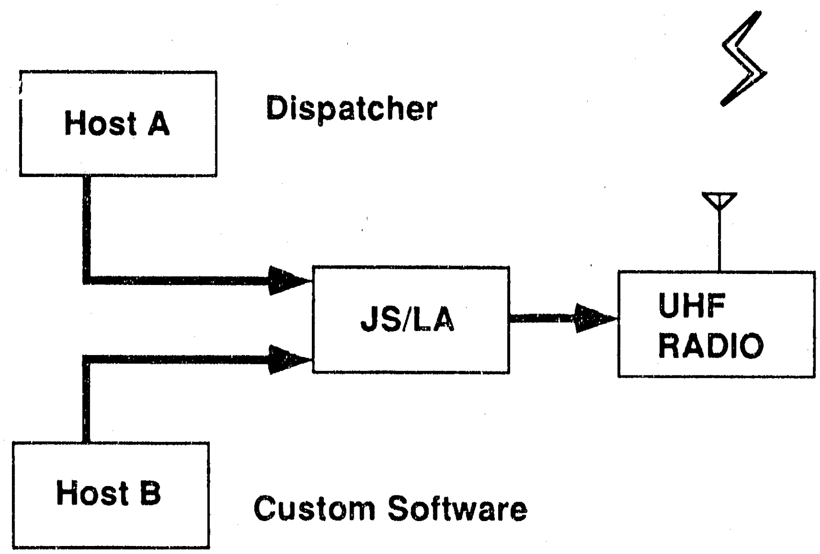

FIGURE 4. SIMON's Host Computers

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