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A MOBILE AUTONOMOUS ROBOT FOR RADIOLOGICAL SURVEYS

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ABSTRACT

The Robotics Development Group at the Savannah River Site is developing an autonomous robot (SIMON) 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 base, 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 uses an ultrasonic ranging system for collision avoidance. In addition, two safety bumpers located in the front and the back of the robot 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. Furthermore, the robot is capable of diagnosing and filtering out false contamination alarms that can occur spuriously. The robot does this by backing up and scanning the same area where it has just encountered an alarm. The robot is currently being used to survey B, C, and D wings of Building 773-A for potential contamination. Future development includes using the contamination data collected to provide a graphical contour map of a contaminated area.

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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 Technology Center (SRTC) is also operated by WSRC, and its purpose is to provide technical research and support for site operations. The Robotics Development Group (RDG) is part of SRTC, 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 SRTC 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. Employees working in an RCA are required to monitor themselves before exiting into a clean area. In addition, personnel working in clean or RCA areas exit the building through portal monitors. These portal monitors are capable of detecting alpha and beta-gamma contaminations. 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 SRTC conducts floor surveys in the hallways of the SRTC 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 a person monitor at a rate of 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. Also, smearing techniques are only capable of locating transferable contamination.

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. This characterization could provide a powerful tool for decontamination and decommissioning purposes. Since the environment that the mobile robot will be operating in 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. Once a path is downloaded, the vehicle acts autonomously until it reaches the end of that path. 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 structured 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. A corner of a building can also act as a marker. SIMON simply "pings" a marker to see how far it is away from it and corrects its position based on that information.

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, hall 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. The vehicle achieves this by "pinging" the wall with its side sonar and collecting eight data points. Once this is done, it tries to fit a straight line through the data points. If it succeeds in the line fit, then the heading is corrected according to the slope of the straight line. Otherwise, the points are deemed to be statistically invalid, and the vehicle rejects them and uses dead reckoning to navigate until it can find a valid wall again. Thus, the wall following routine is robust enough to allow variations in the wall structure (such as door openings).

Hall following is similar to that of wall following except that in hall following two walls are specified to be on either side of the vehicle, a primary wall and a secondary wall. If the vehicle starts getting bad line fits from one wall, it switches to the secondary wall and attempts to get a line fit from it. If it cannot get a good line fit from either wall, it simply dead reckons until it can find a good wall from which it can correct its heading.

Circumnavigation is a technique whereby SIMON autonomously alters its path to go around an obstacle. The vehicle uses its front and side sonar data to dynamically plan a path around an obstacle that is obstructing it. 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 between the radiation monitor and the vehicle.

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 slave on its link for data. A slave, meanwhile, can only talk when interrogated. The host uses the supervisory link to download programs, monitor robot performance, and control the modes of operation of slave computers.

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. It should be noted that the first slot in the TIP is reserved for a vehicle identification card should multiple K2A Navmaster vehicles be used in the same work space.

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 and is capable of planning and coordinating tasks for multiple K2A Navmaster vehicles. 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 path-planning menu allows the operator to plan a path before SIMON is dispatched on a mission. Thus, the operator will know a priori whether or not a certain destination is reachable from the current location and the path that will be traversed to get to it. Another Dispatcher menu also provides the operator with an Autocad map of the workspace, and an icon provides a graphical representation 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 Joystick/Link Arbitrator (Figure 4). This unit contains a joystick 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". Host "B" requests the link once every five seconds to check on the status of the contamination. If none is present, it relinquishes the link immediately. If contamination is present, it flashes a message on the screen indicating the presence of contamination along with the robot's X and Y coordinates. It is important to note that once a program has been downloaded, SIMON can still run if Dispatcher is out of radio communication range 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.

The RM22A has two modes of operation, a thresholding mode and a data-collection mode. In the thresholding mode, the instrument obtains a radiation count and compares it to a predefined alarm setpoint. If the radiation value exceeds the alarm setpoint, the RM22A will trigger its alarm indicators and suspend radiation counting. The alarm must be acknowledged by an operator before the RM22A resumes radiation counting. In the data-collection mode, the RM22A continuously counts radiation data over a specified time-interval. No alarms are triggered in this mode.

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, and 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 level. 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 continuous "Counting" mode, the RM22A obtains a radiation count every six seconds. It automatically subtracts the background level from each 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 alpha and beta radiations 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. 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 the alarm has been acknowledged, the vehicle backs up a distance of approximately one foot and activates an onboard voice synthesizer. The voice synthesizer outputs a message indicating the type of contamination detected (alpha or beta-gamma) and its location (left or right detector). The one-foot backup is needed to remove SIMON from the contaminated area and to allow HP personnel to conduct a more thorough investigation with more sensitive contamination equipment. Should the alarm be determined as bogus, the operator may 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 and beyond radio frequency range.

One observation made during the initial testing of the system is that of the false alarm frequency. False alarms are inherent to most radiation monitors, and the current parameters programmed into the RM22A yield a false alarm rate of about one per hour. This is clearly a nuisance, since HP personnel must come out and survey the area where an alarm takes place. Thus, SIMON was programmed to diagnose and filter out these false contamination alarms. The way SIMON does this is by rescanning the area where it has just encountered an alarm. Once the RM22A sounds an initial alarm condition, the SRL11 computer immediately "acknowledges" the alarm and halts the vehicle. This automatic "acknowledgement" forces the RM22A to return to "counting" mode to obtain more counts. With the vehicle halted, the RM22A obtains two contamination counts. If no alarm condition is initiated during these two counts, then SRL11 instructs the vehicle to back up a detector's width (approximately six inches) and obtain two more counts. If another alarm takes place over that area, it is probable that contamination is present there and that the first alarm was a legitimate one. Otherwise, the initial alarm will be assumed to be bogus and SIMON will continue its survey mission. This false alarm diagnosis is fully autonomous and thus no operator intervention or path replanning is required from the host end.

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. The RM22A is also programmed with a "Background Update Time" parameter. The default value for this parameter is one hour. Thus, after each hour, SIMON stops and updates the background level before resuming its survey mission.

Once the RM22A is put into data-collection mode, SRL11 can be used for data collection purposes. After each counting interval, SRL11 reads all three detectors' counts over the serial link. It also reads the vehicle's X, Y and azimuth values from the K2A computer. The data is then compressed and stored in nonvolatile RAM memory. Up to 1 megabyte 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 raw radiation/position data is decompressed on the host end after being downloaded from SIMON and the processed data is then stored into a file. It is noteworthy to mention that while the radiation data obtained from the RM22A is with respect to the detector's coordinates, the positional data obtained from the K2A computer is referenced to SIMON's center. To make the contamination data more meaningful and accurate, the X and Y coordinates of SIMON's center are transformed to those of the detector's centers. This is a simple transformation since the detectors are a fixed distance from SIMON's center and only this fixed distance and SIMON's azimuth are required to accomplish the transformation. With the radiation and position data, a 3-D map could be constructed to graphically illustrate contamination levels at different locations in an environment. This map could be a powerful tool for decontamination and decommissioning purposes.

RESULTS (TESTING)

As of the writing of this paper, the robot has been used to survey B, C, and D wings of Building 773-A on a periodic basis. These wings are fairly long, and a typical survey mission takes up to four hours. To reduce pedestrian interference with the robot, the surveys are performed at night. During the day, an operator dispatches SIMON to perform a survey mission of a specific wing. The robot then mates with its charging station and waits there until midnight before dispatching on its mission. At 11:00 P.M., it turns on a solenoid valve which causes P-10 gas to purge through the gas-proportional detectors. At midnight, it dispatches on its mission and surveys about 75% of the floor area of that specific wing. SIMON scans the area of the floor that people walk on. HP notified us that whenever they have found contamination in corridors in the past, it usually originated in a laboratory and spread to the corridors by people leaving the laboratory room and walking through the corridor. Thus, there is no real need to scan every square inch of floor surface, only the area of the floor that is most heavily walked upon. At the end of its survey mission, it returns to its docking station and turns off the P-10 gas flow. HP personnel have been trained to operate the robot should it stop and find contamination. No contamination has been found by the robot. Finally, all three wings have been characterized on 3-D maps, and results have shown that the background radiation levels vary significantly from one wing to another.

FUTURE

An 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. 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. A project to develop a robot similar to SIMON, except with a narrower base to ease navigation, is currently being considered by RDG. This narrow-aisle robot would be used to survey the floors of a DOE waste-storage warehouse.

ACKNOWLEDGEMENTS

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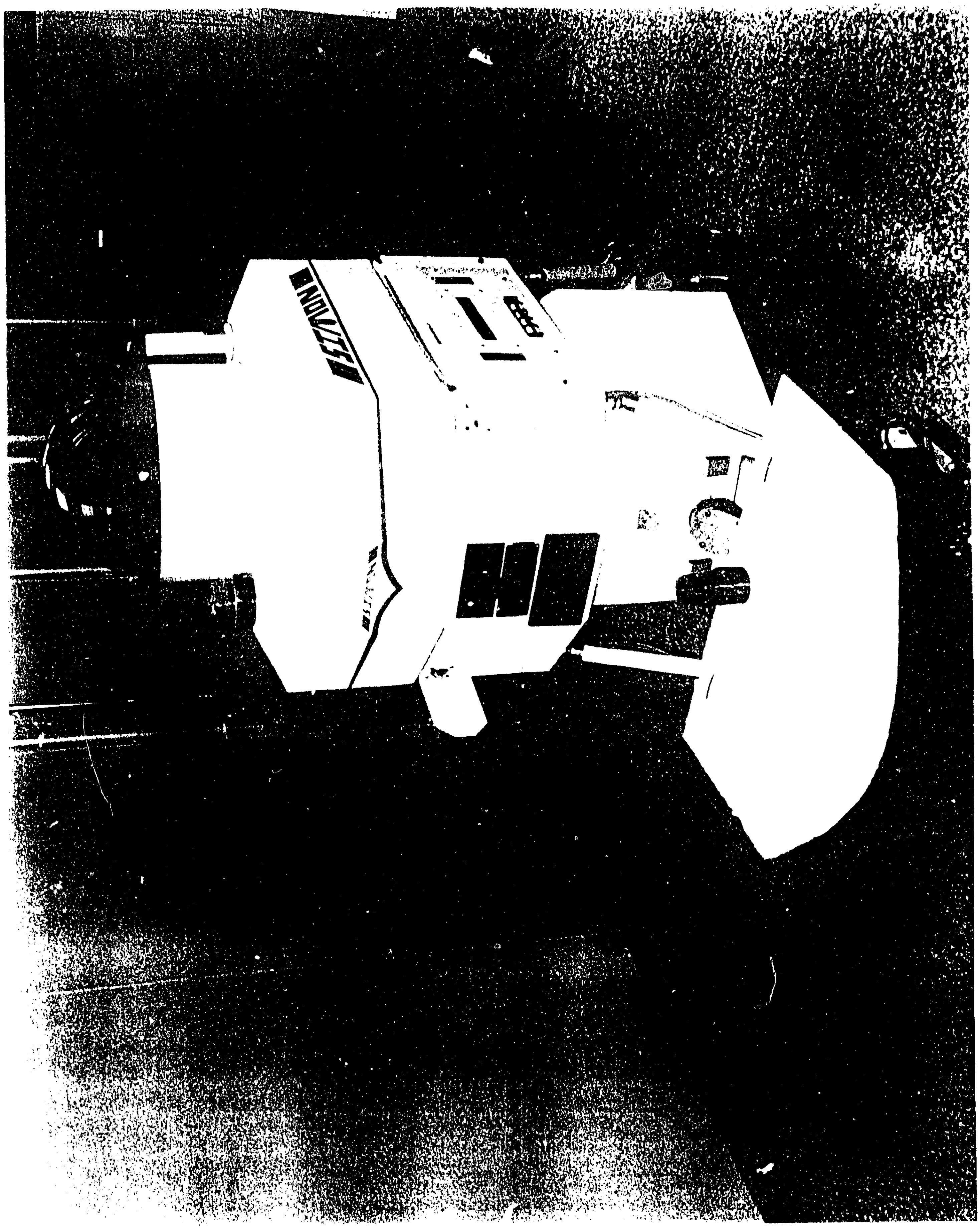

FIGURE 1. The SIMON Vehicle

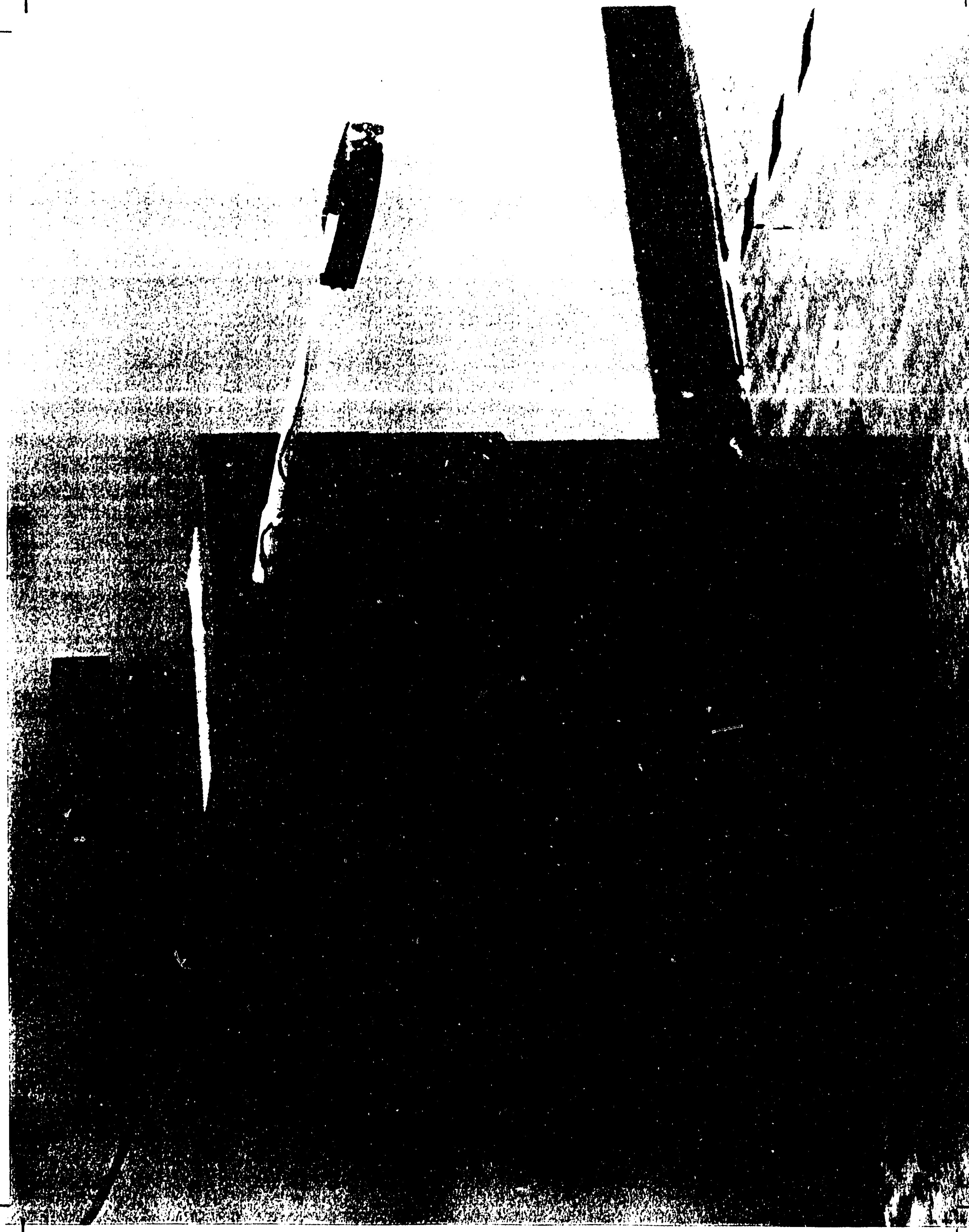

FIGURE 2. SIMON's Docking Beacon

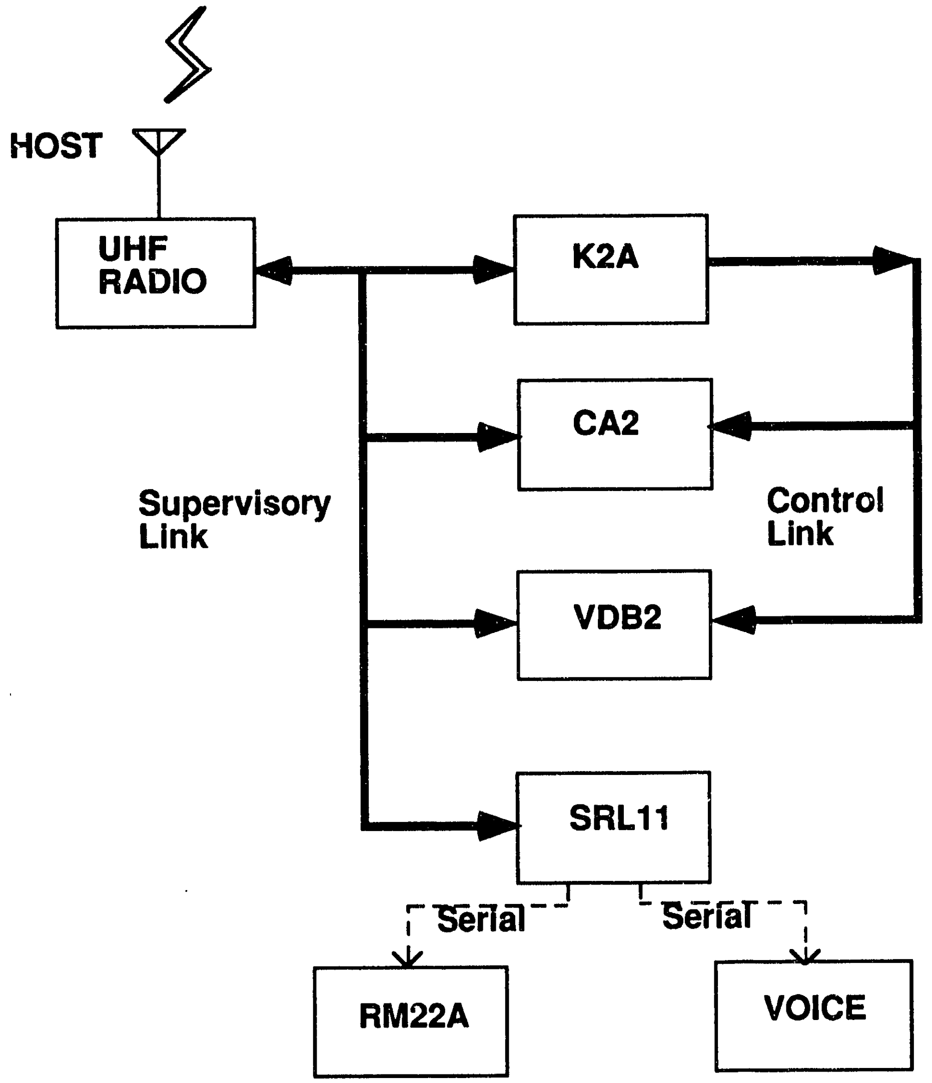

FIGURE 3. SIMON's Communication Links

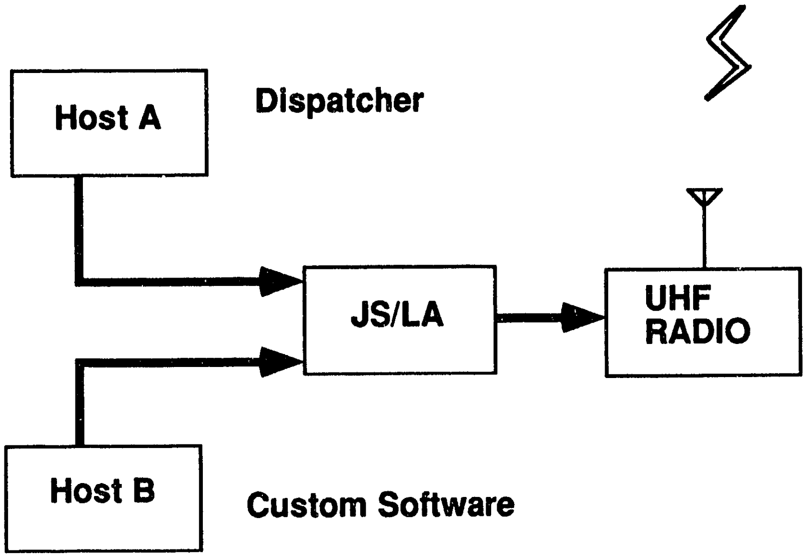

FIGURE 4. SIMON's Host Computers

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