An Overview of Sensor Needs for Robotic Cleanup of Hazardous Waste

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SAND--90-2032C
DE91 005311

ABSTRACT

In considering operational needs for future robotic cleanup of chemically and radiologically hazardous waste sites, the necessity for sensors becomes immediately apparent. Sensors are required to determine the current state of the robot, the characteristics of the operational environment, and the status of robot-environment interactions. It is envisioned that sensors will be essential to the entire environmental restoration, waste management, and waste minimization process. Before remediation efforts can begin, the contents of the waste site must be characterized to determine chemical and radiological hazards and identify physical obstacles. During the remediation process, sensors will be required to monitor and control operations and categorize extracted wastes. After remediation efforts, sensors will be needed to inspect and verify the thoroughness of the removal processes. This paper will review some of the types of sensors that will be needed for these applications and summarize some design considerations unique to hazardous waste site cleanup applications.

INTRODUCTION

In considering operational needs for future robotic cleanup of chemically and radiologically hazardous waste sites, the necessity for sensors becomes immediately apparent. Sensors are required to determine the current state of the robot, the characteristics of the operational environment, and the status of robot-environment interactions. It is envisioned that sensors will be essential to the entire environmental restoration, waste management, and waste minimization process. Before remediation efforts can begin, the

[1]This work was performed at Sandia National Laboratories and supported by the U. S. Department of Energy under Contract #DE-AC04-76DP00789.

contents of the waste site must be characterized to determine chemical and radiological hazards and identify physical obstacles. During the remediation process, sensors will be required to monitor and control operations and categorize extracted wastes. After remediation efforts, sensors will be needed to inspect and verify the thoroughness of the removal processes.

In many instances, new, robust sensors will enable remote survey and remediation operations that previously would have required direct human involvement at the waste site. For example, non-contact, sensor-based remote characterization surveys will provide two important advantages. First, the use of remote sensing technologies will result in less human radiological exposure. Second, remote, non-contact surveys will reduce the required quantity of core and other direct samples of the waste and thus reduce the generation of new contaminated waste during characterization. The advantages noted in this example of a sensor-rich, remote survey can be extended to many of the other characterization and remediation operations required for waste site cleanup.

ROBOT INTERNAL STATE SENSORS

Internal state sensors are used to determine the current physical status of the robot. These sensors measure the robot's current end-effector position, velocity, acceleration, joint torque, kinematic configuration, link curvature and other aspects of the robot's state. Typical robot internal state sensors include: joint encoders, joint resolvers, tachometers, accelerometers, strain gauges, torque sensors, load cells, and external robot location sensors. Although this technology has been the focus of extensive technology development during recent years, some novel specialized internal state sensors specific to waste cleanup applications will require development. In addition, most of these sensors will need to be adapted to operate in the anticipated severe chemical and radiological environments associated with waste sites during extended periods of operation. For example, some of the more radioactive underground storage tanks within the DOE complex are estimated to emit hundreds of rad(Si)/hr at the surface of the waste. One estimate of some of the hotter tanks at the Hanford Site suggests surface dose rates of 400 rad(Si)/hr[1]. This would result in an accumulated dose of 3.5 Mrad/yr. For reference, many pressure sensors used in nuclear reactors[2] only experience 10^5 rad(Si) during their useful life, although most are rated at 2 - 5 x 10^7 rad(Si).

Without careful selection of radiation hardened components, many electronics based sensors will fail at significantly lower accumulated dose than 1 Mrad(Si). For example, manipulators and robots frequently use optoelectronic encoders to report the angular position of the mechanical linkage joints. This information is essential for remote teleoperation or autonomous control of manipulators and robot arms. Unfortunately, many of these encoders utilize silicon based phototransistors and photodiodes which are particularly susceptible to radiation damage; performance in these devices begins to degrade at accumulated dose levels as low as 0.1 Mrad(Si)[3,4].

CHARACTERIZATION SENSORS

Sensors will also be needed to characterize the waste site's physical, chemical, and radiological environment for successful robotic operations. Physical characterization of a waste site's contents will be required to plan the remediation process. The physical characterization process will identify obstacles to be avoided during manipulator motions and locate regions requiring special attention. This survey will also help determine appropriate remediation procedures. Prior sensing of physical characteristics associated with different waste regions should enable better choices of robot end effectors and remediation procedures. Before remediation activities begin, physical measurements of the waste viscosity, bulk density, temperature, physical hardness, thermal conductivity, particle size distribution, shear strength, and friction coefficients would be useful[5]. Objects in the workspace should be identified and their location, extent, and mass should be measured if possible. Surface profile measurement should also be made to provide position information of mounds, bumps, and other non-distinct obstructions that may be present. In addition to the waste site contents, the physical and geological structures in and surrounding the waste site will need to be sensed and monitored to prevent further environmental damage.

Chemical sensing of the waste will be required to determine the anticipated effects of the waste on the robot, the potential for explosion or fire, the magnitude of the health hazard, and the appropriate waste disposal technique. Typical chemical sensors include gas chromatographs, mass spectrometers, atomic emission spectroscopy instruments, fluorescence instruments, hydrogen detectors, humidity detectors, and laser spectroscopy instruments. Integrating information from multiple types of chemical sensors can provide valuable insights into the best technique for handling the waste. For example, multiple miniature chemical sensors may need to be arranged in close proximity to each other on a remote controlled survey arm to infer important information about the flammability of the waste, the potential for explosion, and the corrosive potential of the waste on the remediation equipment.

Radiological sensors will be needed to determine the type of radioisotopes present in the waste and their level of radioactivity. Gamma spectroscopy techniques combined with spatial information from the robot arm moving the gamma detectors can be used to determine and map the species of radioisotopes present. Broadband gamma techniques can be used to create detailed spatial maps of regions with high levels of radioactivity although special shielding may be required to identify some species in the presence of large background signals. This information will also be useful to assess the human health hazards of the waste and to determine the ultimate disposition of the removed waste.

SENSORS FOR ROBOT-ENVIRONMENT INTERACTIONS

Sensors to monitor the interaction between the robot and the environment are necessary for real-time robotic control and for alerting a human operator of developing difficulties. Incomplete knowledge of the waste site environments necessitates sensor rich, closed loop control in many robotic remediation operations. Due to the extremely hazardous content of many waste sites, remediation operations will require robust sensors to monitor remediation processes and inform human operators of abnormal conditions. In the more common mode of human directed (teleoperated) manipulator operations, process monitoring sensors will be needed to provide continuous information directly to the human operator. Examples of interaction sensors include force sensors, tactile sensors, machine vision, and proximity sensors. Multiple vision sensors, ultrasonic proximity sensors, tactile "touch" sensors, and force sensors may be required to approach a tank wall, contact the wall, and carefully scrape objects off the wall. The vision and ultrasonic sensors will provide the operator or the robot controller with approach distance information; the tactile sensor will identify the time of contact and direct the controller to switch from free space motion control to in-contact motion control; and the force sensor will control and monitor the applied forces to prevent damage to the wall. In addition, this class of sensors includes those devices required to monitor end effector tooling parameters such as payload weight, suction status, steam/air pressure, cutting temperature, and tool sharpness. Continuous knowledge of the end effector status will be required to perform in-process control of the remediation processes and alert the control system to abnormal situations requiring operator intervention such as a clogged nozzle or a dull tool.

SENSOR DESIGN CONSIDERATION

In addition to identifying groups of sensors that appear to be important to future robotic waste cleanup activities, sensor design criteria must also be considered when discussing future sensor needs. For many sensors needs described above, sensing technologies exist but have only been demonstrated for applications in conventional industrial environments. In the anticipated severe chemical and radiological environments associated with many waste sites, additional sensor development, testing and evaluation will be required. In addition to environmental durability and conventional sensor criteria (e.g. high accuracy, high resolution, low drift, repeatable operations, low hysteresis, rugged, low cost, etc.), sensors for waste cleanup applications will probably need to meet several other stringent requirements. These additional requirements include the following: light weight to enable deployment by a limited payload robot; miniature to meet limited size constraints; radiation hardened to enable cost effective, continued operation after moderate accumulated dose levels of ionizing radiation; high temperature capable for extended sensor use at elevated temperature; remote maintenance and remote calibration capable; safe response due to sensor failure, loss of power, or exposure to electromagnetic interference; free from spark generating electro-mechanical mechanisms to diminish explosion hazards; remote, automatic self-check capable; sealed to keep environmental contamination out of the sensor housings; capable of being decontaminated; the external housing should be corrosion resistant; cost effective useful life; and designed to minimize the generation of additional hazardous waste at the end of sensor's useful life.

In considering sensors for applications in robotic systems for remediating hazardous waste sites, designers should be aware of the extremely hazardous environment in which these sensors must operate. Synergistic effects from radiation, chemical corrosivity, and elevated temperatures may make many "reliable" sensors unacceptable for hazardous waste applications. In addition, certain operational considerations, such as remote repair/replacement, may become primary selection criteria.

ACKNOWLEDGEMENT:

The author wishes to thank Dr. John Feddema, Dr. Jack Hudson, Dr. Steve Thornberg, and Dr. William Drotning all at Sandia National Laboratories, for their help in preparing the information presented here.

REFERENCES:

1. W. I. Winters, L. Jensen, L. M. Sasaki, R. L. Weiss, J. F. Keller, A. J. Schmidt, M.G. Woodruff,"Waste Characterization Plan for the Hanford Site Single-Shell Tanks", DOE Report, WHC-EP-0210 Aug. 1990.

2. J. E. Hall and D. Ko, "A Pressure Transmitter for Nuclear Reactors" in Sensors - The Journal of Machine Perception, Nov. 1990, Vol. 7, #12, pp 19-27.

3. C. E. Barnes and J. J. Wiczer, Radiation Effects in Optoelectronic Devices, Sandia National Laboratories technical report #SAND 84-0771, Albuquerque, N.M., May, 1984.

4. A. H. Kalma and W. H. Hardwick, "Radiation Testing of PIN Photodiodes", IEEE Trans. Nucl. Sci. Vol. NS-25, #6, Dec. 1978, pp. 1483-1488.

5. K. L. H. Morris, A. F. Shattuck, and W. A. Covert, "Selected In-Tank Property Measurement Methods for Hanford Site Single-Shell Tanks", Sept. 1990. Westinghouse Hanford Company, WHC-SA-0935-FP.

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01 / 25 / 91