Abstract. The Stored Waste Autonomous Mobile Inspector (SWAMI) is a prototype mobile robot designed to perform autonomous inspection of nuclear and hazardous waste storage facilities. The onboard control system, consisting of three Motorola 68030-based microcomputers, controls a number of subsystem components including barcode readers, cameras, and a radiation detector. The control system software, running under the VxWorks real-time operating system, is designed toward the client-server model and is implemented in C++. GENISAS, a communication library developed by the Sandia National Laboratories, is used extensively. Much of the onboard software was generated by a custom code generation tool called Moses.

Keywords: autonomous robots, mobile robots, automated inspection, hazardous waste storage, waste management

1 Introduction

In 1989, U.S. Department of Energy (DOE) Secretary James Watkins established a plan of action outlining a 4-pronged set of research activities to enhance the DOE’s ability to conduct environmental restoration and waste management (ER&WM) operations (Department of Energy, 1992a). The primary goals of the DOE under this initiative are to conduct ER&WM operations:

- safer—reduce worker exposure through remote operation and control
- faster—increase speed and productivity by enhancing capability and automation
- cheaper—quicker completion of tasks and life-cycle reduction of costs

In 1990, visits to DOE sites including Fernald, Idaho National Engineering Laboratory, Savannah River Site, Hanford, and Rocky Flats identified needs and requirements. Waste management operations, including inspection of nuclear and hazardous waste storage facilities, was identified as a primary need. The development of remotely operated and automated visual inspection systems was identified as a requirement (Department of Energy, 1992b).

The Robotic Technology Development Program (RTDP) was created by the DOE to facilitate development of robotic applied technologies to satisfy site requirements (Department of Energy, 1992b, c). The goal of the RTDP is to develop and deploy robotic technologies ranging from bench-scale research and development to full-scale technology demonstration.

Long-term plans are to house nuclear and hazardous waste permanently in underground storage facilities. However, underground permanent storage capability will not be available for several more years. In the near-term, nuclear and hazardous waste is stored in temporary storage facilities at the various DOE sites. Federal and state regulations require periodic inspection of these storage facilities to insure storage vessel integrity and verify inventory. Currently, personnel are required to enter the facility to check for leakage, spillage, and signs of deterioration. This procedure exposes personnel to elevated radiation levels and actually generates more waste material since the protective garments themselves must be disposed of as hazardous waste (Department of Energy, 1994; Peterson & Ward, 1994, 1995).

The University of South Carolina (USC) and the Westinghouse Savannah River Company (WSRC) have developed a prototype mobile robot designed to perform autonomous inspection of nuclear waste storage facilities. The Stored Waste Autonomous Mobile Inspector (SWAMI) autonomously navigates and inspects rows of waste storage drums stacked three-high on each side. SWAMI reads drum barcodes, captures drum images, and monitors floor-level radiation.
SWAMI is a full-scale, automated visual inspection system and participated in a week-long technology demonstration for industry, government, and academia, held at the Savannah River Site in November of 1993. SWAMI continues to serve as a research vehicle at WSRC. Work on a follow-on system, called SWAMI II, is in progress at WSRC and is scheduled to go into service at Fernald in 1995.

This paper discusses the design and development of SWAMI, emphasizing the onboard control system hardware and software architecture. Comparison to two other similar systems, currently in development, is given. The overall system design is discussed and a typical mission scenario at a temporary nuclear waste storage facility is presented. Each subsystem is described in detail and the design of the onboard control software is discussed. Lessons learned from the SWAMI project and opportunities for future work are identified.

2 Comparison to Other Systems

Two other programs, funded by the DOE, are being developed in parallel with the SWAMI systems. Lockheed Martin, formerly Martin Marietta, is developing the Intelligent Mobile Sensing System (IMSS) and is currently working on a second generation system (Byler et al., 1995). The University of South Carolina and Clemson University are currently developing the Autonomous Robotic Inspection and Experimental System (ARIES) (Byrd, 1995).

ARIES and SWAMI are based on commercially available robotic vehicles. ARIES uses a Cybermotion K3A vehicle and SWAMI uses a Transitions Research HelpMate vehicle. The IMSS vehicle is based on technology originally developed for the Mars rover program.

ARIES features onboard image processing being developed at Clemson University. The image processing software for the IMSS is being developed by Lockheed Martin and is based on the Khoros image processing package. Image processing for the phase I IMSS system is performed off-board but will be done onboard in the phase II system. The SWAMI system, described in this paper, only captures and stores images and has no onboard image processing capability. SWAMI II, currently under development at WSRC, will use a version of the Lockheed Martin image processing software that will run onboard.

The IMSS uses the VRTX real-time operating system for the onboard control systems. ARIES and SWAMI use the VxWorks real-time operating system. The IMSS uses a Force single board computer, based on the Motorola 68030, and various I/O boards and controllers on a VME backplane. ARIES uses a Heurikon R3500 board with integrated I/O and serial communication ports. SWAMI uses PEP single board computers, also based on the Motorola 68030, and peripheral boards on a VME backplane.

All three systems use TCP/IP-based communication. ARIES and IMSS use custom communication libraries. SWAMI uses the GENISAS communication library developed by the Sandia National Laboratories as a standard package for DOE robotic applications. Both ARIES and SWAMI use an Arlan radio Ethernet communication link to achieve wireless communication to off-board host computer workstations. The phase I IMSS system requires a communications tether but the phase II system will employ wireless communication technology.

All three programs offer capable automated inspection systems. Sponsoring parallel and varied development efforts provide the DOE with a rich research base to draw on for future development. SWAMI II and ARIES are to go into service at Fernald and the IMSS system is intended to go into service at Hanford.

3 Overall System Design

SWAMI is a mobile robotic platform, based on the Transitions Research Corporation (TRC) HelpMate robot (Robotics World, 1994). Subsystem components, including barcode readers, video cameras, and radiation detectors, have been added to the TRC vehicle. SWAMI is dispatched on an inspection mission by an operator interacting with a graphical user interface. The operator can manually control subsystem functionality and monitor vehicle position and status in real-time via the user interface screens. Vehicle position and radiation counts are plotted on a map of the facility.

Wireless communication with the vehicle is achieved via an Arlan radio Ethernet communication link. All communication with the off-board host computer and all subsystem functionality is coordinated by the onboard control system. SWAMI is operated in one of two modes. In manual mode, the onboard control system acts as a slave to the off-board host computer. In manual mode, all actions are under the direct control of the operator. In automatic mode, the onboard control system autonomously controls and coordinates SWAMI's subsystems. Figure 1 shows the overall system architecture.