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ROSIE: A MOBILE WORKSTATION FOR DECONTAMINATION AND DISMANTLEMENT OPERATIONS

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4.4 Rosie: A Mobile Worksystem for Decontamination and Dismantlement Operations

CONTRACT INFORMATION

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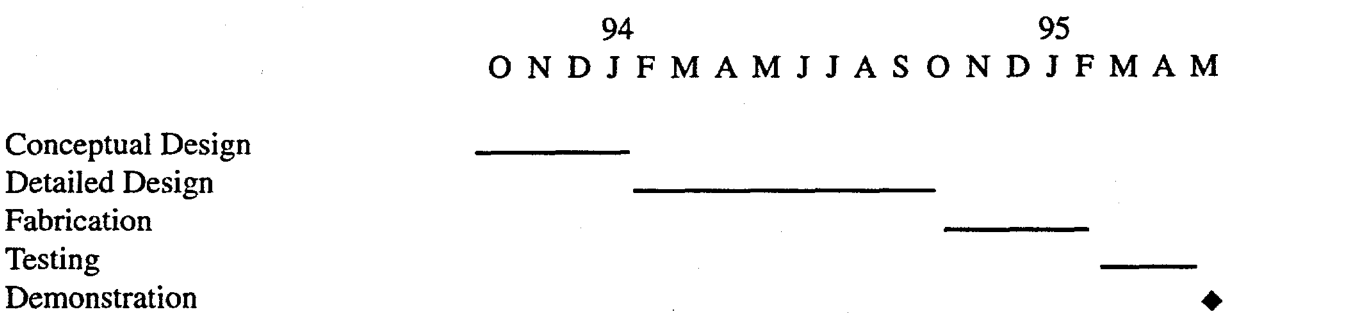
Period of Performance	October 1, 1992 to June 1, 1995	
Schedule and Milestones	FY 94/95 Program Schedule	



OBJECTIVES

RedZone Robotics, Inc. and Carnegie Mellon University's Field Robotics Center have undertaken a contract to develop a next-generation worksystem for decommissioning and dismantlement tasks in Department of Energy (DOE) facilities. This project is funded by the DOE's Environmental Management Office of Technology Development through the Morgantown Energy Technology Center. Currently, we are in the second phase of this three phase effort and are completing the design of the worksystem. Within this project RedZone is designing and fabricating a worksystem: Rosie.

Rosie will include a locomotor, heavy manipulator, control center, and control system for robot operation. The locomotor is an omnidirectional platform with tether management and hydraulic power capabilities. The heavy manipulator is a high-payload, long-reach system to deploy tools into the work area. The heavy manipulator will be capable of deploying systems such as the Dual-Arm Work Module—a five degree-of-freedom platform supporting two highly dexterous manipulators—or a single manipulator for performing simpler, less dexterous tasks. Rosie will be telerobotic to the point of having servo-controlled motions which can be operated and coordinated through the control center.

BACKGROUND INFORMATION

As reported by many sources within the DOE complex, the requirements for a worksystem are very diverse, ranging from human-scale manipulation tasks to large, industrial-scale equipment removal. While it is impossible to build one system capable of meeting all of the DOE's Decontamination and Dismantlement (D&D) needs, we have selected a concept capable of addressing a wide variety of tasks. The concept was developed based on our understanding of the DOE's needs as well as the need to perform a hot demonstration in the third phase of this project. The location chosen for the demonstration has dictated the general specifications for the machine, whereas the broad nature of the DOE's needs has dictated the philosophy of the design.

Technical guidance and leadership has been provided by Dr. William R. Hamel, the DOE D&D Robotics Technology Development Program (RTDP) Coordinator. This has allowed us to build a machine compatible with other equipment already under development within the Robotics Technology Development Program.

Iodox

The location chosen for a demonstration is a site within the Integrated Process Demonstration (IPD) facility located at the Oak Ridge National Laboratory adjacent to the Robotics and Process Systems Division. IPD was built to demonstrate the integrated operation of pilot-scale prototype equipment and processes to be used in advanced reprocessing plants. Within IPD facilities exist to examine areas such as off-gas treatment, fluid transfer, and dissolution studies. The particular piece of equipment targeted for Phase III demon-

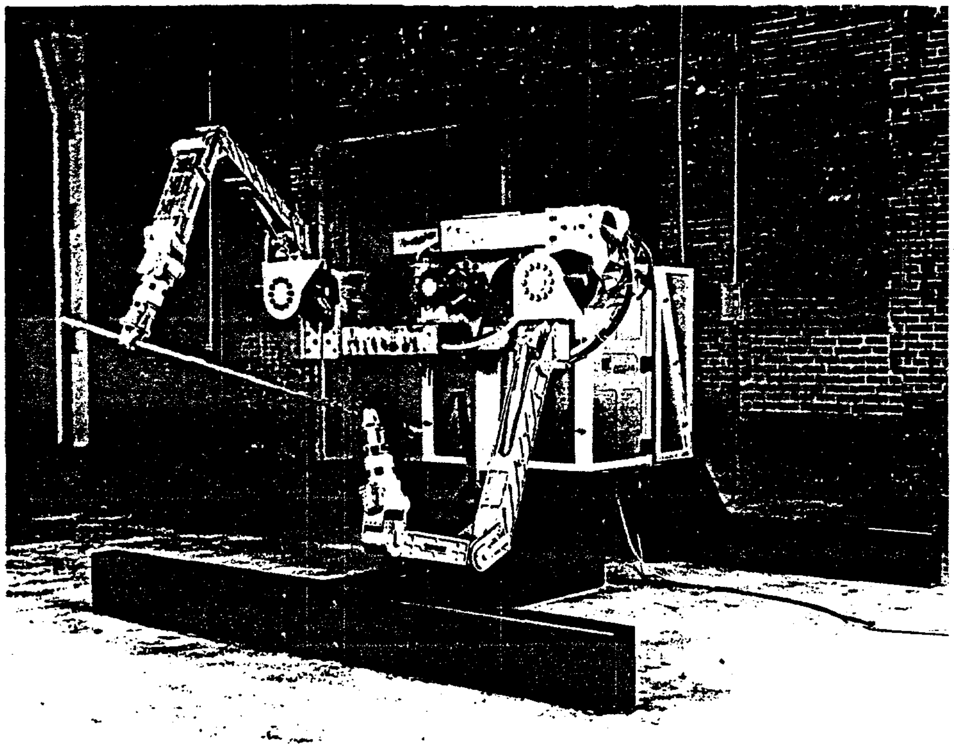


Figure 1. Dual-Arm Work Module

stration is called the Iodox system. The main goal of the Iodox process is to remove iodine from reprocessing plant effluent gasses.

The Iodox system was tested and has since been placed out-of-service on an indefinite basis. The Iodox possesses many of the typical features which must be dealt with in D&D and, as a result, provides an excellent location for a demonstration of Rosie. These features include insulated and uninsulated pipes, pipe supports, instrumentation lines, pressure vessels, pumps, and valves.

Modularity

Rosie's design is modular in nature to allow components to be added or removed, yielding several different configurations. The two main modules are the locomotor and the heavy manipulator. The locomotor provides mobility to carry the heavy manipulator to the work area. The heavy manipulator can then deploy tools or smaller more dexterous manipulators from its tip.

In this modular concept, the heavy manipulator can be removed from the locomotor allowing other equipment to be deployed from its deck. Concepts include systems such as a variable geometry truss (being developed at Pacific National Laboratory) or a scissors lift mechanism which could provide a high lift capability. Alternatively, the heavy manipulator could be deployed from some other platform, such as an overhead gantry crane.

The heavy manipulator can accommodate a variety of more dexterous equipment, including the Dual-Arm Work Module (developed by RedZone under a separate contract). This module provides two manipulators mounted on a five degree-of-freedom platform (see Figure 1). The actuated motions are: a variable offset from center for each manipulator, an adjustable center pivot to orient the arms side by side or above and below each other, and a pivot at each manipulator allowing orientation from elbows-up to elbows down. An alternate tool which will be deployed from the heavy manipulator is a single manipulator. The lower weight of the single manipulator permits greater reach with the heavy manipulator to the sides and rear of the locomotor, but restricts dexterity to single arm tasks.

This modular approach to technology development allows us to build various elements of a tool kit which can be configured in a way which best suits the task at hand. Also, future development can create other modules with capabilities to supplement the tool kit as different task requirements are encountered.

Operations

Several work scenarios are possible with Rosie: it could be a direct assistant to human workers; several robotic systems could be deployed and operate in the same area; or Rosie alone could be deployed to perform hazardous or dangerous tasks. We are targeting a "construction quality" design for Rosie. That is, we want the system to be robust. The system will be able to survive inadvertent collisions with obstacles while driving or manipulating. As much as possible, all cables and hoses will be protected from damage by running them internal to the structure or protecting them in guides. We are focusing on keeping the design simple and over-designing key areas to reduce the likelihood of failure. Critical components in the electrical and hydraulics systems will be easily accessible and can be modularly replaced. In radioactive situations, whole modules—such as the tether reel or electronics enclosure—can be removed for remote maintenance. We regard radiation-hardening as a future requirement for the system. In the design we are identifying any components which cannot withstand 10^6 R and assuring that reasonable upgrade paths exist.

PROJECT DESCRIPTION

Rosie is a tethered machine whose primary motions are hydraulically powered. The system consists of three main components, the control center, the power distribution unit, and the robot, which includes the locomotor, heavy manipulator, and tooling. The locomotor base measures 2 m (6.5 feet) wide by 2.9 m (9.5 feet) long and 1.1 m (3.5 feet) high, but the heavy manipulator extends above and in front of this envelope making the overall dimensions of the robot 2 m (6.5 feet) wide by 4.3 m (14 feet) long and 2.4 m (8 feet) high. Figure 2 shows the vehicle configuration. The overall weight of the machine will be about 6,350 kg (14,000 lb).

Locomotor

Table 1. Locomotor specifications

Width	198 cm	78 in
Height	107 cm	42 in
Length	290 cm	114 in
Obstacle Climb	10 cm (max.)	4 in (max.)
Ground Clearance	15 cm	6 in
Min. Turning Radius	zero	zero
Max. Speed	0.6 m/sec	2 ft/sec

The locomotor is a mobile platform with specifications as shown in Table 1. The frame is a trussstructure which supports wheel modules at each corner. Each wheel module has independent drive and steer motions providing an omni-directional capability. The wheels are controlled in any of three driving modes:

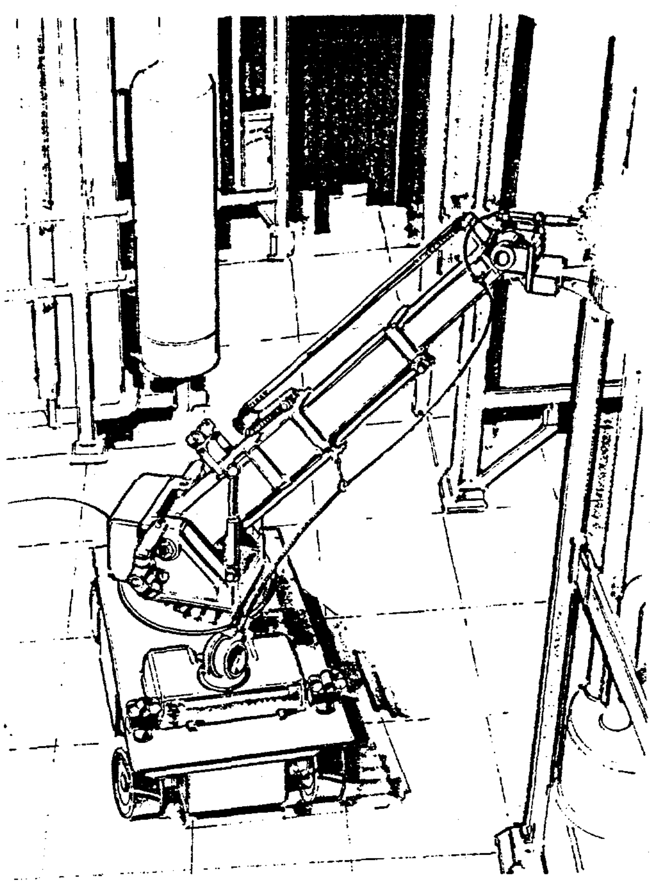


Figure 2. Vehicle configuration

4-wheel steer mode allows the front and rear sets of wheels to steer in opposite directions. This mode allows Rosie to drive along the path of an arc whose center is on the centerline pointing to either side of the machine.

Crab steer mode allows all four wheels to steer in the same direction, allowing Rosie to translate linearly in any direction.

Rotate about a point mode allows the operator to define a point in space that Rosie is to rotate about. In this mode, Rosie can rotate around the tip of the heavy manipulator, around the center of an axle, or around the center of the robot.

The front two wheels are mounted on extensions which can extend the front wheel spread from 193 cm (76 in) to 345 cm (136 in). The rear two wheels are mounted on a beam which pivots at the center to provide ±5 cm (±2 in) of vertical travel for obstacle negotiation.

Located within the locomotor frame is the hydraulic power supply, which is a 45 KW (60 HP) supply, providing 114 l/min (30 GPM) at 20.7 MPa (3,000 psi) for all robot motions. Filters and all locomotor valving is located in one of two side enclosures on the frame. The other side enclosure contains all control electronics for the system. At the rear of the machine is the tether reel which carries up to 61 m (200 feet) of cable.

Heavy Manipulator

The heavy manipulator is mounted on the deck of the locomotor towards the rear. It is a four degree-of-freedom mechanism providing a long reach, high load capability for Rosie. It can carry up to 770 kg (1,700 lb) with a 6,800 Nm (60,000 in-lb) moment load, at a distance of 6.1 m (20 feet) from the shoulder joint. The heavy manipulator consists of four joints; a waist motion on the locomotor deck, a shoulder pitch, a forearm extension and a wrist pitch at the tip of the forearm. Each of the four joints has integral position feedback and is servo controlled based on operator commands. The joints can be controlled in either of two modes:

Joint motion mode allows the operator to individually control each joint on the heavy manipulator. This mode allows the operator to directly control the configuration of the system.

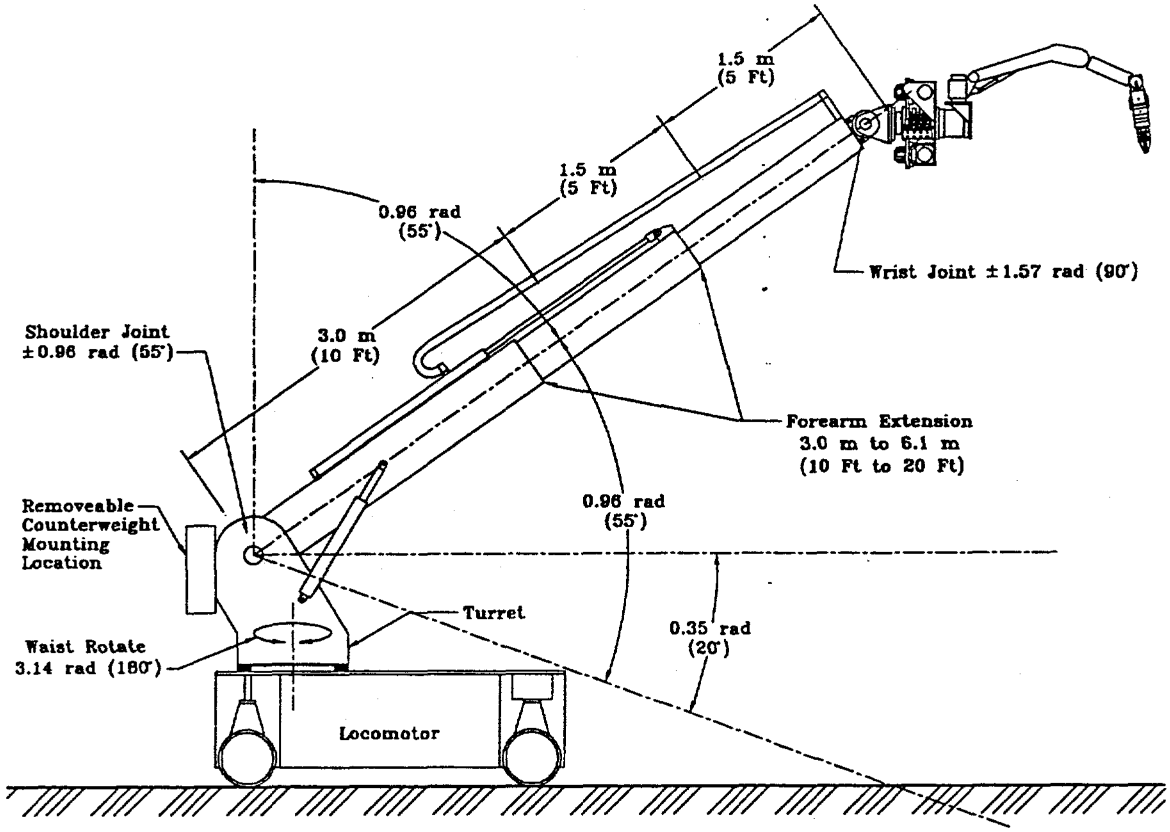


Figure 3. Heavy manipulator configuration

Coordinated motion allows the operator to control the Cartesian position of the endpoint of the heavy manipulator while the computer calculates the resulting joint positions. This motion mode is useful for tasks where the operator must move parallel to a floor or wall or is not moving in a confined area.

The configuration of the different sections and the travel range of each of the joints of the heavy manipulator are shown in Figure 3.

We have performed an analysis of the load capability of the heavy manipulator. The limits are driven primarily by tip over concerns. The tip-over limits are monitored by the system software so that a tip over condition is never reached. This is accomplished by sensing the actuator hydraulic pressure (and thus moment load) at the shoulder joint, while monitoring the position of the boom. When the software senses that a tip over condition is being approached, it alerts the operator and restricts the movement of the boom. Figure 4 shows the results of the stability analysis.

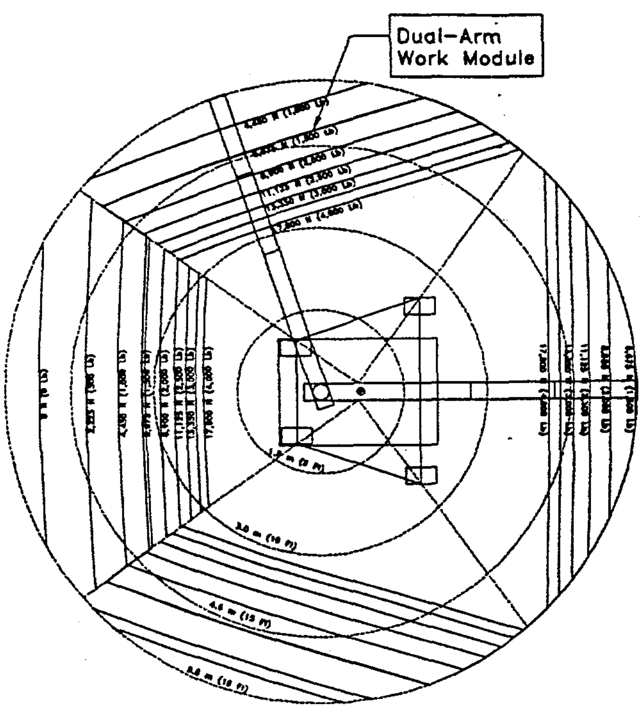


Figure 4. Heavy manipulator vertical load capacities

The vertical load capacities include a safety margin to accommodate dynamic loads. This chart assumes that the rear pivoting axle of the locomotor is locked in position, that a 910 kg (2,000 lb) counterweight is mounted on the rear of the turret structure, that the forearm section is *fully* extended, and that the front wheels of the locomotor are fully extended outward in order to increase the stability of the locomotor base.

Tooling

More dexterous manipulators can be deployed from the tip of the heavy manipulator. Current plans are to deploy either the Dual-Arm Work Module, which provides two manipulators on a reconfigurable platform, or a single manipulator which can be used perform single arm tasks. These manipulators allow the operator to accomplish complex dexterous tasks in the work environment and can in-turn carry other tools. The services available for other tools at the tip include approximately 57 l/min (15 GPM) of hydraulic fluid at a pressure of 19.0 MPa (2,750 psi) and 2,400 watts of electric power (20 A at 120 VAC). For this phase we will adapt the tools used in the first phase of the project. These tools will include: gripper, shears, grinder, reciprocating saw and crow bar.

We plan to mount these tools on T-handles and store them on the front deck of the locomotor. Also locations for storing two tools will be provided at the tip of the heavy manipulator, just behind the wrist actuator. This provides a location to store tools which does not require the heavy manipulator to be fully retracted.

Audio/Video System

The audio/video system takes multiple camera views and microphone inputs from the robot and displays them at the console. The system will have ten cameras including:

- Four cameras with remote focus, zoom, lights and pan and tilt motions
- Three cameras with remote lights and tilt motions (fixed focus)
- Three cameras with remote lights (fixed focus)

Control Console

The control console provides a control location for the system. It combines hard controls for the primary motions of the robot with a touch screen for control of secondary and auxiliary functions. It also displays the system status. The console provides direct control of Rosie as well as the ability to teach the robot motions, which can subsequently be played back. This is useful in repetitive tasks, such as scanning or cleaning a wall or floor surface. Software on the console monitors all operator inputs and displays system status. Onboard Rosie, the console commands are interpreted and turned into actuator commands. The control center is the human interface between Rosie and the work environment (see Figure 5).

There are several important issues to consider in designing the control center, including ergonomics, flexibility, and aesthetics. With respect to ergonomics, it is expected that the operator will spend long periods of time completing a D&D task. Therefore, it is important that the operator is comfortable, that all controls are placed within reach, that lighting and glare be considered, and that audio and video cues alert the operator to potential problems.

The console should be able to accommodate the preferences of several different people. For example, the console uses neither left or right handed joysticks, allowing the operator to use whichever hand is more adept. In addition, the monitors are re-configurable via touch screen controls. This allows the operator to put any camera view on any of the available monitors. The touch screen controls are mounted on a swivel base which allows the operator to position the touch screen where it is most comfortably within reach and sight.

Software

The onboard controller and console software runs on a VME-based 68040 Motorola CPU under the VxWorks 5.1.1 real-time operating system. The onboard software is responsible for communicating with the offboard console, monitoring all onboard sensors, and controlling all onboard actuators. The console software is responsible for monitoring the visual display/touch screen system and all additional hardware devices (e.g. switches and joysticks) at the console panel and sending the console information to the onboard software. The two systems communicate via Ethernet™.

Functionality. The Rosie software has the capability to control the two primary modules, the boom and the locomotor, in several different modes. The selection of these modes and the information needed to control them are passed on from the console. The operator will be able to select different operation parameters via the menu-based touch screen, and control the robot in these modes with the switches and joysticks at the control panel. While the switches and buttons provide on/off state information, the joystick supplies desired velocities for an actuator movement, depending on the mode of operation selected at the time.

The software also gives the capability to record sequences of boom and locomotor movements. The operator uses the console touch screen to select the beginning time and ending time for recording the robot actions. To play back these actions, the particular recording may be selected from a menu of recorded actions.

In addition to the telerobotic operation of the robot, the onboard software has several other responsibilities. The health of the system is constantly monitored. Hydraulic and electronic system temperatures are monitored for overheating, joint limits of the boom are monitored for tip over configurations, and hydraulic requirements are calculated and compared with the limitations of the system. The boom joints have reach limits imposed by the boom design and load limits in real-time. The hydraulic requirements during various movements are also computed in real-time. If the hydraulic system is unable to provide the flow needed for a particular operation, then the rate of the motion is reduced. Messages are sent back to the console and appear on the console screen to alert the operator about the robot's limitations, and in critical cases operation of the robot is halted. The onboard software also uses dead reckoning to monitor the robot's position.

Design. The onboard software is a hierarchical system consisting of several layers. The primary layers are the command layer, the application layer, the motion layer, the servo layer, the sensor/actuator driver layer, and the device driver layer. At each layer, the computations are divided into modules which represent individual processes running on the real-time operating system. Figure 6 shows the building blocks of the Rosie Software as collections of services and collections of process modules.

Modules communicate using shared variables and message passing. Although each module may use variables which are internal to the computation of the module, control flow is the product of variables between the modules. The higher level modules typically orchestrate the modules of the lower levels. In the figure, modules shown in heavy outline represent those processes which will always be turned on during runtime, while lighter outlined modules represent processes which may be turned on/off by higher level modules.

Power & Telemetry

The power and telemetry subsystem allows power and signals to be transmitted from the console to the locomotor and routed onboard to the various sensors and actuators. A Power Distribution Unit (PDU) located between the console and robot provides a location to tie into the higher voltage site power used to power Rosie's hydraulic system. All signals from the console pass through the PDU and are combined with the power and routed into the tether. When operating in a contaminated location, the PDU can be located within containment, minimizing the penetration of conductors into containment. Rosie uses a tether to transmit all power, control, and video signals to and from the robot.

The heart of the electrical system on Rosie is enclosed in a sealed box bolted to the side of the locomotor. This enclosure houses step-down transformers, two 6U VME controller subracks, power supplies, video modulation equipment, and four heat pipe cooling units.

FUTURE WORK

This project encompasses three separate work phases. The first phase consisted of upgrading a pre-existing worksystem with state-of-the-art technologies and enhanced controls for ease of operation, then undertaking a program to test the system and determine its capabilities and weak-

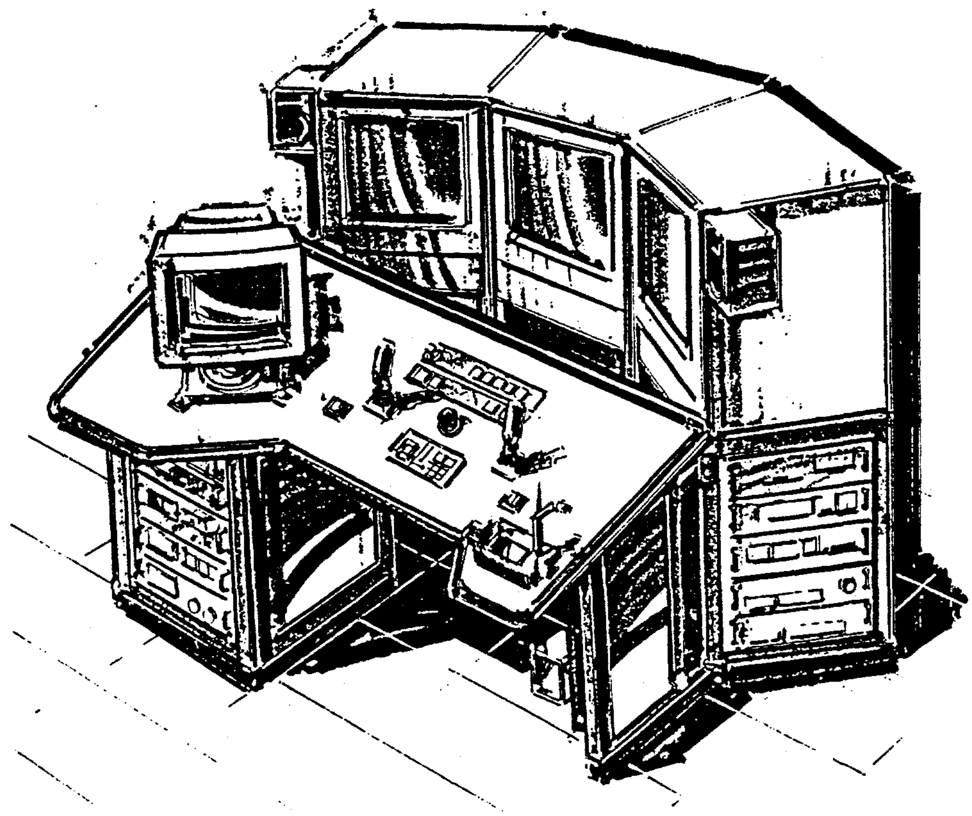


Figure 5. Control Console

nesses. The second phase involves developing a second-generation worksystem to perform D&D operations, and testing it in a mock-up facility. In the third phase Rosie will be radiation-hardened and perform a demonstration in a contaminated facility. The time frame for these phases is presented in Table 2 below. We are currently completing the detailed design and beginning the fabrication of Rosie.

Table 2. Project schedule

	Start Date	End Date
Phase I	10/1/92	10/1/93
Phase II	10/1/93	6/1/95
Phase III	6/1/95	12/1/95

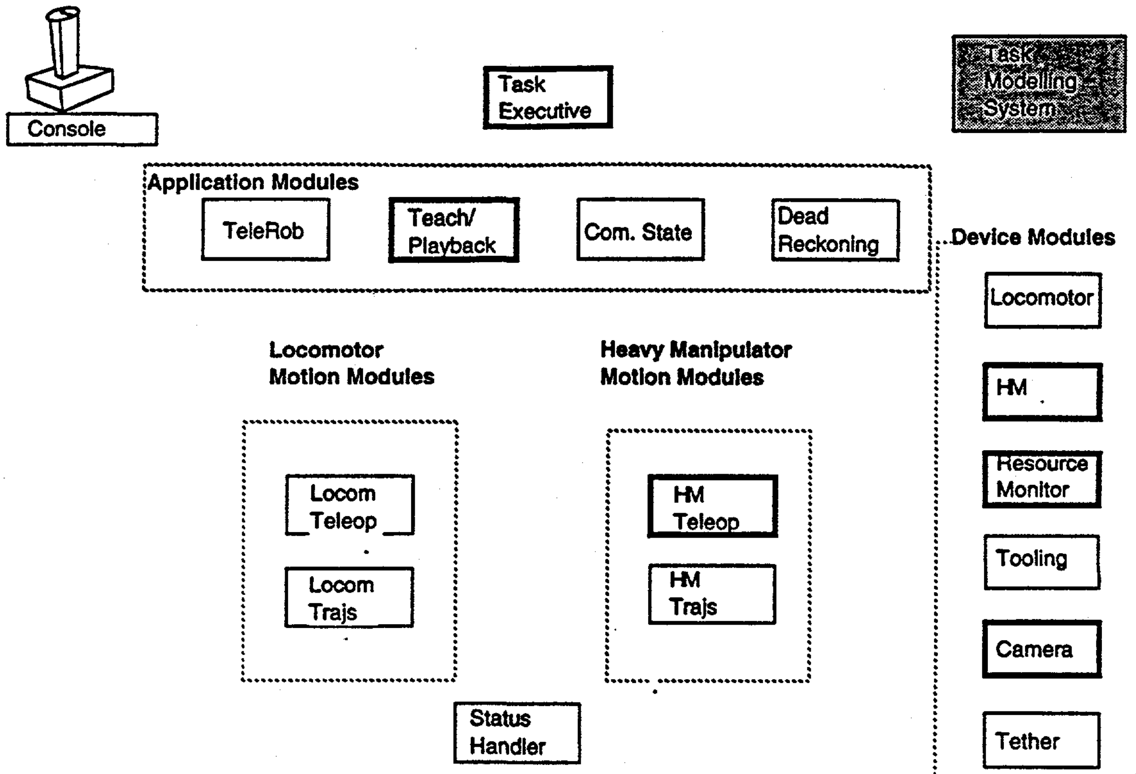


Figure 6. Robot control software architecture