Paper Number:
DOE/MC/33207-97/C0802

Title:
Rosie: Remote Work System for Decontamination and Dismantlement

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Contract Number:
DE-AC21-96MC33207

Conference:
Industry Partnerships to Deploy Environmental Technology

Conference Location:
Morgantown, West Virginia

Conference Dates:
October 22-24, 1996

Conference Sponsor:
Morgantown Energy Technology Center

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Rosie: Remote Work System for Decontamination and Dismantlement

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Abstract

RedZone Robotics, Inc. and Carnegie Mellon University's Field Robotics Center have undertaken development of an advanced remote worksystem — *Rosie* — specifically designed to meet the challenges of performing a wide range of decontamination and dismantlement (D&D) operations in nuclear environments.

The Rosie worksystem includes a locomotor, heavy manipulator, operator console, and control system for remote operations. The locomotor is a highly mobile platform with tether management and hydraulic power onboard. The heavy manipulator is a high-payload, long-reach boom used to deploy a wide variety of tools and/or sensors into the work area. Rosie's advanced control system, broad work capabilities, and hardening/reliability for hazardous duty make it a new and unique capability that facilitates completion of significant cleanup projects throughout the DOE and private sector.

Endurance testing of the Rosie system during the last year has proven its capabilities and appropriateness for D&D applications. Design enhancements are currently being implemented to improve and add features necessary for deployment at an upcoming DOE facility decommissioning. A second Rosie unit is being fabricated for use in the decommissioning of Argonne National Laboratory's CP-5 reactor facility starting late 1996. This paper will overview the Rosie system, testing results, design enhancements, and plans for use of this technology at CP-5.

The work discussed in this paper was funded by the US Department of Energy (DOE) through the Morgantown Energy Technology Center. Opinions expressed in the paper are those of RedZone Robotics, Inc. and are not necessarily shared by METC or DOE.

BACKGROUND

The development of the Rosie worksystem has occurred in three separate work phases. The first phase consisted of gaining a knowledge of the DOE's D&D needs, 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 weaknesses. The second phase involved developing a second-generation worksystem (Rosie) to perform D&D operations based on knowledge gained in Phase I. During the third phase Rosie was tested extensively to determine general capabilities to deploy tools and perform decontamination and dismantlement (D&D) tasks, as well as assess reliability and maintenance issues.

The tasks and constraints which characterize D&D applications are essential background in the development of this technology. The environment in which such worksystems must perform D&D operations range from areas in which no worker protection is needed to areas in which human entry is precluded. Dangers can include exposure to alpha, beta, and gamma radiation; uranium, plutonium, and tritium; volatile organics; acids and caustics; mercury; TRU waste; asbestos; and mixed waste. Facilities in which D&D is likely to occur include uranium enrichment facilities (including gaseous diffusion plants, centrifuge plants, and other separation plants); research and production reactors; hot cells, canyons, and vaults; stacks and cooling towers; silos and waste storage tanks; analytical research labs; and weapons production and assembly facilities.

Given the wide range of tasks that must be executed, the hazards present, and the difficulty in predicting conditions or comprehensively understanding task needs, remote technology must be highly versatile and reliable. These worksystems require capabilities to handle a variety of tools, they must combine brute force for heavy work with dexterity for fine manipulation, they must be reliable for extended use in areas where human intervention is difficult or impossible, and they must be adaptable to a range of work conditions and settings.

In the second phase of this project we undertook the design and fabrication of a worksystem specifically designed to meet D&D needs. We discovered in our Phase I study, 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 D&D needs, we selected a concept capable of addressing a major segment of tasks for which current technology is inadequate.

WORKSYSTEM DESCRIPTION

Rosie is a mobile robot worksystem developed for nuclear facility decommissioning and dismantlement. Its primary function is to perform a variety of dismantlement tasks remotely by deploying tools, sensors, and/or other robotic equipment into hazardous areas. Rosie's capabilities and system design address the need for durability and reliability in these environments, and enable performance of tasks such as piping and process equipment removal, structural demolition, vessel segmentation, waste handling and transport, and wall/floor decontamination.

The system includes a tethered robot, a power distribution unit (PDU), and a control console for robot operation. The robot consists of two major subassemblies, the locomotor and the heavy manipulator. The locomotor is a hydraulically powered, omni-directional platform with onboard tether management. It provides mobility to transport the heavy manipulator, tools, or other payloads within the work area. The heavy manipulator is a four degree of freedom, high-payload, long-reach mechanism capable of carrying a variety of tools, one or more dexterous manipulators, or any other payload of up to 900 kg (2,000 lb) throughout a generous work envelope. Rosie is a teleoperated system with low-level automation features that facilitate more efficient remote operations and allow a single operator to maneuver and work effectively.

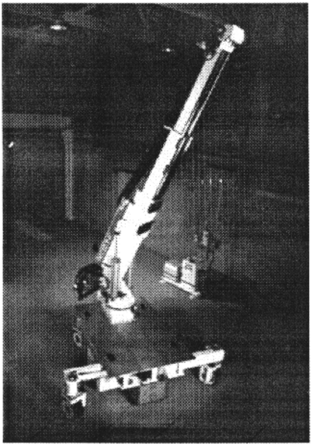

Figure 1. **The Rosie Worksystem for Remote D&D**

Locomotor

The locomotor is a mobile platform with specifications as shown in Table 1. Its frame is an aluminum weldment which supports wheel modules at each corner. Each wheel module has independent drive and steering motions providing an omni-directional capability.

The front two wheels are mounted on extensions which can change the front wheel tread width from 193 cm (76 in) to 345 cm (136 in). The two rear wheels are mounted on a pivoting beam which allows each wheel ±5 cm (±2 in) of vertical travel for obstacle negotiation.

Located within the locomotor is the hydraulic power supply, which is a 45 kW (60 Hp) supply, providing 114 l/min (30 gpm) of hydraulic fluid at 20.7 MPa (3,000 psi) for all robot motions. The hydraulic fluid reservoir is located at the front center of the locomotor. Directly behind it is the hydraulic pump and its electric drive motor. All of the control valving for the system is located above the pump and motor, inside the locomotor frame. Filters, an accumulator, and the hydraulic fluid cooling equipment are all located in one of two side enclosures suspended from the frame. The other side enclosure contains all onboard control electronics for the system. At the rear of the machine is the tether reel which can carry up to 53 m (175 feet) of tether (up to 38 m (125 ft) of unreeled tether can be included to extend the vehicle's range).

Width (extensions in)	203 cm	80 in.
Width (extensions out)	356 cm	140 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.
Minimum Turning Radius	0 cm	0 in.
Driving Speed	0 to 0.6 m/sec	0 to 2 ft/sec
Reservoir Capacity	227 l	60 gal
Fluid	Oil or Water Glycol	
Pump Capacity	114 l/min @ 207 bar	30 gpm @ 3,000 psi
Hydraulic Power Output	45 kW	60 Hp
Tether Reel Capacity	53 m	175 ft
Electric Input Power (sourced at PDU)	240 VAC 480 VAC	@ 45 amps @ 80 amps
Weight	3,950 kg	8,700 lb

Table 1.Locomotor Specifications

Heavy Manipulator

The heavy manipulator is mounted on the deck of the locomotor. It is a four degree-of-freedom mechanism providing a long-reach, high-payload capability for tool deployment. It can carry up to 900 kg (2,000 lb) with a 6,800 Nm (60,000 in-lb) moment load, at a distance of 6 m (20 feet) from the shoulder joint. The heavy manipulator consists of four joints; a waist rotation 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 configuration of the heavy manipulator is shown in Figure 2 and its specifications are shown in Table 2.

Figure 3 shows the tip over load limits of the locomotor for loads at the wrist of the heavy manipulator, with the front wheels fully extended, a 900 kg (2,000 lb) counterweight mounted on the manipulator turret, and the rear pivoting axle in its locked position. These load limits include a 455 kg (1,000 lb) safety margin to accommodate dynamic loads.

	Motion	Speed
Waist Rotation	±175°	0 to 3 deg/sec
Shoulder Pitch	+90°, -20°	0 to 3 deg/sec
Forearm Extension	3 to 6 m 10 to 20 ft	0 to 15 cm/sec 0 to 6 in./sec
Wrist Pitch	±90°	0 to 3 deg/sec
Payload Capacity	900 kg with 6,800 Nm	2,000 lb with 60,000 in.-lb
Boom Tip Services Hydraulic Electric	 57 l/min @ 207 bar 120 VAC	 15 gpm @ 3,000 psi @ 20 amps
Weight	1,720 kg	3,800 lb
Counterweight Capacity	0 to 900 kg	0 to 2,000 lb

Table 2.Heavy Manipulator Specifications

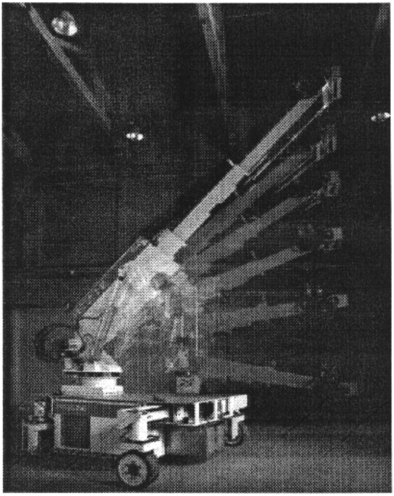

Figure 2. Heavy Manipulator Configuration

Figure 3.Locomotor Work Envelope and Payload Limits

Feedback

Rosie's operator is provided with a complete set of feedback information to support remote operations. Audio and video feedback are provided from onboard microphones and up to ten onboard cameras. Various other onboard sensors provide full system status and health monitoring. Additional user-specified sensors can be installed to provide remote monitoring of key environmental parameters.

Audio/Video System

The audio/video system takes multiple camera views and microphone inputs from the robot and displays them at the console. Rosie can support up to 10 cameras including the following:

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

All cameras are modular to allow easy replacement or relocation in order to accommodate different tooling or task requirements.

System Status/Health

The status and health of the system are constantly monitored by various onboard sensors. These include hydraulic fluid temperature, pressure, and reservoir level. In addition, the voltage levels of onboard electronics components as well as their temperatures are also monitored so that a fault may be detected before it can cause a complete system failure. Control and sensing signals are monitored automatically and error checking is performed to ensure reliable communications.

Position Sensing

All of the remotely controlled motions of the system incorporate position sensing. Locomotor wheel steering and drive motions are equipped with resolver feedback which is utilized by the computer control system to coordinate these motions in several different driving modes. This also provides the operator with a quick means to determine wheel positions. The four heavy manipulator motions (waist rotation, shoulder pitch, forearm extension, and wrist pitch) also have resolver feedback. Again, this allows computer controlled coordination modes and a clear understanding of heavy manipulator position/orientation for the operator.

The front wheel extensions incorporate limit switches so that the operator can easily discern whether they are extended; this information is also used by the control system in performing automated initialization sequences. The tether reel has limit switches so that the tether cannot be completely unwound from the reel, or wound on beyond the reel's capacity.

User-specified Feedback

The system has the capacity to support user-specified sensors installed on the robot and transmit their data back to the console. Such sensors can be used to provide remote monitoring of key environmental parameters, such as radiation levels, ambient temperature, the presence of toxic gases, etc.

Control System

Rosie's control system is comprised of an operator control console shown in Figure 4 and onboard control system components linked by a telemetry system. Control system functions are distributed across two primary computers (CPUs) — one in the console and one onboard the robot. The control console CPU displays status and sensor data coming from the robot, interprets signals from joysticks and other switches, and sends appropriate commands to the onboard CPU. The onboard CPU executes commands from the console by closing motion control loops, acquiring sensor data, coordinating axes, and activating video and other onboard equipment. Both CPUs perform continuous error checking and monitoring of communications between the robot and console.

Using this control system, a single operator stationed at the console can control the Rosie worksystem. Primary system functions—locomotor, heavy manipulator, system power, tether, and cameras—are controlled using switches and joysticks on the desk top. Less frequently used functions and status information are accessed through the touch screen. Three video monitors, with quad-splitting capabilities, display the onboard camera views. The operator can select any camera view for any of the monitors using the touch screen controls. In this way, each operator can configure the control console monitors to suit his or her particular preferences. In addition, the views can be changed during operation of the system, as needs arise.

The control system software is transparent to the operator. No keyboard or mouse is required to run the system. The control system is based on a generalized infrastructure developed specifically for telerobotic systems. The system is flexible and extensible to meet future needs, and provides an efficient and effective interface between operator and robot.

Figure 4. Control Console

Control Modes

All axes are servo-controlled enabling precise, variable speed motion control for dexterous positioning either by teleoperation or by computer control. This servo-control allows the computer to coordinate the motions of the locomotor wheels in any of three different steering modes. In addition, the heavy manipulator can be operated in two different control modes. These modes are as follows:

Steering Modes

The locomotor wheels are controlled in any of three driving modes:

4-wheel Steering: Front and rear wheels steer in opposition, allowing a turn of any radius, including a pivot about the vehicle's center.

Crab Steering: All wheels steer in the same direction. This mode is especially useful for tight maneuvering and allows and operator to translate side-ways and work continuously along a wall surface, eliminating the need to frequently back away and reposition the vehicle.

Rotate-about-a-point Steering: Wheels automatically steer to turn the locomotor about a predetermined point. Assigning the tool location as this point allows the vehicle to be repositioned without moving the tool.

Boom Modes

The heavy manipulator can be controlled in either of two modes:

Joint Control allows the operator to individually control each joint on the heavy manipulator at a continuously variable speed.

Coordinated Control allows the operator to steer the endpoint of the heavy manipulator and all four joints are automatically coordinated to achieve Cartesian motion. This control mode is an efficient and intuitive way to control the heavy manipulator and allows an operator to perform difficult tasks like tracking a wall or floor surface with a single joystick motion.

Power and 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 input site electrical power needed for onboard functions. A tether is used to transmit all power, control, and video signals to and from the robot. 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 inside of containment, minimizing the number of conductor penetrations required through containment.

The heart of the electrical system onboard the locomotor is enclosed in a sealed box mounted on the left side of the frame. This enclosure houses transformers, control computing, power supplies, video modulation equipment, and heat exchanger units.

Tooling and Auxiliary Services

A wide variety of tools or dexterous manipulators can be deployed from the heavy manipulator or locomotor deck. Highly accurate variable-speed motion control allows an operator to position tools quickly and perform work tasks effectively. Rosie's work envelope allows floor to ceiling reach with most tools.

Both hydraulic and electric power are available at the boom tip to power tools. As much as 57 l/min of hydraulic fluid at 207 bar (15 gpm at 3,000 psi) and 20 amps of 120 VAC power are available. Any user specified tooling can be deployed subject to powering and payload (up to 900 kg/2,000 lb) constraints, including:

Component Removal
- hydraulic pipe shear
- reciprocating saw
- abrasive disk
- impact wrench
- plasma torch

Demolition
- jackhammer/breaker
- pulverizer
- concrete hole saw
- abrasive water jet

Material Handling
- wet/dry vacuum
- excavation bucket
- dozer blade
- drum grapple
- cable winch

Decontamination
- pressurized water
- CO_2
- mechanical scabbler
- sealant spray

General Purpose
- dexterous manipulator
- dual-arm work system

SYSTEM FEATURES

The Rosie worksystem incorporates many onboard and offboard features which provide significant benefits in remote dismantling. With construction-grade durability, high maneuverability, and power to spare, Rosie can operate effectively to deploy tools, transport materials, and meet the unexpected challenges of D&D.

Work Capability

Rosie is capable of deploying a wide variety of tools and other payloads throughout a generous work envelope. The heavy manipulator extends to reach 26 ft above the floor and at least 12 ft on all sides of the locomotor. All wheels are independently driven and steered, making Rosie highly maneuverable in tight or cluttered spaces. Front wheels extend for added stability. Rosie can be driven with wheels extended or retracted. The pivot-mounted rear axle provides compliance when working on uneven floors and crossing obstacles. Rosie is hydraulically powered, providing high power density suited to dismantling work; as a hydraulic system, Rosie is intrinsically sealed against contamination.

Reliability

Reliability is essential in environments where manual recovery of failed equipment is difficult, costly, or precluded by hazards. The rugged construction of this system is suited to the abusive conditions of dismantlement operations and it is designed to withstand inadvertent collisions or falling objects. The electrical system is designed with sufficient noise immunity and error monitoring to ensure the reliable communication of control signals between the operator’s control console and the robot. Sensors are used to monitor the status of critical components and automatically alert the operator of potential problems. Critical actuation's, such as driving and steering, are functionally redundant—each wheel module is individually driven and steered, and sufficiently powered to compensate for limited failures. The wheel drive motions free-wheel when unpowered to enable emergency recovery towing.

Rosie is a tethered system for guaranteed communications and power for extended work durations. Onboard tether management ensures that the tether is not endangered by being dragged.

Decontamination

In nuclear environments, the ability to decontaminate equipment is critical to allow maintenance, storage, and transportation of equipment without incurring personnel exposure. All onboard components on this system are sealed for pressurized washdown. The system’s structures are designed to minimize exposed surfaces and areas where contamination can collect and be trapped. Areas that can’t be sealed are left as open as possible in order to facilitate cleaning and washdown.

Radiation Hardening

This system is designed to operate in areas where radiation exposure is present. Materials and components have been selected to reduce the potential for radiation degradation. The robot portion of the system is designed to withstand a cumulative radiation dose of 10^5 R. Higher levels of radiation hardening are achievable if necessary by shielding of critical electronics and using more radiation tolerant components.

Ease of Operations

Rosie can be used to perform D&D tasks without reducing an operator's efficiency or requiring specialized skills. Automation of low-level functions and other control system features allow a single operator to maneuver both the locomotor and heavy manipulator and to work very efficiently.

All motions incorporate position sensing and servo-control, enabling precise motion control for dexterous positioning either by teleoperation or computer control. High resolution and continuously variable speeds allow an operator to move slowly for fine positioning, or quickly for efficient large motions.

Up to 10 onboard video cameras — with lights and pan/tilts — provide an operator with effective views for navigation and tool deployment.

Modularity and Maintainability

The system is designed to be as modular as possible to expedite maintenance and deployment of alternate tools. Modularity allows the quick replacement of components or subsystems in order to keep the system in service, and allowing failed components to be repaired offboard and off-line. Critical components in the electrical and hydraulics systems are readily accessible and can be modularly replaced.

SUMMARY OF ROSIE TESTING AND LESSONS LEARNED

Six months of testing have been performed to date at Oak Ridge National Laboratory using the Rosie worksystem. The goal of this testing was to determine areas requiring refinement or modification and to quantify the system's overall capabilities. Over 180 hours of operations have been logged deploying tooling in concrete demolition and metal cutting exercises. Concrete demolition was performed on more than ten reinforced concrete highway barriers and other pre-cast shapes using a hydraulic breaker tool mounted to the boom tip. Metal cutting tasks have been performed using an abrasive wheel grinder deployed from a master-slave dexterous manipulator mounted to the boom tip. Most testing has been performed outdoors; rain occurred on several occasions (operations were unaffected), and the system was stored outdoors when not in use for several weeks.

Overall, the system performed without failures; some minor adjustments were necessary and several design enhancements have been identified to improve durability and operability. Target areas include:

- improve function and reliability of tether management fairlead.
- add reinforcements to several areas on the heavy manipulator to reduce deflection and weld stress.
- secure hardware and components against long duration vibration loads.
- optimize control console for more efficient, less strained operations (switch and touchscreen layout, joysticks, etc.).
- reduce onboard control system complexity to increase reliability.
- increase hydraulic system cooling.
- upgrade hydraulic valving to improve stability and reliability.

FUTURE WORK

Through endurance testing we have evaluated the system and its ability to perform D&D tasks. Overall, the system performs well and meets the general requirements of D&D applications. Further testing will continue to characterize Rosie's capabilities and test enhancements that are being added. Testing and enhancement activities are being focused on fully addressing issues such as decontamination, and ease of maintenance. We are also focusing toward specific DOE facility decommissioning projects, including Argonne National Laboratory's CP-5 reactor, and commercialization of this system as a broadly applicable worksystem for hazardous applications.