DEVELOPMENT OF A REMOTE TANK INSPECTION (RTI) ROBOTIC SYSTEM

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ABSTRACT:

RedZone Robotics, Inc. is developing a Remote Tank Inspection (RTI) robotic system for Westinghouse Idaho Nuclear Company to perform remote visual inspection of corrosion inside high level liquid waste storage tanks. The RTI robotic system provides 5.8 m (19 ft) of linear extension inside the tank to position a five degree-of-freedom robotic arm with a reach of 1.8 m (6 ft) and a payload of 15.9 kg (35 lb). The primary end effector is a high resolution video inspection system. The RTI Intelligent Controller provides a standardized, multi-tasking environment which supports digital servo control, I/O, collision avoidance, sonar mapping, and a graphics display. The RTI robotic system features an innovative, standardized, and extensible design with broad applicability to remote inspection, decontamination, servicing, and decommissioning tasks inside nuclear and chemical waste storage tanks.

I. APPLICATION

Westinghouse Idaho Nuclear Company (WINCO) will use the RTI robotic system at the Idaho Chemical Processing Plant (ICPP) to perform remote visual inspection of corrosion inside high level liquid waste (HLLW) storage tanks. The ICPP tank farm consists of several HLLW storage tanks that are 15.2 meter (50 ft) in diameter with a capacity of 1,135,500 liters (300,000 gallons). The domed roofs of the tanks are buried 6.1 m (20 ft) below ground level. The bottom of the tanks are located approximately 12.5 m (41 ft) below ground level. The tanks will be drained of liquid prior to inspection; however a 30 cm (1 ft) layer of caustic sludge will remain on the bottom of the tanks. The only access to the tanks is through 25 cm (10 in) and 30 cm (12 in) diameter riser pipes which extend from ground level down into the tank roof dome. Accessible risers are typically located 0.8 m (2.5 ft), 3.6 m (12 ft), and 6 m (20 ft) away from the tank wall. Currently, the RTI system will only be deployed through the 30 cm (12 in) tank risers. Cooling coil arrangements line the tank walls and the tank floor.

The primary mission of the RTI robotic system is to perform remote visual inspection of the interior walls of the tanks for corrosion which may have been caused by the combined effects of radiation, high temperature, and caustic chemicals present. Due to the location and limited number of accessible risers inside a tank, the intent is to inspect only a pie-shaped portion of the tank to qualify the typical condition of corrosion inside the tank. Thus the application does not require a robotic arm with a long reach.

II. SYSTEM OVERVIEW

The RTI robotic system features a vertical deployment unit, a robotic arm, and a remote control console and computer. One of the major design constraints for the RTI system is that the in-tank components are inserted through a 25.4 cm (10 in) diameter riser. This criteria lead to the design of compact, electric actuators for the robotic arm, which provide high torque and absolute position feedback. The RTI robotic system is initially lowered by a facility crane into the top of the riser. The vertical deployment unit then provides another 5.8 meters (19 ft) of servo controlled extension inside the tank. The RTI robotic system transmits minimal loading to the riser pipe since it is self-supporting via a support structure that rests on the ground above the riser. Figure 1 provides an illustration of the RTI robotic system installed inside a tank.

A five degree-of-freedom robotic arm provides 1.8 meters (6 ft) of articulated reach to accurately position a high resolution video inspection camera to examine the tank walls. The arm has sufficient dexterity to position the camera normal to the curvature of the tank wall. The controller provides coordinated end point motion so that the operator can easily jog the arm inside the tank. A graphics display is provided at the control console to give the operator a sense of how the arm is positioned inside the tank. The robotic arm also positions a pressurized spray nozzle to wash down the tank walls prior to inspection. In addition, the end of the arm has an interchange flange to allow the robotic arm to carry a gripper instead of the inspection camera. Another camera system is mounted at the top of the robotic arm to provide the operator with an overview of the arm operating inside the waste tank. The RTI robotic system is capable of manual recovery to retrieve the system in event of motor failure.

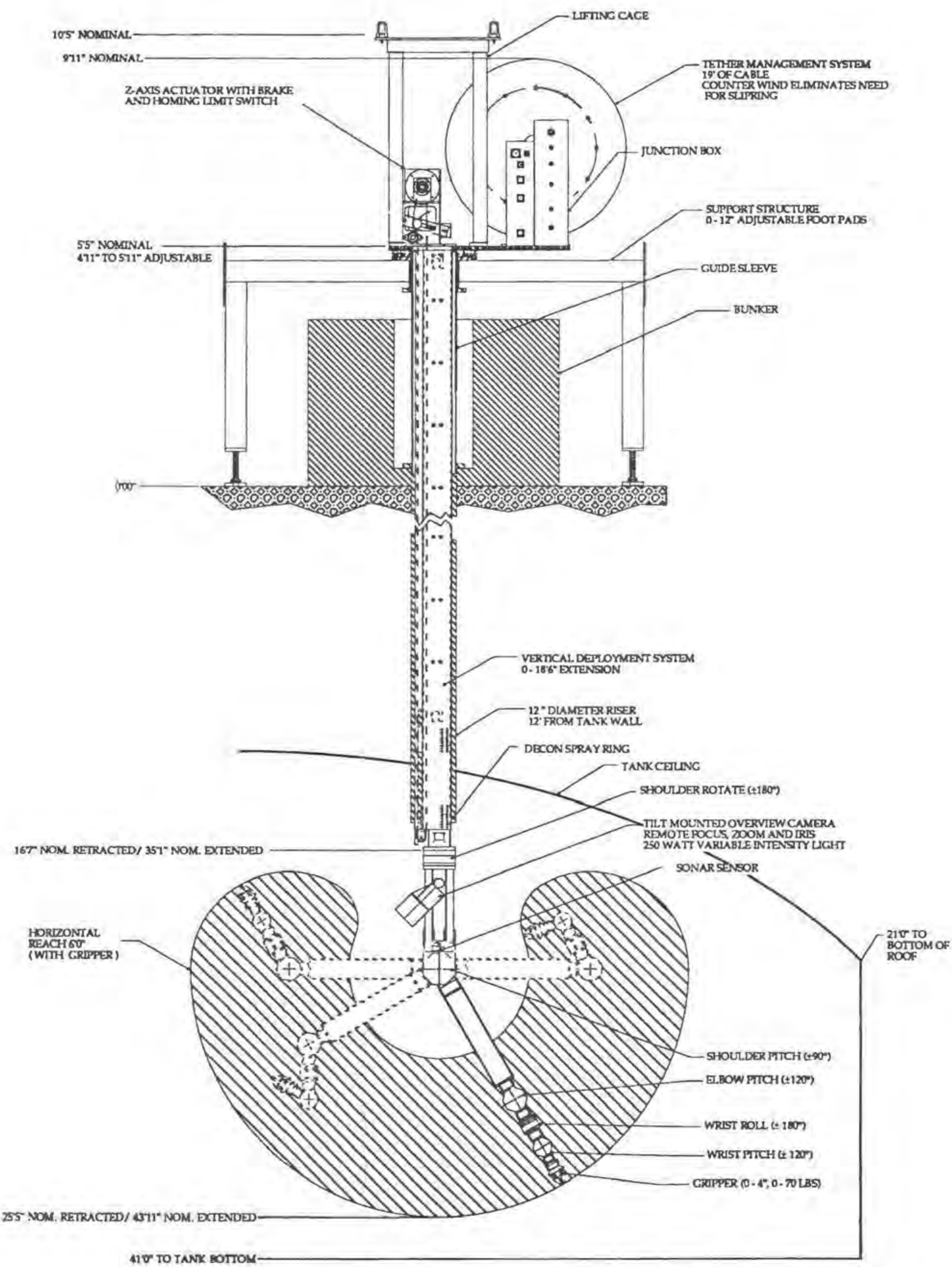

Figure 1. RTI Robotic System Deployed Inside HLLW Waste Tank

The RTI system is radiation and environmentally hardened to assure reliable performance in the tank environment. The design criteria requires that all in-tank components be capable of withstanding a 20 psi washdown of 10% nitric acid and 10% oxalic acid, radiation field of 100 Rad/hr for a total accumulated dose of 10,000 Rad, and operating temperatures of 4 to 49 °C (40 to 120 °F) at 100 percent humidity. The RTI system uses sealed components such as connectors, video equipment, sensors, and actuators to preclude the intrusion of decontamination fluids. Bearing and wear surfaces are stainless steel and non-stainless components are anodized or coated with epoxy paint to prevent damage from caustic decontamination fluids.

The RTI's control system uses RedZone's standardized Intelligent Controller for Enhanced Telerobotics to provide a high speed, multi-tasking environment on a VME bus. Currently, the robot is controlled in a manual, joint jog mode or a coordinated end point motion control mode. Control capability is available to develop a pre-programmed, automated or teach/playback mode of operation. The control system incorporates sensing and software safeguards to prevent an operator from inadvertently colliding with the tank wall. Collision prevention is implemented in software and backed up with four proximity sensors. A sonar range finding sensor is used to establish the orientation of the RTI robotic system inside the tank.

III. MECHANICAL DESIGN

The major components of the RTI mechanical system are the support structure, vertical deployment unit, robotic arm, accessories, and strongback. These assemblies are described in the sections that follow.

A. Support Structure

The support structure rigidly supports the vertical deployment unit at ground level. It consists of the alignment guide sleeve and support stand assembly. The support stand is a four legged structure that spans the riser pipe and bunker. Its leg pads provide 1 foot of vertical adjustment and allow the stand to be levelled. A facility crane is used to position the support structure over the riser and to insert the alignment guide sleeve into the riser pipe. The guide sleeve follows the inclination of the riser pipe to guide the vertical deployment unit during insertion. The objective is to avoid loading the riser pipe if it is not absolutely vertical.

B. Vertical Deployment Unit

The vertical deployment unit provides 5.8 m (19 ft) of servo-controlled vertical extension, at speeds of up to 7.6 cm/sec (3 in/sec), to position the robotic arm inside the waste tank. The vertical deployment unit consists of a telescoping tube assembly, cable management system, drive motor, and junction box. The telescoping tube assembly contains a fixed outer tube and an inner extending tube to minimize the overall retracted height of the system. With the inner tube extended, the wrist flange of the arm can reach the tank floor. An adjustable hard stop is provided to safely reduce the extent of vertical travel. The outer tube is a 20 cm (8 in) square stainless steel tube and the inner tube is a 15 cm (6 in) square tube. The vertical deployment tubes are designed for deployment through 30cm (12 in) risers. However, the robotic arm is designed to pass through a riser as small as 25 cm (10 in). The inner extending tube is supported and guided along the upper tube by stainless steel linear bearings and rails. The rails are mounted along the length of the inner tube and the bearing blocks are attached to the inside of the outer fixed tube.

An electric motor drives the lower tube, Z-axis, by a dumb-waiter arrangement of a drive chain and pulley. The motor package includes an integral gear reducer, brake and resolver. The motor's output shaft is directly coupled to a drive sprocket which drives a steel chain attached to the upper section of the inner tube. The chain moves within the gap between the upper and lower tubes. The drive sprocket was designed so it can be driven from either side. In the event of a motor failure, an identical backup motor package can be quickly mounted in order to drive the telescoping tube assembly. Due to the relatively large gear ratio and large travel of the chain, absolute position feedback on the vertical deployment was avoided. Instead, a resolver is attached directly to the motor shaft and a limit switch is used to home Z-axis position at start-up.

After insertion into the riser, the top flange of the vertical deployment unit is bolted to the guide sleeve. On top of the vertical deployment are located the cable management drum and a junction box. Cabling is payed out from a spring loaded cable drum which has a large diameter so that only two wraps are required to pay out the 5.8 m (19 ft) of cable length. This design obviates the need for electrical slip rings. The vertical deployment junction box is connected to the control console with 30.5 m (100 ft) of cable. The junction box contains some pneumatic and valve equipment and terminal strips but no circuitry. Its main purpose is to serve as a termination point for cables routed down the vertical deployment unit to the robot arm.

At the base of the vertical deployment unit is a mounting flange for the robotic arm. Cables are routed internal to the inner tube and exit the tube at its bottom. At the bottom of the outer fixed tube, a spray ring is mounted to spray decontamination fluid on the inner tube as it retracts upward. This minimizes the spread of contamination inside the telescoping tube assembly.

C. Robotic Arm

The RTI robotic arm mounts to the bottom of the lower extending tube. The arm is a five-degree-of-freedom revolute arm consisting of shoulder rotate, shoulder pitch, elbow pitch, wrist roll and wrist pitch axes. The primary function of the robotic arm is to position the WINCO inspection camera system mounted to the wrist flange. The arm has sufficient degrees of freedom to position the inspection camera normal to the curvature of the tank wall. Coordinated end point motion control allows the operator to move the inspection camera in/out and along the curvature of the tank wall. An overview camera is packaged between the shoulder rotate and pitch joints to rotate with the arm, allowing a continuous view of the end of arm. A spray nozzle is attached to the robot wrist so that the robot can wash down the tank wall prior to corrosion inspection.

The robotic arm weighs approximately 100 Kg (220 lb) and has an overall length of 2.5 m (8 ft). The arm has a 1.6 m (64 in) length to the wrist mounting flange, providing the robot with a 1.8 m (6 ft) reach when positioning the inspection camera. The last three joints of the arm, elbow pitch, wrist roll and wrist pitch, are clustered in close proximity to provide dexterous manipulation. All axes are electrically driven, feature absolute position feedback, and are actively servoed to hold position. Upon loss of power, the controller automatically shorts the motor leads to provide dynamic braking. Gravity will backdrive the arm into a nearly vertical position so the RTI system can be removed from the riser in a manual recovery mode. Table 1 provides performance characteristics of the arm.

Table 1. Performance Specifications

Description	Travel	Max Velocity
Shoulder Rotate	± 180°	1.0 rpm
Shoulder Pitch	± 90°	1.0 rpm
Elbow Pitch	± 120°	2.4 rpm
Wrist Pitch	± 120°	5.5 rpm
Wrist Rotate	± 180°	5.5 rpm
Reach of Arm	6 feet	
Coordinated End Point Motion		2.5 ips

Key: ips = inches/sec, rpm = rev/minute, ° = degrees

The five joints of the robot arm are driven by three different sized actuator packages as specified in Table 2. The three actuators are similar in concept and design but provide differing torque and speed characteristics. The capabilities of these actuators were optimized to meet the goal of providing a 15.9 Kg (35 lb) payload for the robot. The actuators are designed into a compact, pancake-style package. In the case of the shoulder pitch it was necessary to keep the actuator small enough to fit sideways, in profile, through the 25 cm (10 in) riser. Frameless DC high torque brush motors were used as they offer the smallest size, highest torque and lowest speeds available. Each motor is coupled to a pancake type Harmonic Drive gear reducer, providing a single step reduction of up to 200:1. These drive components are integrated with slim line ball bearings and a resolver to produce compact servo-actuators capable of large torques. The integral resolver is directly coupled to the joint output allowing precise, absolute, servo control of the arm.

Table 2. Mechanical Characteristics of Actuator Packages

Robot Joints	Actuator Size	Dimensions	Max Torque (in-lbs)	Max Speed (RPM)
Shoulder Rotate&Pitch	Heavy	9.0" dia x 4.5" 35 lbs	8400	1.1
Elbow Pitch	Medium	6.5" dia x 3.5" 18 lbs	2500	2.4
Wrist Roll & Pitch	Light	5.2" dia x 3.0" 8 lbs	800	5.5

The actuators and links are constructed of aluminum, which is anodized on all exterior surfaces. The actuators are environmentally sealed to protect them from the decontamination solution. Since the actuators are not equipped with brakes, they experience a 100% duty cycle when the arm is loaded, causing the motors to heat up significantly. Analysis of the system indicates that the actuators' capabilities are thermally limited. That is, the maximum payload of the arm is dictated by the motors maximum winding temperature of 155 °C (311 °F) and not by the maximum mechanical torque of the actuators. To increase the actuator and arm payload capabilities an air line is run into the actuators to provide cooling for the motors. Cabling to each of the joints and tooling is routed along the I-beam shaped linkages of the arm. Submersible, molded connectors are provided on each motor.

D. Accessories

Accessories for the RTI robotic arm comprise the quick change interface, decon spray nozzle, gripper, overview camera system, sonar sensor, and proximity sensors. A description of each accessory is provided below:

- A manual quick change interface is provided at the wrist mounting flange to change end effectors (inspection video system and gripper). The interface consists of an electrical connector, pneumatic connectors, and a common mounting plate.
- A decontamination spray nozzle is mounted directly above the wrist flange to wash down the tank walls. It has an adjustable flowrate of up to 15 liters (4 gallons) per minute.
- A pneumatic parallel jaw gripper is provided with a 10 cm (4 in) stroke and adjustable gripping force of up to 482 kPa (70 psi).
- The overview camera system consists of an environmentally sealed color camera with a zoom and focus lens. The camera is mounted inside a cut-out section of the robot shoulder linkage. A rotary actuator provides the ability to pitch the camera along the robot arm while zooming in for close views. Remote control of the camera, rotary actuator, and light intensity is provided at the control console.
- A miniature sonar detector is used to determine the relative orientation of the robot inside the tank. The sonar detector is mounted on the shoulder of the robot arm to calibrate shoulder rotation to distance of the tank wall. Since the risers are not located on the center line of the tank, radial extensions from the riser to the tank wall vary in length. An applications software package automatically controls the sonar sensing and rotation of the shoulder axis. The software processes the data to identify the location of the wall closest to the riser. Once distance to the tank wall is known as a function of shoulder rotation, distance of the robot's end of arm to the tank wall can be calculated based on forward kinematics. Distance to the wall is displayed on the graphics monitor and also used for software collision avoidance. The accuracy of this information is dependent the combined accuracy of the robot, sonar detector, data processing, arm dimensions, and the assumed location of the riser.

- For impending collision detection, four photoelectric proximity sensors are mounted on the leading edge of the robot arm linkages to detect close proximity to the tank wall.

E. Strongback

The strongback fixture rigidly supports the RTI robotic system during shipment. It is designed to attach to the bed of a semi-trailer truck. The strongback consists of a tubular framework to cradle and support the full 10.7 m (35 ft) horizontal length of the RTI system. For additional protection, the robotic arm is housed inside a reinforced cage before it is placed onto the strongback. A facility crane is used to pivot the RTI robotic system vertical from the strongback during deployment at a riser.

IV. CONTROL CONSOLE

The RTI control console is the remote station from which an operator can control and monitor the robotic arm to perform visual inspection of the tank. The control console will be located on a desk top inside a trailer located up to 30.5 m (100 ft) from the RTI mechanical system. The console consists of two side-by-side 48 cm (19 in) racks which maximize the useful working and viewing area to the operator. The racks are encased in structural foam and housed together in one self-contained shipping container. A removable front cover protects the monitors and control panels during shipment. All cables enter the control console through external chassis mounted connectors.

The control console is composed of industrial grade components, rated for operation in indoor, industrial environments. The inspection and overview camera each have their own display monitor and camera control panel. VCR's are provided to record the video output signal of the cameras.

As shown in Figure 2, the control console displays the following equipment to the operator:

- Operator Control Panel
- 8-inch Color Monitor to display Overview Camera
- 9-inch Black & White Monitor to display B&W Inspection Camera
- Two Super VHS Recorders
- Overview Camera Control Panel (camera, zoom, pan, & lights)
- Inspection Camera Control Panel (camera, zoom, pan & tilt, & lights)
- Control Panel (B&W Camera focus & iris)
- 20-inch Color (Video & Graphics) Monitor to display inspection cameras or computer graphics

The control console also contains the following components within its cabinet:

- Intelligent Controller Rack
- Servo Amplifier Rack
- Power Box
- Fan Panels

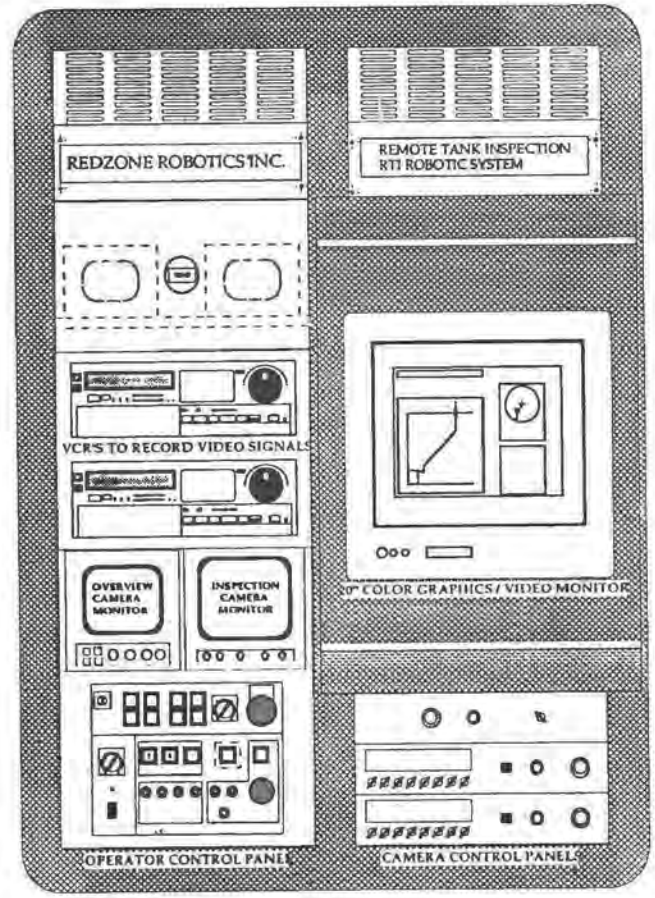

Figure 2. Operator Control Panel (Front View)

A. Operator Control Panel

The operator control panel provides the operator with a complete interface to drive the RTI system. All devices and accessories are operated from the control panel with the exception of the cameras which have independent control panels. The operator control panel is wired directly to the digital I/O boards of the controller. The controller acknowledges operator commands by illuminating activated switches. The controller performs safety checks of operator commands before executing them.

The operator control panel provides switches for speed selection and jogging of each individual axis. To prevent accidental activation, each "Axis Jog" toggle switch must be held down continuously by the operator to jog the axis. The axis will move at the selected speed (slow, medium or fast). Once released, the toggle switch returns to its neutral "off" position. In the event of a controller failure, the robot can be driven in an open-loop mode by hooking up a battery power supply directly to the motor amplifiers. An emergency stop pushbutton is provided on the operator panel.

The operator must depress a pushbutton to select coordinated end point motion. A 4-position joystick is provided to jog the end point of the arm towards or away from the tank wall and clockwise or counterclockwise along the tank wall. Consistent orientation of the end point is maintained. In coordinated motion control, the Z-axis, wrist roll and wrist pitch axis jog keys are also active. Depending on the orientation of the robot arm, wrist roll and pitch control the relative pan & tilt of the inspection camera mounted at the end point.

Controls are also provided to open and close the gripper and to control the decon spray ring and spray nozzle. The operator control panel provides an up/down arrow and enter key so the operator can make selections of menu commands displayed on the graphics monitor.

B. Intelligent Controller

The design of the RTI controller is based on RedZone's Intelligent Controller for Enhanced Telerobotics, a proprietary, standardized platform for computation and communications for the control of a wide variety of multi-axis robotic systems. The Intelligent Controller is housed inside a 12-slot VME bus chassis inside the control console. The Intelligent Controller performs the following functions, in a multi-tasking environment, for the RTI robotic system:

- Translation and execution of all operator commands originating from the operator control panel.
- Digital servo control of all movement including individual axis joint control and coordinated end point motion of the robot arm.
- Execution of automatic routines; system self check, power-up, sonar map control, and shut-down sequences.
- Safety monitoring of proximity sensors, joint overtravel, joint and velocity tracking errors and overtorque conditions.
- Continuous monitoring of potential collision states.
- Logging significant events in a data file.
- Displaying on the graphics monitor: plan view and side view of robot arm inside tank, distance and orientation of end point to wall, absolute position of each axis, error message & diagnostics, and menu prompting of routines.

The computational devices of the RTI Intelligent Controller consist of the following boards:

- 68020 CPU Boards (2) with floating point processors.
- RGB Video Board to interface the controller to the graphics display monitor.
- Resolver to Digital Boards (2) to transform resolver output to the digital signal used to compute current position and velocity of each axis.
- Digital to Analog Board to convert the digital control signal generated by the CPU to an analog control signal to drive the motor amplifiers.
- Timer Interface Board to measure time-of-flight of sonar echoes generated by the sonar ranging module.
- SCSI Interface Board to interface to the removable cartridge disk drive.
- 44 MByte Removable Cartridge Disk Drive to provide portability with hard disk performance. All software resides on the disk drive.
- Digital Input Boards (2) to provide 64 opto-isolated channels that are interrupt driven to the controller. Digital I/O serves as primary interface between CPU and operator control panel.
- Digital Output Board to provide 32 dry reed relay outputs. Allows CPU to control devices and indicator lights on each switch.

Control of robot motion is achieved by a control law implemented in software on the main CPU. Motion control boards are not required as servo control is flexibly implemented in software. The CPU reads resolver inputs, computes forward and inverse kinematics, and generates a digital control signal. This digital control signal is then converted into an analog input to the motor amplifiers. The CPU performs all of the control calculations for robot motion, interprets user commands from the operator control panel, and maintains the graphics display. Two CPU boards allow the computational load to be distributed by running the motion planner on one board, and the remainder of the software modules on the other. This results in stiffer motion control and faster updating of the graphics display.

V. SOFTWARE

Under separate contract to the Department of Energy (DOE), RedZone is developing an Intelligent Controller for Enhanced Telerobotics to provide a standardized, multi-tasking, VX Works ™ environment for software development. The RTI system uses the hardware and software architecture defined by the DOE Intelligent Controller architecture. All software is written in the C-language and resides on the disk drive. Figure 3 is a block diagram of the major software modules of the system. The software is organized into five main modules: the task executive, the motion planner, the motion controller, the data processor, and the graphics module. Communication between (and in some cases within) these modules is performed using RedZone's proprietary Robotic Communications Protocol (RCP) which is the heart of the Intelligent Controller. RCP provides both intra-cpu and inter-cpu communications as well as global variables, functions calls and semaphores between modules. Below, each module is described in detail.

A. System Control

The system control module is the "front-end" of the RTI controller. It contains four sub-modules: digital input/output drivers, task executive, health monitor, and data logger. The digital input and output drivers provide a standardized software interface to the digital I/O boards. The task executive's main function is to monitor the state of the operator panel and of the robot. It directs action based on these inputs. The data logger records events, errors, and change of state into a file. The log is maintained on the hard disk to help understand and troubleshoot failure or accident scenarios.

B. Motion Planner

The motion planner module provides a collection of high level path generating modules, collision detection modules, and kinematics utilities that operate with a nominal cycle time of 10 milliseconds. The path generating modules include joint space profile generation, cartesian space profile generation, and control for sonar mapping. Cartesian space points are transformed via inverse kinematics into joint space goals to generate a smooth trajectory for each joint in motion. The sonar map utility automatically controls the arm while the sonar mapping sequence is in progress. The collision avoidance module monitors the proximity of the arm to the tank wall. The kinematic module contains the mathematical model of the arm, including link lengths and axes of rotations. Forward kinematics are used to compute the end point position of the arm based on axis joint positions for collision avoidance checks. Inverse kinematics are used to compute the axis joint positions necessary to achieve a desired end point position for coordinated motion control.

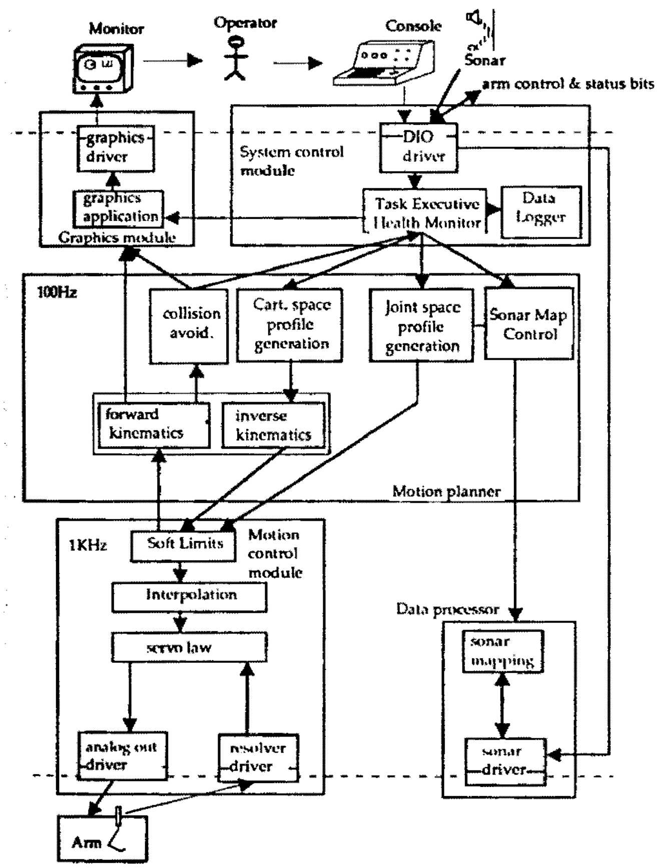

Figure 3. Software Organization

1. Jog Control. Robot motion is initiated whenever the operator holds down an axis jog toggle switch or the coordinated motion joystick. The controller responds to the switch transition state. An acceleration ramp is immediately generated to ramp up to the preselected speed range. The motion control module then generates new, incrementally small, position goals for the joint every 10 milliseconds.

2. Coordinated End Point Motion. The operator's primary objective is to position the robot's inspection video camera relative to the tank surface. It is often difficult and tedious to position the end-of-arm while jogging individual axes. To facilitate easier positioning of the camera, coordinated end point motion is provided in two axes while maintaining a consistent orientation of the tool faceplate: horizontal extension of the arm to the tank wall and following the curvature of the wall at a constant distance. Coordinated motion for the RTI robotic system is constrained in the cylindrical world frame of the tank. Control is simplified by requiring the arm to be in a preferred orientation. Should the operator choose to deselect coordinated motion and jog in joint mode, a resume function is available to allow the operator to return to his former position and resume coordinated motion.

3. Collision Avoidance. The collision avoidance software consists of a real-time background program that continuously checks the position of the arm to avoid a collision with the tank. The computer checks for penetration by the arm into a safety zone that extends from the tanks walls and floor. If the robot enters the safety zone, the computer executes an interrupt of the current motion and warns the operator of the condition. Once the robot arm is in the software collision state, the software only allows the operator to jog arm motion away from the tank surface. Proximity sensors are also provided to detect an impending collision and initiate an emergency stop. A manual override button is provided so the operator can override collision avoidance so that the RTI can touch the tank wall or floor.

C. Motion Control

The motion control module reads the joint absolute position from the resolver-to-digital driver every millisecond. The servo law, an enhanced PID control, uses commanded and actual position read from the resolvers to calculate a command output to send the power amplifiers. Robot motion is controlled in a position controlled mode, not a rate controlled mode, as commonly used on robotic manipulators. Position control provides stiffer motion control with more damping. It also allows an easy upgrade to programmed operation at a later date. Execution of the motion control task is triggered by a clock interrupt to ensure precise timing. The motion control module also enforces soft stop limits and performs linear interpolation on the commanded positions.

D. Sonar Data Processor

The sonar data processor module reads and processes the sonar data to map distance to the tank wall as a function of shoulder rotation. Radial extensions from the RTI to the tank wall vary in length, since the RTI system is inserted through a riser that is offset from the tank center. The sonar sensor produces a digital pulse each time it is fired. The length of the pulse is proportional to the time from transmission of the sonar signal to the return of the first echo. The sonar driver measures this time-of-flight which is converted into distance and recorded in an array with the corresponding shoulder rotation angle. The sonar mapping module performs pre-processing of the signal to remove erroneous data and compensate for the wide beam width of the sonar. Signal processing of the sonar signal is performed to derive a circular model of the tank from the raw data.

E. Graphics Module

The graphics display on the large color monitor provides the operator with a physical sense of the robot arm's position inside the waste tank. Objects are portrayed as two-dimensional diagrammatic models. A plan view shows the orientation of the arm inside the tank and a side elevation view shows the robot arm configuration to the tank wall. The monitor displays robot joint angles, as well as the distance and orientation of the end of the arm to the tank. These views and information will greatly enhance the operator's efficiency in operating the robot within the tank. The graphics software module continuously reads the current position of all axes and uses the kinematic model to compute and display the configuration of the arm. The graphics display module also provides menu commands, status information, and messages to the operator.

VI. CONCLUSION

RedZone Robotics will deliver the RTI robotic system to WINCO in April 1990. The RTI robotic system will then become one of the first robotic systems deployed to remotely inspect hazardous waste tanks. The initial mission of the RTI will be remote visual inspection of corrosion inside the ICPP waste tanks. WINCO is currently planning additional development of the RTI robotic system including advanced tooling to sample the sludge and inspect the bottom of the tank, supervisory control to provide enhanced force control of the tooling, and a programmed mode of operation.

The RTI robotic system provides a 15.9 Kg (35 lb) payload, 1.8 m (6 ft) reach, five degree of freedom robotic arm that can be inserted through a 25 cm (10 in) diameter opening. The vertical deployment unit provides 5.8 m (19 ft) of servo controlled extension. The robotic arm can manipulate a variety of tools: inspection viewing systems, gripper, spray nozzle, or other specialized end of arm tooling. The arm can be flexibly mounted on a variety of platforms or even a mobile base. Its compact, high torque, electric, servo-controlled actuators can be re-configured with different linkages to customize a robotic arm of any configuration and degrees of freedom. The RTI robotic system is radiation and environmentally hardened to assure reliable operation in hazardous environments. The Intelligent Controller provides a multi-tasking environment to support digital servo control, I/O, collision avoidance, sonar mapping, and a graphics display. The controller, based on the standardized DOE architecture, is extensible to servo control almost any multiple axis application. In conclusion, the RTI robotic system and its components offer an innovative, standardized, and extensible design with broad applicability to remote inspection, decontamination, servicing, and decommissioning tasks.

REFERENCES

Griebenow, Bret & Martinson, Lori, "Robotic System for Remote Inspection of Underground Storage Tanks," Proceeding of 1990 American Nuclear Society Winter Meeting, Washington D.C., Nov. 1990.

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