REAL TIME VIRTUAL REALITY 3D ANIMATION AND CONTROL SYSTEM FOR NUCLEAR SERVICE ROBOTICS

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ABSTRACT

The ROSACAD robotic control system developed by Westinghouse Electric Corporation provides a robot operator with real time 3D virtual reality animation of the robot in its environment and provides on-line look ahead collision avoidance. The operator interface is ideal for systems that use teleoperation, or those in which the robot's work envelope is congested with many obstacles. The operations software uses object-oriented coding which allows easy extension to new applications and is specifically design to integrate teleoperation interspersed with autonomous sequences. Any robot and environment can be modeled through the use of the ROBCAD™ solid modeling software, including the presence of moving obstacles. ROSACAD is a generic interface and control system that has been applied in many diverse robotic systems ranging from nuclear steam generator service arms to pipe crawlers.

1.0 INTRODUCTION

Nuclear power plant inspection and maintenance services provide many opportunities for the application of robotic systems. The hostile environment within a nuclear plant (radiation, heat, etc.) makes these systems cost effective and in some cases enabling. Westinghouse is a provider of many of these services and in the past has developed a variety of diverse equipment to meet the needs. The proliferation of services led to the need for a generic robotic control system that could be used on a wide variety of applications. Many of the applications require interleaving of manual and automatic sequences while operating in confined spaces.

To fulfill these requirements, the ROSACAD robotic control system was developed. It was specifically designed as a general purpose control system that could easily be adapted to any robotic maintenance system. The user interface uses a solid model of the environment to provide the operator a 3D virtual reality animation of the work being performed. The solid models also provide the system with the ability to perform collision avoidance. The supporting software is object-oriented to provide simple application customization. Thus far, ROSACAD has been applied to seven different robotic systems that have been fielded in a total of over 20 plant outages that include both Pressured Water Reactor (PWR) plants and Boiling Water Reactor (BWR) plants.

2.0 SYSTEM DESCRIPTION

The robotics control system is currently implemented on an Hewlett-Packard (HP) 725 workstation. The HP workstation is typically located outside of containment in a trailer outfitted with cubicles for the robot operators. The workstation communicates with the hardware controller in containment via a fiber-optic link. The ROSACAD robot control software runs on the workstation. The software is divided into three modules: solid modeling interface, generic robotic functions, and the application-specific functions. The modular software arrangement was designed to provide for rapid implementation of new applications. Each new robotic system requires only a solid model and its application-specific code.

The work environment of the robot is modeled with ROBCAD™ solid modeling software (by Tecnomatics Technologies, Inc.). This solid model provides visual and computational models for all the objects in the work environment. The model also includes the kinematics of the robot arm, end effectors, and any auxiliary equipment. The ROSACAD code accesses and manipulates the solid model via an application programmer's interface (API) to ROBCAD™. The ROSACAD code coordinates the graphical user interface, real time 3D virtual reality animation display, look-ahead collision avoidance, and robot control commands.

The generic robotic functions are code libraries within ROSACAD that provide functions common to all robotic systems. These functions include: manual robot moves (jog, joystick), coordinated motion profiles, point and path moves, path interpolation (linear, spline, spherical, etc.), parametric path generation, model manipulation, setup utilities, and a database. Of particular use is ROSACAD's ability to make robot motion paths that are automatically adjusted based on the details of the solid model. Robot paths (e.g., inspection plans) will remain valid even after the solid model is calibrated to the physical environment, thus displacing the solid model objects. Much of the robotic activity can be preprogrammed even though the precise positions of the components in the environment may be uncertain.

The application-specific functions are those actions that are unique to a given application. ROSACAD provides a user interface window dedicated to the application and the necessary code API to link ROSACAD to the application-specific coding. Examples for application-specific code are: inspection scanning paths for components, end effector controls, and atypical coordinated robot motion. ROSACAD uses object-oriented implementation of all its functionality to permit application-specific exceptions to its standard functions. For example, one application utilized an eight-axis inverse solution for coordinated motion (typical is six axes). This was easily accomplished through a specialized robot object that supplanted ROSACAD's standard robot object.

3.0 APPLICATION EXPERIENCE AT NUCLEAR PLANTS

3.1 Remotely Operated Managed Maintenance System (ROMMRS)

ROMMRS was a joint project by Westinghouse and Public Service Gas & Electric. In this application, a robot would perform all the health physics functions on the steam generator platform during a plant outage. The tasks included radiation surveys of the channel head, platform surveys, air sampler change out, vacuuming the platform, swipe sampling, platform cleanup, and visual inspections. The project was very challenging because of the large range of motions and service tooling needed, and because the environment was very cluttered with

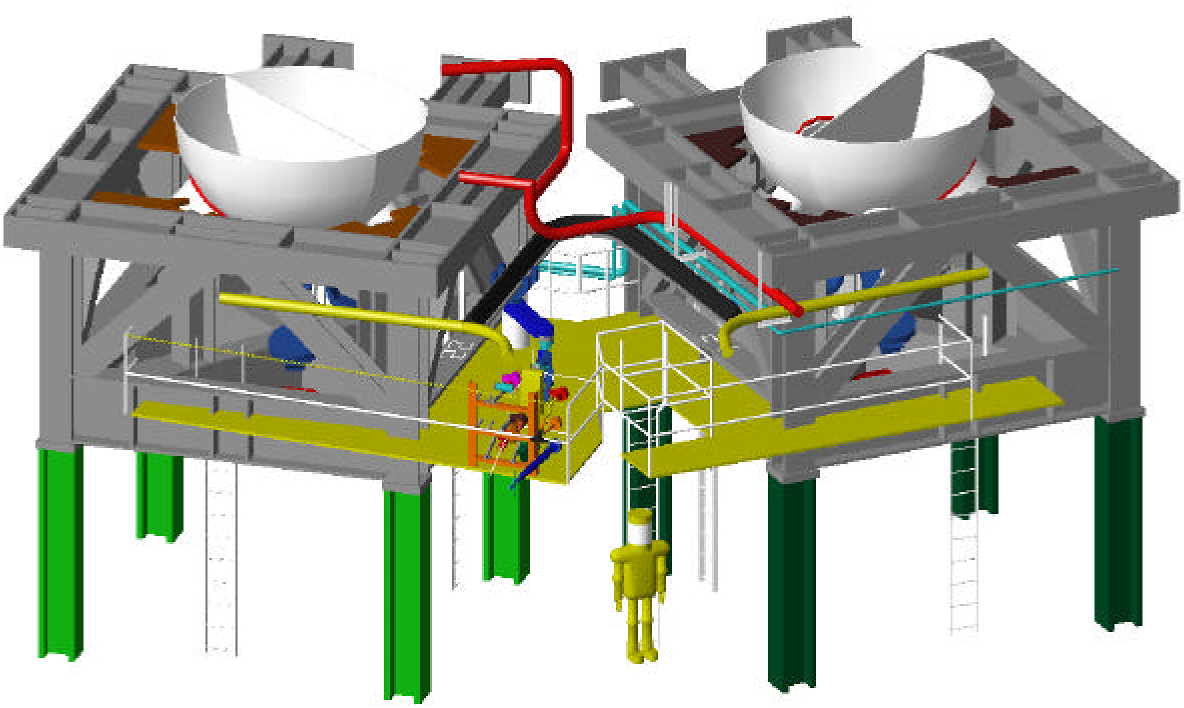


Figure 1 Salem Unit 2 Steam Generator Platform Model for ROMMRS Application

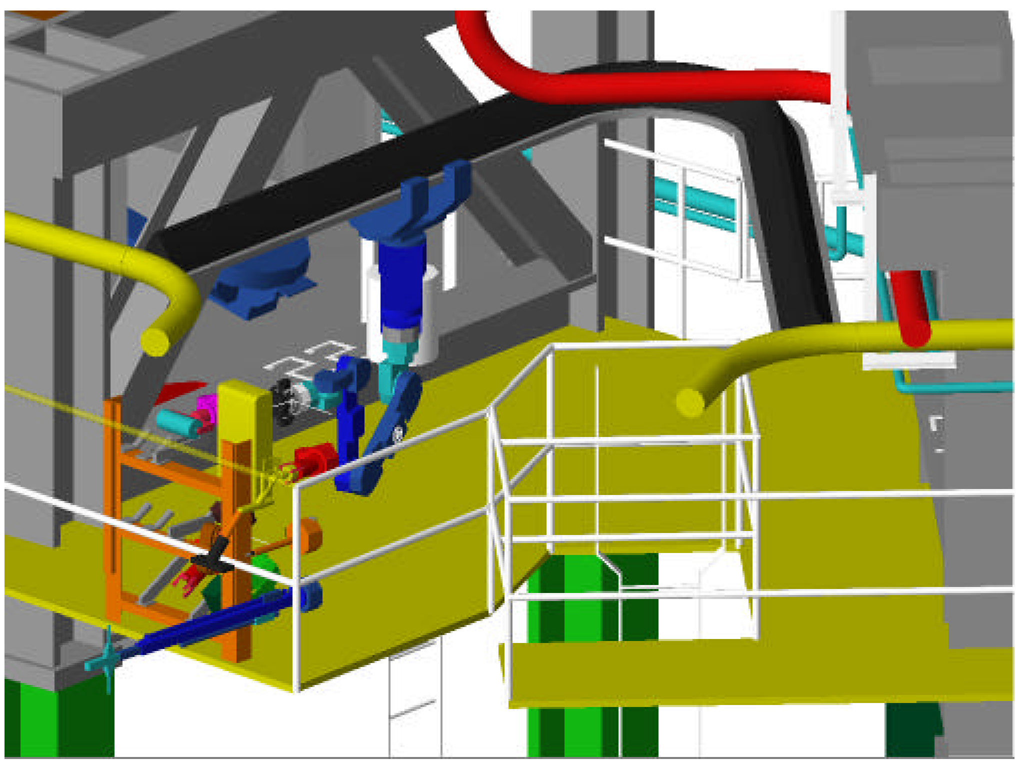


Figure 2 Steam Generator Platform Showing Tool Rack, Robot, Gantry, Trolley, and “V” Track

obstacles. The robot used for this application was a six axis elbow manipulator mounted on a gantry that was attached to a trolley riding a "V" shaped track. The full solid model used in this application for the Salem unit 2 outage in 1994 is shown in Figure 1, with a close-up detail of the work area shown in Figure 2. The robot and "V" track were carried into containment and installed in about four hours. The system was removed at the end of the outage. At the start of operations, the various components in the model were calibrated to the as-installed positions so that all the pretaught automated sequences would position correctly. The only feedback to the operator was through three video cameras that were used to verify the positioning accuracy as compared to the solid model. The tool rack (lower left of Figure 2) held the different end effectors that were needed by the robot to accomplish the tasks. The operator of the robot would dock the robot to a tool, and then command various tasks such a taking swipe samples at specified locations. Because of the tight work area, many of the motions required coordination of all eight axes (six-robot, gantry and trolley) to perform the tasks without collisions. All of the activities specified for the ROMMRS system were performed during the week the system was in operation on the platform. The system is currently in storage at Salem awaiting the next scheduled usage.

3.2 Steam Generator Primary Side Inspection and Maintenance Application

The Remotely Operated Service Arm (ROSA) family of robots has been used for steam generator primary side maintenance since the early 1980s. The services supplied include eddy current inspection, plugging, plug removal, laser welded sleeving, in situ pressure test, and many others. The current arm, ROSA-III, was moved to the ROSACAD control system in 1995. Figure 3 shows a typical solid model of the robot and steam generator channel head used by ROSACAD for ROSA-III maintenance operations. A library of solid models has been created that includes most steam generators, and a new model can be created with two days modeling effort. The ROSACAD 3D display provides the operators with an excellent virtual view of the robot within the channel head and has resulted in a significant decrease in mistakes due to operator confusion. The model shown in Figure 3 features a transparent steam generator divider plate that allows the operator a clear view into the channel head while retaining collision avoidance protection. The solid model has proven to be a highly accurate indicator of true position and clearances with any discrepancies being smaller than the positional accuracy of the hardware. The collision avoidance feature of ROSACAD is used extensively in this application to prevent the robot and end effectors from contacting other components. This allows the operators to move the robot rapidly about the channel head without concern about collisions. The collision feature has also been utilized to perform automated mappings of the all the tubes that can be accessed safely for each specified operation. ROSACAD is currently in use on every domestic outage employing the ROSA-III arm.

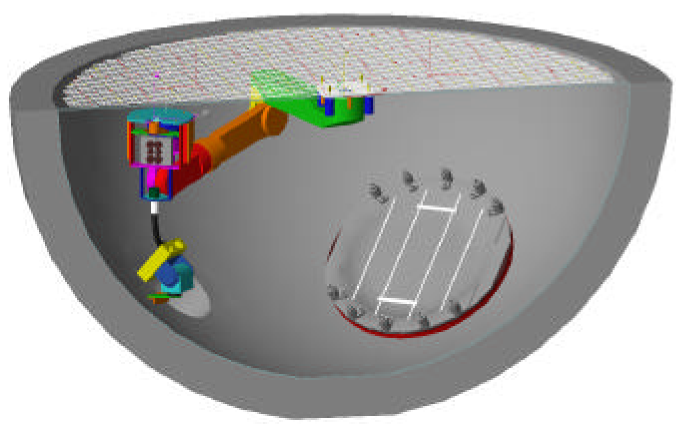
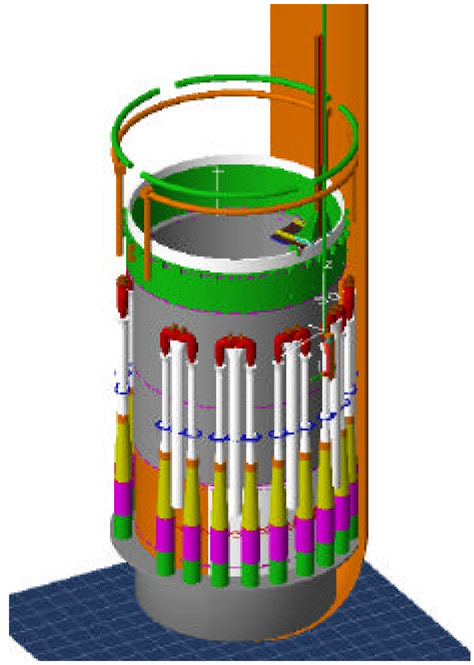


Figure 3 S/G Channel Head Model with Rosa-III

3.3 BWR Shroud In Service Inspection (ISI)

The BWR ISI robots perform ultrasonic testing (UT) in the narrow annulus between the BWR core shroud and reactor vessel. Figure 4 shows the model for a typical application. The weld scans to be performed lie on the outer surface of the shroud. The access to this area is extremely tight due to the jets pumps and numerous other obstructions in the annulus. Prior to each BWR shroud inspection job, a feasibility study is performed using ROSACAD in simulation mode. A detailed solid model is constructed using the reactor as-built drawings. The BWR ISI robot is then run through the entire inspection plan in simulation to verify accessibility of all inspection locations. Often, minor robot design improvements can be identified that improve coverage. ROSACAD is used for the engineering evaluation, and then the exact same model and data are used to perform the job. This seamless interface between engineering studies and field operations has proven invaluable. Shroud inspections using ROSACAD controlled BWR ISI robots have been performed at Grand Gulf and Monticello thus far.



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3.4 PWR Reactor Vessel In Service Inspection

Westinghouse's old PWR ISI platform has been replaced with a new robotic system based on ROSACAD to increase flexibility and productivity. The newest system, named SUPREEM (Boone 1997), consists of multiple robotic arms that perform concurrent UT inspections of the reactor vessel, nozzles, and lower head. Figure 5 shows a typical application using an upper and lower mast, with one arm on each mast. Each robot is controlled from a separate HP workstation running ROSACAD, but the movements of all the robots are transmitted and displayed on each station so that the collision avoidance is enforced among the arms, since multiple arms on a single mast can interact. ROSACAD's 3D virtual reality display was essential in navigating the robot through the forest of instrumentation tubes protruding from the lower head during lower head inspections. The application-specific code included algorithms for generating complex scan motions such as the circumferential scan of the saddle weld between the nozzle and vessel. To date, the PWR ISI robot systems based on ROSACAD have been used at Callaway, Beaver Valley, Palo Verde, and Prairie Island.

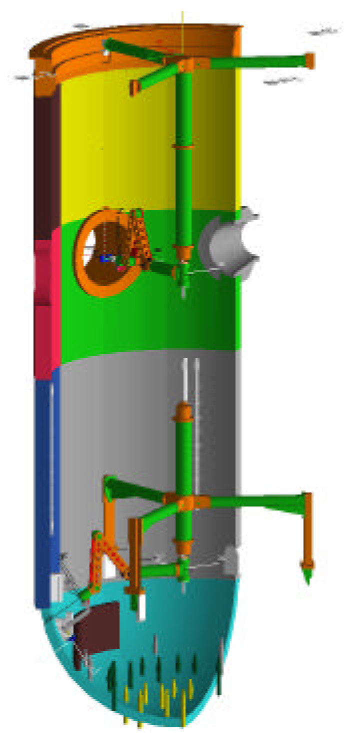

Figure 5 SUPREEM Robots

3.5 Reactor Coolant Pump (RCP) In Service Inspection

Another application of the ROSACAD control system was the RCP casing inspection performed at the Ringhals plant in Sweden. This robot performed UT inspection of all the welds in the pump casing. The robot and pump are shown in Figure 6. The application was challenging because of the extremely tight spaces in the pump, and the awkward positions from which the robot would perform the inspection. The ROBCAD™ solid model for the RCP casing was supplied by the customer.

Extensive engineering studies were performed with ROSACAD to define a robot that could accomplish the task. The only way to squeeze into the pump and yet reach the furthest weld was to design some of the links in the arm with linear actuators to extend and retract the link dimensions. Once the arm properties were verified in ROSACAD, the robot arm was designed and constructed. The application-specific software was written to create the needed UT scan paths. The system, named OASIS (Alford, Davis, et al, 1996), was delivered to Ringhals and performed its first inspection in September 1997.

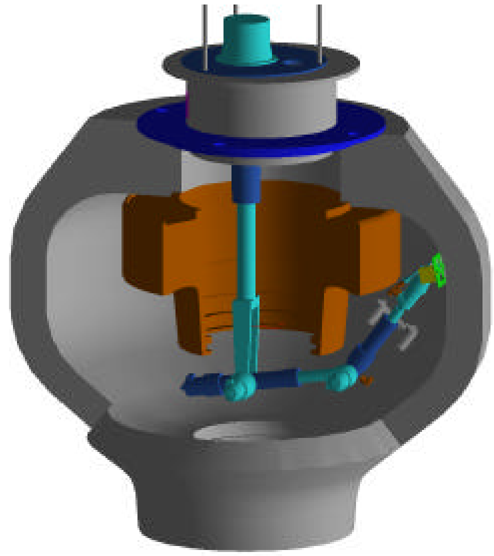

Figure 6 RCP Robot in Pump Casing

4.0 SUMMARY

The ROSACAD control system has proven itself applicable to a wide range of robotic maintenance systems. It provides for rapid engineering evaluation of new systems, with seamless transition to field operations. The modular and object-oriented design of the code minimizes the engineering effort required to field new robot systems. The high quality 3D virtual reality animation greatly aids the robot operators and the collision avoidance protects the robot and equipment from needless damage. The ROSACAD system is being used for all of Westinghouse's field service robotic maintenance systems.

5.0 REFERENCES

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Boone, P.J., "SUPREEM, The Next Generation in Pressure Vessel Non-Destructive Examination Robotics", *ANS 7th Topical Meeting on Robotics & Remote Systems*, August, GA, 1997, American Nuclear Society, Washington, DC, 1997.