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OAK RIDGE NATIONAL LABORATORY

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CRADA Final Report
for
CRADA Number ORNL96-0452

POSITION AND ORIENTATION TRACKING SYSTEM GRAPHICAL USER INTERFACE

R. E. Barry
Oak Ridge National Laboratory

G. A. Armstrong
Oak Ridge National Laboratory

B. L. Burks
The Providence Group

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
managed by
Lockheed Martin Energy Research
Corporation
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**Position and Orientation Tracking System
Three-Dimensional Graphical User Interface**

**RedZone Robotics/ORNL
CRADA Final Report**

CRADA No. ORNL96-0452

**R. E. Barry
G. A. Armstrong
B. L. Burks**

September 30, 1997

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ABSTRACT

Under the Department of Energy's (DOE's) Robotics Technology Development Program (RTDP) Tank Waste Retrieval (TWR) effort, a major program is under way to develop technology for remediating the waste in underground storage tanks that contain radioactive and hazardous waste. A large part of the program's effort has gone towards development of remotely operable robotics equipment, including the Houdini Vehicle and the Position and Orientation Tracking System (POTS). Since planned operation of this equipment is to be completely remote, a significant effort is needed to ensure that operators have sufficient system information to operate the equipment efficiently and safely.

Oak Ridge National Laboratory (ORNL) developed POTS and the RedZone Robotics, Inc., developed Houdini can be operated together to provide both position and orientation descriptions (or pose parameters) of the Houdini vehicle, relative to a world reference frame, while operating inside an underground storage tank. The Houdini vehicle has been outfitted with an optical detection system that houses infrared detectors. The infrared detectors are part of the POTS tracking system. The sensors provide a set of timing pulses to the POTS control computer whenever a laser beam from one of the four POTS laser scanners strikes a detector. Using the pointing angle information from each POTS laser scanners, the POTS control computer is able to compute the pose of the Houdini vehicle at a rate of approximately 25 Hz.^{1,2} This information, along with the orientation of the Houdini's Schilling Titan II robot arm, is used to present the pose information to the operator in a 3-D graphical user interface using software that has been developed by this Cooperative Research and Development Agreement (CRADA). The graphical display presents the data to the operator in a format that is readily understood. The equipment operators are able to use the information in real-time to enhance the operator's ability to safely and efficiently control the remotely-operated vehicle.

STATEMENT OF OBJECTIVES

The scope of this document is to describe the work that was performed by ORNL and delivered to RedZone Robotics, Inc. under the terms of this CRADA, No. ORNL96-0452. Work performed under this CRADA consisted of several tasks to be accomplished by the contractor, Lockheed Martin Energy Research, Corp., and the participant, RedZone Robotics, Inc.

RedZone Robotics was responsible for (1) integration of the POTS hardware with the vehicle, (2) providing vehicle and manipulator system sensor data for display at the user interface, (3) providing a vehicle and mock-up facility for functional testing, and (4) transporting and installing the (Houdini) system to support field testing at a DOE site.

Lockheed Martin Energy Research Corp. was responsible for development of a "flexible, portable, maintainable, efficient, operator interface for remote vehicle and manipulator control that can easily be adapted for use with a wide variety of teleoperated systems."

BENEFITS TO THE FUNDING DOE OFFICE'S MISSION

The system-level POTS graphical user interface (GUI) only displays raw data describing the angle of the laser scanners with respect to the target. This information is helpful for system level diagnostics but is not readily usable by an operator for operation of a remote vehicle. The CRADA developed three-dimensional (3-D) GUI will allow an operator to view a graphical model of the Houdini vehicle in a graphical model of an underground storage tank (UST). The pose parameters are presented to the operator in real-time in a manner that will allow the operator to more effectively and safely operate the vehicle. The GUI can also be used to report possible collisions of the vehicle or its manipulator arm with the tank walls and other obstacles in the tank, as well as to provide tip and tilt alarms to the operator, thereby allowing the operator to recover from a potentially unstable situation that could damage the vehicle or the tank. As a result, 3-D POTS GUI will enable in-tank operations of remote vehicles to be conducted more efficiently and safely.

TECHNICAL DISCUSSION OF WORK PERFORMED BY ALL PARTIES

The Houdini vehicle was shipped to the ORNL where it was successfully deployed in the cold-test facility at the Robotics and Process Systems Division site. Following extensive testing at the cold-test facility, Houdini was relocated to the ORNL South Tank Farm and deployed into tank W3. Both of these deployments were accomplished with the RedZone-supplied control and display system, which provides for camera views of the Houdini vehicle as well as the surrounding environment from cameras located on the base of the vehicle and at the distal end of the manipulator. The Houdini vehicle has been equipped with additional coaxial cables in its tether for use with the POTS system. A fully functioning POTS hardware system was completed in FY 1996. The Houdini vehicle was tested with the POTS system to verify operation of the two systems. All testing of the POTS and Houdini system was successful.

Refinement of the POTS software for data acquisition and analysis is still under way. Mathematical models of pose determination software have been successfully converted to the C programming language and integrated into the VxWorks operating system environment. The current work on the POTS system includes integrating the pose software into the real-time software that controls the POTS system and reporting data back to the POTS system-level GUI display. The POTS real-time software passes raw data counts from the digital finite state machine back to the UNIX-based engineering workstation to display the raw counts in real-time. The raw counts are correlated to the angle from each scanner to the target. Integration of the pitch- and yaw-rotary positioning heads is also near completion. The pitch- and yaw-rotary positioning heads will allow the POTS system to report the pose parameters of the target while maintaining the target in the center of the POTS field of view. The present system-level GUI displays raw counts from the scanners in strip-chart or bar-chart format. In addition, the system-level GUI provides the operator with dialogs that permit control of the laser and rotary positioning heads that aim the laser scanners at the target.

Once the integration of the POTS pose-parameter determination software is complete, pose parameters as well as raw data will be passed to the UNIX-based workstation for graphical display on current system-level GUI as well as the 3-D GUI developed by this CRADA. Current testing of the 3-D GUI developed by the CRADA has used computer-generated pose data.

ORNL has developed a second GUI for 3-D display of the Houdini vehicle and the POTS masts inside a simulated UST. The 3-D GUI includes menu items for selection (or de-selecting) of multiple orthogonal views of the Houdini vehicle and for placement of the POTS masts relative to the tank centerline.

Actual computer screen images taken during operation of the CRADA code are provided below for reference. Figure 1 shows the main display window that depicts the Houdini vehicle and the simulated UST from a top-down perspective view. In all the display-windows, top, front, and side- the grid squares are drawn at a one foot² size. Figure 2 shows the same information from a front view (90 degrees from top). In each view, the shaded segments of the tank wall occur in one-foot increments.

Figure 3 shows the POTS mast position entry window. There are actually two of these windows that are selectable, one for each mast. In these windows, the user enters the survey results for each mast so that they can be drawn in their proper location relative to the Houdini vehicle. Figure 4 shows the tank data entry window. This window accepts the tank diameter and height. The tank is not drawn in any other window until data are entered in this window.

Figure 5 shows other menu options that are selectable from the REGISTRATION pull-down menu. The only other options not yet discussed are the "READ Registration Data," "SAVE Registration Data," and "SAVE AS ..." items. These menu items simply provide a standard file system access widget for saving or retrieving mast transform data and tank parameters.

Figure 6 shows the COMMUNICATIONS pull-down menu. This menu allows the user to selectively turn on or off each communications channel that is used by the software.

Figure 7 shows the WINDOWS selection pull-down menu. This window allows the user to open two additional views of the Houdini vehicle, both orthogonal to the top view. To close either view, the right mouse button is selected with the cursor on the window border, and the "DISMISS" menu item is selected.

DELIVERED SOFTWARE

The software development effort for this CRADA was based on the use of several commercial software packages as well as a public domain OpenGL compliant library. All development was performed on a SUN Sparc station running Solaris 5.4. For the development of the user interface, ORNL used the commercial software package X-Designer, version 4.0.* This program generates X-Windows R11V5 code. The generated code was then coupled with the MesaGL OpenGL compliant library.[†]

Software delivered to the participant as part of this CRADA will contain all the X-Designer GUI description files, all of the X-Designer generated X-Windows code modules, all of the MesaGL library files, all of the ORNL-generated source code files, make files, and the final executable file.

In addition to the above, a separate C program was developed on an SGI computer running IRIX 6.2. This program was used to read an IGRIP version 11 part file and to generate an OpenGL polygon object. Since ORNL had a preexisting CAD representation of the Houdini vehicle in an IGRIP part file format, the simple igrip2gl.c program was used to generate the OpenGL compliant representation used for display within the CRADA-developed software. The program igrip2gl.c will also be delivered.

INVENTIONS

No inventions were made during the development of the POTS 3-D GUI. The POTS system is currently being patented (POTS Patent Application SN 08/646,187), and the patent is scheduled to be complete by the end of December 1997.

*Imperial Software Technology Limited, 95 London Street, Reading, Berkshire RG1 4QA, United Kingdom. Tel: +44 1734 587055; Fax: +44 1734 589005; Email: sales@ist.co.uk; support@ist.co.uk; license@ist.co.uk

[†]Brian Paul, Avid Technology, 6400 Enterprise Lane, Suite 201, Madison, WI 53719; Email: brianp@elastic.avid.com.

COMMERCIALIZATION POSSIBILITIES

Redzone Robotics, Inc., is planning on incorporating the 3-D GUI into the control station for the Houdini vehicle.

PLANS FOR FUTURE COLLABORATION

There are no current plans for future collaboration related to the POTS and 3-D GUI. Redzone Robotics Inc., and the ORNL Robotics and Process Systems Division have several on-going collaboration efforts related to other technologies.

CONCLUSIONS

The POTS 3-D GUI can be used to display the pose parameters of a remotely-operated vehicle or manipulator arm in a highly unstructured environment such as the USTs used to store radioactive and hazardous waste at the DOE sites. The integration of the POTS tracking system and the Houdini remotely-operated vehicle will be enhanced through the use of the 3-D GUI display. The 3-D GUI provides real-time display of the vehicle's position and orientation in the UST in a graphical manner that is easily interpreted by the operator. The operator can use the information to prevent collision of the vehicle or its manipulator arm with the tank walls as well as other obstacles in the UST. In addition, the operator can use the pose information to detect possible tip-and tilt-situations that could make the vehicle unstable and result in damage to the vehicle, the tank, or other equipment in the tank. Since these tank interiors look very much the same in all directions, the 3-D GUI also provides a rapid means of display to the operators, the vehicle location for general purpose task planning, and execution in the tanks.

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Fig. 1. Top view of a simulated UST with a 10 ft x 10 ft grid pattern drawn on the tank floor.

Fig. 2. Side view of the simulated UST with the Houdini hanging from a vertical pipe penetrating the dome of the UST.

mastShell

Enter the POTS Mast A Position and Rotations

Mast A X-Position	0
Mast A Y-Position	48
Mast A Z-Position	54
Mast A X-Rotation	0
Mast A Y-Rotation	0
Mast A Z-Rotation	0

Fig. 3. POTS mast position entry window.

tankParamShell

Enter the Tank Diameter and Height in

Tank Diameter (ft)	15
Tank Height (ft)	8

Fig. 4. Tank data entry window.

Fig. 5. REGISTRATION pull-down menu.

Fig. 6. COMMUNICATIONS pull-down menu.

Fig. 7. WINDOWS selection pull-down menu.

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