DOE F 1430.22 Notice of Energy RD&D Project
GRANT #DE-FG07-96ER14728:
'Advanced Sensing and Control Techniques to Facilitate Semi-Autonomous Decommissioning of Hazardous Sites'

Submitted to:
Dr. Robert Price, ER-15;
Dr. Ramoncita Massey, EM-52; and
Ms. Ladonna Foster; Idaho Operations Office
by:
Robert J. Schalkoff, Project Director

Period of Performance: 9-15-96 to 9-14-97

1 Accomplishments

The first year of this effort emphasized independent development and refinement of each of the three major subsystems (imaging/AI, robotics and virtual reality). Two of the three efforts emphasized the critical task of site. 'virtualization', prior to telepresence-guided D&D. Substantial algorithm refinement and software and hardware development occurred in each area. Relevant publications resulting from this work are cited below.

Specific Results for Image Processing/AI Effort. Our major effort was conversion of all the existing "Line-to-Curve Mapping" code to UNIX, for implementation on the newly-acquired SGI O2 workstation as well as a port of the software to Linux. In addition, numerous algorithm enhancements were made, including: (1) Integration with the Khoros image processing system for preprocessing and segmentation; (2) Substantially enhanced ellipse estimation[5], which approximates the use of a Euclidean norm and does not necessitate parameter normalization; (3) Algorithms for active (laser) and passive camera calibration; and (4) Extension of the LCM algorithm to direct input of projected plane parameters; and (5) Design and fabrication of a customized 'vision head' (see Figure 1 in [5]. The implementation of RCS (Revision Control System) on this machine facilitates efficient and structured multiple-programmer software development. The next phase of activity involves determining the overall accuracy of the quadric estimation procedures, as well as extension to multiple-patch quadric environments.

Specific Results for Robotics Effort. The robotics group has been investigating implementation of a PC based control system for the Puma 560 industrial manipulator. A standard Unimation Mark II controller has been retrofitted with a TRC-004 interface board, which is connected to a PC. The PC is running QNX, a real-time, distributed, microkernel based operating system. A simple PD controller for the Puma 560 has been implemented on the QNX based PC, along with software for calibration of the robot. The new QNX based low level controller has been interfaced to RCCL (robot control C library) through RCCL's simulator interface. A server which interfaces to a force/torque sensor which will be used in the disassembly process has also been developed under QNX. Hardware timing facilities for interrupt generation and watchdog timers have also been implemented.

The next stage involves either porting of ARCL (advanced robotics control library) to QNX or development of our own trajectory generator and kinematics library. This is needed because RCCL's source code is very difficult to work with and almost impossible to port to QNX, whereas ARCL was designed in a modular fashion and has operating system dependant code isolated in certain

modules to allow easy porting to other operating systems. A tool changer suitable for this project has been identified and ordered. A gripper has not yet been identified since more information **about** the disassembly target is needed before that decision is made. Software must be developed for the tool changer and gripper hardware.

Specific Results for VR Effort. Construction of the virtual environment begins with a scene description in terms of sets of quadric parameters. These sets have been provided by the geometry- recognition stage of the process. Passive camera images are then used in conjunction with the deduced geometry to generate surface colors and textures. Real-time rendering on electromagnetically tracked, helmet-mounted displays is accomplished through the use of radiosity, hardware texture-mapping, and glint-layering. The initial approach to the recognition and rendering stages was sufficiently successful to warrant publication in the leading journal on teleoperators and virtual environments [1]. Since that effort, there has been substantial improvement in the algorithms used for extraction of surface colors and textures. The new approach is based upon an inversion of the rendering equation used in generating the virtual environment for real-time display, rather than a traditional, first-order lighting model. Texture extrapolation has also been improved through the use of a discrete cosine transform. A second paper, illustrating the improvements, is now under review [2].

2 Other Information and Pending Activity

Our web page coverage of this activity has been continually upgraded as results became available. The URL is http://ece.clemson.edu/iaal/doeweb/doeweb.htm. In addition, we are disseminating research results at major national conferences, as shown below [2, 5, 6, 7, 8].

The next large-scale milestone for the project is the move to a large laboratory space on the 2nd floor of the Engineering Innovation Building. This should occur about mid-Fall 1997. Overall integration of the vision, robotic and VR subsystems should follow.

During the first, year, we have taken a careful and conservative approach to equipment specification and ordering, to make sure components in all subsystems were both appropriate and compatible. Since the grant was put into place September 15, 1996, most of the Graduate Research Assistants were not put on the payroll until January 1997. While this led to underexpenditure of funds during the first year, it is clear that current manpower and anticipated additional equipment, procurement will rectify this situation.

References

[1] R. Geist, R. Schalkoff, T. Stinson, and S. Gurbuz. Autonomous virtualization of real environments for telepresence applications. ***PRESENCE: Teleoperators and Virtual Environments,*** 6(1997), to appear.

[2] R. Geist, D. Vernon, and R. Schalkoff. Rendering inversion in the automated construction of virtual environments. ***Robotics 98: The 3rd Conference and Exposition/Demonstration on*** Robotics ***for Challenging Environments, in*** review.

[3] Sorgel W., and Schalkoff, R.J. Direct surface parameter determination using an enhanced line-to-curve mapping approach. ***Optical Engineering,*** Vol. 36, No. 7, July 1997, p. 2000-2009.

[4] Geist, R. and Schalkoff, R.J., Autonomous virtualization of unstructured quadric environments. ***IEEE Trans. on Robotics and Automation,*** in review.

[5] Schalkoff, R.J. Geometric Elements of the Direct and Autonomous Virtualization of Quadric Environments. ***Robotics 98: The 3rd Conference and Exposition/Demonstration on Robotics for Challenging Environments,*** in **review. Note: This document is available electronically on our web page, cited above.**

[6] N. Costescu and D. Dawson. QMotor **2.0** - A PC based real-time multitasking graphical control environment. ***Proc. of the American Control Conference.*** May 1998, submitted.

[7] W.E. Dixon, **M.S.** de Queiroz, D. M. Dawson, and F. Zhang. Tracking control of robot manipulators with bounded torque inputs. ***Proc. of the International Conference on Robotics and Automation.*** Leuven, Belgium, May 16-21, 1998, submitted.

[8] F. Zhang, D. M. Dawson, M.S. de Queiroz, and W.E. Dixon. Global adaptive output feedback tracking control of robot manipulators. ***Proc. of the 36th IEEE Conference on*** Decision ***and Control. San*** Diego, CA, Dec. 10-12, to appear.