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LOCKHEED MARTIN

CRADA Final Report
for
CRADA Number ORNL93-0226

ENHANCED CONTROL & SENSING FOR THE REMOTEC ANDROS MK VI ROBOT

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for
CRADA Number **ORNL 93-0226**
between
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and
REMOTEC,Inc.
(Participant)

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For the Participant:

Howard W. Harvey
(Name)

Vice President, REMOTEC, Inc.
(Title)

5/15/97
(Date)

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Abstract

This Cooperative Research and Development Agreement (CRADA) between Lockheed Marietta Energy Systems, Inc., and REMOTEC, Inc., explored methods of providing operator feedback for various work actions of the ANDROS Mk VI teleoperated robot. In a hazardous environment, an extremely heavy workload seriously degrades the productivity of teleoperated robot operators. This CRADA involved the addition of computer power to the robot along with a variety of sensors and encoders to provide information about the robot's performance in and relationship to its environment. Software was developed to integrate the sensor and encoder information and provide control input to the robot. ANDROS Mk VI robots are presently used by numerous electric utilities to perform tasks in reactors where substantial exposure to radiation exists, as well as in a variety of other hazardous environments. Further, this platform has potential for use in a number of environmental restoration tasks, such as site survey and detection of hazardous waste materials. The addition of sensors and encoders serves to make the robot easier to manage and permits tasks to be done more safely and inexpensively (due to time saved in the completion of complex remote tasks). Prior research on the automation of mobile platforms with manipulators at Oak Ridge National Laboratory's Center for EngineeringSystems Advanced Research (CESAR, B&R code KC0401030) Laboratory, a BES-supported facility, indicated that this type of enhancement is effective. This CRADA provided such enhancements to a successful working teleoperated robot for the first time. Performance of this CRADA used the CESAR laboratory facilities and expertise developed under BES funding.

Objectives of the CRADA

This project sought to determine the particular set of sensors and motor encoders required for suitable operator feedback and task automation. Determination of the specific set of such devices required research on the installation and use of a variety of sensors and encoders, in order to ascertain which specific ones work with this platform and for the particular tasks for which the robot will be used. Part of this effort was to center on the degree to which certain tasks can be automated, and which cannot. The suitably equipped ANDROS robot could serve as a research vehicle to explore the degree of automation which can be safely obtained while still retaining the original factory-designated robot capabilities. This CRADA sought to create in a unique vehicle capable of both extensive and productive research, as well as productive work in contaminated environments. The process of creating such a sensor-equipped vehicle also resulted in some transfer of technology to the industrial partner for incorporation into their production robots.

Meeting CRADA Objectives

The objectives, as originally presented for this CRADA, were extremely ambitious for the size of the CRADA funding. This was because it was expected that the CRADA activities would be augmented by the program (DOE/NE Robotics for Advanced Reactors Program) which originally purchased the ANDROS robot, and through which much of the sensor and encoder techniques had been developed. With the demise of the Robotics for Advanced Reactors program, the supplementary funding was gone, and staff members either changed tasks or left the Laboratory. These circumstances resulted in an inability to explore the automation of robot tasks. However, a number of sensors and encoders were purchased, installed and tested. These devices permitted the development of a considerably improved operator interface to aid in controlling the robot.

Benefits to DOE and ORNL

The work done in this CRADA provided an opportunity for ORNL and REMOTEC to renew a working relationship which has also expanded to cover other technology transfers to REMOTEC.

YOu should discuss how the CRADA research on the improvements to the mark VI robot and the interaction with Remotec benefited DOE missions in enviromental management, the BES-supported robotics program, ORNL, your research program, etc. Be honest, yet tactful.

Technical Discussion of Work Accomplished

Contractor ORNL	Done ?	Participant REMOTEC	Done ?
Determine and install additional computing power	**Yes**	**Engineer/install hardware for computer boards**	**Yes**
		Integrate new dual-CPU controller board	**Yes**
Select and test sensors and encoders needed	**Yes**	**Engineer sensor and encoder installation**	**Yes**
Integrate sensors and encoders electronically	**Yes**	**Integrate sensors and encoders (support)**	**Yes**
Develop software for using sensors and encoders	**Yes**	**Continue engineering support to Contractor, add infrared sensing**	**Yes/ No**
Develop demonstrations and prepare final report	**Yes**	**Develop demonstrations and prepare final report**	**Yes**

Table 1. Table of tasks adapted from Appendix A for CRADA No. ORNL93-0226

showing tasks for CRADA and accomplishment of tasks.

Specific CRADA accomplishments: The table above summarizes the original formal tasks in this CRADA, along with an indication of their accomplishment. As can be seen from this table, all tasks were completed with the exception of the addition of infrared sensing to the robot. Explanation for not accomplishing this task is included in the material which follows.

Computing Power: The computing power added to the system is incorporated into a computer board cage (VME) in the form of two cards (a Motorola MVME 167-0334a and a Motorola MVME 162-020a board) each containing a Motorola M68040 central processor unit (CPU) with associated memory, and Motorola MVME 712M transition board which provides signal inputs. The cage, which also contains the power and data communications channels in the backplane, is mounted on a custom-designed plate which attaches to the robot at the base of the pan/tilt camera tower in such a way that there is no permanent alteration to the configuration of the robot. This is desirable because the unit needs to be usable as a telerobot to perform tasks in contaminated areas, and to permit returning the robot to its factory-original configuration for use after the CRADA is concluded. Thus, one of the important goals of the CRADA was to be able to recover the original factory configuration of the robot, and to add the needed equipment in such a way that no permanent alterations were made which would, for example, reduce the contamination resistance of the unit. A thin-wire ethernet connection was also installed, permitting software developed off-board the robot to be downloaded at runtime. The VxWorks real-time operating system by Wind River Systems, Inc., was used, since this was the standard system being used at the time in the CESAR robotics laboratory at ORNL.

Sensors and Encoders: In addition to the computer power added to the robot, a number of encoders and sensors were added. These devices serve several purposes. Four tilt sensors (Penney & Giles, Ltd., CETS/300) were installed, two on the main robot chassis and one on each of the two articulators. These sensors provide angular position information through ± 300° with ±2% accuracy at 33.3 mv/°. Sensors with such sensitivity provide information through the control console screen to the operator about the fore-aft and left-right tilt of the chassis, as well as the position of the articulators at the front and rear of the robot. This information aids the operator in safe manipulation of the robot chassis when maneuvering out of direct visual contact. Robot arm joints were instrumented with a variety of Spectra Symbol SoftPots (membrane potentiometers). These devices are very thin mylar-based carbon potentiometers which change resistance as a function of the movement of an electrically passive pressure pointer along the device. Thus, as an arm joint changes position, the resistance of the SoftPot changes, indicating the degree of joint change. This type of encoding device is desirable because of the limited real estate on the robot for attaching sensors, and because of the need for a simple, sealed device which can be used in hostile environments. Engineeringtechniques for attaching these devices and the required pointers was taken from robotic applications already done at ORNL.

In order for sensors such as the SoftPots to be suitable for applications in sensing and controlling a robot arm, the change in resistance must be linear and proportional to the degree of joint change. In the case of the SoftPots installed on the ANDROS, this was decidedly not the case. In fact, different SoftPots of the same design displayed different non-linear changes to arm movement. This necessitated the creation of a formula with constants and exponents which translated the on-linear functions into linear ones. It turned out that the constants and exponents were unique to each SoftPot. These formulae were developed at ORNL and delivered to REMOTEC to be encoded into the robot display software.

Overall, the robot arm and articulator positioning, as well as the robot chassis tilt angles, were successfully displayed on the control console screen, where they are an aid to the operator in effectively controlling the robot. Additional robot data which REMOTEC has made available to the operator are the battery voltage and time of operation, from which mission time can easily be derived.

Original CRADA plans: It was intended that one of the two added processors handle the incoming signals from the sensors and encoders aboard the robot. These data must be processed through an analog-to-digital (A/D) signal converter prior to being sent to the first processor. This processor interprets and stores the incoming data, updating the data tables with new sensor and encoder information as required. The second CPU serves as a monitor of the control signals generated by the operator and sent along an RS-232 link between the control station and the robot. This unique arrangement permits this processor to either pass the control signals along unmodified or to alter them so as to modify the commands before they reach the control CPU in the robot. When the monitor CPU provides no signal modification, the robot operates exactly as the factory delivered it, in keeping with the CRADA goal of preserving the original factory specifications as a fall-back position. Certain of the automated functions were planned to be permanent, while others were to be invoked at some times and not at others. Many of the permanent functions fall into a class which can be designated as safety functions. For example, the original robot is able to contact the pan/tilt camera tower with the manipulator arm, and it is the operator's responsibility to prevent this from occurring. With the enhanced control system in place, a software-derived envelope would have been created around the camera tower, thus precluding accidental contact by the arm. Similarly, a variety of "illegal" configurations and poses can be defined which would protect both the robot and the environment from undesirable or dangerous situations.

Additional sensors which were originally planned for installation on the ANDROS robot include the Riegal Laser Tape (a laser-based distance sensor), infrared presence sensors for use in darkness or heavy smoke environments (to replace the CCD light-sensitive cameras), and a KLH Compass Engine which would provide accurate directional data to the operator. The combination of these sensors with the computer power described above would permit the automation of a variety of robot actions, such that the operator could drive the robot to a work site, and give the "go" signal for the robot to perform a pre-programmed automated task. However, as indicated in the section above, these refinements were not accomplished for the reasons indicated there.

Publications from CRADA

Jones, S. L. & P. F. Spelt Control enhancements in a commercial mobile telerobot. Proceedings of the 42nd Conference on Robotics and Remote Systems, New Orleans, LA, June, 1994, pp 97-102.

Spelt, P. F. Task automation in a successful industrial telerobot. Paper delivered at the AIAA/NASA Conference on Intelligent Robots in Field, Factory, Service and Space (CIRFFSS'94), and Proceedings of AIAA/NASA Conference on Intelligent Robots in Field, Factory, Service and Space (CIRFFSS'94), Volume I, pp 88-92.

Spelt, P. F. & S. L. Jones, Operator-centered control of a semi-autonomous industrial robot. Paper delivered at the 38th Annual Meeting of the Human Factors and Ergonomics Society, Nashville, TN, October 24-28, 1994; also in the Proceedings of the 38th Annual Meeting of the Human Factors and Ergonomics Society, Volume 2, pp 1048-1051.

Inventions

There were no inventions made or reported associated with this CRADA.

Commercialization possibilities

At present, there are no imminent plans to incorporate any aspects of this CRADA into production. However, some of the interface tehcnologies developed during this CRADA could be incorporated into production robots.

Future collaboration

There are no plans for future collaboration, primarily due to the lack of funding for robotics work for the ORNL PI.

Conclusions

In summary, this CRADA accomplished the tasks originally set out in the CRADA agreement. However, the expectations of both parties to the CRADA, in terms of "extra" accomplishments, were not met. This was primarily due to the demise of the robotics program from which the CRADA was leveraged. Due to the fact that there is no more funding available for robotic work, it appears that the completion of this project represents the end of developments on this ANDROS robot at ORNL.

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