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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

CRADA Final Report
for
CRADA Number ORNL93-0152

DEVELOPMENT OF A MODULAR INTEGRATED CONTROL ARCHITECTURE FOR FLEXIBLE MANIPULATORS

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MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

C/ORNL--92-0152

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December 8, 1994

Mr. Peter D. Dayton
Director, Procurement and Contracts
Department of Energy, Oak Ridge Operations
Post Office Box 2001
Oak Ridge, Tennessee 37831-2001

Dear Mr. Dayton:

Final Report for CRADA No. ORNL92-0152 with Spar Aerospace Ltd.

The subject CRADA has been completed and enclosed is the Final Report for this project.

This report does not contain proprietary information or Protected CRADA Information. Neither Energy Systems nor the participant object to public distribution of this report.

If you have any questions, please feel free to contact me.

Very truly yours,

C. A. Valentine

Brian Bovee
for Business Manager
Office of Technology Transfer

BBB:cav

Enclosure - As Stated.

cc: File - RC

MARTIN MARIETTA

I/18873
NO ESAMS

Internal Correspondence

MARTIN MARIETTA ENERGY SYSTEMS, INC.

Date: November 30, 1994

To: W. P. Painter

c: D. C. Haley, J. N. Herndon

From: B. L. Burks, 7601, MS-6304, 6-7350 - NoRC Barry L. Burks/lpa

Subject: **Completed CRADA ORNL92-0152 (Spar Aerospace Limited)**

Please find attached the final report for CRADA ORNL92-0152 with Spar Aerospace Limited. This final report does not contain any "Protected CRADA Information." This report may be distributed publicly without restriction since the material therein is of a summary nature and contains no Proprietary Information. If further information is required please call me at the number above.

BLB:lpa

Attachment

ABSTRACT

For CRADA No. ORNL92-0152
with Spar Aerospace Limited (SPAR)
for
Development of a Modular Integrated Control Architecture
for Flexible Manipulators

Dr. B. L. Burks (ORNL) and G. Battiston (SPAR)

In April 1994, ORNL and SPAR completed the joint development of a manipulator controls architecture for flexible structure controls under a CRADA between the two organizations. The CRADA project entailed design and development of a new architecture based upon the Modular Integrated Control Architecture (MICA) previously developed by ORNL. The new architecture, dubbed MICA-II, uses an object-oriented coding philosophy to provide a highly modular and expandable architecture for robotic manipulator control. This architecture can be readily ported to control of many different manipulator systems. The controller also provides a user friendly graphical operator interface and display of many forms of data including system diagnostics. The capabilities of MICA-II were demonstrated during oscillation damping experiments using the Flexible Beam Experimental Test Bed at Hanford.

Final Report

For CRADA No. ORNL92-0152
with Spar Aerospace Limited (SPAR)
for
Development of a Modular Integrated Control Architecture for Flexible Manipulators

Dr. B. L. Burks
Oak Ridge National Laboratory

and

G. Battiston
Spar Aerospace Limited

Abstract

In April 1994, Oak Ridge National Laboratory (ORNL) and Spar Aerospace Limited (SPAR) completed the joint development of a manipulator controls architecture for flexible structure controls under a CRADA between the two organizations. The CRADA project entailed design and development of a new architecture based upon the Modular Integrated Control Architecture (MICA) previously developed by ORNL. The new architecture, dubbed MICA-II, uses an object-oriented coding philosophy to provide a highly modular and expandable architecture for robotic manipulator control. This architecture can be readily ported to control of many different manipulator systems. The controller also provides a user friendly graphical operator interface and display of many forms of data including system diagnostics. The capabilities of MICA-II were demonstrated during oscillation damping experiments using the Flexible Beam Experimental Test Bed at Hanford.

CRADA Objectives

The objective of this joint effort was the design and development of a widely applicable manipulator system controls architecture based upon the MICA approach previously developed by ORNL. The primary deliverable from this joint effort was a demonstration of the resulting architecture, dubbed MICA-II, for control of a flexible structure such as the long reach manipulator systems envisioned for use remediating Hanford single-shell tanks.

Task Summary

Funding for the CRADA was provided by the DOE Office of Technology Development through the Robotics Technology Development Program (RTDP) ($150K). The CRADA was approved in July, 1993. Tasks included in this CRADA were joint design of the revised MICA architecture, joint selection of software tools for the user interface, and development of separate software modules by both SPAR and ORNL. ORNL was responsible for revision of the MICA kernel and much of the user interface development. SPAR was responsible for development of portions of the interface including data logging and display. All design and development tasks were completed by March of 1994. Integration and testing were finalized in early April, 1994. Two technical papers have been prepared containing further details of the MICA-II development and testing [References 1 and 2].

MICA is portable across manipulator systems; that is, it can control manipulators of very different configurations and types, (e.g., 1 degree-of-freedom to many degrees-of-freedom, electric or hydraulic, serial link, closed-link, etc.). It is also portable across operating environments. MICA's portability allows for common code to be shared among many different systems. Another feature is the ability to run multiple processors in a coordinated fashion to control a manipulator system. MICA controls the processor synchronization so that control code can be developed that takes advantage of multiple processor capabilities without the system designer having to be concerned with processor timing. MICA's capabilities also include standard trajectory generation functions and the ability to include custom trajectory generators. It provides rudimentary manipulator system simulation capabilities so that developed code can be tested on the control computer system without risk to the manipulator mechanical system.

MICA-II has several improvements over the MICA. The foremost improvement is more efficient coding in C++. MICA-II is approximately 25% the size of MICA. The C++ implementation made strong use of inheritance in the design of the kernel. Code that was replicated many times in MICA is reduced to only one copy in MICA-II. The use of inheritance with other C++ language features dramatically reduced the code size while enhancing functionality. MICA-II includes interfaces to a Graphical User Interface and a data post-processing routine. This allows the system designer to optimize control codes, analyze test results, and to debug system problems in an efficient and timely manner. MICA provides for both synchronous and asynchronous operations. The recognition of the orthogonality of the synchronous and asynchronous functions is essential to the design of MICA. Thus the underlying premise of MICA is that robotic control requires some code in a system to run at a set frequency and that other code be executed in response to infrequent external events.

On April 26, 1994, ORNL presented a technology demonstration showcasing flexible structure robotic control algorithms developed for control of arm-based waste retrieval systems. This demonstration concluded a series of controls tests performed using the Flexible Beam Experimental Test Bed at Hanford. Also included in these experiments was a demonstration of the CRADA final product, the MICA-II controller. Tests of four different oscillation damping techniques were very successful. Oscillation damping is required to move flexible structures safely, rapidly and accurately. The MICA-II graphical operator interface offered a highly automated interface for operating the experiments and analyzing results. The demonstration audience included the RTDP Program Manager and prospective users from the Hanford site.

No inventions have been reported as a result of this CRADA, however, the software developed by ORNL and SPAR could be copyrighted if desired. ORNL and SPAR are interested in a further collaboration in the area of algorithm development for flexible structure control. This scope was deleted from the original CRADA scope because of complications related to SPAR's status as a foreign-owned company.

Commercialization Status

SPAR has during the past year been awarded two major contracts for manipulator system development for applications in underground storage tanks. In both cases the MICA-II architecture would be an appropriate controller for the intended systems. Although SPAR has not marketed MICA-II as a stand alone product this software will undoubtedly be embedded in some form in one or both of these major systems.

References

1. D. S. KWON, D. H. HWANG, S. M. BABCOCK, and B. L. BURKS, "Input Shaping Filter Methods for the Control of Structurally Flexible, Long-Reach Manipulators," *Proceedings of the IEEE International Conference on Robotics Automation*, San Diego, California (1994), Vol. 3, pp. 3259-64.

2. D. H. THOMPSON, B. L. BURKS, P. L. BUTLER, R. L. KRESS, D. S. KWON, and G. BATTISTON, "A Second Generation Modular Integrated Control Architecture For Robotic Manipulator Control," accepted for presentation at the American Nuclear Society Sixth Topical Meeting on Robotics and Remote Systems, Monterey, California, February 5-10, 1995.