Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR TP 96502

ARCADE
An automation & robotics demonstrator project

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DOCUMENT CONTROL SHEET

	ORIGINATOR'S REF. **NLR TP 96502 U**		SECURITY CLASS. **Unclassified**

ORIGINATOR
National Aerospace Laboratory NLR, Amsterdam, The Netherlands

TITLE
Arcade
An automation & robotics demonstrator project

PRESENTED AT
the Annual Congress 1996 of the "Deutsche Gesellschaft für Luft- und Raumfahrt" (DGLR), Dresden, Germany, 24-27 September 1996.

AUTHORS	DATE	pp	ref
M. Schoonmade	**960814**	**22**	

DESCRIPTORS

Man-computer interface
Microgravity applications
Payload control
Payload integration plan
Payloads
Prototypes
Requirements
Robot arms
Test facilities

ABSTRACT

Based on the national study Automation and Robotics for Microgravity Applications Demonstrator (ARMADE) a model-payload facility has been developed for ESA. This contribution to the Columbus Automation and Robotics testbed (CAT) at ESTEC was designated ARCADE, for ARMADE in CAT Demonstrator.
The primary objectives were the development and demonstration of Automation and Robotics (A&R) technology in support of microgravity experiment facilities.
The ARCADE facility consists of an incubator, an analysis instrument and a sample cartridge to be transferred between the two by a robotic manipulator, It enhanced CAT with a more realistic payload - the first one with actual 'science' data output -.
This paper addresses some aspects of the development, integration, test and demonstration of this A&R model-payload as performed by a Dutch industrial team. It will document how existing designs are integrated into an automated facility, which can be operated by a robot arm.

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An Automation & Robotics demonstrator project

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Based on the national study Automation and Robotics for Microgravity Applications Demonstrator (ARMADE) a model-payload facility has been developed for ESA. This contribution to the Columbus Automation and Robotics Testbed (CAT) at ESTEC was designated ARCADE, for ARMADE in CAT Demonstrator.
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1. Introduction

When the number and duration of experiments in space expands as foreseen, the need to assist or replace astronauts in demanding, dangerous or monotonous tasks will grow. In this way not only more experiments can be performed, but moreover executed in a predictable and repeatable manner. For these reasons a study on spacecraft-internal Automation and Robotics (A&R) was initiated in 1990 and funded by the Netherlands Agency for Aerospace Programs (NIVR). This A&R for Microgravity Applications Demonstrator (ARMADE) project led to a concept for a payload testbed and demonstrator facility, concentrating on modularity and 'smart' sub-systems (i.e. payload modules with local control and high-level commanding).
A harmonised implementation of this concept was then proposed to ESA as a contribution to the Columbus A&R Testbed (CAT) at ESTEC. In 1994 the ARMADE in CAT Demonstrator (ARCADE) contract to ESA and NIVR was launched, with NLR as prime contractor and contributions from an industrial team consisting of Comprimo Consulting Services B.V., Fokker Space and Systems B.V. (FSS), ICT Automatising/Aerospace B.V., Stork Product Engineering B.V. (SPE).
The primary goals of ARCADE are the validation of A&R payload concepts and development through the implementation of a model facility, and demonstration of its performance to the scientific community and ESA.
The combination of testbed and demonstrator goals fits very well to those of CAT. The difference between this payload and the other ones in CAT is, however, that it returns house keeping and science data to the user. This makes the testbed implementation and demonstration more challenging and appealing to the team and the scientist or Principal Investigator (PI).

2. Constraints and requirements

In view of the demonstration and testbed objectives the primary requirement was to create a working facility, in which an user can execute actual (demo-)experiments.
Because of the desire, also for budgetary reasons, to build upon existing design and implementations, and the compatibility to CAT, a number of additional constraints and requirements were identified. Most important constraints for compliance with CAT were the 19-inch rack environment, the employed standard robot grapple fixtures and the general laboratory environment. The last constraint limits the use of certain sample fluids, temperature, power etcetera. Also the - to be developed - model facility, based on existing/commercial equipment, cannot be compatible with space requirements such as triple containment and non-disturbed microgravity levels.
Requirements that should be mentioned are:

- an user/scientist Man Machine Interface (MMI) that allows for payload monitoring and full control,
- experiment execution without robot interference (in 'astronaut/crew' mode) and
- hierarchical control of smart payload subsystems with only high level commanding and monitoring.

For CAT it was relevant also to acquire a payload that generates actual output data.

3. Design of the payload facility

As indicated before, cost effectiveness and ease of development imposed a design largely based on existing parts. The analyzer, as supplied by Comprimo, was derived from High Performance Capillary Electrophoresis (HPCE) devices widely used in earthbound bio-chemical laboratories. Electrophoresis is a technique in which the migration of charged particles under influence of an electric field, is used to separate components of a sample. In the HPCE instrument sample fluid is injected in a capillary with a buffer medium. Ultra-violet absorption detection then yields the sample composition.
The adaptation of the sample cartridge, by SPE, to the so called Liquid Box, enabling robot manipulation, has been a new development. This Liquid Box holds four vials which contain flush, buffer and sample liquids for the HPCE instrument. During robot manipulation the Liquid Box is covered by a lid, which is automatically forced open when the box is placed in the HPCE.
The Incubator is based on an FSS thermal interface plate developed for sounding rockets experiments. The thermal conditioning is by means of a Peltier element. The Incubator incorporates two Liquid Box locations behind separate doors, one location with and one without active temperature control. The payload interfacing and control box by NLR also stems from this flight-proven sounding rocket experiments technology.
The payload MMI as, implemented by ICT, is a follow-on development to similar existing CAT Payload Monitoring and Control Stations (PMCSs).
The interface design for ARCADE, integrating it with the existing CAT, was performed by FSS with NLR support. The programming of the robot, using a computer (kinematics) simulation as preparation, was done by NLR also.
The ARCADE payload facility which is created in this way allows for sample (Liquid Box) storage, temperature conditioning (Incubator) and analysis (HPCE). All functions are remotely operated and monitored by a PI from a PMCS. From this PMCS also manipulation tasks are requested for robot and/or ’astronaut’ crew execution. For the PI it is indifferent whether the required sample manipulations (e.g. to open the left Incubator door, to remove the Liquid Box and to install it in the HPCE) are performed by the robot arm or an astronaut, as long as the experiment execution is not hampered.

4. Integration, test and demonstration

The integration and testing of ARCADE has been schemed as a three phased approach. The strive for modular design permitted separate HPCE, Incubator and control box tests at the suppliers using a check-out PC, serial communication links and existing software.
This was followed by a subsystem integration in a standard Columbus 19-inch rack at the NLR robotics laboratory, where the robot operations and the complete system were tested. However, this did not yet include the PMCS, as this required the availability of the CAT network, which is only present at ESTEC. So for that purpose the check-out PC was used once again.
Following successful integration and tests the complete payload rack has been transferred to and integrated with CAT. There the robot manipulations were updated and verified, because the employed robot and gantry differ from the NLR set-up. Also the PMCS was acceptance tested at CAT as mentioned before.
It has been demonstrated that the facility can indeed be operated by the robotic system under PI control and monitoring. The envisaged science data link, however, is not yet completely implemented due to some required communication network updates.

5. Results and concluding remarks

The development posed a number of subsystem communication interface challenges concerning protocols and speed, which were all found to be solvable until now. One obvious reason for this is the use of available parts and design.
A tool which was found to be very useful in overall design was the kinematics simulation of the robot and its environment. This showed graphically the optimum layout for the manipulation tasks.
Although the final CAT integration is not completely finished due to unfinished communication software modules, it has already been demonstrated that it is indeed possible to develop an A&R microgravity model payload incorporating ARMADE concepts and ’off-the-shelf’ designs. The first testbed results also indicate that even more design effort is required for more ’robot-friendly’ manipulator operations. For instance the limited manipulator accuracy, reach, access and dexterity, dictate guided, short, unobstructed and straightforward moves. This will, however, be of less importance when the ARCADE robot tasks have been fully upgraded to the usage of the enhanced CAT control features stemming from the Space A&R Controller (SPARCO) contract, including sensor based impedance control programs.
It should also be stressed at this point that A&R devices for microgravity experiments are not advocated as a replacement for astronauts, but as a cost effective, predictable aid in executing uncomplicated and repetitive tasks.
Future work based on the current ARCADE effort could include an MMI for facility monitoring and (contingency) control, a more authentic demonstration with an actual PI’s experiment and extensions to an external A&R payload demonstrator.

Abbreviations

A&R	Automation and Robotics
ARCADE	ARMADE in CAT DEmonstrator
ARMADE	A&R for Microgravity Applications DEmonstrator
CAT	Columbus A&R Testbed
ESA	European Space Agency
ESTEC	European Space Research and TEchnology Centre
FSS	Fokker Space and Systems
HPCE	High Performance Capillary Electrophoresis
MMI	Man Machine Interface
NIVR	Netherlands Agency for Aerospace Programs
NLR	National Aerospace Laboratory
PI	Principal Investigator
PMCS	Payload Monitoring and Control Station
SPARCO	SPace A&R COntroller
SPE	Stork Product Engineering

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Appendix A Overhead sheets