EUROPA (External Use of Robotics for Payloads Automation)

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To demonstrate the potentiality of in orbit use of robotics for external applications, ESA and ASI decided to fly a technology demonstration mission, named JERICO (Joint European Robotic Interactive and Calibrated Operations).

Different mission scenarios were considered: a cooperation with NASDA, a mission on the Space Shuttle, on MIR and on Russian segment of ISS. Unfortunately, none of them went on. In the mean time, it has grown up the general opinion that robotics is a valid tool for in orbit operations and therefore a mere demonstration mission can be considered as no longer necessary.

As consequence, ASI is now proposing to NASA a payload called EUROPA (External Use of Robotics for Payloads Automation) to be flown on ISS late 2002. The preferred ASI approach is to keep the same JERICO elements and the involvement of the same partners. This possibility is now under discussion and will be finalised in the next future.

1. EUROPA OBJECTIVES

The EUROPA payload is intended to perform, as first objective, a realistic end-to-end robotic technology demonstration to show the advantages and the feasibility of a versatile robotically tended exposed payload infrastructure.

Following this, the infrastructure shall allow exposure payloads or payload units to be installed, pointed, serviced/manipulated, inspected, analysed and retrieved in a flexible way without the need for human EVA.

This would constitute a unique service to the world-wide user community of relatively low-cost, rapid and reliable logistics support for scientific experimentation on the ISS.

The payload is built around the SPIDER medium-sized dexterous robot arm.

It can perform the following tasks:

- installation/removal of small payload containers on exposure attachment ports;
- handling of payload units (experiment samples or sample cassettes) for the purpose of scientific/technological investigations;
- close-up visual inspection of payload units by means of a camera.

All of the above tasks can be pre-programmed and checked on ground and then performed automatically on orbit with ground monitoring and possibility to intervene and correct the situation in case anomalies are detected.

2. EUROPA DESCRIPTION

2.1. EUROPA flight segment

The flight segment of EUROPA is the part aimed to the execution of the robotic capability demonstration and the payloads handling.

It will be accommodated on one of the six Adapters of the EXPRESS Pallet (ExP) (fig. 2.1-1).

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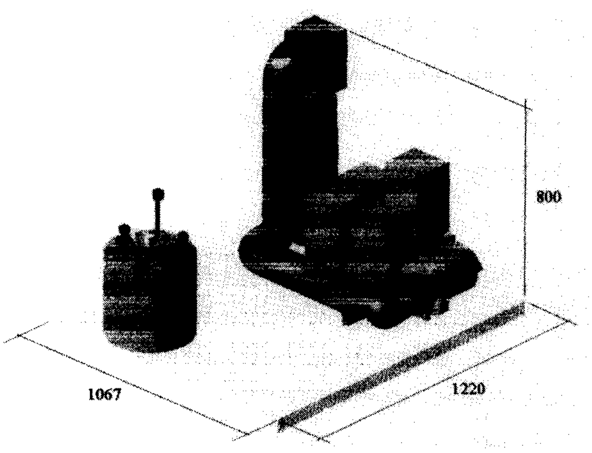


Fig. 2.1-1 : EUROPA flight configuration.

The EUROPA consists of the following subsystems:

- manipulator composed of:
  - hold down - to fix the arm during launch and re-entry phases;
  - arm - to perform, when integrated with its avionics, all the required activities (such as open drawer, close door, install peg, etc. ...);
  - Force/Torque (F/T)- to allow force and torque control during the execution of operations;
  - End Effector (EE) - to grasp the items to be handled;
  - RObot CAlibration Tool (ROCAT) - to calibrate the system;
- avionics composed of:
  - controller - to send the operating sequence in a pre-programmed automatic way, to receive the resolver signals and to provide the interpretation and execution of commanding and the collection and transmission of engineering telemetry data. For local commanding, a man machine interface is provided running on one or more crew computers;
  - driver - to provide the signals to the motors;
  - Power Distribution Unit (PDU) - to distribute power from EXPRESS Pallet Adapter (ExPA) power bus and EUROPA items;
  - harness - to electrical connect all EUROPA items;
  - emergency unit - to allow arm stowing in emergency conditions;
- supervisor camera - to provide an overview of the overall scene while robot is operating;
- taskboard - to provide all the required in-orbit infrastructure to demonstrate the technology and evaluate/measure the performance capabilities of the arm and its avionics (such as compliant motion capabilities, accuracy, repeatability).

Fig. 2.1-2 shows the EUROPA breakdown.

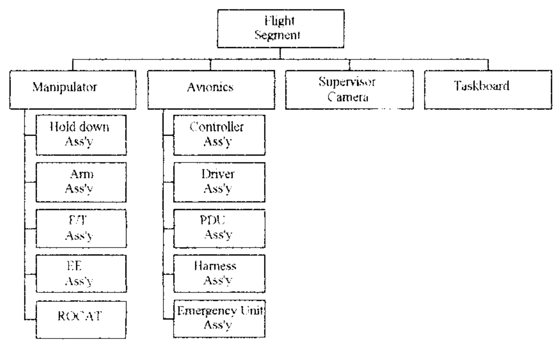


Fig. 2.1-2.: EUROPA Flight Segment breakdown.

2.2. EUROPA Ground segment

The ground segment of EUROPA is the part aimed to:

- ground calibration;
- program preparation and verification on the Ground Reference Model (GRM);
- flight robot monitoring and command;
- on-ground data handling.

The EUROPA ground segment consists of the following subsystems:

- Ground Support checkout Equipment (GSE) - to provide the necessary equipment to support the complex integration test and the acceptance testing before launch;

- engineering support equipment - to provide all the necessary HW and SW to execute support activity;
- preparation and verification work station - to provide the necessary HW and SW environment to prepare and verify all the activities of EUROPA and the Payloads;
- GRM - to provide a ground replica of the flight segment;
- Robot Monitoring and Command work Station (RMCS) - to provide the necessary HW and SW environment to execute and monitor a complete EUROPA activity plan. The monitoring will be achieved both using graphic simulation based on the flight segment telemetry data and possibly compressed image(s). The RMCS will be connected to the GRM in order to have a real emulation of flight segment operations;
- Payload Monitoring and Command work Station (PMCS) - to provide the necessary HW and SW environment for a scientist, in a user home base, to plan, execute and monitor pre-defined activities on his payload. The monitoring will be done both using high level graphic simulation based on the telemetry data and possibly compressed image(s).

Fig. 2.2-1 shows the EUROPA ground segment breakdown.

All the ground segment items will be located at ASI-Matera.

The GSE will, on the contrary, follow the Flight Segment helping during integration phase.

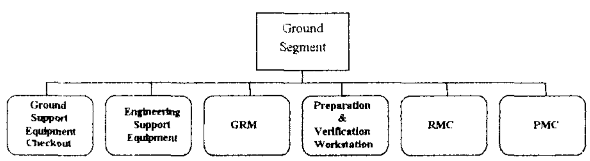


Fig. 2.2-1.: EUROPA Ground Segment breakdown.

2.3. EUROPA Operations

Two payloads will be used for the demonstrations::

- the taskboard assembly, with representative elements to systematically exercise the typical expected payload tending tasks (open/close sample drawers, extract/insert sample containers, point sample containers, ..) with well defined degree of difficulties;
- one dummy payload, to make the demonstration of operations on a 'real' payload.

3. EUROPA KEY ELEMENTS

The two key elements around which EUROPA payload is built are:

- the SPIDER robotic arm;
- the CESAR robot controller.

3.1. SPIDER Robotic Arm

The Arm Ass'y is the one developed in the frame of SPIDER project an ASI contract (see fig. 3.1-1) with the following modifications:

- mounting of ROCAT system between the wrist and the Force/Torque,
- addition of external end strokes (to apply only if needed) for joint 1, 2 and 7;
- addition of heaters;
- change of the external connectors and fixation on a dedicated flange (shoulder side).

The **Arm manipulator** is anthropomorphic and features 7 rotational degrees of freedom (d.o.f.).

The Arm kinematic structure of the arm is schematically represented in fig. 3.1-2.

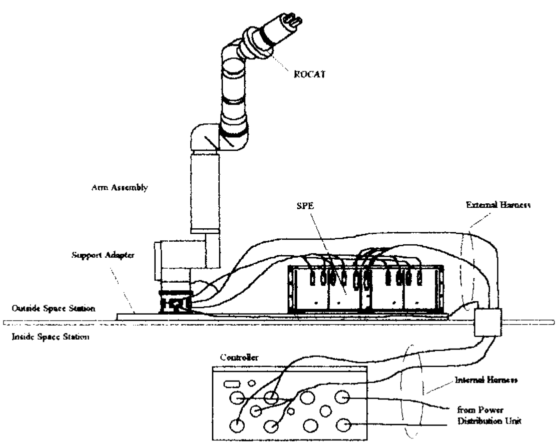


Fig. 3.1-1: SPIDER Arm.

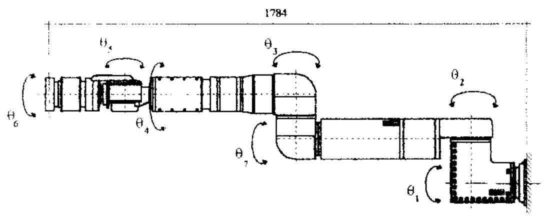


Fig. 3.1-2: Arm kinematic structure.

Each joint (numbered from 1 to 7) corresponds to a degree of freedom, in sequential order from shoulder to wrist, apart form joint 7 which is located between joint 2 and 3.

The rotation angle of each joint is shown in table 3.1-1.

Joint 1	Joint 2	Joint 7	Joint 3	Joint 4	Joint 5	Joint 6
± 180 °	± 180°	± 180°	± 180 °	± 180 °	± 120°	± 180 °

Table 3.1-1: Maximum joints stroke.

Joints 1 and 2 are in the shoulder assembly, joints 3 and 7 are in the elbow assembly and joints 4, 5 and 6 are in the wrist assembly.

Each joint of the arm is powered by an electromechanical actuation group composed of motor, gearbox, input and output shaft sensors and brake.

Table 3.1-2 summarises SPIDER arm key characteristics at 0g conditions, valid in all points of the operational envelope at the environmental conditions shown in table 5.1-3. The Arm can also be operated at 1-g conditions, without any support equipment.

Parameters	***Characteristics***
Max load carrying (COG at 500 mm from Arm end flange)	up to 250 kg
Continuous actuation force - isotropic	25 N (100 N short period < 10 s)
Continuous actuation torque:	
• shoulder joints	40 Nm (200 Nm short period < 10 s)
• elbow joints	30 Nm (100 Nm short period < 10 s)
• wrist joints	30 Nm (50 Nm short period < 10 s)
Position repeatability	1 mm
Orientation repeatability	0.05 °
Position accuracy (before cal.)	3 mm
Orientation accuracy	0.1 °
Max linear speed	0.1 m/s
Max rotational speed	0.1 rad/s
Mass	65 kg
Stowing volume	510x1040x310 mm
Power consumption (estimated)	30 W to 45 W (90 W at 1g)

Table 3.1-2: SPIDER arm characteristics in 0g condition.

Thermal	• survival	-60 °C to +150 °C
	• operational	-40 °C to +80 °C
Pressure in orbit	• survival-operational	10^{-4} to 10^{-6} Pa
Launch vibration	• first frequency	> 35 Hz
	• sinusoidal	Max level 6 g; sweep rate 3 oct/min up and down
	• random	Max load 13.8 gr.m.s; time duration 150 s

Table 3.1-3: SPIDER arm and End Effector environmental requirements.

A **Force/Torque Sensor**, mounted on the wrist end, has been developed to measure and control the force and the torque exerted by the arm during operation.

Its main characteristics are:

F/T Characteristics	
Sensor type	strain gauges
Measuring range	± 200 N, ± 20 Nm
Measuring accuracy	± 3% (temperature range -40 °C +80 °C)
Measuring resolution	0.1 N, 0.01 Nm
Overload protection	± 2000 N, ± 200 Nm
Mass	1.15 kg
Power consumption	< 2 W

The F/TS is shown in fig. 3.1-4.

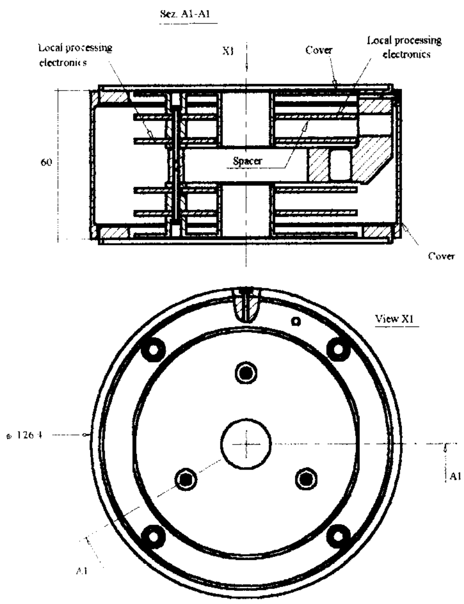


Fig. 3.1-4: Force/Torque Sensor drawing.

The main characteristics of the **End Effector** (see fig. 3.1-5) are shown in the following table.

Parameters	*Characteristics*
Max opening width	76 mm
Min opening width	0 mm
Max gripping force	300 N
Max dimension of grasping object	70 mm
Mass	3.995 kg
Power consumption	6 W

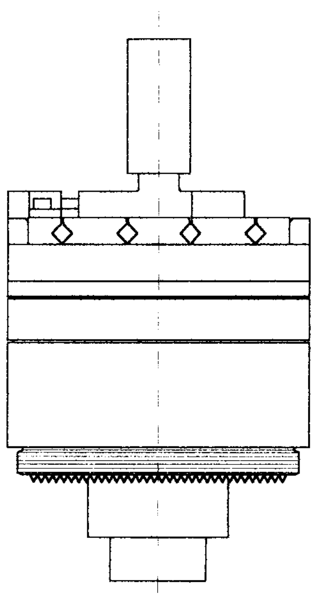


Fig. 3.1-5: End Effector schematic drawing.

The End Effector is equipped with two Tactile Sensors (located on the End Effector jaws) in order to monitor the force exerted during gripping.

The characteristics of the Tactile Sensors are:

Parameters	*Tactile sensors Characteristics*
Sensor type	strain gauges
Max force	200 N
Accuracy	± 3% (temperature range -40 °C +80 °C)
Resolution	0.1 N

On the End Effector a latching/delatching mechanism has been implemented to easy disconnect the End Effector from SPIDER arm.

4. THE CESAR ROBOT CONTROLLER

Considering that the development of a mature robot controller is a multi-million, multi-year effort, ESA has embarked on the development of a common Controller for European Space Automation and Robotics (CESAR) in hardware and software by starting from a mature, well-proven industrial product: the COMAU C3G controller.

The architecture of CESAR (Fig. 4-1) is composed of a Robot Control Unit (RCU), which performs the most computation intensive high level tasks, and a set of more or less intelligent slave modules, named Servo Control Units (SCU), which control the robotic hardware (servo drives, sensors). Due to this strict master-slave structure CESAR does not need any sophisticated multi-processor bus (such as VME). Instead a multi-drop master-slave serial bus is adopted to allow for communication between RBU and SCUs. This serial bus enables both the concentrated and distributed control.

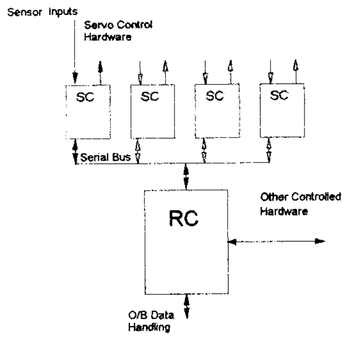


Fig. 4-1: CESAR general architecture.

The software architecture (fig. 4-2) features three types of tasks:

- system tasks (implementing the interface to Telemetry/Telecommands, a monitor shell and some built-in test logic)
- robotic tasks (robot program interpretation, motion control)
- user tasks (to interface to external auxiliary hardware)

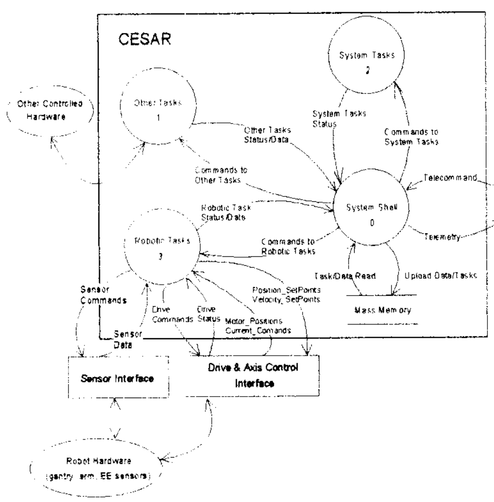


Fig. 4-2: CESAR software architecture

The RCU software architecture allows for the easy replacement or addition of tasks to modify/augment the CESAR functionalities.

The real-time operating system chosen for the CESAR SW is vxWorks, which supports many microprocessors, including the newly available radiation tolerant microprocessor ERC32 and Digital Signal Processors (TSC21020E) developed on behalf of ESA by European industry.

The software modularity and the wide micro-processor support for the operating System, enable the adoption of HW architectures even different from the CESAR general one.

Hardware Implementation

The CESAR-HW uses two different types of electronic boards to implement the RCU and the SCUs. The RCU uses a Standard payload Computer (SPLC) CPU module fitted with a mezzanine SPLC LAN Adapter and a MIL-Bus Adapter, while the SCUs are developed specifically for the CESAR-HW.

The SPLC uses a common mezzanine bus for their mezzanine slots (MIL-Bus, LAN). The same bus concept is also used for the SCU Boards.

A common mezzanine bus concept over the whole CESAR-HW reduces costs since all the elements can make use of existing SPLC Adapters.

The SCUs are designed in a modular manner. Each SCU consists of a Base-Board, a Core-Board and one or two Mezzanine-Boards.

A Base Board carries Core- and Mezzanine-Boards and provides the required interfaces to the robot servo amplifiers.

Core-Boards include a DSP CPU, drivers, non-volatile memory and program/data RAM.

Mezzanine-Boards are used to interface to the serial bus. They feature a micro-controller, which performs data–communication tasks up to the Application Layer of the ISO/OSI model. With this arrangement the Core-Board is not affected by the specifics of the serial bus used.

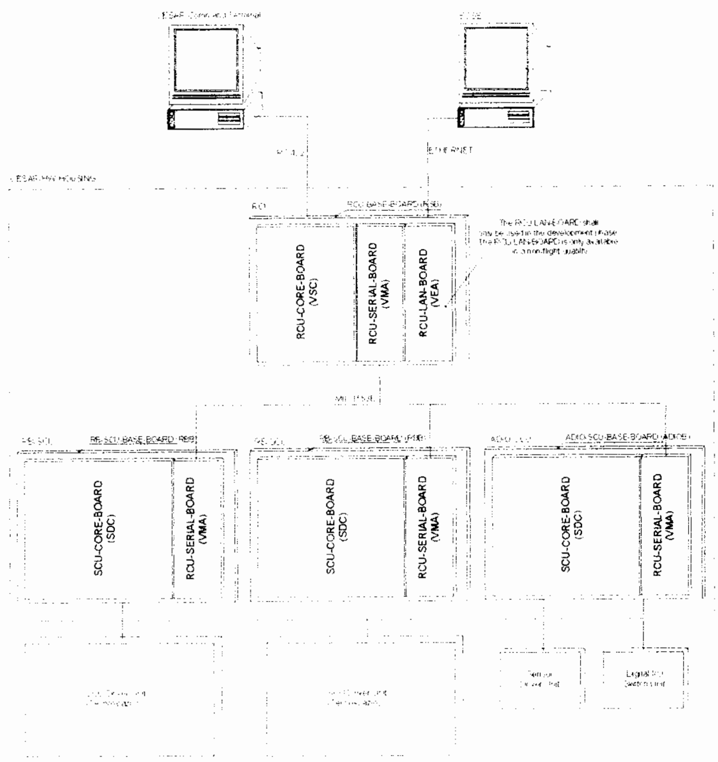


Fig. 4-3: A CESAR hardware implementation.

The RCU and the Command terminal communicate via a RS422 interface with a baud rate of up to 19200 baud. The communication between the RCU and the SCU's will be realised via the MIL-Bus 1553B.

For development and debugging of the system software an Ethernet interface is provided. This interface is implemented through a SPLC Ethernet Mezzanine card.***SW Tests***

For what regards the software, the porting work has been finished. CESAR-SW now runs on a ERC32-compatible platform using the VxWorks real-time operating system.

An extensive test campaign was performed to validate the software using:

- a standard test suite (normally used in industrial robot applications)
- a series of space related tests involving normal and contingency cases (e.g. loss of communication with remote interface).

For the purpose of demonstrating the software, a series of graphical man machine interfaces (MMI) has been produced. These allow to command and monitor robot operations trough a CESAR command terminal. Figure 4-5 shows one of these MMIs, which mimics a teach-pendant appearance.

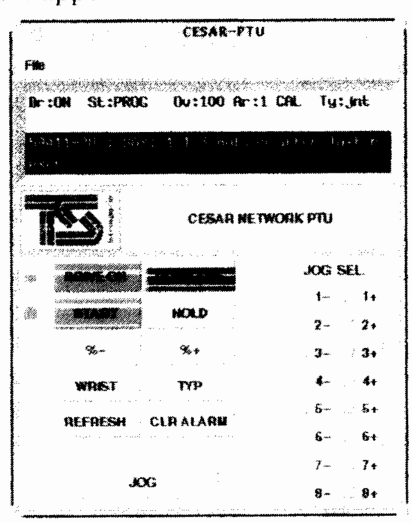


Figure 4-4 Teach Pendant MMI.

5. CONCLUSIONS

The payload is aimed to perform a realistic end-to-end robotic technology demonstration to show the advantages and the feasibility of a versatile robotically tended exposure payload infrastructure. This infrastructure shall allow exposure payloads or payload units to be installed, pointed, serviced/manipulated, inspected, analyses and retrieved in a flexible way without need of human EVA.

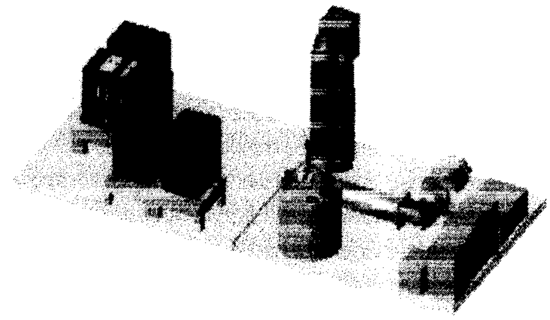
It could be seen as a unique service to the world-wide user community of relatively low-cost, rapid and reliable logistics support for scientific experimentation on the ISS, able to perform all the manipulation activities for payload operations.

The payload is built around a medium-size dexterous robot arm. It can perform the following tasks:

- installation/removal of small payload containers on exposure attachment ports;
- handling of payload units (experiment samples or sample cassettes) for the purpose of scientific/technological investigations;
- close-up visual inspection of payload units by means of a camera.

All of the above tasks can be pre-programmed and performed automatically, with ground monitoring and the possibility to interfere and correct in the case of anomalies ("interactive autonomy").

The first possibility to show the capability of this Robotic Adapter in operating real payloads is to place it close to the European Technology Exposure Facility (EuTEF), in order to provide the manipulation services to this facility.



6. REFERENCES

[1] P. Putz, "SPARCO: an Advanced Space Robot Controller", Preparing for the Future Vol. 5 No 4, Dec. 1995