PAYLOAD TUTOR (PAT) A RELOCATABLE PAYLOAD ROBOT FOR ISS INTERNAL AUTOMATION SYSTEM

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1. INTRODUCTION

In 1996, a call for proposal was issued by NASA (NRA 15-OG3-6-16P), with the aim to collect ideas to enhance operations on Space Station.

Among more than 120 proposals to NASA, one of the three selected was a concept proposed by ASI for Internal Automation, called **Payload Tutor (PAT)** and consisting in a small relocatable robotics system which can be mounted by the crew close to the rack to be serviced.

A bilateral co-operation ASI/NASA is now in progress, with the aim to prove the validity of the concept on an American payload rack: once validated, the concept could be applied extensively to American payloads.

A draft memorandum of understanding between ASI and NASA on PAT development is now ready for its finalisation and signature.

This foresees the following main steps:

- in orbit demonstration by end of 2003;
- use of PAT on American payloads in 2004.

For the first demonstration NASA will provide Shuttle launch services plus crew time and ISS infrastructure, while ASI will provide the system with a dedicated task board to demonstrate PAT capabilities. The demo phase will end with the operation on ASI and/or NASA payload.

Particular care will be given to MMI aspects, in order to allow monitoring and control from ground and/or from the on board crew.

It is worth mentioning that ASI is now planning the development of a ground prototype, for which a co-operation with ESA for the robot controller is under definition.

This paper presents the concept and the programmatics aspects of the development.

2. TECHNICAL DESCRIPTION

2.1. The Express Rack

The International Space Station (ISS) is an international, Earth orbiting, research facility. Its mission is to conduct scientific, technological and commercial application research in a microgravity environment, with emphasis on long duration activities.

In order to ease and widen the utilization of ISS, NASA has created the Expedite the Processing of Experiments to Space Station (EXPRESS) program.

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EXPRESS provides payload accommodations that will allow quick, simple integration with the use of standardised hardware interfaces and a streamlined integration approach.

The EXPRESS Rack utilizes (see fig 2.1-1) an International Standard Payload Rack (ISPR) in conjunction with secondary structure and avionics hardware, resulting in a simple payoad interface.

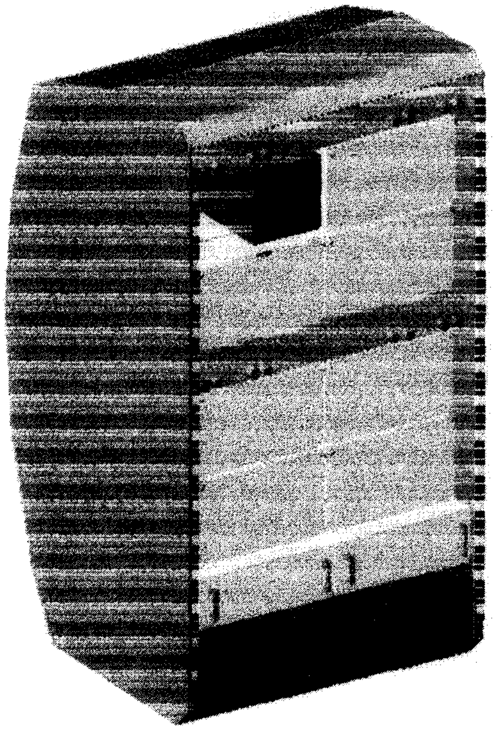


Fig. 2.1-1: EXPRESS Rack concept.

EXPRESS racks are used to provide payload services to facilitate payload operations for all types of payload users. The rack provides accommodations for eight middeck lockers and two Standard Interface Rack (SIR) drawers. Each middeck location can accommodate 72 pounds of experiment equipment, including container weight. A total of 2 kW of 28 Vdc power is provided to the payloads in the rack, with each payload position receiving up to 500 W. Interfaces for EXPRESS Rack payloads on the ISS will include RS422, ethernet, analog, discrete and video. In addition, air cooling will be available at each payload location.

Payload may be arranged in (see fig. 2.1-1):

- lockers;
- large or small drawers;
- mounting plates, these may occupy 1 or 2 (contigous) middeck locations.

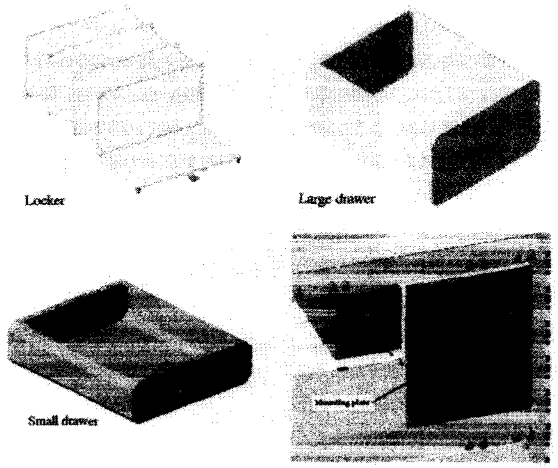


Fig. 2.1-1: Payload accommodation possibilites.

The EXPRESS Rack eases the work of payload developers, offering a set of standard hardware and interfaces. The concept, however, still requires crew for operations. To save crew time for payload operations, the relocatable robot is planned to be used.

2.2. PAT Concept

The basic idea is to perform the most common operations on payloads in a similar way an astronaut would do it. This has a double effect:

- first it minimise the changes in classical payload developments;
- second, it allows the users to think at operations in the same way as they were supported by an astronaut.

The robotics concept is shown in fig. 2.2-1.

The robot is mounted at the rack on which it has to operate. It is a short manipulator arm with 6 d.o.f., mounted on a vertical rail.

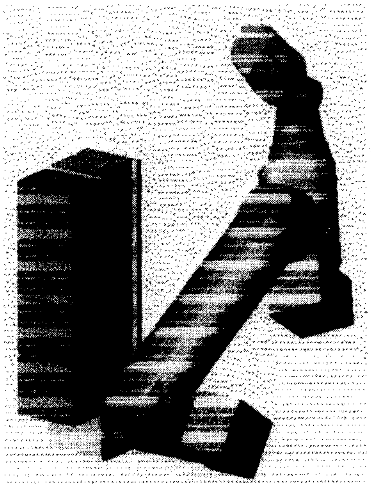


Fig. 2.2-1: ISS Relocatable Payload Robot Concept.

The Arm is mounted on the rail in order to provide full dexterity in performing rack operations. At the tip of the Arm an End Effector is mounted. The electronics is mounted partially on the rail and partially on the arm.

The Robot kinematics provides a very good dexterity to the system. End Effector orientation is provided with axes 4, 5 and 6 of the Arm, while its position is mainly provided by the vertical rail and the axes 1,2 and 3 of the Arm. The End effector is sensored and a camera is mounted on it for inspection purposes.

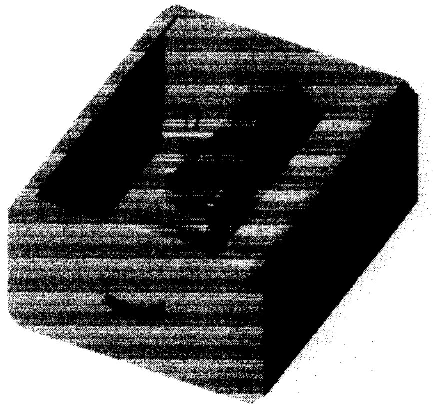
The whole robot can be removed, by the astronaut, from the rack and placed on another rack to be serviced. For operating in parallel different racks, more than one robot can be used. During initialisation activity, an automatic Robot calibration procedure is foreseen, to calibrate the Robot w.r.t. the rack it has to operate.

It has to be highlighted that, once the Robot has been 'plugged' on the rack to be serviced, no astronaut intervention is necessary, as the robot can be controlled directly from ground. The control from ground consists of simple commands to start robot program tasks already present inside the robot controller, according to a user defined sequence and with user defined parameters.

Required crew activities for PAT are summarised the following:

Installation

- PAT retrieval from the Drawer (see fig. 2.2-2)



- Mechanical connection in front of the rack
- Electrical connection
- Switch on

During nominal operations

NONE.

During non-nominal operations

- Switch off power
- Backdrive the Arm

The PAT system is being designd to fullfill the following requirements:

- PAT operates on payloads hosted in the EXPRESS Rack;
- PAT has no impact on EXPRESS rack design;
- the Crew deploys PAT wherever is needed. That means that PAT may be mounted in different locations on the same EXPRESS rack as well as on different racks;
- PAT operates on payload subjects (e.g. samples, drawers, trays, doors) accessible on/beneath the aisle-facing surface of an EXPRESS rack;
- the basic PAT operations are the classical sample manipulation (extract, transfer, insert),

opening/closing of lockers/drawers, plus some actuation (e.g. flipping switches, rotating dials). The subjects for manipulation and open/close must be equipped with appropriate grasping interfaces;

- PAT operations can be started and monitored from ground, as well as from a Crew PC.

3. PAT SERVICING OPERATIONS

3.1 PAT Servicing Operations on EXPRESS Rack Standard Items

Among the possible operations PAT needs to perform, there are some which are related to EXPRESS Rack items. In fact payloads sometimes make use of standard middeck lockers or drawers to store samples or consumables.

PAT is designed to be able to handle such items. Examples are reported in fig, 3.1-1 (PAT opening a middeck locker by hinging its door. The door launch locks have been previously released by the crew. The door is kept closed by the magnetic latch. PAT grasps a flap and hinges out the door.) and fig. 3.1-2 (PAT sliding out a large middeck drawer. The drawer is pulled out by its handle).

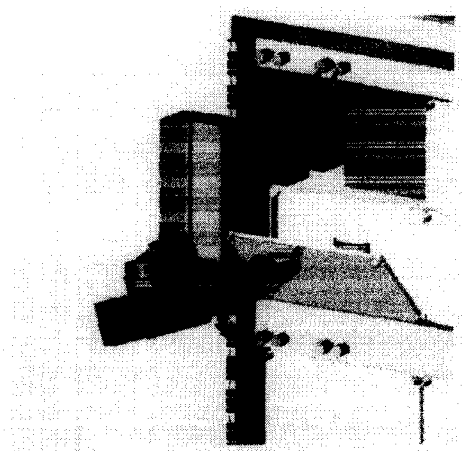


Fig. 3.1-1: PAT opening a middeck locker.

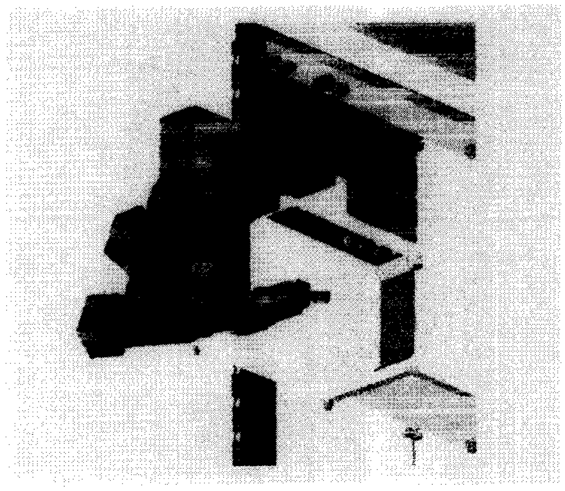
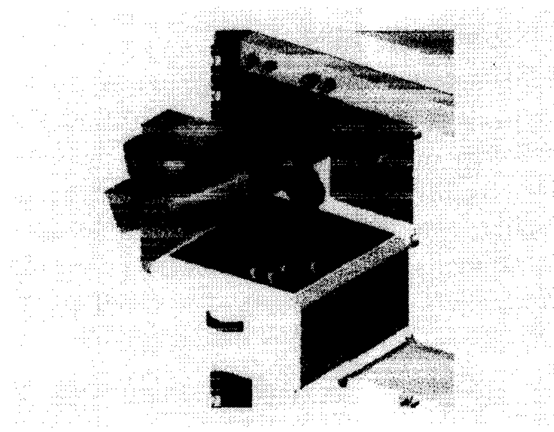


Fig. 3.1-2: PAT sliding out a large middeck drawer.

3.2 PAT Servicing Operations on Payload Samples

The main use of PAT is, of course, the handling of samples. The operation is logically divided into three steps: picking, transporting and placing.

Fig. 3.2-1 shows PAT feeding three samples (in this case vials of liquid) into a facility. The vials are picked-up from their storage position (in a foam mat inside a standard middeck drawer) and inserted into three holes of the facility.



3.3 PAT Servicing Operations on Payload Mechanisms

PAT is also able to actuate payload mechanisms. Some actuation tasks are shown in fig. 3.3-1 (rotation of a knob), fig. 3.3-2 (actuation of a slider), fig. 3.3-3 (open/close of shutters) and fig. 3.3-4 (actuation of flip switch).

Fig. 3.3-1: Rotation of a knob.

Fig. 3.3-2: Actuation of a slider.

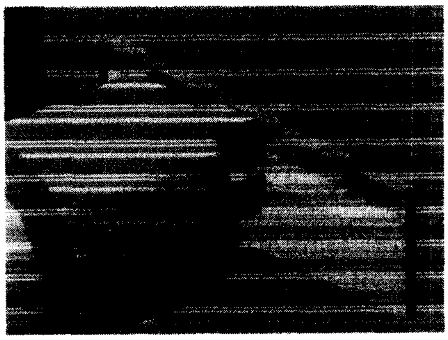


Fig. 3.3-3: Open/close of shutters.

Fig. 3.3-4: Actuation of flip switch.

4. PAT MAIN ELEMENTS

4.1 PAT Arm

The PAT Arm can be considered 'classic' for what concerns the architecture.

It is a machine with double offset and six plus one degree of freedom.

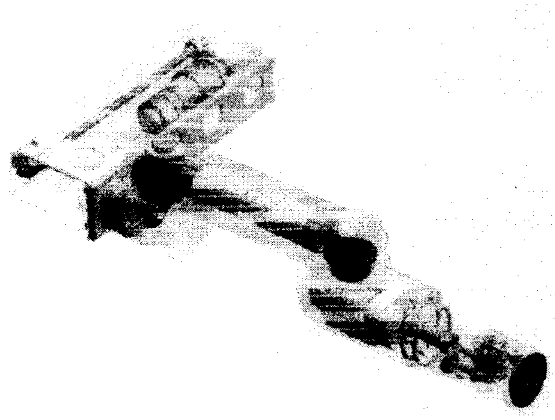


Fig. 4.1-1: PAT Arm.

PAT design is done in order to:

- capitalise on the well known performance in real environment, of certain well known components, such as ETEL actuators, in order to benefit the reliability of the system;
- attempt a standardization of these components even in cases where the specific performance does not necessitate it, to benefit the imminent industrialization of the product;
- use of proven rather than experimental technology and components.

4.2 PAT Electronics (CIRCUS)

The CIRCUS system shall be implemented in a modular way (fig. 4.2-1) and shall consist of one Electrical Distribution/Power Supply Unit, one RCU board and four SCU boards. RCU and SCU shall be based on the same type of board, differently configured. RCU, SCUs and the Power Supply Board shall be ORU, replaceable with a simple exchange of boards.

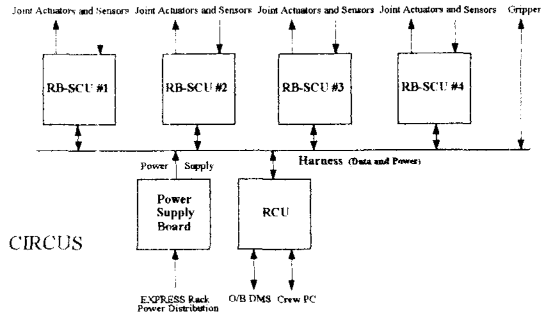


Fig. 4.2-1: CIRCUS module overview.

RCU represents the interface between the EXPRESS Rack or the Crew PC and SCU's. RCU and SCUs will make use for the computational part of the Epson Card-PC, in order to minimise volume and mass. The Epson Card-PC will contain the required amount of RAM and the resident code on non-volatile memory support.

The communication between RCU and SCU's will be realised via a dedicated bus implemented as a part of the Electrical Distribution/Power Supply Unit.

A modular Electrical Distribution/Power Supply Unit, allowing for data exchange and power distribution, will be developed. The Electrical Distribution/Power Supply Unit will be composed by:

- a common, stand-alone Power Supply Board;
- a Bus Interface Card for each of the SCU units.

The Electrical Distribution/Power Supply Unit will be implemented in a distributed layout, thanks to the Bus Interface Cards. In this way, each of the SCU units will be able to be physically detached from the others, except for the required cabling.

The mass memory storage device will provide a non-volatile support for data to be preserved when the system is in hibernation mode.

RB-SCU Concept

The Resolver Brushless - Servo Control Unit (RB-SCU) shall consist of one board (Base-Board), supporting, in a modular way:

1) the CPU Card EPSON Card-PC;
2) the bus interface;
3) one Motor/Resolver Interface Unit;
4) one R/D and S&H Unit;
5) two servo amplifiers;
6) solid state current limiters.

The EPSON Card-PC shall provide the computational power required to receive position and velocity set points and operation commands from RCU and perform the functions of μ-interpolator, position/velocity/current control, motor commutation (based on resolver reading) and on/off brake control. It shall also implement watchdog functions with status/error reporting to RCU.

The bus interface, which shall be part of the Electrical Distribution/Power Supply Unit, shall connect to the Card-PC either via the card ISA bus or the card parallel port and shall allow data exchange with RCU.

The Motor/Resolver Interface Unit shall interface the Card-PC with the resolvers and the servo amplifiers. The unit shall be able to drive up to two servo amplifiers and acquire the input signals of up to two Motor Shaft Resolvers, for which it shall also provide the resolver excitation signal.

The R/D and S&H Unit shall contain the Resolver to Digital converters and the Sample & Hold function to hold the current reference vector values for the servo units.

The servo amplifiers shall be a re-use of the SPEAR servo amplifies whose implementation shall make use of custom-designed hybrid circuits. The servo amplifiers shall therefore implement thermal and current monitoring/protection and interface to robotic joints equipped with brushless DC motors (2 or 3 phase) and failsafe brake. The servo amplifiers shall also implement active current limitation by means of a solid state current limiter.

4.2.1 RCU/SCU Base-Board Standardization

In order to allow for minimal base-board differentiation between RCU and SCUs, a modular approach shall be followed on these units. They shall be based on the same, standardised base-board and configured via software and additional plug-in boards to behave like a RCU or a SCU. This approach also eases the implementation of a redundancy concept.

The Carden, the EPSON Card-PC and the DiskOnChip2000 are COTS products. The Servo Amplifiers shall be a miniaturisation of the SPEAR ones. The internal Bus Interface shall be a part of the Electrical Distribution/Power Supply Unit. The special functions of Motor/Resolver, RS422 and I/R interface units are implemented on the base-board itself.

The configuration requirements needed to make the standard board behave like a RCU or a SCU are shown in fig. 4.2.1-1. The dashed rectangles imply the absence (logical or physical) of the corresponding part. Weight saving can be obtained by not mounting unnecessary components and/or connectors on the boards which shall perform only as RCU or SCU.

The operating system delivered with CIRCUS RCU shall consist of a VxWorks operating system including a Board Support Package for CIRCUS constituents.

Both are foreseen to be executed on RCU processor.

The VxWorks operating system as well as the Board Support Package are commercial off the shelf products which are both configured to meet the needs of CIRCUS project.

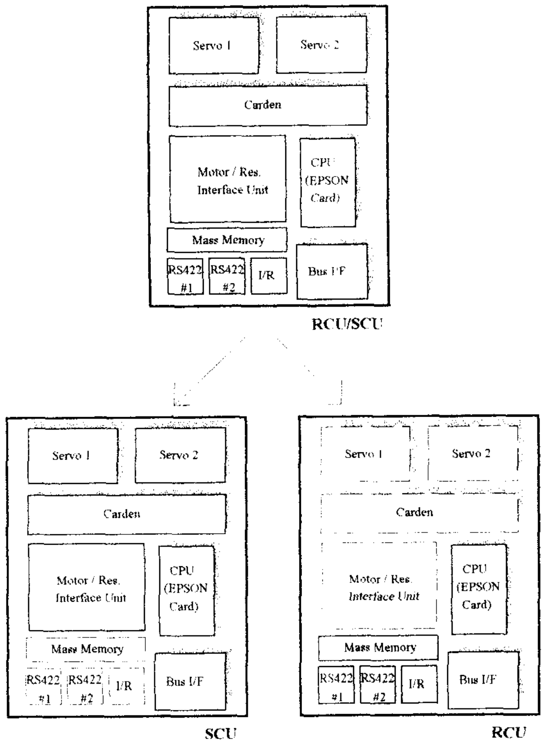


Fig. 4.2.1-1: RCU/SCU configuration.

5. CONCLUSION AND EVOLUTION

PAT can be considered as a general purpose tool, flexible enough to support the crew for payload servicing operations.

PAT, in fact, would allow to free the crew from tedious, repetitive tasks (such as exchanging experiment samples) and, as consequence, to increase the efficiency, throughoutput, cost and accuracy of standard payload operations.

In addition, PAT offers the possibility that the "real" investigator, namely the scientist on Earth, monitors and interacts with her/his experiment through the telescience link and the robot.

We estimate the following mission advantages for replacing crew members in the different activities:

- *Enhance crew time efficiency more then 25%*
- *Reduce routine task time and complexity.*
- *Advance autonomous capabilities in all station systems*
- *Enhance microgravity environment.*

It is planned to have by the end of the year 2000 a ground prototype, which will operate on EXPRESS Rack payloads on ground. This will be used to validate the concept and to consolidate interfaces to payload developers and users.

The concept will evolve towards ground programming and control based on virtual reality (i.e. to give the ground operator the impression to operate directly himself on the payloads like he was close to them) especially for telepresence operations.

The operator interacts with the scene and the robot motion is controlled with a glove and 'head' which allows the operator to modify and correct the planned sequence.

The operator has full control on the manipulator and the relevant anthropomorphic hand.
It is possible to execute on the payloads either automatic operations (defined during the programming and verification phase) or in a direct teleoperated mode.
Also during the execution of automatic sequence, the operator has the possibility to stop and modify the sequence if necessary.