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EUROBOT END-EFFECTORS

S.Michaud(1), M.Dominguez(1), U.Nguyen(1), L.Zago(2), S.Droz(2)

(1)Contraves Space AG
Schaffhauserstr. 580
CH-8052 Zurich (Switzerland)
stephane.michaud@unaxis.com

(2)Centre Suisse d'Electronique et de Microtechnique SA
Rue Jaquet-Droz 1- P.O. Box
CH-2007 Neuchâtel (Switzerland)

ABSTRACT

The EUROBOT is a robotic system designed for replacing or assisting human astronauts in Extravehicular Activities (EVA). The target application is the International Space Station (ISS) where the EUROBOT would assist the crew in maintenance and repair of the station. For interaction of the Space Station, the service experiments and the Orbital Replacement Unit (ORU), different end-effectors are being prepared during ESA activity labelled: "EUROBOT End-Effector". The Eurobot activity is under prime contractor Alenia Spazio and the End-Effector activity is carried out jointly by Contraves Space and CSEM. This paper describes the current results of the End-Effector study and the utilisation of the end-effectors and tools for grasping handrails, interfacing with ORUs and other specific EVA operations.

INTRODUCTION AND MOTIVATION

The next generation of space robots for the International Space Station will be required to perform more dextrous tasks than their predecessors in order to perform maintenance on the ISS and reduce the need for costly and hazardous Extra-Vehicular Activity (EVA) [5]. The minimisation of crew time in general and EVA time in particular is an operational goal of all ISS partners and a pre-requisite for long term manned space activities. Using robots in support of crew during EVA will considerably enhance efficiency of the astronauts, but development is necessary to ensure that aspects such as safety and reliable design are properly demonstrated before an operational system exits. The objective of the Eurobot development programme (ESA) is to make a robot for use on the ISS, which will also constitute the sound basis for future planetary missions (landing on the Moon or on Mars) and for other future human space flight scenarios.

The Eurobot will translate along the Space Station structure utilising standard EVA interfaces for performing or support routine EVA tasks. Thanks to dextrous end-effectors (EEs), the Eurobot is able to inspect the space station, install or remove small payloads and ORUs, set up and take down EVA work sites and assist the astronauts in contingency operations. Although, in principle, all of these functions could be provided by a single highly dextrous end-effector (i.e. anthropomorphic hand), a detailed task and interface analysis shown that a combination of several different end-effectors could be globally more efficient.

Miniaturisation effort has been made to fulfil the Eurobot mass and envelop requirements. This work has been started by defining a strategy for reducing the complexity of the EEs and tools integration. The strategy is to sub-divides the functions in a way that dedicated EEs can be developed (i.e. each EE is specialised for performing a set of similar tasks and interact with similar I/F). The final number of end-effectors will be as small as possible and the integration of some tools can be directly done on the dedicated EE. Moreover, if additional functionality is required for future Eurobot operation, additional EEs can be developed.

This paper briefly describes the methodology and key performance requirements established in general for Eurobot and in particular for its end-effectors, to meet its mission objectives, as well as the nominal operational procedure. The paper focuses on the different concepts under development for interfacing with the Space Station. Finally, the last section relates the first results, the future work and concludes this study.

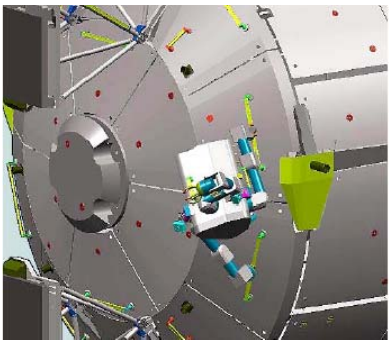
METHODOLOGY

EUROBOT shall be comparable in size and functionality to an astronaut. The strategy applied to this study is not the design of an anthropomorphic robot with the same complexity and degree of freedom as a human. Interacting and utilisation of an astronaut tool is a very complex task in terms of mechanics and control. The Robot Systems Technology Branch at NASA's Johnson Space Center in a collaborative effort with DARPA is currently investigating this way in the "Robonaut" activity [3]. However, because ISS standardised hardware and equipment design allow interaction with robotic systems [2], the study team are convinced that a non anthropomorphic approach can be more efficient in term of functionality, performance, cost and development time.

Humanoid robots are more flexible and can perform theoretically the same EVA task as an astronaut. However, advanced state of the art in anthropomorphic robotic systems shows that such a structure requires telepresence control by a human operator. The objective of Eurobot activity is to develop a robot with the same functionality as an EVA crewmember or assist them during EVA missions. This strategy reduces EVA time by performing standard maintenance operations.

The Eurobot is specialised in pre-identified EVA missions and in this case can achieve them with the best efficiency. As defined in [Figure 2], in function of the mission and the tasks, dedicated end-effectors (EEs) will be plugged at the end of the arm. When stored on the Eurobot tool tray, the EEs can also be used as an interface between the Eurobot and the Space Station.

The main activities that the Eurobot could perform once it has reached the work site are:



- Install and remove ORU's with the robotic interface end-effector.

- Replace small P/L with the specific operation or general gripper end-effector.

- Set up and take down work sites with the general gripper end-effector. This includes installing and removing foot restraints [Figure 11].

- Connect itself to an active work site for power provision with the WIF end-effector.

- Assist crewmembers in specific operation or transporting/holding equipment.

Figure 1: Eurobot concept (Alenia Spazio)

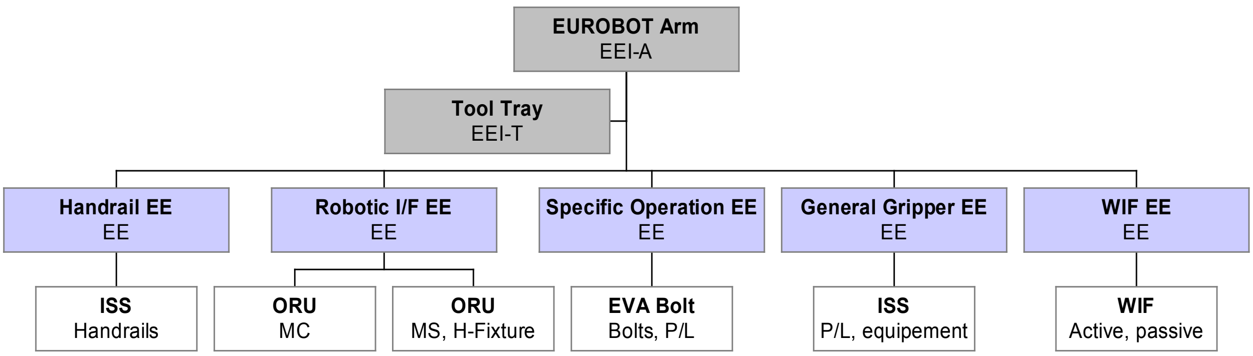


Figure 2: EUROBOT End-Effectors mehodology flow-chart

END-EFFECTOR CONCEPT

To perform the whole spectrum of planned Eurobot EVA operations [Figure 2], specific end-effectors need to be mounted on the robot wrist, located at the end of the arm. Eurobot will carry for each EVA operation a set of end-effectors stored in its backpack (i.e. tool tray), which can be picked-up and placed-back by its arms. A common end-effector I/F (EEI) will allow the exchange of end-effectors without human interaction.

As shown in [Figure 3], the part mounted on the end-effector permits a mechanical and electrical connection to the part mounted on the arm (EEI-A). Additionally, a specific interface (EEI-T) would provide interaction with the tool tray for EEs storage purposes.

Trade-off is still continuing for selection of the best EEs design strategy. Some tasks are very similar in terms of DoF, torque and force requirement but not in terms of interfaces. For reducing weight, it becomes more efficient to change only the mechanical part [Figure 3] of the EE instead of developing several EEs with the same actuators and electronics. Also utilisation of robotic tools developed for the ISS robotic systems or astronauts is under investigation.

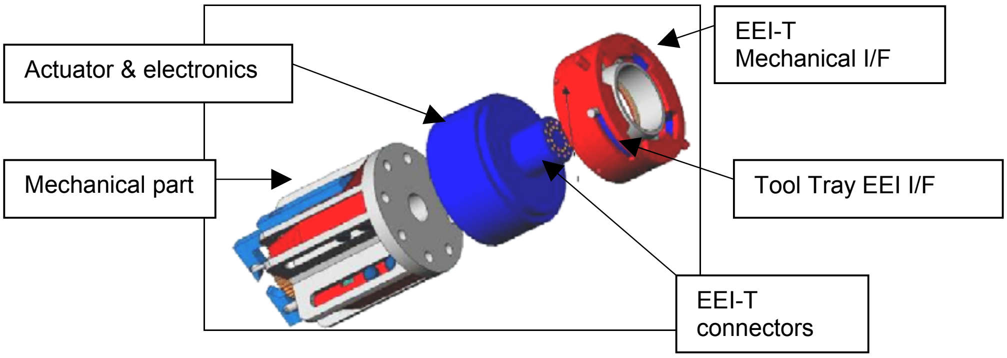


Figure 3: End-Effector concpet

In order to establish specific requirements for each end-effectors and tools adapted to the Eurobot extravehicular activities, tasks, interfaces and mission analysis has been carried out in collaboration with the ESA and Alenia Spazio.

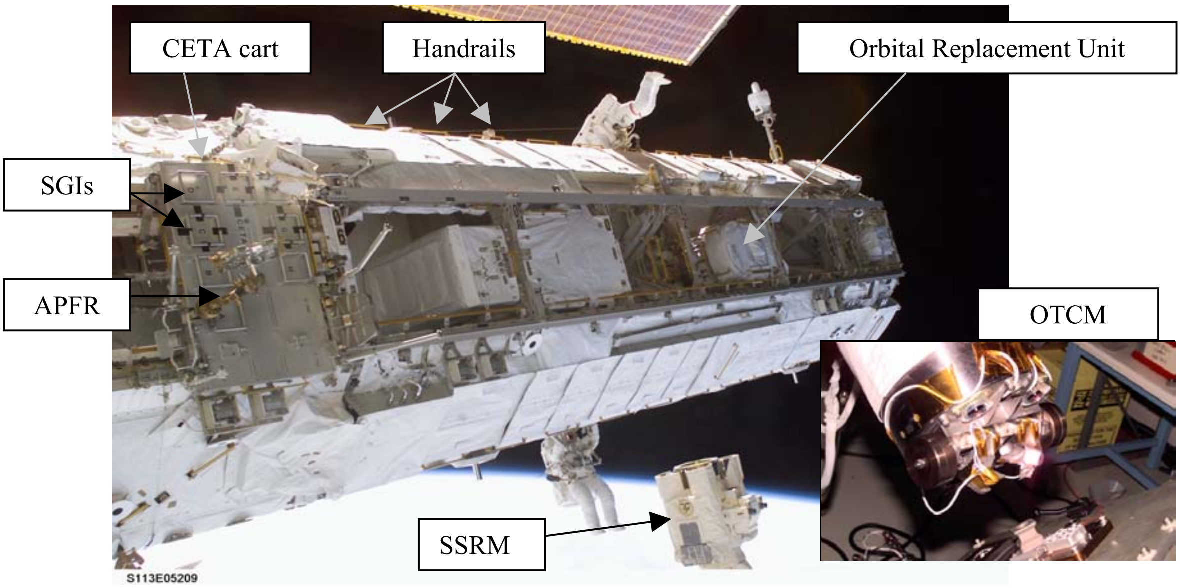


Figure 4: International Space Station and the ORU/Tool Changeout Mechanism (OTCM)

EUROBOT Motion Performance Requirements

To reach the ISS working area, Eurobot needs advanced motion capabilities. Using its three arms, the motion is done by grasping the same handrails as the astronauts. Eurobot has also the possibility to use other interfaces apart from the handrails for the motion, by exchanging automatically its EEs. When the transport of equipment (e.g. ORU’s, P/L, tool box) is required, the Eurobot will translate using only two arms.

For security reason it is of high priority that the Eurobot never lose the physical contact with the space station. The end-effectors used for the motion will stay in grasping position even in case of failure mode (i.e signal or power loss). The EE mechanical design meets this requirement with a self-looking system [Figure 5]. This system also reduces the power consumption, because in grasping position the motor is not powered. In terms of control, two different sensors will be implemented and the grasping operation supervised by the Eurobot vision system to assure that the handrail release can be achieved only after Eurobot is connected to ISS with another arm or the body.

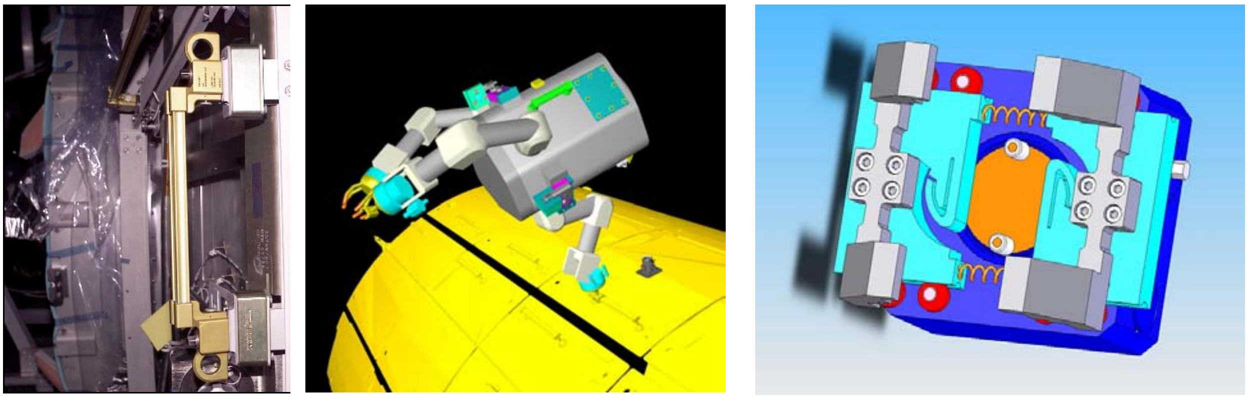


Figure 5: *Left* - handrail installed on USL Aft and Fwd Endcone; *centre* - EUROBOT concept (Alenia Spazio); *right* – EE for handrail grasping concept (CSAG/CSEM)

Robotic I/F EE

The Orbital Replacement Units (ORU's) can actually by easily removed and then replaced by either an astronaut or the Special Purpose Dexterous Manipulator equipped with the ORU/Tool Changeout Mechanism (OTCM) [4]. The main tasks are grasping, rotation of the central bolt and ORU insertion/extraction. In the current approach, there are over two hundred and fifty different robotic compatible ORUs on the Space Station [4]. General requirements are provided to ensure that Space Station external equipment is compatible with robotic systems [2] and the insertion procedure for each is briefly described below:

The Eurobot positions the arm with the appropriate end-effector in such a way that the ORU grasp fixture is inside the capture envelope of the end-effector gripper. There are two standard ORU grasp fixtures, the micro-handles (i.e micro-conical or micro-square) and the H- fixture as shown in [Figure 6].

Figure 6: *left*- Micro-conical fixture; *centre* – micro-square and ist alignement target; *right* – H-fixture

It is important that the arm allows passive compliance when the jaws grasp the interface because the initial misalignment can be important. The performance requirements during grasping are that the peak transient contact forces and moments must not exceed the normal operating loads of the micro fixture and the arm must not "drift" out of the capture envelope during the grasp [4]. The last stage of ORU berthing is following the ORU/bolt.

The central bolt needs to be rotated for activation of specific mechanism. The ORU extraction or installation can then be perform by moving the box along the alignment guides [4].

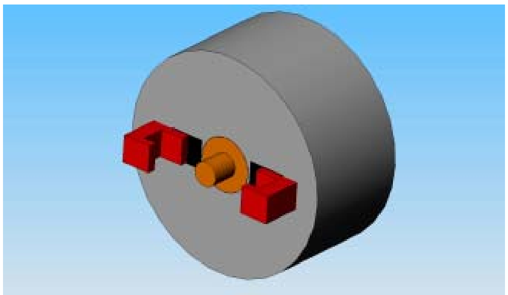


Figure 7: Robotic I/F end-effector concept (CSAG/CSEM)

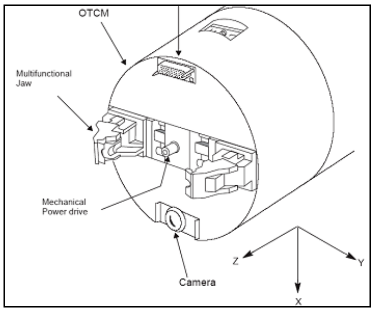


Figure 8: ORU/Tool Changeout Mechanism (OTCM) [2]

The robotic I/F end-effector concept [Figure 7] is an adaptation to Eurobot specification of the OTCM [Figure 8] in terms of miniaturisation and control.

Specific Operations EE

If a large variety of ORUs are design to allow robotic manipulation, other EVA activities performed mainly by the astronauts required specific sequence of action and tools. The Pistol Grip Tool (PGT) [Figure 9] is used by the crewmember to bolt/unbolts different EVA standard and robotic bolts. As explain in the methodology, the Eurobot end-effector strategy is not to develop an anthropomorphic hand to use this tool but to design an end-effector with the same functionality. A pistol grip tool end-effector that can apply torque in both directions is under development. Thanks to the different socket extensions, the specific operation end-effector can interface with the more used EVA standard and robotic bolts. The end-effector can automatically exchange or activate the socket but the selection of the appropriate tools has to be achieved by the Eurobot system. A dedicated socket design is under investigation for interfacing the T-Handle I/F. This will allows the Eurobot to remove the Meteoroids and Debris Protection System (MDPS) [Figure 10].

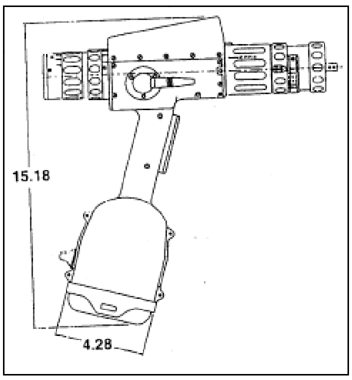


Figure 9: The Pistol Grip Tool (PGT)

Figure 10: The end-cone Meteoroids and Debris Protection System

General gripper EE
In order to assist the crewmembers in EVA tasks, the Eurobot should set up EVA work sites by installing or removing foot restraints such as the Articulating Portable Foot Restraint (APFR) [Figure 11], the Portable Foot Restraint Workstation Stanchion (PFRWS) and the Temporary Equipment Restraint Aid (TERA).

For the installation of removal of this equipment several operations of folding, unfolding, latching and unlatching with different shapes and sizes interfaces are involved [Figure 11]. Thus, a general gripper end-effector capable to interface with different shapes (e.g. knobs, unlatching pedals) and to perform basic movements (e.g rotate, press, grasp) is necessary. The forces and moments to be applied are limited to that produced by a single astronaut hand.

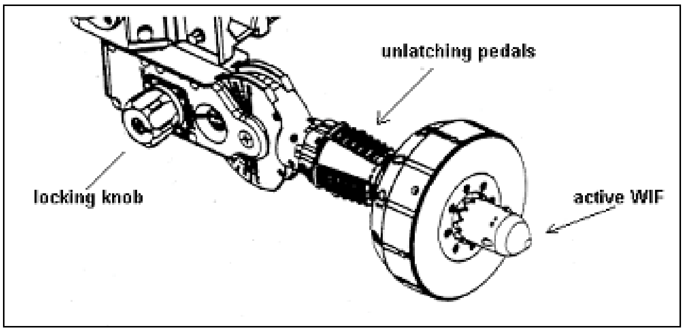


Figure 11: Part of the Articulating Portable Foot Restraint (APFR)

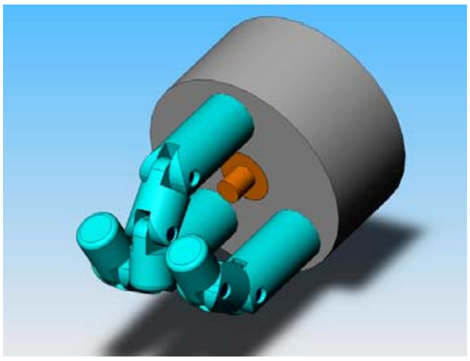


Figure 12: General gripper end-effector (CSAG/CSEM)

EUROBOT EEI

For automatic exchange of the end-effectors, the study team proposes the following preliminary passive design:

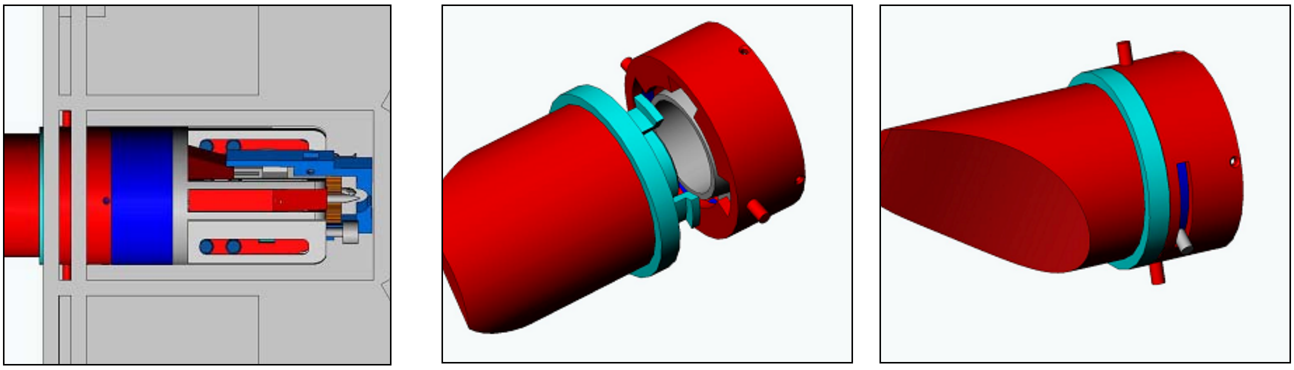


Figure 13: *left*- detail of the EE into the tool tray; *centre*- Insertion into the arm; *right* – Passive locking system.

The end-effector stored in the tool tray can be fixed to the arm by following sequence of actions. The arm positions itself closed to the end-effector and performs a vertical motion. A cone shape is used to align both parts during interfacing. Then the arm applied a force to the end-effector, in particular the cone shape piece for liberating the bolt ring is by pushing the inside spring. Finally the arm rotates about 60° for unlocking the end-effector from tool tray and mating it onto the arm.

A similar sequence of action allows the end-effector to be plug into tool tray. The end-effector matting/de-matting can only be done inside the tool tray with simple arm motion sequence. This prevents inadvertent de-mating of the end-effector during the utilisation phase. The electrical connection is achieved after the mechanical one to avoid critical power and signal issue. An active system will be investigated by ESA in near future, however, the study team are convinced that the Eurobot can automatically exchange its end-effectors with appropriate motion of one arm and in particular the rotation of the wrist. This functionality can be achieved only with appropriate tool tray design. The main advantage of the passive system is the complexity reduction and in particular, to minimise the envelope size and mass.

CONTROL AND ELECTRONICS

Current considerations favour a dedicated solution with a local controller per actuator. This architecture allows the Eurobot to control each actuator independently or to send a higher motion order to the end-effector. In the second option, a simple but efficient closed-loop system will achieve autonomously one motion sequence like for example grasping the handrail. Sensor feedback is required for controlling the motion. When one basic motion sequence is finished, an acknowledgement is sent to Eurobot for operation supervision purposed. This strategy and the implementation of two different sensors allow the system to be two failures tolerant.

The utilisation of specialised end-effectors reduced the number of actuators to one or two. Each layer should have a closed-loop control system with its own sensors, and interconnect and communicate one layer above and below for co-ordination. The Eurobot supervisor controller checks for consistency and identifies faults or errors in the global end-effector behaviour as the next figure illustrates for the robotic I/F end-effector:

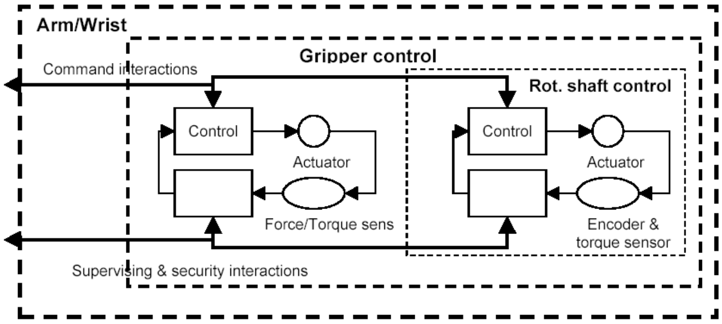


Figure 14: Preliminary design of end-effector control system

The local control units and power amplifiers relative to active degrees of freedom can be located in the end-effector base or in the EEI-Arm part. With the second option, the control electronics stay on the arm when the end-effector is exchanged. Because the number and actuator characteristics are similar for the different end-effectors, the study team is investigating this option, however a feasibility study needs to be done to estimated the viability of this concept.

STATE OF THE ART AND FUTURE WORK

The development strategy adopted in the current program allows the evolution of the models by continuing refurbishment, from a breadboard to a 1g-demonstrator to a 0g-demonstrator and finally to a full flight model. The actual production of these models will be performed next phase.

CONCLUSION

The Eurobot is a robotic system designed for replacing or assisting human astronauts in Extravehicular Activities (EVA). The target application is the International Space Station (ISS) where the EUROBOT would assist the crew in maintenance and repair of the station.

In this paper we focus on the Eurobot end-effectors sub-system. We study different specialised end-effectors to grasp the Space Station handrails, ORU and P/L, interface with standard robotic interfaces and perform other specific EVA operations.

The Eurobot will be similar in size and functionality to an astronaut, but the strategy followed by the study team is not the development of a humanoid robot and in particular an anthropomorphic hand. The goal is to develop a robotic system adapted to the needs, by understanding the extra-vehicular missions. This decreases the complexity of the end-effectors to one or two active degree of freedom (a hand has 22 DoF and 38 actuators [6]). However, because the mechanical design and control of each end-effector is simpler, the Eurobot needs to exchange the end-effectors in function of the task. Eurobot will carry for each EVA operation a set of end-effectors stored in its backpack (i.e. tool tray), which can be picked-up and placed-back autonomously by its arms. A preliminary passive design concept was studied and presented in this paper.

In conclusion the Eurobot, thanks to the end-effectors, will be a robotic system adapted to the International Space Station to replace the astronauts or assist them. By performing standard maintenance operations on ISS, Eurobot will reduced EVA time. In the future, the Eurobot missions can be extended to other on-orbit servicing and assembly. Additionally the technologies developed in the frame of this activity constitute a sound basis for future planetary exploration missions and for other future human space flight scenarios.

REFERENCES

[1] SSP 30256:001, Revision H, Johnson Space Center, NASA, Houston, August 2003.

[2] SSP 30550 Volume 1 Revision C, Johnson Space Center, NASA, Houston, September 1998.

[3] http://robonaut.jsc.nasa.gov/

[4] Raja Mukherji et al., *Special Purpose Dexterous Manipulator (SPDM) Advanced Control Features and Development Test Results*, Proceeding of the 6th i-SAIRAS, Canadian Space Agency, June 18-22, 2001.

[5] Werstiuk, H.L , Gossain, D.M., *The Role of the Mobile Servicing System on Space Station,* IEEE International Conference on Robotics and Automation, 1987.

[6] M.C. Carrozza, F. Vecchi et al., Proceeding of the Advanced Space Technologies for Robotics and Automation ASTRA 2002, ESTEC, the Netherlands, 19-21 November 2002.