DEVELOPMENT OF AUTOMATION & ROBOTICS IN SPACE EXPLORATION
27 - 30 June 2006, Pasadena, California, USA.

Paul Acquatella(1)

(1)*INSA Lyon – Bat. H -410. 20, Av. Albert Einstein, 69100 Villeurbanne, France. - paul.acquatella@gmail.com*

Abstract

Since the beginning of space exploration, the space community had the common belief that in the near future, the Automation & Robotics will be an important element for such missions. Today, this has become a reality. The implementation of this technology will play an important role in future missions, as robotic systems and "Artificial Intelligence" keeps developing further. The development of robotics arms as Canadarm and the ERA are citated as examples of contribution this kind of technology has made and how it will influence in the future. The main discussion in this paper is how this technology has been implemented in space exploration and how it will continuously keep contributing in such missions. A brief state of the art of how this technology has contributed to the space missions and a future approach for the coming years is proposed.

1. INTRODUCTION

Space exploration has been tremendously marked by the development of Automation & Robotics (A&R). Since the beginning of space exploration, the space community held the common belief that in the near future, the A&R will be an important element for such missions [1]. Today, we've seen this become a reality with all the applications and functionalities achieved as well as through the implementation of this technology in the space missions. The growth and evolution of complex spacecraft and space exploration missions demands a fast development of intelligent automated systems and robotic devices. This technology has to be adapted and developed in sense of reaching specific goals.

Robotics enables the exploration on orbit, deep space and planetary surfaces missions in addition to serving as a tool for complex in-space activities and missions. The development of this technology throughout the years has permitted an immense achievement in space missions and will continue to be an important and essential contributor to these activities.

For a successful development of space projects, A&R is a key technology. Automated processes and efficient robot implementation could lead to a better achievement in space missions, helping with their wide functionality and reducing the astronaut's workloads thus improving efficiency.

2. SPACE ROBOTICS

The "space robotics" is in many ways quite different than the standard "terrestrial" robots. In simplistic terms, the main difference would be the lack (or lower) of gravity, which is an important fact to consider in the whole system design reducing dynamic loads.

Fig. 1. The Canadarm2

It all begun with robots like the Surveyor, Mariner, Ranger and Lunakhod [2]. Since then, many proposals for robotic and automated applications in space missions have appeared. There is a wide range of functionalities and applications of robots in space; they can be listed as in [1]:

- Low Earth Orbit – Intra Vehicular Activities (IVA)

    - Payload Operations
        - Load/unload samples
        - Exchange measurement instrumentation
        - Inspect/monitor samples
        - Exchange of life – limited items

    - Payload Servicing
        - Preventive maintenance
        - Corrective maintenance
        - Cleaning
        - Diagnostics assistance
        - Calibration

    - Spacecraft Servicing
        - Inspection
        - Item replacement
        - Module exchange
        - P/L reconfiguration
        - Repairing

- Low Earth Orbit – Extra Vehicular Activities (EVA)

    - Mobile platform for EVA astronaut
    - ORU exchange
    - Inspection/diagnostics
    - Mechanical assistance
    - Connect/disconnect
    - Capture & berthing

- Polar Orbit

    Similar tasks as EVA in LEO, and in addition:

    - Instrument reconfiguration/exchange
    - Contingency assistance (deployment)

- Geostationary Servicing - GSV

    - Deployment assistance
    - Inspection, diagnostics assistance
    - Capture & berthing
    -Graveyarding

- Planetary surface exploration

    - Rovering
    - Instrument deployment
    - Sampling, shoveling
    - Building infrastructure

A&R will permit in an early future to have more "intelligent" space stations reducing the workload of astronauts, this will permit to improve efficiency.

3. ROBOTICS IN LOW EARTH ORBIT

The Low Earth Orbit (LEO) has been the domain of most manned spaceflights. Some of the spacecraft and space stations belonging to this class are the US Skylab, the Space Shuttle, the International Space Station, and the Russian space station Mir.

In LEO there are most of the in-space A&R applications, such as component assembly, maintenance and inspection, component replacement, and experiments in microgravity, which is the main purpose in such missions: research.

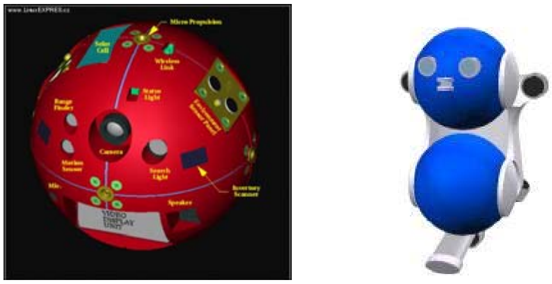
3.1 Intra-Vehicular Activity (IVA)

The Intra vehicular activities are all those related to payload operations, payload servicing and spacecraft servicing, as well as inspection and maintenance activities inside the spacecraft in space missions.

For example, the NASA has developed several concepts for IVA and microgravity experiments, as the Charlotte in 1995, and recently a concept for an internal payload tending robot to automate the routine logistics operations of microgravity facilities in the International Space Station called the Payload Tutor (PAT). It consists on a short 1 m. arm with five rotatory axes mounted on a vertical rail in front of a payload rack [3]. Once the robot has been "plugged in", no astronaut intervention is necessary anymore, since its routine payload tending operations will be automatically executed with high level commanding and monitoring from ground. The PAT concept allows to free the crew from tedious, repetitive payload tasks and thereby considerably increase the efficiency, cost and accuracy of standard payload operations.

Also, regarding the problem of the human resources shortage in space, especially in the International Space Station (ISS), NASA developed a small free flyer robot for IVA support, the PSA (Personal Satellite Assistant) which is equipped with several sensors and cameras and can easily communicate with the crew and observe experimental setups inside the ISS (figure 2).

In Japan, a new Intra-Vehicular Free Flyer System (IVFFS) was proposed in 2003 [4]. It has a mobility function similar to that of the PSA, and in addition, there is a manipulation function as well (allowing to perform contact tasks). A prototype called "Space Humming Bird" (SHB) has been introduced. It has a variably structured body which can adapt to and perform various tasks and multiple SHB's can be combined to realize more complex tasks.



(a) (b)
Fig. 2. (a) the PSA. (b) IVFFS prototype SHB

Some other previous concepts have been developed for older missions and experiments as the German ROTEX robotic arm developed in 1993 by the DLR and the EMATS/AMTS developed by ESA for the European laboratory of the ISS which essentially consisted of one 7 - axes dexterous 2 m. arm whose base could move throughout the central aisle of the laboratory on a 3 – axes Cartesian gantry system [5]. However this concept was stopped before going into detailed design and manufacturing. Some other concepts for in-module experiments have been developed by ESA, as the BIOROB.

3.2 Extra-vehicular activity (EVA)

Regarding extra vehicular activities, many A&R systems have been designed. By using such robots, risk related to astronaut's EVA are reduced. The applications of this kind of robots are related to:

- Inspection/diagnostics
- Mechanical assistance
- Connect/disconnect
- Capture & berthing

Dextre [6], a recently concept for maintenance and servicing in EVA operations, will be launched to the International Space Station in 2007 (Fig.3). Developed by the Canadian Space Agency, Dextre works by grabbing an ISS stabilization point to anchor itself. It will do the hard and delicate tasks in EVA that astronauts are capable of, reducing their long and exigent activities outside de station, permitting them to dedicate more time for inside operation or IVA.

Fig. 3. The DEXTRE

3.2.1 Space Shuttle robotics

The Remote Manipulator System (RMS), or Canadarm (Fig. 4), is the most known and famous robot in the space. It is used in widely applications but most common are for in-space assembly operations, releasing satellites into space and for EVA support. The capture and repair of the Hubble Space Telescope has been possibly the most impressive use of the RMS [5]. It consists of a 480 kg. – 15 m. length robotic arm capable of transporting and operate payloads of 30.000 kg.!

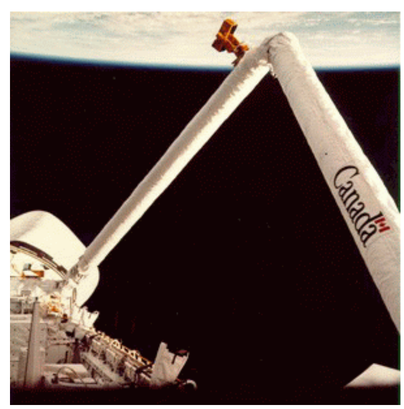


Fig. 4. The RMS

3.2.2 Robotics in the Russian space station MIR

For the Russian Space Station "MIR" there have been also wide robotic applications for system servicing, assembly and inspection operations.

PELIKAN, developed in Russia in 1998 it's an external system servicing robot, to install and remove payloads. Also JERICO (Fig. 5) developed in 1999 by ESA, an external payload tending and inspection robot [5].

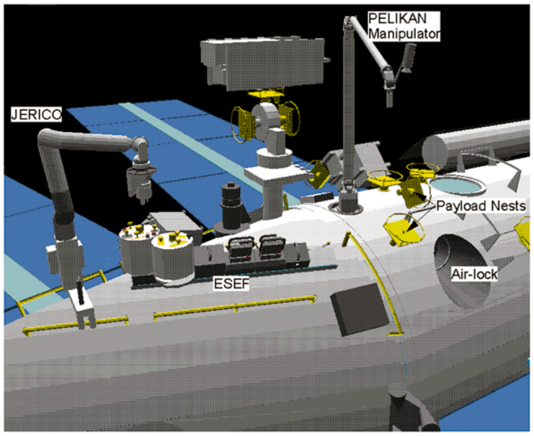


Fig. 5 PELIKAN and JERICO in MIR

3.2.3 Robotics in the International Space Station

The International Space Station (ISS) offers a unique infrastructure to enable scientists and engineers to conduct their experiments over a large timescale and to gain experiment results on a regular basis [futapps]. For a number of reasons, manipulative tending of payloads and servicing of the Space Station system elements cannot be completely performed by astronauts. This is why robotic systems are expected to play an ever increasing role in the operation of the ISS.

As mentioned in the survey paper [5], the applications of robotics on the ISS can be classified into four categories:

-Internal payload tending robots to automate the routine logistics operations of microgravity facilities (as seen before in the IVA section).
-External payload tending robots, doing the same for facilities on exposed payload platforms like the JEM-RMS (Japan), and the PELIKAN (Russia) and the EVA robots we've mentioned before.
-External system servicing robots with attached base, used to assemble larger Space Station structures and to exchange whole modules or platforms.
-External system servicing robots on free flying vehicles, for inspection and maintenance of Space Station elements.

There are three main robotic elements in the ISS (Fig. 6). The Space Station Remote Manipulator System (SSRMS) developed in Canada, a 7- m., 7-DOF robotic arm. The Special Purpose Dextrous Manipulator (SPDM), a smaller 2- m., 7- DOF robotic arm that can be used independently, or attached to the end of the SSRMS. And the Mobile Base System (MBS) which is used as a support platform and will also provide power and data links for both the SSRMS and the SPDM [7].
The MSS is used for assembly, external maintenance, to deploy, service, and retrieve external payloads on the Space Station.

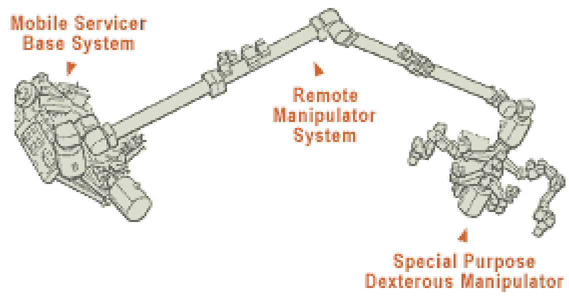


Fig. 6. ISS Remote Manipulator System

Also, for the Russian modules of the ISS, the European Robotic Arm (ERA) has been developed by ESA in 1999. It consists of a 630 Kg, 11.3 m. length robotic arm (Fig 7). ERA [9] is designed to perform missions like:
-Assembly of large station elements
-Installation and exchange of ORU's.
-Support to EVA astronauts in a variety of tasks.
-Installation of scientific payloads.
-Inspection of the Space Station exterior.

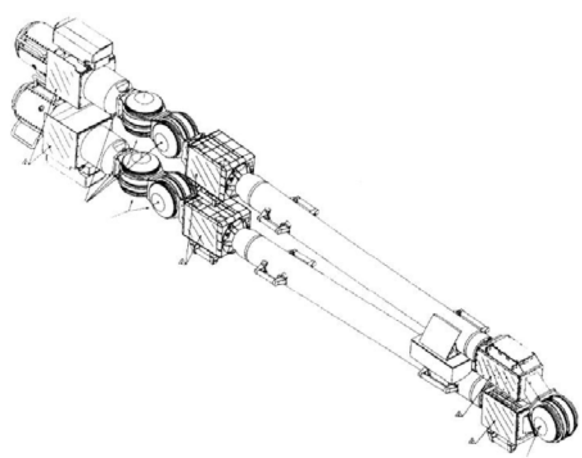


Fig. 7. ERA in folded configuration.

We can also find some external system servicing robots (from a free flying base) for systematic inspection of the Space Station shell and for preventive/corrective maintenance like the OMV, the Ranger and the Spider [5].

3.2.4 In-space experiments

The in-space experiment is a field which evolutes real fast as A&R technologies and Artificial Intelligence (AI) concepts keeps developing more and more within the years. The Ranger [2], which was developed in the US to repair and upgrade orbiting satellites, particularly the Hubble, is one beautiful example of robotics applications in space operations. In fig. X a ground testbed for the Ranger to simulate the repairing of the Hubble Telescope is showed.

Fig. 8. A diver works on a model of the Hubble Telescope, assisted by the Ranger robot.

Other space robots for experiments such as ROTEX [8] and AERCam, has demonstrated dexterous operations and the usefulness of tele-operated robots for inspection tasks. Ground testbeds have demonstrated teleoperated robots performing fine assembly operations, like the Robonaut [2] developed by NASA (Fig. 9). The Robonaut project seeks to develop and demonstrate a robotic system that can function as an equivalent EVA astronaut. It has five-fingered, multi-jointed hands permitting to work with a real human mobility.

Fig 9. Robonaut

4. ROBOTICS IN GEOSTATIONARY EARTH ORBIT (GEO)

The Geostationary Earth Orbit (GEO) is where most communication and Earth observation satellites are placed. The orbit is important because it allows a satellite to orbit the earth at a fixed point viewed from the earth, so communications and earth observations are well suited with this orbit. Regarding the geostationary servicing robots, there have been concept studies for Geostationary Vehicles (GSV) which flies around GEO performing operations such as:

- Deployment assistance
- Inspection, diagnostics assistance
- Capture & berthing
- Graveyarding

In 1998 Japan developed the Engineering Test Satellite ETS -7 to perform simple repair tasks in GEO. Also in Germany, the Experimental Servicing Satellite (ESS) was developed for a servicing demonstration and de-orbiting of expired satellites.

5. ROBOTS FOR PLANETARY SURFACE EXPLORATION

Planetary surface exploration is another domain of research in space missions. A&R are widely applied in this field. Actually, most of these kinds of missions are unmanned, so this is viewed as a big challenge for A&R systems.

The robots for this category are expected to do such activities as:

- Rovering
- Instrument deployment

- Sampling, shoveling
- Building infrastructure
-Search for life

The pioneers are the Lunakhod 1&2 (Soviet Union, 1970-1973 respectively) which were developed to explore, rove, deploy instrument, and for sample collection [5]. Also the Viking arm (NASA, 1976) for the same purposes and in addition to search for past life.

Concerning Mars exploration, since the successful and popular Pathfinder mission by NASA, many concept studies have been treated to explore this planet. The most representative is the Sojourner, launched almost ten years ago in 1997 [1], also there is the family of Mars Exploration Rovers (Fig. 10), which are optimized versions of previous rovers. They are both autonomous within small local segments, with images sent back from Mars each day and a rigid sequence of robot motions uploaded for the following day. MERs will be more capable due to a larger size, greater science instruments, and a better communications infrastructure, but otherwise will be operated in a similar manner.

Fig. 10. Mars Exploration Rover

In Mars exploration there is also the proposals from Russia and Germany: The Marsokhod and the Nanokhod, respectively.

Some studies for comet/asteroid landing have been developed as well. For example the Rosetta Satellite (Fig 11) by ESA [5] which will be the first space mission to journey beyond the main asteroid belt.

Fig. 11. The Rosetta Satellite

Shortly after its arrival at the comet, the Rosetta Orbiter will dispatch a robotic Lander (Fig. 12) for the first controlled touchdown on a comet nucleus.

As it arrives on the comet, the Rosetta Lander uses three different techniques (self-adjusting landing gear, harpoons and a drill) to ensure that once it has arrived on the surface of the comet, it stays there [10].

Fig. 12. The Rosetta Lander

6. CONCLUSIONS

This "review" paper has showed and summarized the different A&R applications in space missions, and the evolution of robotic devices for spatial research. It gives a brief overview of the most impressing robots sent to space and some of the ground testbed for future research.

The space robotics has been and will always be necessary as an important key for space missions. Due to the development of the technology concerning A&R, space robots will keep being proposed for many purposes, and in a near future, most of them will highly assist in-space operations and reduce the "low intelligence" tasks of astronauts and allow safer EVA operations, for instance.

Planetary exploration seems to be a field which will be more and more researched since actual rovers are very effective in this kind of missions. Also, the research on asteroids and comets will be an important field of research in the near future.

For a future approach, as space robots go further and further, many others applications and technologies should be studied. For instance, nanotechnology applied in small robots for surface exploration could lead to future mission's approaches. On the other hand, artificial intelligence could contribute by making space robots "learn" while being in orbit, creating smart robots "communities" which would be more and more independent from human assistance to do their tasks. Also, flying deployable robots for surface inspection, observation and exploration with solar array-wings are expected to be studied further.

7. REFERENCES

[1] W. De Peuter. Development programme on space automation and robotics. Intl Symposium "Artificial Intelligence, Robotics and Automation in Space". Toulouse, September 1992.

[2] L.Pedersen, D. Kortenkamp, D. Wettergreen, I. Nourbakhsh. *A survey of Space Robotics*. NASA Exploration Team. 2003

[3] S. Di Pippo, G. Colombina, R. Boumans, P. Putz. *Future potential applications of robotics for the International Space Station*. Journal of Robotics and Autonomous Systems 23 (1998) 37 – 43.

[4] Y. Tsumaki, M. Yokohama, D. Nenchev. *Intra-Vehicular Free-Flyer System*. Proceedings of the 2003 IEEE/RSJ Intl. Conference on Intelligent Robots and Systems. Las Vegas, Nevada. October 2003.

[5] P. Putz. *Space robotics in Europe: A survey*. Journal of Robotics and Autonomous Systems 23 (1998) 3-16.

[6]http://www.space.gc.ca/asc/fr/iss/mss_spdm.asp

[7] C. Sallaberger. *Canadian Space Robotic Activities*. Elsevier Acta Astronautica Vol. 41. pp 239 246, 1997.

[8] B. Hannaford, A. Bejczy, P. Buttolo, M. Moreyra, S. Venema. *Mini-Teleoperation Technology for Space Research*. Proceedings of MIMR-95, Sendai Japan, September 1995.

[9] R. Boumans, C. Heemskerk. *The European Robotic Arm for the International Space Station*. Journal of Robotics and Autonomous Systems 23 (1998) 17- 27.

[10] World wide web. www.esa.int