ASI's Space Automation & Robotics Programs: the Second Step

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INTRODUCTION

The strategic decisions taken by ASI in the last few years in building up the overall A&R program, represent the technological drivers for other applications (i.e. internal automation of the Columbus Orbital Facility in the ESA Manned Space program, applications to mobile robots - both in space and non-space environments, etc...). In this context, the main area of application now emerging is the scientific missions domain.

The ASI strategy has been based on the following main guidelines [1]:

- **Long-term program**
  SPIDER: SPace Inspection Device for Extravehicular Repairs

- **Robot/Telerobot Control System Architecture**
  SAREM: SPIDER Architecture REference Model

- **Technological program**
  SARTDP: SPIDER Automation and Robotics Technological Demonstration Program
  - SPIDER manipulation System
  - TV-Trackmeter
  - Advanced man-machine interface

  BARTEX: Balloon for Automation and Robotics TEchnological Ex.

- **A&R Support and Testing facilities**
  CSR: Centre for Robotics Simulation
  ST-Lab: Sensor Testing Lab. for Space Robotics

- **Planetary Rovers**
  ARPE: Autonomous Rovers for Planetary Exploration
  IMEWG: International Mars Exploration Working Group

- **Italian Cooperation with ESA programs**
  ROSE-D: RObotics SErvicing Demonstrator
  AMTS: Automated Manipulation and Transportation System
  EUROMIR '95: Robotic Exp.
  ROSETTA Surface Science Package
  Moon Lander and Rovers

Due to the broad range of applications of the developed technologies, both in the in-orbit servicing and maintenance of space structures and scientific missions, ASI foresaw the need to have a common technological development path, mainly focusing on:

- control
- manipulation
- on-board computing
- sensors
- teleoperation

Before entering into new applications in the scientific missions field, a brief overview of the status of the SPIDER related projects is given, underlining also the possible new applications for the LEO/GEO space structures.

NEW ACTIVITIES IN THE FRAME OF SPIDER AND RELATED PROJECTS

The SPIDER New Phase

In the last years, ASI made great investments on A&R in space, due to growing importance of internal and external in-orbit servicing, maintenance and operations. In this context, ASI started a long-term program named SPIDER (SPace Inspection Device for Extravehicular Repairs) [2] and a Technological Program in order to support and guarantee system assembling with state-of-art technology. SPIDER is a free-flying space robot, designed to operate in external environment of manned and unmanned orbiting structures, both in LEO and GEO.

The phase B, now starting, beside the redefinition of the SPIDER operational missions in view of the changed world space scenario, will implement two of the major SPIDER system development stages identified in the phase A [3]

- the development and setup of a dedicated ground test-bed to perform hardware-in-the-loop tests for supporting the development and tuning of the items and technologies (rendezvous sensors, image processing, flyaround techniques, arm operation, grasping tools, etc...) enabling an autonomous rendezvous and capture of non-cooperative target, in a simulated space environment [see fig. la.,b].

- the design of a technological on-orbit demo mission (and of possible precursor tests in low-gravity environment - see BARTEX) and characterization of the SPIDER system performances in rendezvous and capture operations, in the real space environment and in a situation similar to an actual operational mission [see fig. 2].

SPIDER Manipulation System

The development of the SPIDER manipulation system is currently scheduled in three phases and will conduct to the engineering model of a bi-arm manipulation system, with the capability to operate both in robotics and teleoperated mode, provided with collision avoidance, vision and proximity sensors and with a co-operative bi-arm control capability. The first phase, which will end in mid '95, concerns with the development of the engineering model of a 7 d.o.f. robotic arm, belonging to the 1.5 meter length class and the breadboard of its controller [4].

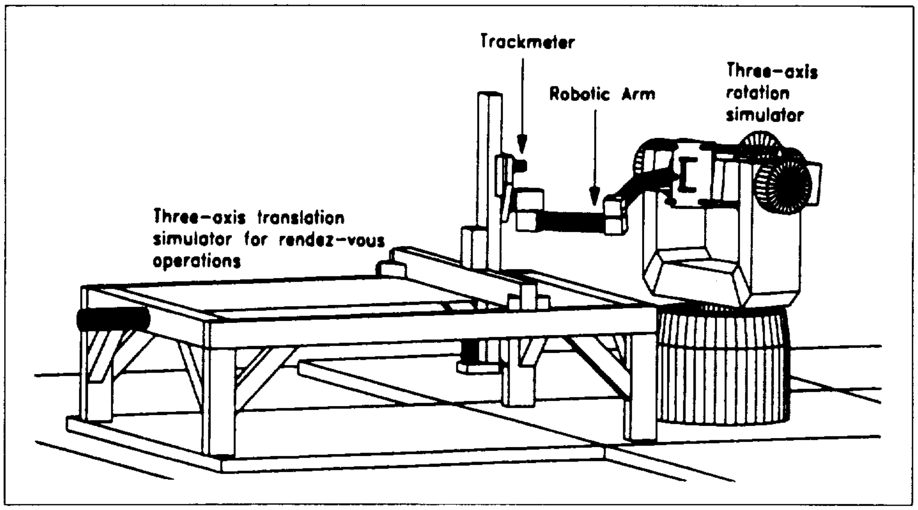

Figure 1a. SPIDER test-bed for rendezvous and arm alignment manoeuvre simulations

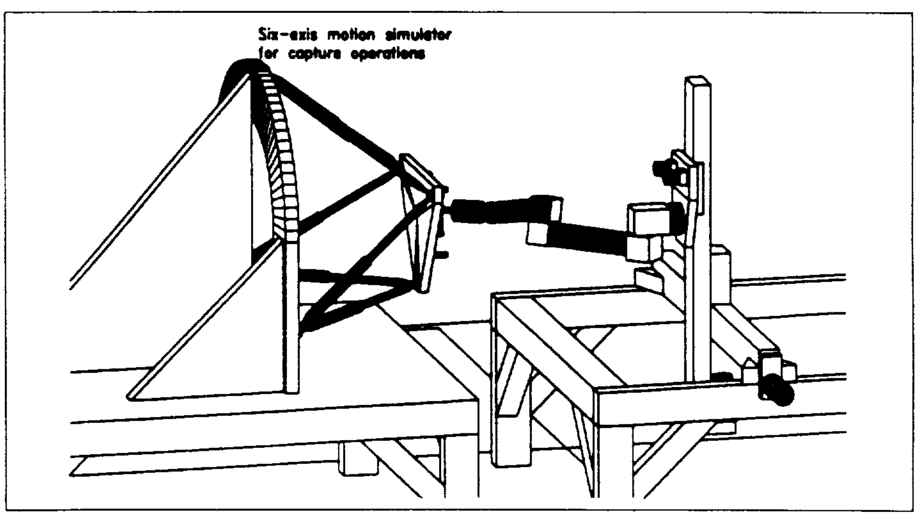

Figure 1b. SPIDER test-bed for the capture operation simulations

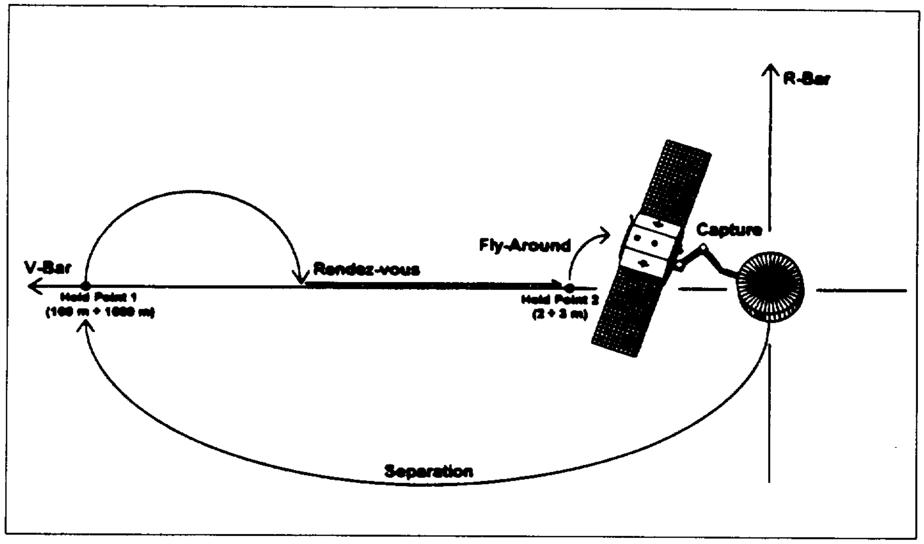

Figure 2. Example of operation profile of the SPIDER Technological demo mission

The manipulation arm is provided with a parallel gripper type end-effector and force/torque sensors. The kinematics configuration of the arm is shown in fig. 3. Two types of arm internal configuration were investigated in detail, specifically:

- internal configuration based on "Distributed joint approach" which implies cable passage in the out-skirt of the actuator bulk,
- internal configuration based on "Integrated joint approach" which implies cable passage in actuator central allowed shaft.

The arm basic design, after detailed analysis, foresees six out of seven axes based on the "distributed approach" and the seventh axis based on the "integrated approach".

The "distributed" joint will be tested next year; in fact, in the framework of the ESA Columbus precursor flights program-EUROMIR 95 mission, the approved Italian "In-Orbit Robotic Technology Experiment" is aimed at verifying, in actual 0g environment, the main performances of the breadboard robotic joint/technology already developed in the frame of the SPIDER contract, under ASI responsibility.

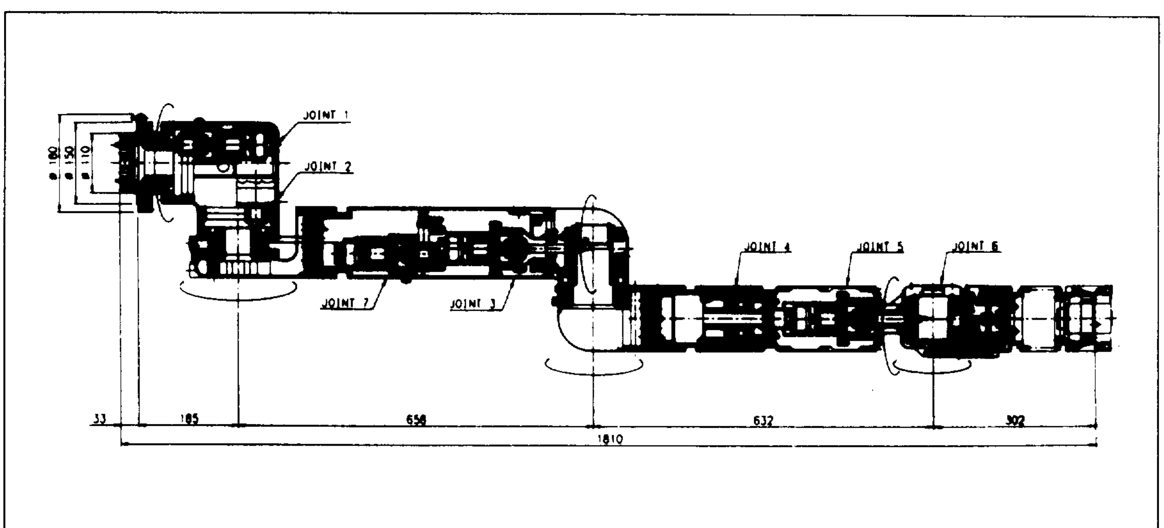

Figure 3. Kinematics configuration o f the SPIDER arm

The in-orbit experimental phase will be structured to allow the testing of variants of the reference control algorithms with different gains. The proposed experimental verification is important also in view of the possible use of the SPIDER robotic arm in the frame of microgravity applications. The experiment concept is described in fig. 4.

Referring to the possible applications, the SPIDER manipulation system development contract has been redirected to take into account the ESA activity named AMTS (Automated Manipulation and Transportation System). The objective of the ongoing AMTS phase B is the detailed definition of the system, including robot arm, gantry, controller and support subsystems. The cross-analysis between AMTS and SPIDER arm requirements showed many commonalities, so that a certain degree of harmonisation between the two programs have been accomplished without additional effort. To be cooperative with ESA activities, ASI performed the evaluation of the micro-G disturbances of the SPIDER arm technology in order to analyse the possible impacts on the AMTS operational conditions.

For what concerns the "integrated" joint technology, ASI started few months ago an internal evaluation for the applicability of the SPIDER arm technology to the Lunar exploration, having in mind the need to reduce drastically the associated mass. The use of the integrated joint could reduce the total mass of the arm, but also can contribute to modify the length of the arm in any desirable shape [see Moon Exploration].

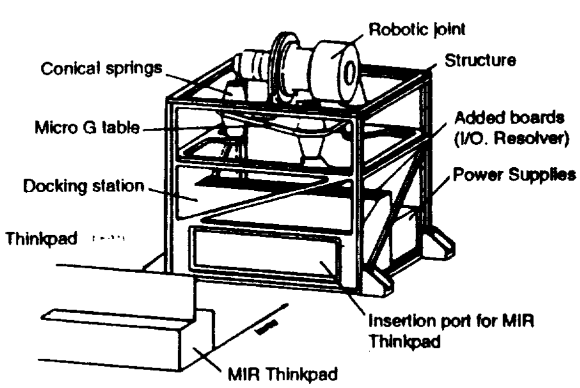

Figure 4. EUROMIR 95 robotic experiment layout

BARTEX

ASI has started an activity called BARTEX (Balloon for Automation & Robotics Technological EXperiment) [5] carrying out A&R technological experiments in a micro-gravity environment obtained within a capsule, lifted up to 40-45 km of altitude by a stratospheric balloon and then dropped down. During its free-fall motion, micro-gravity conditions are obtained inside the capsule.

As the reference experiment, ASI has chosen the Object Capture experiment, aiming at demonstrate the capability of capturing flying objects by means of an integrated telemanipulation-vision system with robotic functions.

The experiment will be performed using existing hardware, developed under ASI contracts (a Chinese copy of the SPIDER manipulator arm and the TV-trackmeter), taking advantage also of the development of the capsule, named GI-ZERO, under a parallel ASI contract.

The first flight opportunity has been selected in the '97 summer. The fig. 5 shows the layout of the BARTEX experiment.

A&R FOR SCIENTIFIC MISSIONS

The main characteristic of Automation and Robotics is to be applicable mainly to all the scientific missions, in particular to the deep space missions and the planetary exploration enterprises.

At the present time, there are several future missions under evaluation in the international framework based on automatic systems and autonomous mobile vehicles.

Looking at the main international enterprises, we will focus mainly on three of them as reference, underlining the primary Italian role in this missions. i.e.:

- Mars Exploration
- Moon exploration
- Deep space missions

Mars Exploration

First of all, the exploration of Mars. In the 1993, the International Mars Exploration Working Group was created by the main spacefaring agencies with the main goal to constitute a forum for discussing the various phases of the exploration and the possible contribution coming from each space agency, member of the group [6].

Taking into account the technological state-of-art, the first phase of the exploration of the Red Planet is based on remote sensing (i.e. without contact with the surface) to gain information for the subsequent phases, the network phase and the automated phase.

In the network mission, up to 12 fixed stations will be released on the Mars surface; ASI has now started the definition activity related to the possible use of microrovers for Mars Geo-Exploration, named MIGEMA (MIcrorovers for Geo-Exploration of MArs). The microrovers are seen as an "extension" of the capability of the fixed stations, allowing the exploration of a few meters around the landing site. Such a microrover could help in performing the following scientific measurements:

- thermal conductivity, using temperature probes to be placed under the martian surface at different depths
- seismic parameters, using seismometers (geophones); these sensors shall be placed some centimeters under the surface
- local radioactivity, using radioactivity probes in the subsurface
- soil consistency, using sensorized drilling tools

The technical feasibility of a 10 kg microrover has been already investigated and assessed by ASI in the activity named ARPE (Autonomous Rovers for Planetary Exploration) [7], conducted with the strong involvement of Russian firms and institutions.

Moon Exploration

The new Moon exploration program, now under evaluation in the frame of the ESA new activities, will follow a progressive phased approach, starting with the initial exploration using small satellites and surface probes, progressing to the use of robots for scientific and resource exploitation and culminating in manned lunar bases [8]. Italy has proposed two possible participations in this enterprise: the so-called "robotic lunar science kit" and the responsibility for the proximity and in situ operations for a mobile robot. Due to the know-how gained by Italy in the area of A&R, the robotic lunar science kit has the main goal, starting from theexisting technologies, to activate lunar surface collection and inspection, to store on-board collected material, performing also a scientific analysis, supporting in addition different scientific and servicing tasks. The idea

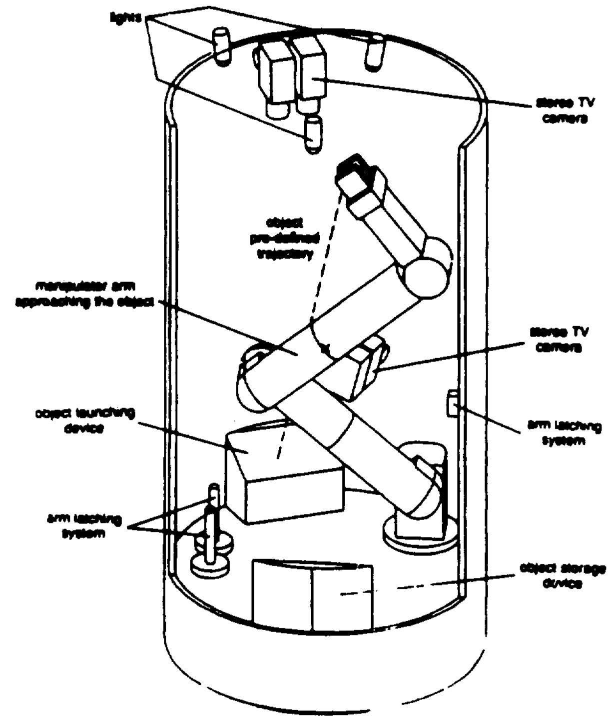

Figure 5a. BARTEX workcell layout and experiment accommodation

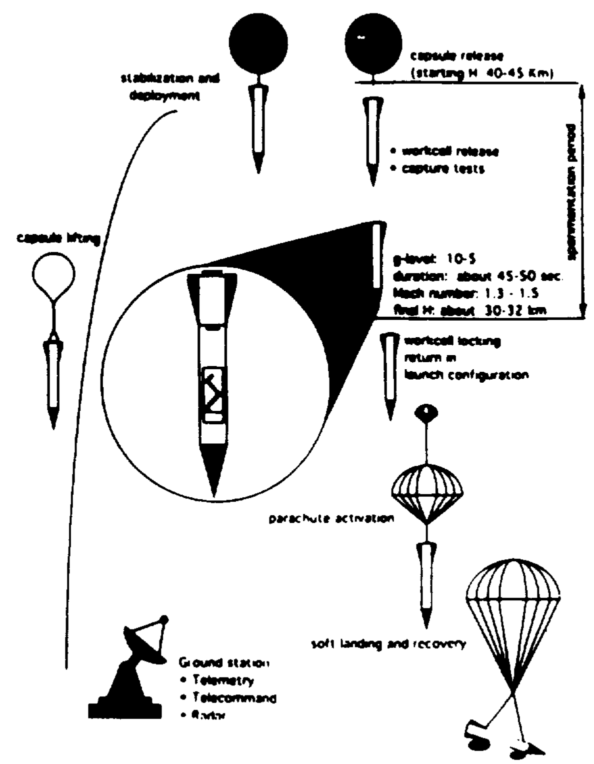

Figure 5b. BARTEX workcell layout and experiment accommodation

to include an Earth return capsule has been also presented. A possible Italian role for the mobile robot has been already discussed, in particular focusing on the in situ analysis and operations, due to the Italian expertise, gained also in the framework of the ESA ROSETTA mission at breadboard level.

The possible re-use of the SPIDER robotic arm is under evaluation (see SPIDER manipulation system).

Deep Space Missions

In the framework of the on-going ESA ROSETTA cometary mission, to be launched in 2003, one of the key elements to be developed is a small lander, to be released on the comet surface, in order to perform nucleus scientific measurements. Due to the Italian expertise, gained both on the national activities described above and on the development activities performed for the ESA Sample Acquisition System critical parts (Corer, Anchor and Surface tools) [9], Italy is claiming to get the primary responsibilities for the "Automated Interfaces" between the Surface Science Package (SSP) and the cometary soil, plus for the activities and subsystems aiming at improving the automation and, therefore, the scientific return of the overall mission [10].

CONCLUSIONS

The paper mainly deals with some of the new ongoing activities in the Italian Space Agency in the field of Automation & Robotics.

Due to the strategy adopted in the past few years, in this second step ASI is stressing its intervention in scientific missions in which the robotic technologies under developed and/or under development in the A&R area can be useful and easily transferred.

Taking into account the complexity of such exploration missions, ASI approach is looking forward in parallel to achieve cooperation agreement with international partners, focusing also on possible joint developments of challenging technologies.

REFERENCES

[1] Di Pippo S.,1994. ASI's Space Automation and Robotics Programs. In *Proceedings of the IAP second workshop of Robotics in Space.* Montreal, 6-8 July

[2] SPIDER phase A contract:final report. ASI contract n.108/AF/90,1991

[3] Di Pippo S., Barraco I. 1994. New Perspectives for the SPIDER project. In *Proceedings of the IAP second workshop of Robotics in Space.* Montreal, 6-8 July

[4] Mugnuolo R., Magnani P.G., Terribile A. ,Gallo E. ,Dario P. 1994. SPIDER: Design and development of the high performance dexterous robotic arm. In *Proceedings of the IARP second workshop of Robotics in Space.* Montreal, 6-8 July

[5] BARTEX phase A final report. ASI contract 1993.

[6] IMEWG activities. Presentations to COSPAR symposium. Hamburg, July 1994

[71 Di Pippo S. et al., 1993. Autonomous Rovers for Planetary Exploration. *Executive summary*, October 1993

[8] A Moon Program: The European View. *ESA BR-101*, May 1994

[9] Costa P.A., Fenzi M., Heiden M. 1993. Collecting cometary soil samples: development of the ROSETTA Sample Acquisition system.

[10] ASI scientific and technological potential involvement in the Surface Science Package. *Presentation to the Workshop on Rosetta SSP.* Estec, 9 February 1994