IPSE: a robotic micro laboratory for in situ science on Mars

R. Mugnuolo (ASI)*
F. Angrilli - S. Debei (CISAS)**– B. Saggin (Politecnico MI) ***
E. De Marchi - A. Nista - A. Terribile - S. Valdes (Tecnomare SpA) ****

* Agenzia Spaziale Italiana, Matera – Italy
** CISAS, Università di Padova – Italy
** Politecnico Milano, Facolta di Ingegneria di Lecco – Italy
***Tecnomare Spa – Venezia - Italy

1 ABSTRACT

IPSE, *Italian Package for Scientific Experiments*, is an autonomous micro-laboratory for Martian soil and environment parameter analysis.
The leading concept is to implement a modularity philosophy in the design of the main subsystems, in order to allow the maximum level of de-coupling between IPSE and the experiments, being able to support very different types of payload and suit each launch opportunity.
This paper will provide an overview of a possible design of IPSE. The current design is based on an accommodation opportunity formerly hypothesised on NASA Mars Sample Return Mission, scheduled for 2003 and now being reconsidered. A future opportunity is under consideration.

2 INTRODUCTION

As a founding member of the International Mars Exploration Working Group, Italian Space Agency (ASI) has signed an agreement with ESA and NASA for collaboration in the exploration of Mars [Ref.1].
These agreements initiate the participation of the Italian scientific community as well as the Italian industrial community in the international program to explore Mars. ASI and NASA have agreed to co-operate in a long-term systematic program of robotic exploration of Mars sustained by a series of missions to Mars in support of their respective strategic goals. ASI is expecting to participate in the future missions with the provision of a subsurface drill and a scientific package.
The drill will be capable of drilling and collecting several samples and delivering them to instruments located within a scientific package fixed on a landed platform. The goals of the investigations are to study physical and mineralogical properties of bulk soil and dust (atmospheric and surface) as well as geochemical, structural, radiation and geophysical properties of subsurface materials to a depth of 0.5 meters.

3 IPSE: LEADING CONCEPT AND GENERAL OVERVIEW

The original idea of IPSE, Italian Package for Scientific Experiments, was proposed by CISAS. ASI has identified in CISAS itself the developer of IPSE, in conjunction of Tecnomare SpA as industrial partner.
IPSE, is an autonomous micro-laboratory for the in-situ analysis of Martian soil and environment to be installed on the Lander of the carrying mission. It's endowed with A&R facilities for payload servicing The aim of the IPSE facility is to provide a set of services to Scientific Payloads having wide differences both from functional and performance point of view. Such services include thermal-structural decoupling of the Payloads from the Lander, Mission Management, scientific data processing, interface with the Lander for power and communication, sample management.
IPSE is a challenging project in which state of the art solutions were included. Its general configuration is based on a structure with an external envelope to fit within the available room on the Lander deck.
IPSE is designed to operate in Martian environmental conditions and for a lifetime of one Earth year. This means that it will be able to operate at severe temperatures and low pressures in a sandy and windy atmosphere.
The leading concept of the design is to implement a modularity philosophy in the design of the main subsystems, in order to allow the maximum level of de-coupling between IPSE and the experiments. This means being able to support very different types of payload and suit each launch opportunity.

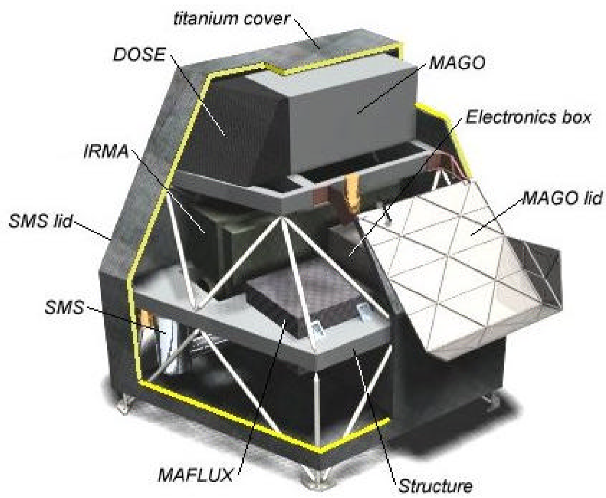

Figure 1 – Proposed configuration

Central to its being a multi-purpose facility is its flexible automation system, providing the following functions:

1. Capability to collect soil samples from the deep soil driller (DEEDRI), prepare and deliver them to the P/Ls, discharge them.

2. Bidirectional Micrometric displacement of the samples to allow spectrometric analysis with sample scanning and optimal auto-focus facilities;

3. Sample preparation prior to analysis. In case of dusty or soft soil samples, the sample will be slightly compressed prior to measurement to reduce it to a proper layer. This preliminary operation provides a way to evaluate correctly the proper sample position underneath the instruments for optimal focusing.

4. Autonomous thermal control. A dedicated insulating cover has been studied to fulfil the thermal requirements both in terms of power and in terms of temperature.

5. Capability to expose Payloads to external environment to achieve the scientific goals, and to protect them when critical events are detected.

All such services, apart from item 4, are provided by a robotic Sample Management System (SMS) and by an automatic lid opening system included in the IPSE housing structure.
Technological advances are required to face such challenging requirements as:

- The demanding scientific requirements set by the experiments;
- Safety, reliability requirements;
- Limited availability of resources to minimise the impact of the servicing system on the already reduced overall mass, volume and power budgets;
- Extreme environmental condition (-130° to +30°C).

To perform Mission Management, IPSE is equipped with a processing unit, allowing for a high degree of operational autonomy and flexibility in the operational sessions:

- Capability to communicate with Lander to receive high level commands, telecommands from ground and to transmit back the collected scientific data, Housekeeping and status parameters;
- Capability to manage power conditioning and distribution from the Lander to all IPSE S/Ss and P/Ls;
- Capability to provide Autonomous Mission Management, including scientific mission scheduling, instruments power on/off, scientific instruments supervision and control;
- Capabilities for scientific data acquisition, processing, compression, temporary storage and transmission to the Lander;
- Capability to control of the sample management system and housing structure mechanism.

4 PRESENT ACCOMMODATION

The IPSE general configuration, for the formerly hypothesised 2003 MSR mission, is based on a structure having an external envelope fitting the available volume.

IPSE main resource requirements are mass 11.5 kg, communications 9600 kbit/s, day energy(7h) 175 Wh, night energy(17h) 50 Wh
The aim of the scientific instruments contained in IPSE box is the analysis of Martian soil and atmosphere. A sample of Martian soil is collected from a driller by IPSE SMS, taken inside IPSE box and delivered to scientific P/Ls to achieve scientific analysis. An automatic door system puts proper P/L in contact with external environment in order to achieve atmosphere analysis.
The following subsystems are identified in IPSE:

- Scientific Payloads;
- IPSE Electronic Unit (IPSE-EU);
- IPSE Housing Structure (including lids and thermal cover);
- Sample Management System (SMS).

4.1 SCIENTIFIC PAYLOADS

According the current baseline, the resource envelope of IPSE accommodates the following scientific experiments [Ref.1]:

IRMA (*InfraRed Microscope Analysis*) is an IR spectrometer that will provide a detailed mineralogical analysis of the Martian soil approximately 4 years earlier than the Earth returned samples. This goal shall be fulfilled using a microscope/spectrometer The in-situ measurements have the considerable advantage with respect to remote sensing observations of permitting an unprecedented spatial resolution allowing removal of mineral identification ambiguities due to the contamination of the spectroscopic features by the atmospheric gases and aerosols.
As IRMA does not contain mechanisms for image production and sample focusing, it shall need support from IPSE SMS. IRMA requires the sample to be moved in two orthogonal directions axis with an accuracy of few microns.

DOSE (*DOSimeter Experiment*) is the instrument proposed for the measurement of the β and γ radioactivity in space and at the Martian soil. This goal will be accomplished by means of two sub-systems: a dosimeter and spectrometer package. The dosimeter is based on thermo-luminescence pills which emit an optical signal proportional to the absorbed dose when heated. Because the dosimeter is reset by heating, characterisation of the different environments and determination of their dose rates will be possible.
MARE-DOSE is based on passive dosimeters working without any powering or support after the annealing. The space monitoring sequence requires the total Earth to Mars travel duration time. The remote sensing measurements requires because of the radiation environment integration periods of the order of about 20 days.

MA-FLUX (*MArs X FLUorescent Experiment*) will investigate the Martian surface using the X-ray fluorescence technique, thus allowing the detection of the major and trace chemical elements in the Martian soil, down to a few ppm, using simultaneously the gamma scattering method and the X-ray fluorescence technique. This instrument investigates the interior of samples to a depth ranging between one mm and one cm. Furthermore it defines precisely the X-ray absorption capacity of samples and permits the estimation of the abundance of elements heavier than iron.
By analysing the Compton and Raleigh scattered photons at different energies and at different angles, it will be able to

estimate the abundance of the major elements. By analyzing the hard X-ray fluorescence features, this system should evaluate the chemical composition of the trace elements within a few ppm.

MAGO (*Martial Atmospheric Grain Observer*) is a dust analyser which will monitor the dust flux and dynamic properties of single intercepted particles as a function of time. It allows determination of grain mass, size and shape distribution, and dynamic behaviour of airborne dust. To achieve the scientific goals, MAGO is equipped with three different detection subsystems: 3 Micro-Balance Sensors (MBS), 1 Grain Detection System (GDS) and 1 Impact Sensor (IS).

It is required that the accommodation of MAGO in IPSE must be such to guarantee the clearance of the fields of view (FoV) of the sensors, so to allow a proper collection of the grains. MBS FoV is a cone having an opening angle of 40°, GDS FoV is a square based pyramid having an opening angle of 47°. MBS are oriented along three mutually orthogonal axes. MAGO must be protected during heavy dust storms to avoid risks of possible MBS saturation.

4.2 IPSE ELECTRONIC UNIT (IPSE-EU)

It is in charge of providing IPSE elements with all the required services in terms of Electrical Power supply and Supervision, Control and Monitoring in all the Operational Phases. The Electronic Unit and the SW subsystem have been designed in order to fulfil functions described in sec.3.

Due to the restricted mass and volume budget, optimisation has been necessary to minimise the number of utilised boards (only 3U size fit the available volume) and to guarantee the mission to be single failure tolerant.

Thanks to optimisation all the functionalities considered essential for the mission have been made redundant, without duplicating the boards.

An example of the optimisation operated in the design phase is the introduction of a universal motor driver to command all the moving mechanism has been adopted. A single motor driver is foreseen to be used in nominal mode. A second motor driver is present on the same board and could be activated in the nominal mode for operating more than one d.o.f. at the time and in case of faulty condition to guarantee motor control anyway.

To reduce volume and mass dedicated to electronics inside IPSE, a centralised main CPU (also for P/Ls servicing) have been chosen. The idea of modularity in the services to the P/Ls has been implemented in the SW Architecture design, that could be divided in Mission Management modules and customised P/Ls SW modules to perform on board data processing in order to satisfy all the different P/Ls scientific requirements.

4.3 IPSE HOUSING STRUCTURE

IPSE housing structure is to:

- guarantee mechanical stiffness and resistance to loads and vibrations relative to all phases of the mission;
- provide thermal insulation form external environment;
- support all servomechanisms, auxiliary elements and P/Ls according the established layout.

IPSE double-decked structure is made of a titanium truss and two aluminium alloy ledges. It has to suit the layout imposed by scientific P/Ls requirements with minimum mass and size of external envelope.

The structural behaviour has been evaluated by a finite element analysis. The FE model has been verified under a static load of 18g acting on 14 different directions in space. Vibration behaviour, global and local buckling, have been checked as well. Due to preliminary phase of design, high safety factors have been taken into account.

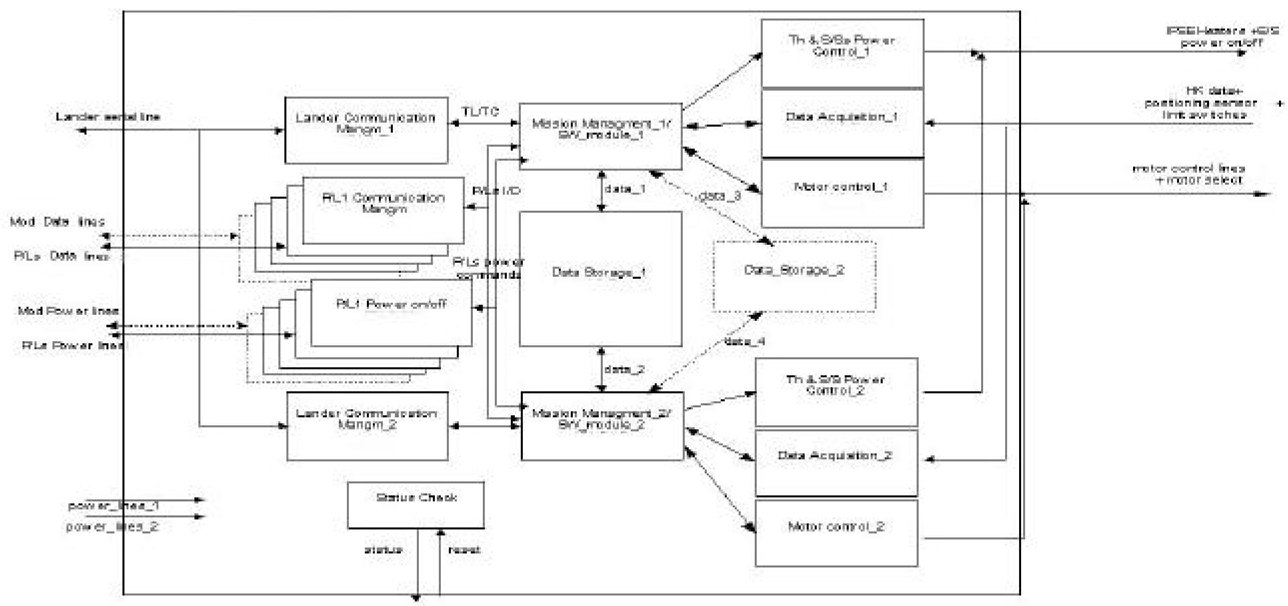

Figure 2 – IPSE EU/SW Logical Model

Proper dimensions and material of lower truss have been adopted to limit heat transfer trough the deck. A high efficiency thermal cover, composed of two special evacuated embossed titanium plates, ensures thermal insulation from the extreme environmental conditions of the Martian surface. An additional Aerogel layer has been foreseen in all the critical junction zones.
To achieve the scientific goals, IPSE box shall not always be isolated from external environment; in particular, it shall have at least two openings in order to:

- Allow the withdrawal and disposal of a sample of Martian soil (through the so-called "SMS opening").
- Put in contact the proper instruments with the external atmosphere (through the so-called "MAGO opening").

Both lids relative to MAGO and SMS openings are made of aluminium ribbed plates actuated by two stepper motors, through a worm reduction and properly designed linkages.

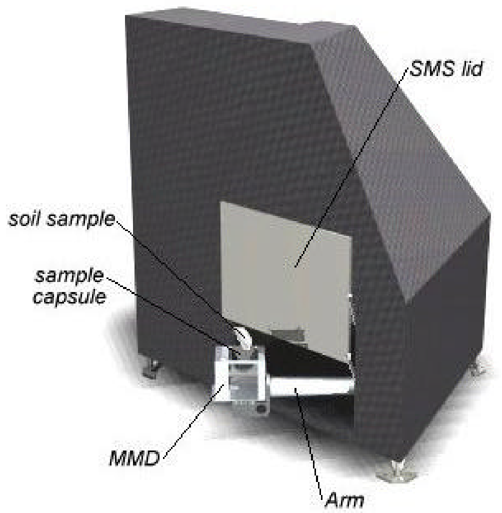

Figure 3 – Sample withdrawal

Different architectures and geometry have been evaluated for the two lids, taking into account different needs and possible failure that could prevent correct door actuation. Stepper motors are equipped with special hall sensor for position control; these sensors, with a ceramic substrate, have a working range up to –175°C. Motors are built in special construction to withstand extreme environmental conditions. All stepper motors are redundant to suit safety and reliability requirements.
Both MAGO and SMS lids achieve the following functions:

- guaranteeing thermal isolation when closed;
- remaining in closed position until operational procedures require their opening;
- withstanding to vibrations and other stress during launch and any other phase of the mission
- allowing the correct carrying out of all operations by instruments and devices requiring their opening;
- Dynamic envelope does not interfere with other structures and devices mounted on the Lander, or with their correct working.

4.4 Sample Management System (SMS)

SMS performs all the IPSE Operations that require motion of the samples. The SMS is composed of a mini robotic arm of about 120mm with three d.o.f, normally stowed inside IPSE envelope, in charge of gross positioning movement, and by a special mechanical device provided with active micro-mechanism (Micro Movement Devices (MMD)), used to move sample container both parallel and normal to the focal of the spectrometer with precision of few microns.
A latching device holds the arm during the launch.

4.4.1 Arm

According to the present IPSE configuration, three degrees of freedom are required to the robotic arm to carry out the mentioned operations: rotational joint, linear joint, wrist.
A combination of rotational movement and linear movement allows the arm to reach all proper operational positions, while wrist is needed to discharge the sample at the end of all experiment operations.
Three different constructions of stepper motors have been foreseen to actuate the robotic arm.
shoulder: The arm shoulder is fixed to IPSE structure; a redundant stepper motor actuates shoulder joint through an external planetary reduction unit.
linear joint: linear actuation is implemented by a modified stepper motor in which the rotor is the nut of a precision mini ball screw. The stepper motor is connected to the link to be moved; any angular step involves a translation of the motor and of the connected link.
This mechanism is more efficient than traditional linear actuation made by common screw/nut mechanism; it allows saving a great amount of volume and mass, and achieving a reduction of the number of components.
wrist: wrist actuation is realised by a special two-position stepper allowing the wrist to rotate by the desired angle to discharge the sample and to come back in the standard position.
Hall sensors are used for position measurement of all the joints.

4.4.2 MMD

MMD (Micro Motion Device) is a small device for bi-directional micrometric displacement of the samples to allow

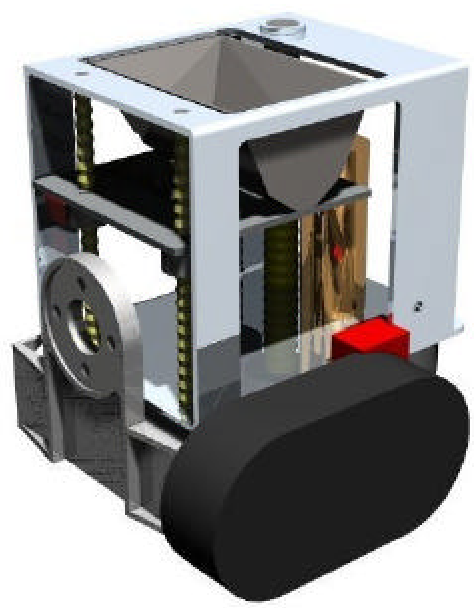

Figure 4 - MMD

spectrometric analysis with sample scanning and optimal auto-focus facilities. In the actual IPSE configuration these services are foreseen for IRMA instrument.

During co-operation between IRMA and MMD, the sample is hold in a suitable container fixed to MMD itself; the operations that have to be carried out, requiring micrometric displacement of the sample by MMD, are listed below:

calibration - to be done at the beginning of each measurement sequence; sample is moved vertically towards a volume checker (named calibration rod) to primarily set the correct distance between sample surface and instrument optics.

sample acquisition – sample is scanned as it moves horizontally by steps of few microns, along a direction perpendicular to the slit axis of the spectrometer.

focusing - to periodically check optimal distance between sample surface and instrument optics.

To implement the mentioned functions, two orthogonal precision linear motions are required. Both horizontal and vertical movements are carried out by the architecture adopted for arm linear joint.

Performances achieved by the present configuration are a vertical and horizontal stroke of 10 millimetres with accuracy of 5 microns.

5 CONCLUSIONS

The main features of the IPSE facility have been presented. IPSE is an autonomous micro-laboratory housing scientific instruments for in-situ soil and environment analysis on Mars.

Particular emphasis has been given to the IPSE Automation and Robotics capabilities.

The system has been designed to be modular so as to be adaptable to different scientific instruments and different mission opportunities.

6 BIBLIOGRAPHY

[1] E. Flamini & al. 2000, Italian Participation in the Mars Exploration Program, *2nd Conference on Academic and Industrial Cooperation in Space Research*, Graz, Austria