VIRTUAL REALITY APPLICATIONS AS DESIGN&VALIDATION SUPPORT FOR A&R EXPLORATION

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ABSTRACT

The scope of this paper is to describe how Virtual Reality can be an important support instrument for Automation and Robotics exploration systems design, development, validation, test phases and operations.

Thales Alenia Space Italia is provided with a facility called COllaborative System Engineering (COSE) Centre, which supports the engineering activities during all the product lifecycle. The Centre includes a Virtual Reality Laboratory (VR-LAB), where some established technologies are used by the aerospace system disciplines and other new ones are continuously integrated and tested in the frame of the Research and Development activities.

In particular the VR-LAB can simulate from the early phases:

- The operative environment
- The robot
- The user control side

Among all, in the VR-LAB some experiments were done for remote control of robotic arms and rovers:

- Robotic arm control using a Haptic device
- Rover motion tracking
- Rover driving using two Nintendo Wiimote.

1. INTRODUCTION

A&R (Automation and Robotics) space exploration is widely diffused since it allows scouting environments which can be hostile or not accessible to humans. The most diffuse exploration systems (for planetary surfaces in particular) are composed by rovers (either manned or unmanned) provided with robotic arms or other devices capable of interaction with the external environment.

Some systems are almost completely automatic, so they do not require human control except for emergency situations. Other systems, on the other side, are generally piloted by operators. In both cases, anyway, the HMI (Human Machine Interface) plays an important role in the outcome of the missions: in the first case the HMI facilitates the management of emergency situations in the most effective and immediate way; in the second one it needs to be optimized for long and continuous usage.

TAS-I (Thales Alenia Space Italia) acquired a long experience using VR (Virtual Reality) in support of the design and validation phases. Thanks to the VR-LAB (Virtual Reality Laboratory) facility of the COSE (COllaborative System Engineering) Centre, in fact, it is possible to simulate all the situations that need to be taken into account for the products design and validation:

- The AIT (Assembly Integration Test) phases: are the planned AIT procedures feasible?
- The human presence in some of the products: what is the habitability of a module?
- The regular activities (IVA -Intra Vehicular Activities-, EVA -Extra Vehicular Activities-): what is the reachability of a particular area? What about the environmental conditions? What is the operability of the tools?
- The maintenance of the products: what are the maintenance procedures if a failure occurs?

In particular, for the A&R exploration, the VR helps to design, test and validate:

- What is the best design for the HMI?
- What are the best interaction devices?
- What are the best HW (Hardware), SW (Software) and GUI (Graphic User Interface) configurations?
- What are the environmental conditions in which a robot (or a rover) has to operate?

The main technologies used in the mentioned cases are:

- For the virtual AIT: virtual mannequin, motion capture, haptic device, physical simulations
- For the habitability verification: virtual mannequin
- For the virtual IVA and EVA (including A&R operations): virtual mannequin, motion capture, haptic device, physical simulations

- For the virtual maintenance: virtual mannequin, motion capture, haptic device, physical simulations.

The following chapters describe the VR instruments which can better support the A&R systems used especially for EVA and for exploration:
- VERITAS (Virtual Environment Research In Thales Alenia Space): virtual reality framework developed in the COSE Centre which supports different applications.
- DesiRe (Design Review application): one of the VERITAS applications, specific for the design phase.
- RoSi (Rover Simulator application): the VERITAS application specific for rover simulations.

The conclusions will present a summary of the results up to now and what are the ideas (new technologies and applications) for the future.

2. THE VR-LAB AND VERITAS

The facility used in TAS-I for the VR simulations is the VR-LAB. It is equipped with a CAVE (Cave Automatic Virtual Environment), which is a room composed by some retro-projected stereoscopic walls (in this case three) on which the virtual simulations are visualized.

The users can interact with the virtual simulations by means of various devices, among which (see Fig. 1):
- Mouse devices and keyboards
- Bluetooth controllers with accelerometers (Nintendo WiiMotes)
- Data Gloves
- Haptic device (HAPTION - Virtuose 6D35-45 Force Feedback Device)
- Tracking System (A.R.T.)
- Motion Capture Suit (Optitrack)

Figure 1 - COSE Centre/VR-LAB: HW platform

The COSE Centre team developed a SW platform for the virtual simulations: VERITAS. It can be used both in the VR-LAB, providing 4D (3D+time) stereoscopic, immersive and interactive simulations, and on a simple PC, with a limited set of functionalities.

In a few words, VERITAS allows defining a virtual scene, analyzing it and interacting with the simulation thanks to the interfaced devices. VERITAS manages the graphic rendering, the physical behaviour of each simulated object and the user interaction.

Some specific applications were developed on top of VERITAS, in order to provide different services depending on the user needs:
- TraVis (Trajectory Visualization): it is used for Solar System and Universe exploration, and for trajectory visualization.
- vCAST (Virtual Cargo Accommodation Support Tool): used to test rack and bags allocation in a spacecraft module.
- VIRTooS (Virtual Radiation Toolset): used to show radiations on a spacecraft and around the Earth.
- DesiRe (Design Review): used for design review and to virtual mock-up analysis.
- RoSi (Rover Simulator): used to simulate a rover moving on a planetary surface.
- LandS (Lander Simulator): used to simulate a lander arriving on a planetary surface.
- PataTrack (Parse To Ascii Tracking data application): used to log the Tracking System output.

3. DESIRE AND THE HAPTIC DEVICE

DesiRe is the application specific for design reviews. It allows analyzing the virtual mock-ups and interacting with them, in order to verify if the products meet the requirements (e.g. accessibility, habitability).

Some devices were integrated to simulate the AIT procedures, the IVA or the EVA step by step, to test the habitability of a module, to take measurements in order to validate some requirements and so on. The main simulation tools are:
- The virtual mannequin: it can be placed in the simulation in order to assess, for example, the habitability of a module or the feasibility of a procedure. In more advanced project phases it can be used also for training. The mannequin motion can be the reproduction of the real user wearing a motion capture suit or it can be controlled interfacing DesiRe with other applications specific for virtual mannequin simulations.
- The haptic device: it allows simulating some operations (e.g. move parts, perform operations with tools) with force feedback. Like the virtual mannequin, it is used both in the design and training phases.
- The tracking system: it can be used to track the motion of some interaction devices (e.g. to navigate in the scene) or to make some measurements in the testing or validation phases. For example it was used

to prepare a report about the vibrations of a rover during a drilling test (with PataTrack application).

Talking more specifically about the support to the A&R systems design and validation, the haptic device in particular can be used at the same time to control a real robotic arm and a virtual robotic arm.

Fig. 2 shows:

- on the left the user, who can control the virtual simulation moving the haptic device
- in the centre is shown a monitor with the virtual simulation of a rover robotic arm
- on the right a small-scale rover provided with a robotic arm connected to the virtual simulation.

Using the haptic the user can move the end effector of the arm in the virtual simulation. The virtual simulation calculates the position of each joint and sends this information to the small-scale rover, which moves like the virtual one.

Figure 2 - Rover Robotic Arm (small-scale model) controlled by Haptic Device

4. ROSI

RoSi is the application for rover simulations. The virtual rover motion can be:

- Calculated real-time by one of the VERITAS modules, nG, which is a wrapper of the physical engine NVIDIA® PhysX®
- Calculated real-time by an external SW and sent via network to RoSi
- Pre-calculated by an external SW and exported to RoSi, which can read trajectories files.

The rover can be piloted by the user with a simple keyboard or thanks to two Nintendo WiiMotes. Four driving modes have been tested since now (see Fig. 3 and Fig. 4):

- Skid Steering: the rover steers like a tank. The left WiiMote pitch[1] inclination determines the torque which has to be applied to the left wheels and the right WiiMote controls the right wheels.

- Slip Steering: also in this mode the PLR steers like a tank, but the left WiiMote pitch inclination controls the rover total torque, which is differently divided to the right and left wheels according to the right WiiMote pitch angle.
- Steering Mode: the rover front and rear wheels steer according to the right WiiMote roll[2] angle and the rover torque changes accordingly to the left WiiMote pitch.
- Turn on Spot: the rover turn on spot with a torque determined by the right WiiMote roll angle.
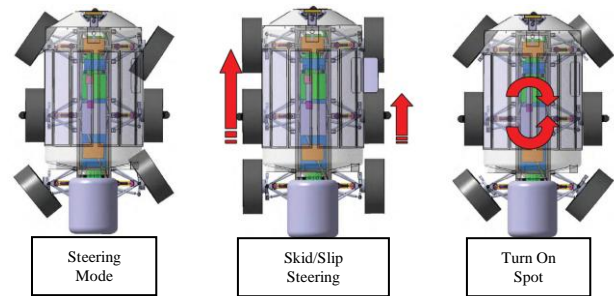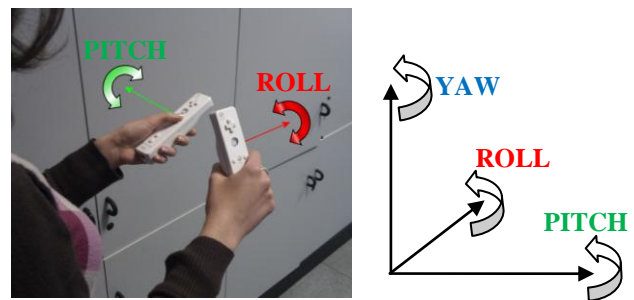

Figure 3- Rover driving modes

Figure 4- WiiMote Roll and Pitch inclination for rover driving

A hypothetical rover cockpit was designed to provide the main information in a glance. It is composed by two control panels and some other information displayed in the GUI (see Fig. 5):

- Statistics panel: a panel with information about the rover state and the operational environment (speed, acceleration, pitch, battery level, external temperature). The six monitored data are displayed around a hexagon which changes shape and colour: if one of the data is below/over the admitted thresholds the colour of the related vertex become red and the vertex moves far from its correct position.
- Hazard panel: a panel with the top view of the operational area with red points indicating hazard points (ex. rocks) and hazard warnings appearing

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[1] Wiimote pitch inclination means to grab the WiiMote with the buttons facing towards the user and to tilt it forwards and backwards.

[2] Wiimote roll inclination means to grab the Wiimote with the buttons facing to the right and to tilt it sideways.

when the trajectory intersects one or more hazard points.

- Rover projection: a blue cylinder indicates the hypothetical future position of the rover on the basis of the present direction and speed.
- Checkpoints: it is possible to add to the virtual scenario two checkpoints to indicate the starting and final position of the planned trajectory of the rover. The checkpoints are useful for the rover driving training and test.
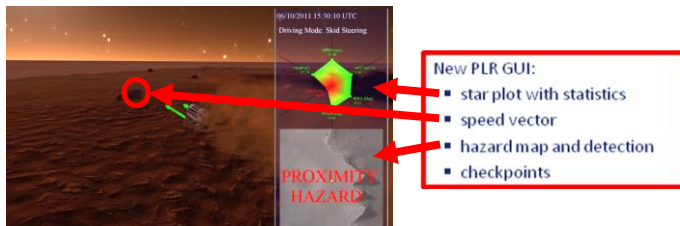

Figure 5 - Rover cockpit

In conclusions, RoSi allows testing different rover configurations and driving modalities, facilitating the assessment of the best design. In addition, it enables to compare different cockpits and virtually test them to establish the more intuitive configuration. Moreover, the application can be also used for training activities.

5. CONCLUSIONS

The usage of the VR-LAB facility in general has a great success because of the realistic, immersive and interactive aspects. Anyway, the interaction can be improved with more precise devices and new data and simulations can be continuously integrated.

Referring in particular to the haptic simulations, the main positive comments are that the interfaces are good and that the system reacts to the user actions as expected.
Regarding the negative aspects, some users met some difficulties using the haptic: this is mainly due to the fact that for an optimal haptic usage it should be recommended a minimum time of training. One of the main difficulties, for example, is due to the fact that the reach of the arm is limited, so some operations have to be divided in several sub-movements.

The main user feedbacks about rover simulations with RoSi are:
- the graphical quality is quite good
- the interaction devices are easy-to-use
- the simulation helps to understand some important issues of the rover motion, like for example: the inertia makes it difficult to drive the rover, the dusts can be a problem for the visibility and the mechanical parts

- some aspects should be added to the simulation (e.g. sounds, vibrations)
- some aspects could be improved: the breaking system, the roughness of the terrain, the stereoscopy and the illumination.

In conclusion, the VR is already an important support to the A&R exploration. Improvements are always possible accordingly to the incoming technologies and integrating additional data, but the first results of the current applications are satisfactory.

Starting from these firsts encouraging outcomes, the possible future steps are:
- new technologies tests and, in some cases, integration (especially regarding graphics and interaction)
- design and development of VR HMI to be used on orbit (or in on ground bases) for robot control
- usage of VR systems for the control of robot used in other fields (e.g. medicine, industry).

6. ACRONYMS

Table 1- Acronyms Table

A&R	Automation and Robotics
AR	Augmented Reality
CAVE	Cave Automated Virtual Environment
COSE Centre	COllaborative System Engineering
DesiRe	Design Review
EVA	Extra Vehicular Activity
GUI	Graphical User Interface
HMI	Human Machine Interface
HW	Hardware
IVA	Intra Vehicular Activity
LandS	Lander Simulator
Patatrack	Parse To Ascii Tracking data application
R&D	Research and Development
RoSi	Rover Simulator
SW	Software
TAS-I	Thales Alenia Space Italia
TraVis	Trajectory Visualization
vCAST	Virtual Cargo Accommodation Support Tool
VERITAS	Virtual Environment Research In Thales Alenia Space
VIRTooS	Virtual Radiation Toolset
VR	Virtual Reality
VR-LAB	Virtual Reality Laboratory