IMIS Tool implementation at SONC for Philae on Comet Operations Monitoring

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This paper will explain how we built the Philae monitoring system for comet operations at SONC (Science Operations & Navigation Centre). This system is based on the reuse of the CNES generic tool IMIS (Instrument Monitoring Interactive Software) and additional scripts for interfacing the SONC database and developing dedicated treatments regarding the instruments’ execution and the resource consumption. From the telemetry received and recorded in the IMIS database, the complete storyboard for the Philae comet operations can be accessed through a secure VPN connection on the Internet. Thanks to the IMIS client, it is possible to stay tuned into the mission to react to and make an assessment report at each telemetry pass. This is done through a large panel of displays, within a hierarchical and contextual presentation, templates for plotting or calculating other parameters, alarms and warnings. To conclude, this paper will present the benefits of the implementation of monitoring facilities for the project and the perspectives for monitoring instruments on board space missions.

Nomenclature

AU = Astronomical Unit
CNES = Centre National d’Etudes Spatiales – French Space Agency
DLR = Deutsches Zentrum für Luft- und Raumfahrt – German Space Agency
ESA = European Space Agency
FSS = First Science Sequence
GUI = Graphical User Interface
HK = House Keeping telemetry
IMIS = Instrument Monitoring Interactive Software
LCC = Lander Control Centre
LTS = Long Term Science phase
RF = Radio Frequency
RGS = Rosetta Ground Segment
RLGS = Rosetta Lander Ground Segment
RSSI = Received Signal Strength Indication
SAM = Science Activity Management
SDL = Separation, Descent and Landing phase
SONC = Science Operations & Navigation Centre
TC = TeleCommand
TM = TeleMetry
VTS = Visualization Toolkit for Space data
XML = eXtensible Markup Language

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I. Introduction

In the framework of the ESA Rosetta space mission, the Philae lander was designed to land and perform a series of scientific observations in-situ on the surface of the comet 67P/Churyumov-Gerasimenko. Philae created a buzz on the 12th November 2014 when it landed and started its operations for five comet days and then fell in hibernation due to a lack of energy. It was located at approximately three AU from the sun, with a one way propagation delay from Earth of about thirty minutes for communication. Philae once again experienced success after its revival and first contact in June 2015. This was possible due to the comet approaching the perihelion on its trajectory closest to the sun. The French Space Agency (CNES) has contributed to this ambitious mission, mainly inside the European Philae consortium, as the second major contributor, after DLR (Germany). Since its launch in March 2004, together with the LCC (Lander Control Centre) in DLR Cologne, the SONC (Science Operations & Navigation Centre) in CNES Toulouse has been involved for over 10 years in flight operations of the scientific payload of Philae, composed of 10 different instruments. It was the central hub for the scientists to retrieve data and request flight operations to be included in the Rosetta/Philae mission plan. SONC also took the lead for the landing site selection process with the support of its flight dynamics team. The on comet operations scenario was divided into three main phases: - the Separation, Descent and Landing (SDL) phase, - the First Science Sequence (FSS), a five comet day sequence relied on batteries following the immediate orbiter delivery - and the so called LTS (Long Term Science) powered by solar panels and a rechargeable battery for the Philae life duration under comet conditions.

II. Rosetta and Philae operations organization for the comet phase

The mission ground segment for operations is made of several parts as described in Fig.1. The ESA Rosetta Ground Segment (RGS), in interface with the ground stations, handles the overall plan of commands with the probe and is also the data central hub for telemetry.

After separation, Philae is operated through Rosetta orbiter radio visibilities thanks to a dedicated telecommunication system on both sides. The Rosetta Lander Ground Segment (RLGS), devoted to Philae Operations, is made of two different centres; the SONC and the LCC.

For the SDL and FSS comet phase, it was decided to move all the operational representative lead teams for each unit of the platform and the payload (red annotation in Fig1) to the LCC in order to co-locate on a core planning team in case of emergency. This decision had an impact on the SONC operational organization for monitoring the SDL and FSS operations. The SONC operated without its SAM (Science Activities Management) team managers who discussed and froze the final FSS plan after numerous versions and without any remote displayed feedback of the platform monitoring from the LCC. SONC was of course in contact with LCC by audio and video means. This situation was accepted because SONC remained connected to its users and managers by phone and web means. In particular the scientific products, the results of calculations and of Philae location on the comet after landing, lot of auxiliary data were accessible to the scientists. However it was decided to put in place an autonomous platform of key parameters monitored at SONC, in order to avoid being disconnected or behind of the progress of Philae operations. This support was also available for our delocalized SAM team.
III. Philae Overview

PHILAE Lander (Fig.2) weights about 100 kg. The platform itself is composed of ten subsystems and includes ten instruments for measuring chemical and physical properties of the comet. The science payload represents around 30 kg, making up nearly one third of the total mass.

A. The Platform units [1] [2]

- **ADS (Active Descent System)** is a GN2 based 1-axis-thruster system (thrust axis in Lander +Z-direction) designated to provide a hold-down thrust immediately after touch down to support the Anchor system and to prevent the Lander from rebounding from the comet surface.
- **FW (Flywheel)** provides attitude stabilization of the Lander during its descent to the comet.
- **ANC (Anchoring Subsystem)** is required to ensure, together with the Landing Gear and ADS, landing on the comet. At touch-down two identical harpoons will be fired and penetrate into the comet surface.
- **LG (Landing Gear)** provides the mechanical interface between the Lander main body (Internal compartment, Solar hood and Baseplate with Balcony) and the comet by damping of the kinetic energy at touch-down during and enabling a Lander re-orientation by rotating and/or tilting of the Lander main body.
- **MSS (Mechanical Support System)** provides firm attachment of the Lander to the Orbiter in its ground handling, launch and cruise position and ensures accurate and safe release at separation.
- **PSS (Power Subsystem)** is the central power management system of the Lander. Power provision is given by a Battery system consisting of a Primary and a Secondary unit and a Battery management system. The Secondary Battery will be refilled by Solar cells.
- **TCS (Thermal Control Subsystem)** follows a two-step insulation strategy. An inner Multi-Layer Insulation (MLI) tent is used to form the warm compartment. It will be thermally conditioned by two solar radiation absorber units and additionally controlled by electrical heater systems. A second MLI tent surrounding this inner tent but without touching it is installed to achieve the required temperature environment during all mission phases.
- **CDMS (Command and Data Management System)** is one of the central units of the Lander providing access to the Lander and its units via commanding, return of science, housekeeping and status information from the Lander via telemetry, autonomous control of the Lander operations via predefined S/W routines. Therefore CDMS operates interfaces to ESS (electrical interface on the Orbiter) via harness (Umbilical) or RF (TxRx subsystem) and to Lander units via an internal communication bus called Subsystem interface (SSIF).
- **ESS (Electrical Support System)** is a part of the overall Philae system, but not mounted within the Lander itself. It is integrated on the ROSETTA Orbiter and provides all electrical interfaces required between the Orbiter and the Lander.
- **TxRx (S-band Telecommunication System)** provides the link between Orbiter and Lander. The limited RF output power of this system requires the Orbiter as a relay station for data transfer between Earth and the Lander. Each side of Philae’s TxRx subsystem consists of two TX-units, two RX-units, one TX- antenna and one RX-antenna.

*Fig.2: Philae Platform units.*
B. The Payload units [3]

- **APXS** (Alpha Proton X-ray Spectrometer) the APXS spectrometer provides information on the elemental composition of the material underneath the Lander.
- **ÇIVA** (Comet Nucleus Infrared and Visible Analyser) is composed of 7 Panoramic cameras (CIVA-P), a Visible Microscope (CIVA-M/V) and an Infrared Spectrometer (CIVA-M/I) designed to characterize the landing site, the 360° panorama as seen from the Rosetta Lander. ÇIVA is sharing a common Imaging Main Electronics (CIVA/ROLIS/IME) with ROLIS.

![Fig.3: View of instruments](image)

- **ROLIS** (Rosetta Lander Imaging System) consists of a highly miniaturized CCD camera. It has operated as a descent imager, acquiring imagery of the landing site with increasing spatial resolution. After touchdown ROLIS took multispectral images of the comet’s surface below the Lander.
- **CONSERT** (Comet Nucleus Sounding Experiment by Radiowave Transmission) is a radar performing the tomography of the nucleus by measuring electromagnetic wave propagation from Philae and Rosetta throughout the comet nucleus in order to determine its internal structures.
- **COSAC** (The COMetary SAmping and Composition) experiment includes a pyrolysis device and two analytic instruments: an eight column gas chromatograph (GC) and a powerful high-resolution time of flight mass spectrometer. The experiment’s aim is to analyse soil samples and identify volatile components.
- **PTOLEMY** is a gas chromatograph-isotope ratio mass spectrometer designed to provide chemical and isotopic analyses of both volatiles (including water) and refractory materials drilled from the comet nucleus.
- **MUPUS** (MUlti-PUrpose Sensors for Surface and Sub-Surface Science) is dedicated to temperature profile (thermal mapper) of nucleus’ subsurface layers to a depth of 40 cm and thermal conductivity of cometary material. It includes a mechanical device designed to insert a penetrator (PEN) into the cometary nucleus and acceleration and thermal sensors in anchors (ANC).
- **ROMAP** (Rosetta Lander Magnetometer and Plasma Monitor) is a combined instrument consisting of a Magnetometer (MAG) and a Simple Plasma Monitor (SPM) which complements the plasma packages on-board the ROSETTA Orbiter. The SPM sensor is able to determine the major solar wind parameters like density, speed, temperature, and flow direction. The MAG sensor is able to determine the magnetic field vector.
- **SESAME** (Surface Electric Sounding and Acoustic Monitoring Experiment) is a set of three experiments: a Comet Acoustic Surface Sounding Experiment (CASSE), a Permittivity Probe (PP) and a Dust Impact Monitor (DIM) sharing a common electronics. The CASSE part investigates acoustically the surface material, while PP measures the dielectric properties of the environment (electrodes are attached to APXS and MUPUS PEN) and DIM is a dust impact monitor.
- **SD2** (The Sampling, Drilling and Distribution subsystem) is on board to support some experiments (COSAC, PTOLEMY, CIVA M) as it is able to collect cometary surface samples at given depths and distribute them to 26 dedicated ovens mounted on a carousel. Then each sample could be step-wise heated and the resulting gas piped is presented to the dedicated experiment (CIVA-M or PTOLEMY or COSAC).

IV. Philae Monitoring Requirements at SONC

The monitoring is made to fulfil several operational requirements as detailed hereafter.

A. **Give an immediate assessment on the course of FSS through synoptics**

The first requirement is to provide a clear assessment on the course of each block of the FSS during the RF visibilities (Fig.4) [3] where we receive telemetry with a delay of less than 30 minutes due to the electro-magnetic propagation time at this far distance from Earth (3.4 AU).
To perform this assessment as soon as possible two main synoptics have been prepared in order to have a global view at the first glance.

1) **Philae Status and Events showing:**
   - the mission timeline progress starting after separation,
   - the resources budget (memory & power),
   - the solar arrays illumination around the lander used to determine the rotation during descent and the attitude on comet,
   - the mechanical activities of the platform (ANC, FW, LG)
   - the mechanical activities of the payload (APXS, MUPUS, SD2)

2) **Philae Electrical Overview showing:**
   - the activated platform units and their consumption,
   - the activated payload units and their consumption.
   All of the parameters come from the telemetry data packets or are calculated. Expected values are displayed in green while alarm values are displayed in red.
   The refreshment of the synoptics is given by the programmed request period of the TM packets available on the DDS (Data Distribution Server) of ESA which is around five minutes.
   The synoptics are limited to the monitoring of the mission progress in real time, but are reusable in replay within a programmable refresh period.

**B. Perform a detailed analysis using templates of charts and reports**

An operational assessment needs to be complete and based on the analysis of all the occurrence of the TM parameters made of TC execution or configuration word status and analogic HK values.
This assessment is provided by the creation of templates of charts. These templates are created following two points of view:

- Templates sorted by units,
  - Platform subsytems
  - Payload experiments
- Templates sorted by operational phases: SDL/FSS, LTS.
These charts can be annotated and exported into template reports.

**C. Alert on event**

Notification by email of telemetry events has to be implemented for the LTS phase notably for the detection of the lander wake-up after hibernation when the thermal constraints and power resource will be sufficient again.
Indeed, this time is not predictable with accuracy and has to be triggered automatically in order to react at the soonest to start the LTS operations.

**D. Permanent accessibility**

In complement of our SONC Web server which distributes to the scientists by instrument the raw telemetry packets and the reduced science data products (L1, L2) processed at SONC, the monitoring system is also web accessible through the CNES VPN limited to authenticated users.

Fig. 4: Prepared sequence for FSS on PHILAE lander: general blocks vs day/night and RF links
V. Technical Implementation using IMIS Tool

The Instrument Monitoring Interactive Software (IMIS) is born in CNES Toulouse to fulfill the requirements for operating the French instrument contributions on board the NASA MSL payload Rover on Mars and CNES multi-mission altimetry payload operation centre. Operators can use it remotely within a large facilities of displays from anywhere through an Internet connexion. Its concept and design allows to be integrated as a generic component into several mission centres at CNES. The tool is currently supported by Thales Services company.

A. General presentation [4] [5]

The IMIS software is a client/server service oriented architecture through a channel of communication using a common protocol where the server is passive (slave mode) listening for multi-clients requests (Fig.5).

![Fig.5: IMIS Software Architecture](image)

Java is the programming language selected for developing IMIS because of the IMIS distributed architecture and the complexity of the IMIS GUI. Java applications can run on any operating system. Finally Java development environment offers a great number of APIs (Application Programming Interface), IDE (Integrated Development Environment), frameworks and a continuous integration environment. One particular API that is used in IMIS is Java RMI (RemoteMethod Invocation) which enables to create distributed Java technology-based applications, in which the methods of remote Java objects can be invoked from other Java virtual machines, possibly on different hosts. Java RMI is the technology used to implement the communication channel between IMIS server and the clients.

PostgreSQL is the object-relational database management system used to store all persistent information of IMIS except telemetry parameters values which, for performance reasons, are stored in binary files using a CNES proprietary technology named “TelemetryTable”. The principle is to store the telemetry covering a specified period in a binary file (.dtm) with an extensible time index. Each file is self-sufficient in the sense that it includes a description of its own data dictionary necessary to read / write the data blocks. The advantages of this binary structure that is temporally indexed are its minimum disk space footprint (data are not encoded in ASCII) and the optimal performance for inserting and retrieving data on a time criterion.

The GUI of IMIS rich client application is developed under the EclipseRCP technology which improves productivity and enables developers to implement highly interactive and user-friendly applications. The architecture is based on plugins that can be made available gradually throughout the development phase. Moreover, as a generic tool, IMIS has to take into account the specificities of every mission it operates and the modular architecture of EclipseRCP offered the possibility to add or remove plug-ins depending on the user requirements.
B. Philae configuration and interface

1) Data Dictionary

IMIS configuration for Philae is applied on a data dictionary which describes the TM & TC parameters in a system structure (mnemo, type, raw and engineering value, transfer function, position in the structure). This description is provided in a XIF format (CNES native format based on XML). The structure of the dictionary builds the interface browser through the IMIS GUI to access to the parameters as presented in Fig. 6.

2) Data Acquisition & Interface

Telemetry CCSDS packets retrieved from the ESA server are processed as soon as their arrival at SONC. This process has been specifically developed and extracts the parameters per APID (Application Process ID) corresponding to a Philae unit. This process calculates also the ground computed parameters if any. Each parameter record contains the UTC date, the raw and engineering value and the significance of the value. They are all stored in a decommuted telemetry file (.dtm) in a dedicated storage repository of the IMIS server. The data files are automatically ingested in the Telemetry Table and referenced in IMIS database by specific daemons.

C. Creation of displays

1) Synoptics Perspective

It enables users to get the values and status of a set of parameters at a given time. Depending on the mission or on the user current objective, the set of parameters to monitor and the way to display them can vary. Thus, this information is not hard-coded in the software but is defined in a synoptic file, loaded by IMIS. Fig. 7 shows the synoptics developed for the Philae mission accessible from a master synoptic used as a home panel. In this view all the synoptics are open, switching from a view to another one is done by a simple click on the tab.

Synoptic display files (.opi) are created under the open source software CSS (Control System Studio) [6] which is an Eclipse-based collection of tools to monitor and operate large scale of control systems. Synoptics are made of referenced widgets being animated through a Javascript or Python code.
2) **Chart Perspective**

Line charts plot one or several parameters over a period of time. Line charts allow time series and XY series (i.e. plot of parameters in function of another). Line charts provide a wide range of interactive and useful functions. Among many others, let’s mention the zoom facility, the 2 layouts available for multiple series (overlapped or mosaic modes), the possibility to plot a combination of parameters using standard math function, the tangent line function and its corresponding slope, the polynomial regression function, etc.

In addition to telemetry parameters series, occurrences of a given command can also be plotted so that it is possible to correlate the evolution of a parameter with the execution of commands.

As an example, the figure below (Fig.8) plots the currents of the TxRx subsystem during the complete SDL/FSS from a predefined template created per Lander Units.

![Fig.8: Chart view](image)

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3) History Table

History table enables users to get the evolution of a set of parameters over a time period in a text format. This was implemented to monitor the execution of the TC per units during the SDL/FSS operation phase. The figure below shows the history table of Philae TCs, they can be sorted by unit of by date. 

In this figure we can notice on the left, in the file navigator that we used the templates created for operation phases.

![History Table](image)

**Fig. 9**: History table view of Philae TCs

D. Alarm & Alert notification

1) Alarm table configuration

Rules for survey are prepared using the IMIS GUI, which requires to login with an expert profile. A large panel of monitoring rules to be applied to the parameters is proposed as range, delta, laws conditional clauses, personalized laws. In case a parameter transgresses a monitoring rule, an alarm is generated and displayed in a dedicated view called Alarm log. Once the alarm cause has been identified, users can acknowledge the alarm (pending they have rights to do so). Here after we present a special use of the alarm that we implemented for the detection of lander wake up with RF contact between Orbiter and Lander during the LTS phase.
Using the IMIS GUI as shown above the RRSI of the ESS receiver on board the orbiter has a minimum sensibility of -124 dBm, over this threshold the alarm is raised and stays open until new 25 values less than – 124 dBm occurred to close the alarm. This alarm corresponds in fact to an actual contact.

Fig.10 : Alarm Rule set up

Fig.11 : Alarms logged and plotted for RF contacts
2) Alert notification by email

A dedicated script has been developed to handle these email notifications. It is based on a periodic scanning of the IMIS Alarm Table via the IMIS batch command mode. As soon as detection occurs a new batch command will retrieve a chart of the ESS RSSI parameter in JPG format. Finally the script copies the chart into an email annotated with the start date of the contact and the end date (if known) and sends to the email distribution list. We got twelve RF contacts after Philae wake up; the figure below lists all the contacts notifications received by email.

![Email Notifications](image)

**Fig.12 : SONC Monitoring email notifications**

Note that IMIS proposes also an Android application that could have achieved this notification function, but which was not used because of a lack of time and security constraints.

E. Synchronisation with 3D visualization system for mission replay

A better way to replay the mission and perform a more accurate analysis is to couple IMIS data monitoring with a 2D and 3D graphic visualization tool which recreates the space mission context with the comet, orbiter and lander models. The animation is performed using the orbit and attitude files, as well as HK mechanical parameters with the VTS CNES tool supported by Spacebel [7]. The tool is based on Celestia freeware and handles starting and synchronizing all the chosen applications. Its core element, the Broker, offers functionality for navigating in visualization time, displaying the units’ operation plan, controlling 3D cameras and defining a range of other display attributes. In our case we replaced the internal time navigator of IMIS by the time broadcasted and controlled by VTS on the TCP port of the IMIS client machine. In Appendix A and B, print screens of the different views of VTS and IMIS after separation with CIVA farewell images, and then at first touchdown, are presented. In Appendix C, an example of views for the mechanical monitoring of SD2 drill translation and carousel rotation is presented.

VI. Main Observation Results

Most of these results were detected or confirmed by IMIS monitoring. Here after some major events during operations are recalled.

A. SDL/FSS Phase

1) Subsystem units

Nominal behaviour of the subsystem units of Philae during this phase except the Anchor which failed the firing of the two harpoons and led to have a rebound at touchdown and go further the expected site. After the first touchdown, a continuous Philae’s rotation was observed on the solar panels illumination view until the third and
final touchdown two hours later. This view helped us also to analyse Philae position versus the order of the lightening on the different solar panels during day light.

2) Payload units
Nominal behaviour of the payload units of Philae even if we had not played the sequences as they should have been initially planned due to the change of landing site leading to manage new constraints and refine the sequences plan, and a cancel for some of them. Fortunately, the new site did not change significantly the expected RF visibilities pattern. SD2 did not retrieve any sample from the soil because the maximum translation of the drill was insufficient to reach the surface under the body. This was the same case during APXS deployment. These mechanical movements including body rotations have been observed on IMIS thanks to adequate synoptic displays prepared in advance. The monitoring of the power consupption of the instruments, of the primary and secondary battery showed a nominal behaviour in regard of the flight operation blocks. The data management within the mass memory went also smoothly, no data loss except some CIVA images after touchdown due to a bad programming.

B. LTS phase

1) Subsystem units
IMIS monitoring was the only mean at RLGS level to check automatically lander-orbiter contact into the orbiter telemetry and send a notification email to the operational team. Moreover, an algorithm was added to the decommutation process in order to correct data timestamp. Actually, Philae on board time is not synchronized after a boot, which occurs at each comet rotation if solar power is sufficient. The time synchronization requires at least one RF link with the orbiter. The first contact with orbiter occurred on June 2015 the 13th. Telemetry analysis revealed that Philae woke up close to April 2015 the 25th.

At the time of this first contact, the secondary battery was fully charged and ready for operation. Unfortunately, the seven following contacts, until July the 9th, revealed also some issues in TxRx currents and mass memories behaviour. Considering Philae estimated position and attitude, more RF links should have been observed. It was unclear if this lack of contacts was due to lander behaviour itself, RF multipath or local topography. It has not be noticed that Rosetta was not able to go to a nominal distance for RF links until end of November 2015.

2) Payload units
Unfortunately we did not succeed to perform payload operations in spite of several upload attempts all of them in blind commanding. On one of them, the last RF link in July the 9th, we got a start of the Consert instrument and that was the only and last contact we had from the payload.

VII. Conclusion

SONC IMIS monitoring was not the operational reference system for flight operations during the comet phase as this task is naturally allocated to the LCC. Nevertheless, it has enabled CNES to follow the flight operations at SONC and provided support for our operations and flight dynamics teams autonomously from the LCC. We did not see any discrepancies either in our observation or those of the LCC. This meant that we were aware of the situation before starting coordination operations meetings between the RF visibilities. The comet phase was very mediatized by ESA TV at SONC and other French media. IMIS monitoring was also very useful in order to give and show the progress status of Philae operations. The system has recorded the complete storyboard of the comet phase operations and the telemetry parameters can be reviewed. Now, as the system is coupled with the VTS 3D visualization system (another generic tool at CNES), it is very efficient to have the data viewer and the 3D space mission context at the same time for analysis. The IMIS implementation of Philae took one engineer closely involved in this project approximately six months. This implementation has also required some minor evolutions of interface on IMIS software. Finally, this initiative was very positive for the project and for the product itself. It has proved once again its adaptive capability for a new mission. As it now exists in several mission centres at CNES, upgrades with new services coming from needs in different missions, are integrated in a generic version to benefit all. Perspectives are still envisaged on IMIS tool to increase the performance of real time monitoring for higher sampling rates of parameters and to insert algorithms of data mining based on statistic and trend analysis on parameters to prevent failures of components on-board.
Appendix

A. VTS & IMIS printscreens at CIVA farewell imaging just after separation
B. VTS & IMIS printscreens fixed just after Philae first touchdown
C. VTS & IMIS printscreens for SD2 drill translation and sample carousel rotation for delivery
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References


