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THE ULYSSES SPACECRAFT CONTROL AND MONITORING CONCEPTS AND REALITIES

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ABSTRACT

Ulysses is a joint ESA-NASA mission the primary purpose of which is to make scientific measurements of the Sun outside the plane of the ecliptic.

The delay in launching Ulysses, due to the Challenger disaster, meant that the hardware on which the Spacecraft Control and Monitoring System (SCMS) resides was becoming obsolete and it was decided to convert SCMS to run on a DEC/VAX machine under VMS.

The baseline for the conversion was an exact copy of the existing ModComp system from a functional point of view. However, following conversion and installation at the Jet Propulsion Laboratory (JPL)in Pasadena, California, further requirements were identified by the spacecraft control team and this lead to the baseline being substantially upgraded to support the mission fully.

The paper will cover the spacecraft, the conversion, the converted SCMS, problems found and the upgrades implemented for solutions. It will also discuss the future for and enhancements already made to the converted SCMS.

Key Words: Ulysses, spacecraft operations, mission control.

1. INTRODUCTION

The Ulysses spacecraft and mission is divided as follows. ESA provides the spacecraft, half of the science instruments and the spacecraft-dependent mission operations personnel, hardware and software. NASA provides the remaining science instruments, the radioisotope thermal generator (which powers the spacecraft), the launch system and the tracking, telemetry data acquisition and command support via NASA's Deep Space Network (DSN).

The Ulysses spacecraft has a scientific payload of nine experiments and is spin-stabilised, rotating at approximately 5 rpm. It has low gain antennas used in the early stages of the mission and a high gain antenna capable of X and S band transmissions. The spacecraft also has a 72 metre Radial Dipole antenna and a 7 metre axial monopole antenna, both for experiment use.

There is an onboard storage capacity for periods of no ground station coverage, i.e. 2 magnetic tape recorders that can each hold 22 hours of data at the nominal record rate of 512 bps.

Telemetry is available in two formats, Engineering and Science and can be transmitted at rates of between 64 bps and 8192 bps. The higher rates are used to transmit scientific formats from the onboard recorders interleaved with realtime data. The nominal realtime bit rate during routine operations is 1024 bps in science format with 512 bps during the recording periods.

The original SCMS software was developed by Burd Voor Systeem Montwikkeling of Holland (BSO) for ESA to meet the launch date of May 1986. The rescheduling of the Ulysses mission meant that the ModComp hardware would become obsolete during the four year delay and as a consequence SCMS was converted by Cray Systems (formally MARCOL) for ESA to run on a DEC/VAX under VMS keeping FORTRAN as the language used, albeit a different dialect.

2. THE CONVERSION

The conversion process itself could not be performed automatically using a Code Conversion program since the hardware architecture and the low level software interfaces to them were significantly different between the ModComp and VAX machines. This meant that all of the SCMS lower level subsystems had to be completely rewritten. These lower level tasks included the interprocess communication, file management and the terminal interface.

The software development followed the ESA BSSC life-cycle (Ref. 1) which meant the Functional Requirements Document produced for the ModComp system had to be rewritten as a Software Requirements Document (SRD). Within the Software Requirement (SR) phase any new requirements raised on the existing system considered essential were included in the document for review.

As mentioned above the differences in the Architectural Design (AD) of the system were due to hardware differences so the functionality of the design remained the same.

The Detailed Design (DD) and Coding stages saw the development follow the standard approach of reviewing the design prior to implementation.

The Software Transfer (TR) phase proceeded very smoothly resulting in a delivery of the first version of SCMS at ESOC some three months ahead of schedule. This was particularly important as no simulator was available so data reception from the spacecraft itself was regarded as essential for thorough testing and operations training. A paper written by Dr. Richard Corkill (Ref. 2), the Cray Systems project manager for the conversion, details the conversion process.

3. THE CONVERTED SCMS

The converted Spacecraft Control and Monitoring System (SCMS) resides on a DEC/VAX 8250. Two of these machines make up the Ulysses Mission Control System (UMCS) and are installed at NASA's Jet Propulsion Laboratory (JPL).

Interestingly, SCMS although originally designed over 8 years ago, contains many of the facilities associated with more modern spacecraft control and monitoring systems. Of special interest to SCMS are:

- *Databases*
- *Telemetry Processing*
- *Telecommanding*
- *Archiving of Telemetry*
- *Display of Telemetry*

The SCMS is comprised of a number of intercommunicating tasks. Prioritisation is used to ensure that realtime tasks, i.e. those driven by incoming telemetry get preferential use of the CPU. The relationships between the processing and data can be seen in Figure 1 - SCMS Major Architecture

3.1 Databases

Most SCMS subsystems rely on the contents of one or more databases for their operation. Each database can be accessed via the database editors to update information contained for displays, modes, parameters, limits and commands.

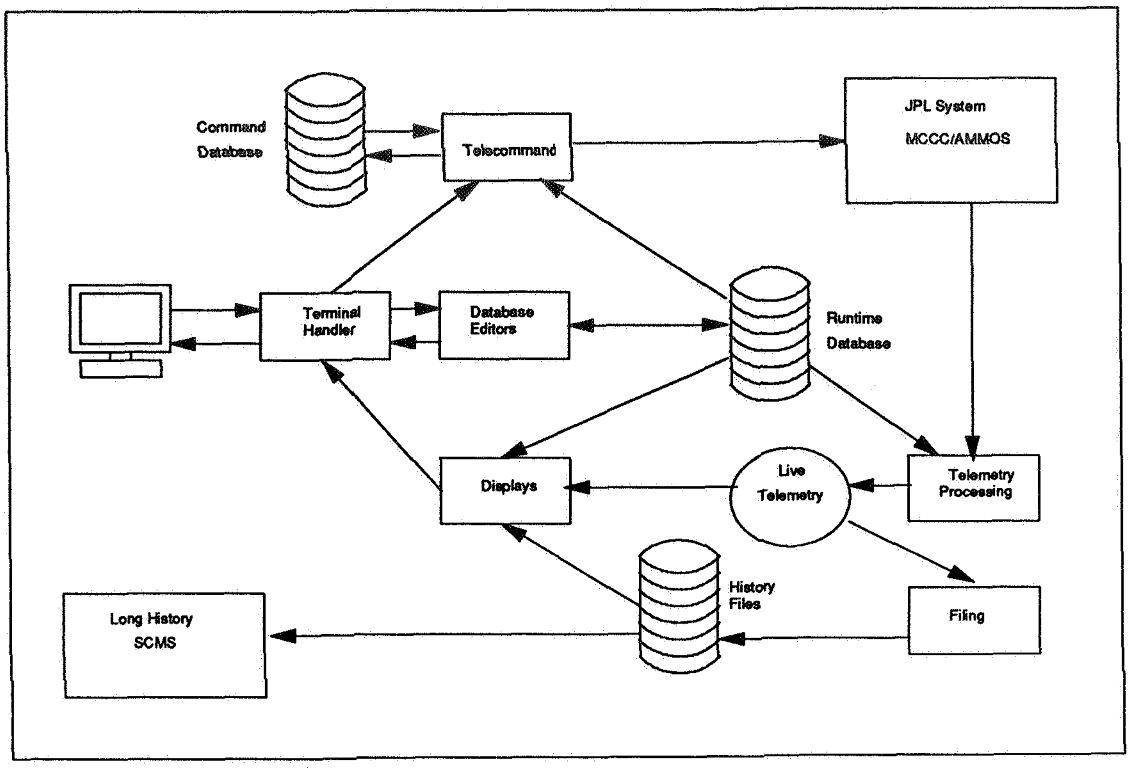

Figure 1 - SCMS Major Architecture

3.2 Telemetry Processing

Telemetry is received from the JPL Ground Data System (GDS) which, as of time of writing is the Data Capture and Staging system (DACS). This is part of the Mission Control and Computer Centre (MCCC) but will be replaced by the Advanced Multi Mission Operating System (AMMOS).

The GDS sends data in the form of Standard Format Data Units (SFDUs) which consist of a header and a 128 byte frame containing spacecraft telemetry. These frames are collected into the number of frames required for a complete telemetry format, which depends upon the type of data : 2 for engineering and 32 for science.

The data can be received in two ways, either realtime or recalled and the data itself can consist of either realtime or playback data.

- *Realtime Data:* This is data received directly from the spacecraft and must be processed immediately.
- *Playback Data:* This is data recorded onboard and is received interleaved with the realtime data to be processed later.

Each telemetry format is processed to produce a processed telemetry record (PTR) which is made available for display and archiving. The record consists of certain portions of raw telemetry associated with platform housekeeping and some 800 derived parameters for spacecraft and scientific data.

3.3 Telecommanding

The way in which telecommanding for Ulysses is performed is one area which differs from most modern systems. This is because commands are ultimately sent via the JPL MCCC system which has no physical link to the SCMS hardware where the commands are prepared. Compare this to modern systems where command preparation and delivery are normally performed on the same machine.

3.4 Archiving of Telemetry

This is achieved by using fixed size circular files, called Short History Files, that contain the PTRs for the last 15 days, an out of limits file that contains the out of limits records for each PTR and a science file that contains the last 3 days of science data. Also archived is a history of commands radiated to the spacecraft during the mission.

3.5 Display of Telemetry

Displaying telemetry in realtime and from the history files is handled by both alphanumeric and graphical displays using either DEC VT340 or Tektronix TK4211 terminals.

A more detailed description of the software architecture is given in the Ulysses SCMS Architectural Design Document (Ref. 3).

4. PROBLEMS AND SOLUTIONS

Following the delivery of SCMS, about one year before launch, it became apparent that the converted system would require upgrading to support the mission fully.

4.1 Excessive CPU loading

Extensive tests using the flight model spacecraft were performed at the European Space Technology Centre (ESTEC) in Holland in late 1989 and early 1990. This testing revealed that the VAX CPU was 100% utilised during periods when both SCMS and flight dynamics software were running simultaneously. This was especially the case when graphics were being used by SCMS and flight dynamics.

The solution to this was two fold. Firstly, an additional processor was added to the system and secondly, a re-write of the graphics subsystem was performed on SCMS. This re-write replaced the all purpose and highly CPU intensive Graphics Kernel System (GKS) with a tailored system using Tektronix commands to drive Tektronix TK4211 graphics terminals. This also took the graphics facility from one graph with four parameters available per screen to up to twelve parameters and a maximum of eight graphs per screen with a choice of fifteen colours, eight line styles and marker types. The interface for creating graphs was also improved to use menus and contained useful facilities for creating new graphics proformas.

4.2 Long Term Data Retrieval

The converted SCMS uses History Files that contain only the last 15 days of data with older data being lost. This is obviously not acceptable if one is to carry out long term trend analysis or study of an anomalous spacecraft event beyond 15 days when data on the Short History Files would be lost.

The solution to this problem was again two fold: first was the development of the Long History File system which is basically the same as the normal telemetry system but with a history file that contains one format of telemetry every 24 minutes and is sized to allow enough records to cover the duration of the prime mission. (Instead of every 32 seconds with space for fifteen days in the short history file.)

In this way development time and cost were kept to a minimum and, as all user interfaces remained the same, operations team members could easily access the data without special training.

The second part of long term data access allows for a resolution of greater than 24 minutes. This uses data read into an adapted version of the SCMS from Master Data Record tapes which are routinely produced by the JPL Data Management Team. This again uses the standard SCMS for data access by the operations team.

Both the graphics and long history file system upgrades provide powerful tools for data analysis. (See Figure 2 - Example Graphical Display)

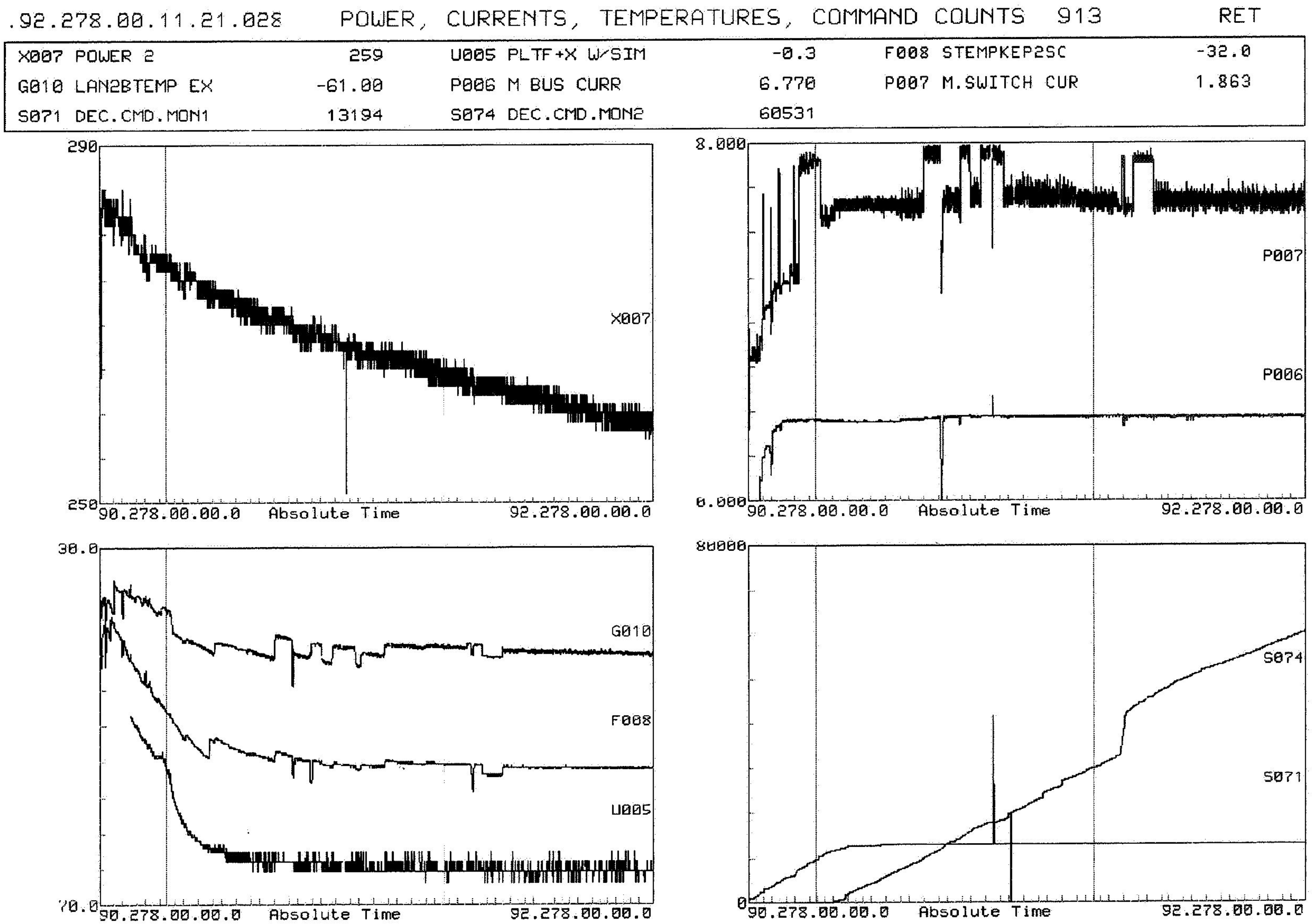

Figure 2 - Example Graphical Display

4.3 Database Editors

As mentioned earlier much of the processing carried out by SCMS involves the use of various databases and following the successful launch of Ulysses in October 1990 improvements were made in utilities to edit these. The original database design was based on the ESA MSSS card system and editing using a standard text editor was error-prone. To reduce the risk of error a menu driven editing system was created for each of the databases. These have been in use since mid 1991.

4.4 Further Post Launch Enhancements

In addition to SCMS enhancements, a need arose for the operations team to have access to information not provided directly by SCMS. These additions were made as functions to be run directly under the VMS operating system. However, the need to understand the operating system was considered an unnecessary addition for the use of the system and so these functions too are accessible via a menu under SCMS. The functions include telemetry statistics packages and a telemetry map function to provide a picture of the whole history file and its contents in terms of data type and quality.

5. FUTURE ENHANCEMENTS

Ulysses has passed Jupiter and is currently leaving the ecliptic with some three years of its prime mission left. As this mission has developed and the operating team refined their needs so SCMS has been enhanced to meet those needs.

The weakest point for SCMS is commanding and as mentioned earlier the MCCC system currently being used for down-link from and up-link to the Ulysses spacecraft is being replaced as part of a JPL program to modernise the ground system and interface to the DSN. This will bring with it a chance to update the Ulysses command interface for the operations team.

CONCLUSIONS

Following the delay of launch the Spacecraft Control and Monitoring System was successfully transferred from the ModComp to a VAX environment. As no simulator was available for system testing it was less than a year before the scheduled launch that the system's deficiencies became apparent. Additions and modifications were made before the launch with the spacecraft operations and software development team working together to ensure a *user-friendly* system was completed in a timely manner.

Since launch, the SCMS has performed almost flawlessly, although many minor upgrades have been made to enhance the system as a result of new user requirements. With the arrival of AMMOS and as new needs arise these upgrades will continue throughout the mission.

ACKNOWLEDGEMENTS

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