

ELECTRONIC GROUND SUPPORT EQUIPMENT FOR PALAMEDE SOFTWARE AND HARDWARE TEST

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ABSTRACT

The Palamede project, started in 1997 at Politecnico di Milano, is an invaluable opportunity for students to participate in the design, development and realization of a microsatellite. Besides this educational goal, the satellite is also designed to use commercial off-the-shelf (COTS) components and technologies. This could end up in cheaper, smaller and faster missions. However, this approach implies supplementary analysis and test campaigns to make sure that those components are reliable and suitable to the space environment.

In order to evaluate the behavior of software and hardware devices available on Palamede, an Electronic Ground Support Equipment (EGSE) is developed. The EGSE mainly simulates the space/orbit/attitude scenario Palamede is expected to experience. It is connected to Palamede through two I/O boards which send to and receive analog signals from the Palamede on board computer. The data sent by the EGSE replace the real signals coming from sensors (Sun sensors, voltage and current sensors, magnetometer) available on Palamede. The data received by the EGSE coming from the Palamede computer are telemetry data and actuators-related signals. In this way, the correctness of the commands sent by Palamede can be checked. Included into the EGSE simulation process is the battery charge/discharge cycle in order to verify the correctness of the strategy implemented to avoid the complete discharge of the battery. Further task is to simulate a malfunction of one sensor in order to evaluate the behavior of the control software. It must recognize the malfunction and take the appropriate recovery action.

1. INTRODUCTION TO PALAMEDE MICROSATELLITE

Palamede is a microsatellite designed by students of the Dipartimento di Ingegneria Aerospaziale of Politecnico di Milano [1]. It will be launched into a sun-synchronous low earth orbit. The main scientific purposes are observing the Earth with a CCD camera and testing a new type of triple junction solar cells. It is built using both terrestrial (COTS) and space-qualified components, preferring the first one, if possible. As a consequence, a secondary purpose is testing the possibility of using COTS components in low-cost space applications. In addition, this project is an important and exciting training experience for involved students.

The prior studies carried out in this project analyzed a large range of solutions for the design of a microsatellite. Many different orbits were evaluated, ranging from GTO to LEO and corresponding to different kind of mission. After this preliminary study, the baseline selected for this mission was to put a satellite into a sun-synchronous low earth orbit with the aim to take pictures of Earth. Anyway, since at this moment a launch opportunity has not yet been definitely selected, the design process has been carried out in a way to obtain a spacecraft extremely tolerant to orbital variation. In this way we will be able to match different launch opportunities, carrying the spacecraft to an orbit with inclination higher than 40° and 450 - 1000 km high. At this stage of the project, the orbit decided is a sun-synchronous one, at an altitude of 650 Km and an inclination of 98°. The launcher foreseen at the moment to carry Palamede to space is the Dnepr. The main spacecraft features are the following (Figure 1) :

- aluminum alloy structure, 400x400x400 mm, for a total mass below 30 kg;
- electrical power system composed of 5 solar arrays made by triple junction cells, a Li-Ion battery, a battery charge regulator and two DC-DC converters;
- ADCS: nadir pointing stabilized with 1 magnetometer, 1 sun sensor made up by 6 solar cells, 3 magneto-torquers;
- PC-104 standard electronics, not redundant, shielded by aluminum box;
- passive thermal control.



Figure 1 Layout of Palamede microsatellite

2. PALAMEDE HARDWARE ARCHITECTURE

The on-board data handling (OBDH) hardware is made by PC104/PC104plus standard boards and custom boards designed and built by students. All custom boards are equipped with COTS electronic components. The Palamede hardware architecture is composed by the following elements:

- a general purpose computer board, based on PC104 standard architecture, having a 486DX processor and an integrated Solid State Mass Memory as storage device (capacity: 92 Mb);
- a PC104 acquisition board, which receives measures from the sensors available on the microsatellite (24 channels, subdivided as follows: 16 single ended channels and 8 differential channels);
- a PC104 relay board, which controls the power supplied to the available devices in an independent way in order to minimize the electrical power consumption;
- two voltage DC/DC converters and a battery charge regulator, to manage the power distribution;
- three custom sensor boards, for signal conditioning;
- three custom magneto-torque driver boards, controlled by the digital outputs of the acquisition board;
- two routing boards, dedicated to the routing of signals and power supply to the correct items;
- a Ashtech G12 GPS board.

Palamede is equipped with a GPS system for science data acquisition and orbital position calculation. Moreover an Orbcomm transmitter will be used for communication with Earth. The Orbcomm system has never been used on a satellite as the main apparatus for receiving and transmitting data. The choice of this hardware architecture meets one of the main mission goals to use general purpose not space qualified electronic components. The flexibility of the physical configuration of the PC104 boards allows the creation of a simple, light and compact system. These boards have been verified to work appropriately in absence of atmosphere and for temperature ranges acceptable by the mission requirements.

3. EGSE HARDWARE ARCHITECTURE

The EGSE hardware is made by two general purpose PCs.

The first one is a common desktop computer operating essentially as a simulator of the operating scenario. It is equipped with two acquisition boards: a National Instrument 6071-E board (64 analog input channels, \pm 10 V input range) to receive analog signals from Palamede, and a ADVANTECH 1724-U board having 32 analog output channels to send signals to the Palamede acquisition board. Two variable resistances are used to ground the channels not directly connected. During the first part of the EGSE development not all the channels on Palamede acquisition board are used even if all channels are linked and a default value is set in order to evaluate the correct behavior of the channel.

The other computer, still a common desktop, is used as a developing bench for the software. This choice is due to the absence of a compiler on the Palamede computer. An Ethernet link between the Palamede computer and the development PC allows to use the first one in flight configuration.

4. SOFTWARE ENVIRONMENT

The COTS philosophy followed for the definition of the hardware architecture has also been fully adopted for the software environment. A general purpose operating system has been selected without neglecting the specific requirements of the application in terms of quality and reliability. Linux has been chosen as the best compromise in terms of quality, code availability, customizability, performance and cost. Since vanilla Linux is not able to guarantee suitable timing performances [2] [3], the real-time kernel patch RTAI is used to manage those tasks having time critical requirements. The RTAI system implements a separation between hard real-time processes and standard Linux processes, allowing an efficient communication/synchronization and an effective interaction between the two environments. The main feature of RTAI is to give the Linux kernel a deterministic behavior and complete pre-emption, so that the system can react in real time to critical events.

The simulator software is designed under MATLAB/Simulink. It mainly simulates the space/orbit/attitude conditions Palamede is expected to experience. The simulation is run as a real-time task under RTAI-Lab, a powerful and reliable RTAI tool for the design, implementation and execution of real-time applications within rapid prototyping design systems. In order to use the board ADVANTECH 1724U under such an environment, a driver has been written starting from a Comedi driver available for the board ADVANTECH 1720.

On the development computer, a suitable environment has been created in order to compile statically the on board software which is transferred to Palamede computer by Ethernet to perform the simulation. All data generated during the simulation are archived in several files on the development computer for post processing and analysis. The Ethernet link will be available after the assembly phase in order to test the functionality of computer and electronic components until the launch phase.

5. EGSE SOFTWARE

As mentioned before, the EGSE has been developed to test the software and hardware of Palamede. The main task required is to generate suitable signals representing the sensors available on the microsatellite (Table 1) in order to evaluate the correct behavior of the on board software designed for Palamede. The Palamede attitude control system has been implemented, with the appropriate sensors, i.e., a solar sensor, made up by six solar cells, and a magnetometer.

	Measures			Range	
	Subsystem	Element	Туре	Min	Max
AOCS	AOCS	Magnetometer X direction	Voltage [V]	-5	5
	AOCS	Magnetometer Y direction	Voltage [V]	-5	5
	AOCS	Magnetometer Z direction	Voltage [V]	-5	5
	AOCS	Magnetometer Temperature	Voltage [V]	-4	10
	AOCS	Sun Sensor +X	Current [A]	0	0,13
	AOCS	Sun Sensor –X	Current [A]	0	0,13
	AOCS	Sun Sensor +Y	Current [A]	0	0,13
	AOCS	Sun Sensor –Y	Current [A]	0	0,13
	AOCS	Sun Sensor +Z	Current [A]	0	0,13
	AOCS	Sun Sensor –Z	Current [A]	0	0,13
ESA	ESA	Solar Array (1)	Voltage [V]	0	22
	ESA	Solar Array (1)	Current [A]	0	2,5
	ESA	Solar Array (1)	Temperature [°C]	-4	10
POWER	Power	Solar Arrays	Voltage [V]	0	22
	Power	Solar Arrays	Current [A]	0	5
	Power	Battery Temperature	Temperature [°C]	-4	10
	Power	Battery Voltage	Voltage [V]	8	18
	Power	Battery Current	Current [A]	-6	6
	Power	DC/DC Converter (input)	Voltage [V]	0	22
	Power	DC/DC Converter (input)	Current [A]	0	6
	Power	DC/DC Converter (output) +12V	Current [A]	0	2

Table 1 List of sensors on Palamede and their operative ranges

Moreover to test the software it was necessary to simulate on EGSE the presence of the actuators, i.e., three magnetotorquers and the GPS board. The software used to develop the EGSE, as mentioned before, is MATLAB/Simulink. A custom library is used which provides some RTAI-specific blocks to manage the real-time communication between the software and the I/O boards and the communication through the RS232 serial bus. The serial link is used to simulate the presence of the GPS board. The software, once developed in Simulink, is automatically translated in C code by the MATLAB Real-Time Workshop. The generated code is compiled and executed under RTAI-Lab. RTAI-Lab provides a graphical user interface to visualize different variables, such as outputs and inputs by I/O boards, latitude and longitude of the current position of Palamede during the simulation, angular velocity of Palamede and other information.

The GPS board is simulated by using an ad-hoc RTAI Simulink block. This block has been designed to receive data about position of the satellite and the simulation time from other blocks of the Simulink EGSE software, and to translate them into strings having the same format of the position and time variables coming from the GPS board. The GPS simulator waits until a request is arised from Palamede by RS232, about one of the two data available. The answer is utilized by Palamede to synchronize the internal clock (time information) or to reset the on board orbital simulator (position information). This task is accomplished once per orbit by Palamede.

The EGSE is responsible to simulate the orbit of the Earth around the Sun and the orbit of Palamede around the Earth. The result is the vector between Sun and the satellite. This information is used to correctly replicate the behavior of the Sun sensor available on Palamede. Palamede's orbit is simulated with J2 and gravity gradient perturbations. Moreover the magnetic field is included and represented by a standard IGRF model [4]. All the data about orbital simulator and magnetic field simulator were verified with data calculated by the Satellite Tool Kit (STK) [5]. The difference between the two models was evaluated to be about 1% after three orbits. This discrepancy between STK and EGSE data doesn't influence the validity of simulation because the data of Palamede computer and EGSE are synchronized every orbit.

The software on EGSE simulates the output from Palamede sensors, as mentioned before, so the output of EGSE boards simulates the voltage that Palamede sensors will send to the acquisition board via the sensors board. The software of Palamede is the flight software and reacts to the stimulation from EGSE. The only condition not replicable on ground during the test phase is to use the GPS board, so it is necessary to use the EGSE to simulate it.



Figure 2 Scheme of EGSE software. In light grey the output from EGSE to Palamede and in dark grey the input from Palamede to EGSE

6. EGSE FOR AOCS

The AOCS system simulator receives data from the orbit simulator concerning orbital position and Sun-Earth vector. All data about starting conditions and geometrical and inertial information are introduced into the software by an input file. The solution of providing input information allows to select different release conditions from launcher. On the other hand, this solution can be useful to reuse this simulator, against small changes, for different kind of orbits and satellites.

The orbital and inertial information are computed by the EGSE to produce the outputs of the Sun sensor and the magnetometer. The outputs of the EGSE are calculated in the inertial reference system. They are subsequently translated into sensors reference system and sent to the ADVANTECH analog output board. These channels are connected to the input channels of the Palamede acquisition board. The Palamede software reads the analog input data, as in the real operation scenario, and computes the currents to send to the magneto torquers to control the angular velocities around the three axis. These physical values are converted into voltage values and sent to the EGSE via the analog output channels of the Palamede acquisition boards. They are subsequently acquired by the EGSE through the National Instruments board. The information concerning the magneto torquers are used to estimate the interactions between the Earth and torquers magnetic fields.

Due to the proximity between the magneto torquers and the magnetometer mounted on Palamede, the readings by the magnetometer are influenced by the activity of the magneto torquers. This influence is simulated into the EGSE. It depends on the value and distribution of the currents sent to the magneto torquers. Thus, the information regarding the magnetic field evaluated by the magnetometer and sent to Palamede are spurious. The Palamede software knows which currents are commanded to magneto torques and can purge the value read by the magnetometer and calculate the real Earth magnetic field.

As the reader can see from Figure 2 all data about the AOCS subsystem are simulated by the EGSE. The only thing that is simulated but not yet tested is the interaction between the magnetometer and the magneto torquers. A good analytical approximation has been performed by taking into account the magnetic field produced by the three magneto torquers and the distance between them and the magnetometer [6]. The interaction between the magnetometer and other electronic components and the presence of an aluminum shield is not taken into account for the moment. After a test with the in-flight hardware configuration a correct evaluation can be performed.

7. EGSE FOR POWER SUBSYSTEM

As showed in *Table 1*, the sensors, foreseen on Palamede, concern AOCS data and power data, with special care for ESA data, which are related to the Top solar array. The array is built with a new kind of solar cells and represents a payload of the satellite. The simulation of power subsystem sensors concerns several current, voltage and temperature sensors. The most important data of this subsystem are related to the energy stored in the battery. The amount of energy stored in the battery drives the possibility of producing pictures, transmitting data to the ground station and switching on the GPS board to update information on clock and orbital position.



Figure 3 Scheme of EGSE software dedicated to simulation of power subsystem

During the operative life of the satellite not all the following devices, GPS board, ORBCOMM radio-modem and CCD camera, are powered. The relay board can switch on or off the three items mentioned before. To evaluate the consumption of energy from Palamede, the EGSE should know which "users" are switched on at every simulation step.

With this information and the evaluation about how much energy can be produced by the solar arrays, the EGSE can evaluate the state of charge of battery and transmit it to Palamede.

Palamede can communicate to the EGSE if a "user" is switched on or off by the serial link RS232, in the same way the EGSE can communicate to Palamede the GPS information.

The other information concerning power system sensors are sent to Palamede by analog channels but are not critical. In any case the other data are related to the state of switching on or off of different users.

8. EGSE USE

The EGSE is used to simulate the environment that is not possible to simulate on the ground, like orbit conditions, and to simulate the presence of sensors which are placed on the satellite. All that allows to evaluate the behavior of on board software during the development and test phases in different work conditions of satellite.

The first result achieved by use of EGSE is the evaluation of high variations of data read by the acquisition board. This was unexpected because during preliminary tests, with static or sinusoidal signals, on single channel, this effect was not evident. In fact the channels on Palamede acquisition board are not completely insulated and, in any case, there are some influences by the electro-magnetic radiation of wires linked to others channels (reader can evaluate the problem of interaction among the wires from [7]). Only a test with several channels linked was useful to highlight this phenomenon. In order to avoid this problem a first order digital filter was introduced in software and the disturbance on analog channels was reduced from about 25 mV to about 10 mV.

After that, a huge job has been done to debug and calibrate the AOCS software. The software has been derived from a previous MATLAB/Simulink AOCS design model which did not considered so huge fluctuations on the signals acquired from sensors. With the help of EGSE an hard work on calibration had been performed in order to evaluate several parameters of the on board software. At the same time the logical debugging of the on board software has been undertaken in order to verify its correctness.



Figure 4 Link between EGSE and Palamede computer

9. CONCLUSION

The activity carried out up to now allows to claim that the EGSE system is able to satisfy the requirements of accuracy of the simulation of space environment and sensors. Unfortunately, the maximum output voltage on the output board adopted on the EGSE is \pm 10 Volt and the maximum current output is 20 mAmpere, so it can't simulate the sensors in their real work range. In order to test the complete measure chain (with the sensors boards), an additional board must be developed to convert voltage into current for Sun sensors and current sensors and to amplify the voltage values from \pm 10 Volt to a larger range.

Another capacity that will be implemented on the EGSE is the simulation of anomaly on one or more sensors, in order to evaluate the capacity of the Palamede software to recognize the anomaly and, if foreseen, to provide the correct recovery action.



Figure 5 Scheme of connections between EGSE and Palamede computer

After these improvements the EGSE will be substantially complete and ready to interface the Palamede electronic box even after the assembly, to go on with the tests to check the development and test of software. The EGSE is developed by taking into account the opportunity to reuse it for further missions and for different tasks as

The EGSE is developed by taking into account the opportunity to reuse it for further missions and for different tasks as well as to simulate only the power subsystem or AOCS.

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