Using the PLUTO language on functional tests of a Brazilian Satellite's On-Board Data Handling Computer

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The testing of the functionalities of an On-Board Data Handling Computer (OBDH) is a highly complex task, especially when a standard language, appropriate for procedures execution, is not available. To reduce the complexity degree, the European Cooperation for Space Standardization (ECSS) specified a language that can be used to standardize the test procedures, called Procedure Language for Users in Test and Operations (PLUTO). The use of such language implies some resources that are considered essential for procedures execution. One of them is the existence of a system data model, called Space System Model (SSM), also specified by ECSS. The Brazilian Institute for Space Research (INPE) wants to use this language to standardize the creation and execution of its test procedures, but does not have all the needed resources yet. To achieve this goal, a computational environment is being developed at INPE through the following steps: definition of an architecture that contains the key resources to execute PLUTO procedures; creation of procedures in the language syntax; modeling of the system under test through SSM specifications; and the development of common communication interfaces between the model and the system to be tested. Functional requirements of an OBDH were selected to be used on the construction of test procedures. These requirements are related to attitude and orbit control functionalities executed according to input data acquired by simulation result of a sun sensor. This paper describes the architecture defined to the development of this environment.

Nomenclature

ACDH	=	Attitude Control and Data-Handling
AIT	=	Assembly, Integration and Test
DSV	=	Domain-Specific View
ECSS	=	European Cooperation for Space Standardization
EGSE	=	Electrical Ground Support Equipment
ESA	=	European Space Agency
IDE	=	Integrated Development Environment
INPE	=	Brazilian National Institute for Space Research
OBDH	=	On-Board Data Handling
PLUTO	=	Procedures Language for Users in Test and Operations
SIA	=	Inertial Systems for Aerospace Application
SSM	=	Space System Model
STEPS	=	Spacecraft Test Procedures System
SUT	=	System Under Test
SVDA	=	Sun Vector's Determination Algorithm

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I. Introduction

IN order to validate the functionalities of a satellite, sets of test procedures are executed in different abstraction levels during the development phases of the space system. It is common to create test procedures using different languages, at different development and integration stages that do the same (or almost the same) thing. To avoid such "re-creation" effort, the solution is the standardization of the procedures using only one language. Once standardized, a single procedure could be applied in different scenarios.

The Brazilian National Institute for Space Research (INPE) lacks such standardization. Each Electrical Ground Support Equipment (EGSE) developed to test the subsystems and equipments of INPE's satellites has its own test procedures execution system that implements "ad-hoc" technologies or processes. This generates high costs that could be reduced if a single standard were followed.

The European Cooperation for Space Standardization (ECSS) defines engineering, product assurance and project management standards to be applied to space activities. These standards allow a better organization of satellite's development processes. One of this standards is the 'Test and Operations Procedure Language' that specifies a language standard called Procedure Language for Users in Test and Operations (PLUTO) [1].

This language can be used to describe test and operation procedures to be executed in computational environments. In recent years, the European industry and universities and research institutes are using it in projects for the ESA's missions and human resources training [2, 3].

INPE's goal is to develop a computational environment that allows test procedures creation and execution with the PLUTO language. This system was named 'Spacecraft Test Procedures System' (STEPS). A STEPS prototype and its architecture will be shown in this paper. To develop this prototype, a Sun Vector's Determination Algorithm (SVDA) was used as a case study. This algorithm is executed by an on-board computer that is being developed through Inertial Systems for Aerospace Application (SIA) project.

II. Our approach to standardize procedures with PLUTO

A. The Procedures Structure and Needs to Use It

Using this language for test procedures brings a set of advantage for INPE:

1) Allows the re-use of test procedures at different levels (unit, subsystem and system);
2) Increases the information exchange between test and operation activities; and
3) Analyze it for application at satellite's operation procedures.

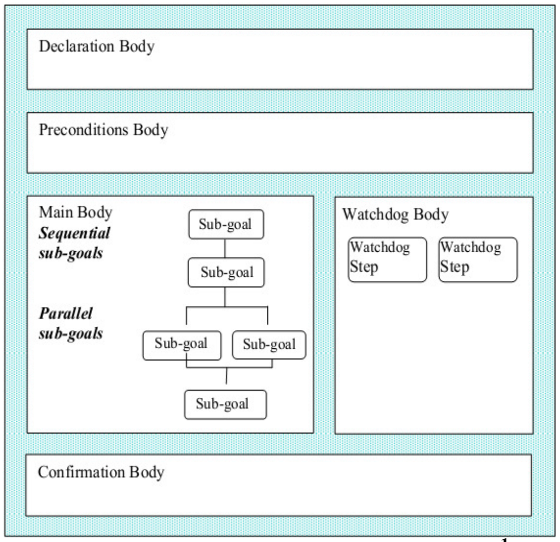


Figure 1. Structure of a PLUTO procedure [1].

PLUTO language is similar to a high-level programming language. Its structure is shown in Figure 1. Some instructions are optional, except the 'Main Body' that is composed by steps. The steps can be a command or a set of commands, an action request to the operator or a call to another procedure.

The language allows logical conditions construction; operator interaction during execution; loop routines; arithmetic operations with various engineering data; and scheduling of execution.

In a 'Declaration Body' the user can declare global variables or events that can occur in the System Under Test (SUT) during the procedure execution. The 'Preconditions Body' allows the description of conditions to start the procedure execution. These conditions can be: wait some time, wait until a condition or set of conditions become true.

The 'Watchdog Body' purpose is to detect events at system level, for example, anomalies on some equipment. On a given anomaly detection, the watchdog interrupts the procedure execution.

The instructions written in the 'Confirmation Body' verify the equipment under test or operation to make sure that the 'Main Body' steps were executed correctly. As PLUTO is an interpreted language, it needs an interpreter to execute its instructions set in conformance with the ECSS standard that specifies it. INPE aims to develop a PLUTO language interpreter for applying it in test activity during the development of its equipments and subsystems, and also at AIT activities. Having an interpreter, PLUTO test procedures start to be a deliverable item, together with contracted subsystems and equipments.

B. The Space System Model

The use of the PLUTO language requires a SUT data model. ECSS has proposed a data model for the entire space system in its ‘Ground Systems and Operations’ standard.

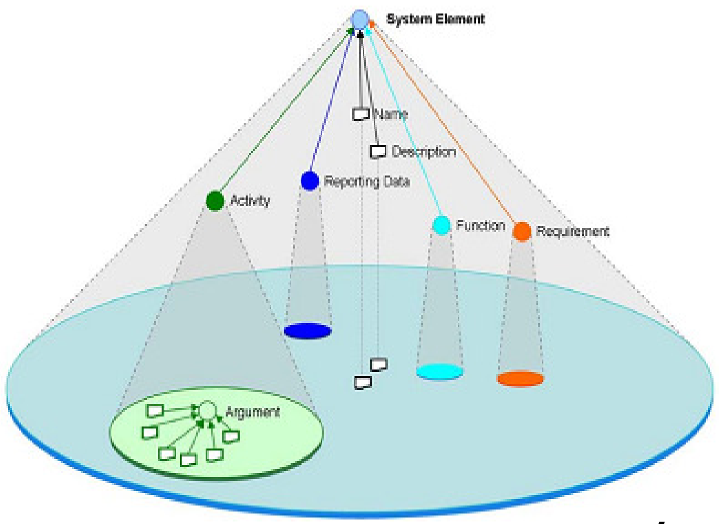


Figure 2. Object types associated to a System Element [5].

The data model structure must be hierarchical in order to represent the real functional decomposition of the system. This structure is called Space System Model (SSM) [4].

The SSM is composed by different data types which are identified as objects. The object types are classified as System Element; Activity, that can be executed by it System Elements; Report Data that reflects the System Element state; and Events that can be handled for its control and monitoring.

Figure 2 shows a System Element composed by Activities, Report Data and other data that are used for configuration management and requirements control during its life cycle. Any System Element can also comprise other System Elements.

Due to the large amount of information in a SSM, there is the need to extract, for a given problem, only the required data. In order to do so, ECSS has specified the Domain Specific View (DSV) [4]. A DSV is composed by a subset of the model needed for a given application. This concept can be used during the development of equipments and subsystems and only the interest data for that application are used into SSM.

Croce[6] applied PLUTO language and SSM concepts in its work. He stated that a PLUTO procedure must reference a SSM object and, in order to write or execute the procedures the best way is to maintain the SSM structure between the procedure executor and the SUT. During the execution, the access to the model is encapsulated. Seymour[7] also says that a PLUTO procedure must refer to the SSM to read or write values into its objects. The data read and write into the model are done by a language interpreter during execution.

III. STEPS Architecture

From those presented concepts, INPE is developing a computational environment called ‘Spacecraft Test Procedures System’ (STEPS) to prepare and execute test procedures. Figure 3 shows its components.

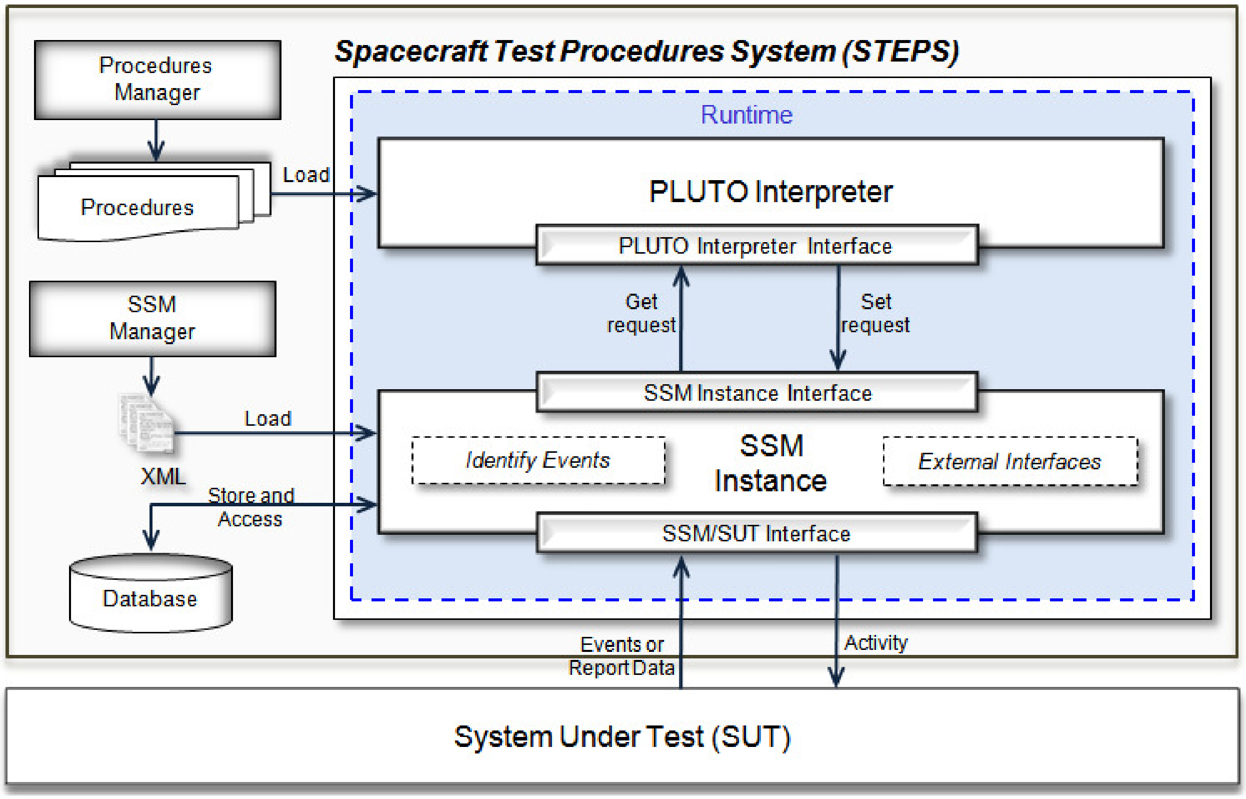


Figure 3. STEPS’s architecture.

To start procedures execution, the SSM must be loaded in memory in order to be accessed by the language interpreter accesses its objects. This image of the SUT’s model is called ‘SSM Instance’. This module allocates a data structure into memory with the same hierarchical characteristics as the SSM specifications. Its basic operation is to search the model objects through parameter identification. The access to model is done through Get and Set requests generated by language interpreter and sent to the ‘SSM Instance’.

A Get request reads an object of type Event or Report Data. A Set request writes data into a SSM object or requests an execution, if the object is Activity type. If the SSM receives a Get request from ‘PLUTO Interpreter’, it returns the last acquired value and if it receives a Set request, it interacts with SUT through transmission of telecommand and telemetry. The communication between ‘SSM Instance’ and ‘SUT’ is done by an interface that interprets the object purpose and transcribes its purpose into telecommand.

‘SSM Instance’ module is composed by the ‘Identify Events’ and ‘External Interfaces’ components. The first can be used by the user to define customized Events in SUT context. An Event can be the occurrence of conditions that can be configured by the user into SSM or generated by SUT. The second component allows communication from procedure interpreter with external equipments. In some cases, a test procedure requires interaction of other equipment with SUT to achieve the test objectives.

Once instantiated, the SSM can be accessed by the ‘PLUTO Interpreter’. ‘PLUTO interpreter’ interprets the procedure steps to execute it and sends Get and Set requests to the instantiated model. This architecture also has support elements to prepare and monitor the SUT model and PLUTO procedures and to store test results.

IV. Developing a STEPS Prototype

A. A Case Study for the STEPS Prototype

The INPE's On-Board Data Handling team is developing an on-board computer to the SIA's project orbital platform. As this on-board computer will execute both On-Board Data Handling and the Attitude Control functions, it is being called Attitude Control and Data Handling (ACDH) Computer. The ACDH Computer has communication interfaces with other equipments and subsystems including four solar sensors, each one measuring the intensity of sunlight on one face of the platform.

ACDH Computer flight software runs a Sun Vector's Determination Algorithm (SVDA) to define the satellite control parameters. It receives measurement values from four solar sensors and determines the current satellite attitude with respect to the Sun and, if necessary, to perform an attitude maneuver to point the solar panels to it. Figure 4 illustrates the four solar sensors scenario.

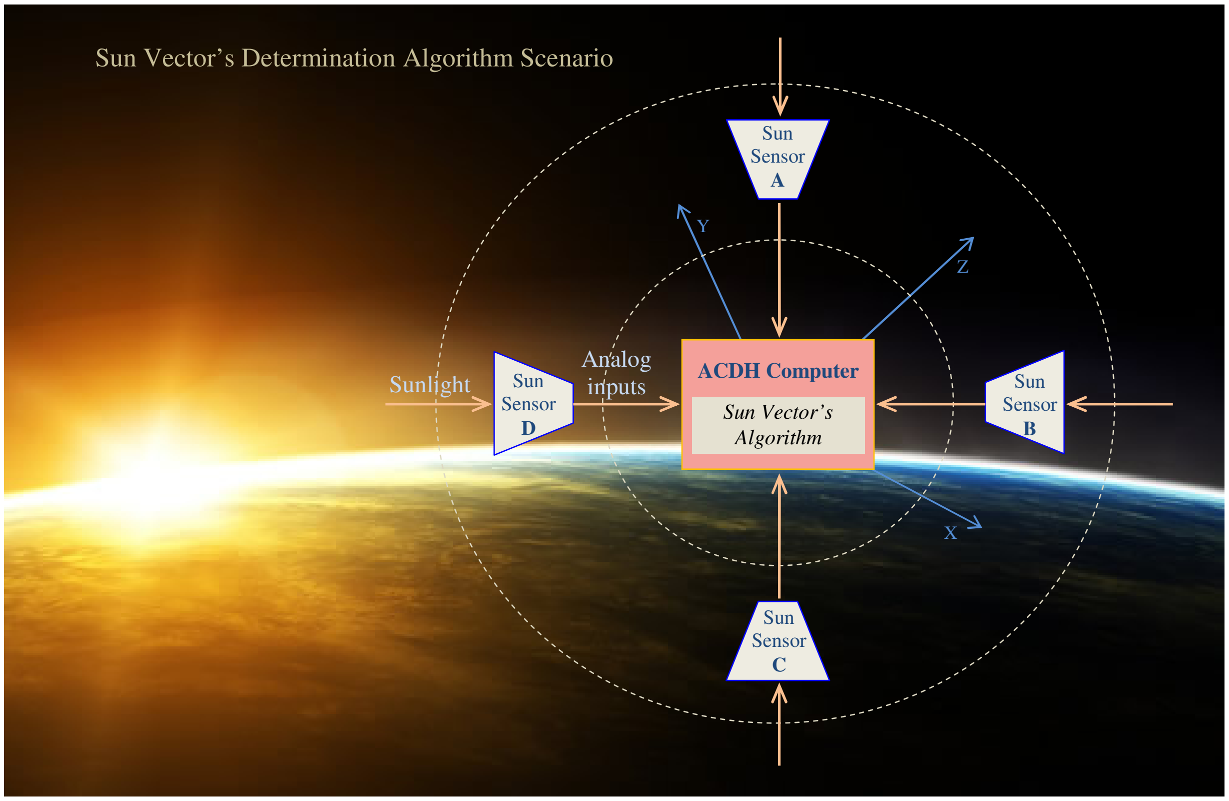


Figure 4. Case Study (Sun Vector's Determination Scenario).

SVDA calculates the X, Y and Z axis from sensors values and release it to satellite attitude control with three-axis stabilization. To test this case, the EGSE communicates with ACDH Computer through analog and digital interfaces to send analog values to simulate the solar sensors. The on-board computer receives the EGSE analog values and uses it as parameters to SVDA execution.

This case study was created to exercise the STEPS prototype, not being representative of a real attitude determination scenario.

B. The STEPS Prototype

From the case study a SSM and a PLUTO procedure to test SVDA were developed. The SSM includes all data relevant to the SVDA context: four input parameters generated by solar sensors and three output parameters generated by SVDA. The procedure has instructions to access the objects from model. Figure 5 shows the procedure created for this case study.

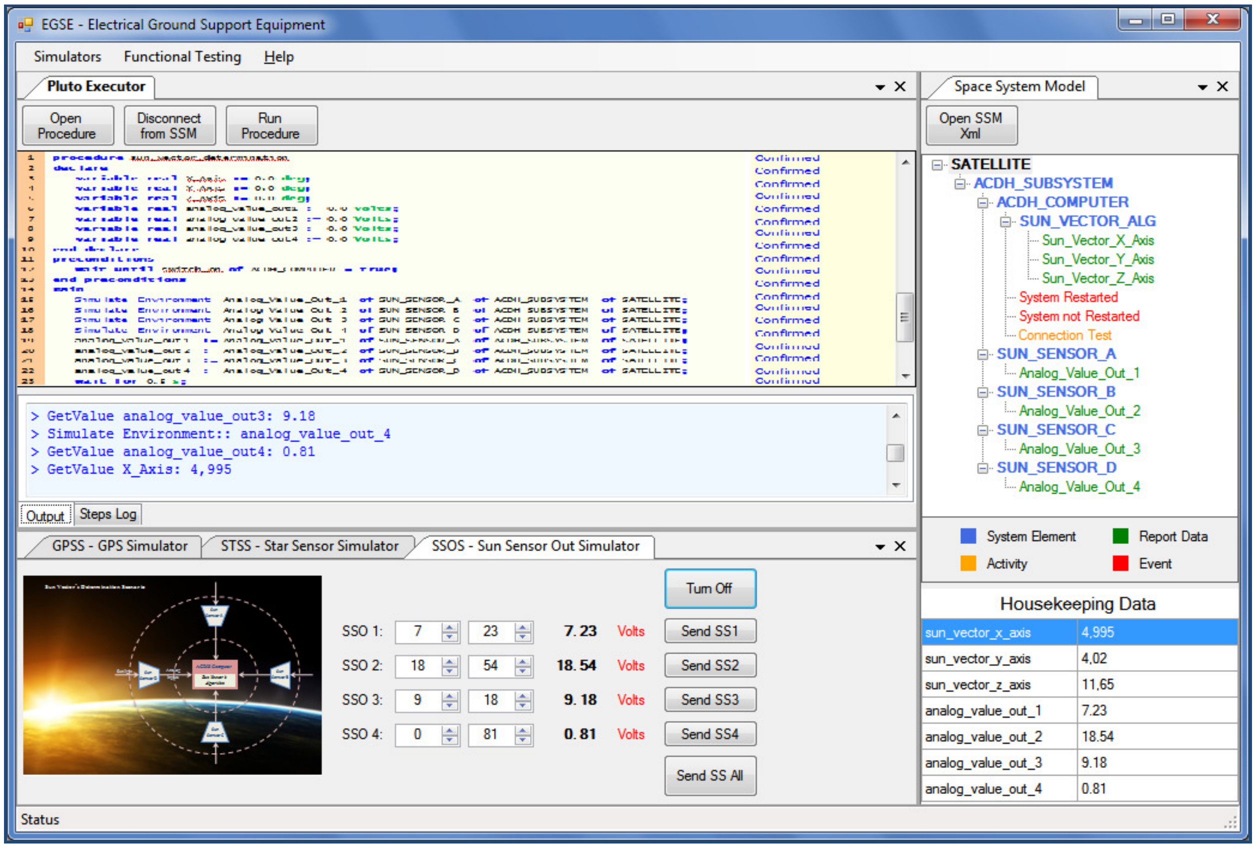
```
procedure Sun_Vector_Determination
Declare
    variable real X_Axis := 0.0 deg;
    variable real Y_Axis := 0.0 deg;
    variable real Z_Axis := 0.0 deg;
    variable real analog_value_out1 := 0.0 Volts;
    variable real analog_value_out2 := 0.0 Volts;
    variable real analog_value_out3 := 0.0 Volts;
    variable real analog_value_out4 := 0.0 Volts;
end declare
preconditions
    wait until switch_on of ACDH_COMPUTER = true;
end preconditions
main
    Simulate Environment Analog_Value_Out_1 of SUN_SENSOR_A of ACDH_SUBSYSTEM of SATELLITE;
    Simulate Environment Analog_Value_Out_2 of SUN_SENSOR_B of ACDH_SUBSYSTEM of SATELLITE;
    Simulate Environment Analog_Value_Out_3 of SUN_SENSOR_C of ACDH_SUBSYSTEM of SATELLITE;
    Simulate Environment Analog_Value_Out_4 of SUN_SENSOR_D of ACDH_SUBSYSTEM of SATELLITE;
    analog_value_out1 := Analog_Value_Out_1 of SUN_SENSOR_A of ACDH_SUBSYSTEM of SATELLITE;
    analog_value_out2 := Analog_Value_Out_2 of SUN_SENSOR_B of ACDH_SUBSYSTEM of SATELLITE;
    analog_value_out3 := Analog_Value_Out_3 of SUN_SENSOR_C of ACDH_SUBSYSTEM of SATELLITE;
    analog_value_out4 := Analog_Value_Out_4 of SUN_SENSOR_D of ACDH_SUBSYSTEM of SATELLITE;
    wait for 0.5 s;
    X_Axis := Sun_Vector_X_Axis of SUN_VECTOR_ALG of ACDH_COMPUTER of ACDH_SUBSYSTEM of SATELLITE;
    inform user “X axis result: ” X_Axis;
    Y_Axis := Sun_Vector_Y_Axis of SUN_VECTOR_ALG of ACDH_COMPUTER of ACDH_SUBSYSTEM of SATELLITE;
    inform user “Y axis result: ” Y_Axis;
    Z_Axis := Sun_Vector_Z_Axis of SUN_VECTOR_ALG of ACDH_COMPUTER of ACDH_SUBSYSTEM of SATELLITE;
    inform user “Z axis result: ” Z_Axis;
end main
end
```

Figure 5. PLUTO procedure defined for the case study.

Access to objects from model is done through procedure either for data reading or writing. The procedure described at Figure 5, has a command called Simulates Environment that is not specified in PLUTO standard. It was defined due to an expected need regards to the interaction from SUT with other equipments during the tests. At this work, ADVS depends on interaction between ACDH Computer and solar sensors. When the Simulates Environment command is interpreted, the PLUTO Interpreter sends a Set request to SSM Instance. Then SSM Instance uses the communication mechanism that was defined in the External Interfaces to keep communication with these solar sensors.

Although due to the lack of these solar sensors, a simulator was created to send relevant data to ACDH Computer. This simulator sends four individual values to be used as input data by ADVS. The usage of this simulator can be manually or automated by a PLUTO procedure as presented in this work.

Figure 6 shows the STEPS prototype Graphical User Interface (GUI). This prototype loads the SSM, shows SSM hierarchical and waits for start of procedure execution. It also affords data visualization through ‘Housekeeping Data’ area during execution. The procedure and model were described in text format and XML scheme. The confirmation status of each procedure command is informed as ‘confirmed’, ‘not confirmed’ or ‘aborted’ and each operation made by interpreter is also informed in the Output Log area.



```
procedure sun_vector_determination                                                    Confirmed
declare                                                                               Confirmed
    variable real X_Axis := 0.0 deg;                                                  Confirmed
    variable real Y_Axis := 0.0 deg;                                                  Confirmed
    variable real Z_Axis := 0.0 deg;                                                  Confirmed
    variable real analog_value_out1 := 0.0 volts;                                     Confirmed
    variable real analog_value_out2 := 0.0 volts;                                     Confirmed
    variable real analog_value_out3 := 0.0 volts;                                     Confirmed
    variable real analog_value_out4 := 0.0 volts;                                     Confirmed
end declare                                                                           Confirmed
preconditions                                                                         Confirmed
    wait until switch_on of ACDH_COMPUTER = true;                                     Confirmed
end preconditions                                                                     Confirmed
main                                                                                  Confirmed
    Simulate Environment Analog_Value_Out_1 of SUN_SENSOR_A of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    Simulate Environment Analog_Value_Out_2 of SUN_SENSOR_B of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    Simulate Environment Analog_Value_Out_3 of SUN_SENSOR_C of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    Simulate Environment Analog_Value_Out_4 of SUN_SENSOR_D of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    analog_value_out1 := analog_value_out_1 of SUN_SENSOR_A of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    analog_value_out2 := analog_value_out_2 of SUN_SENSOR_B of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    analog_value_out3 := analog_value_out_3 of SUN_SENSOR_C of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    analog_value_out4 := Analog_Value_Out_4 of SUN_SENSOR_D of ACDH_SUBSYSTEM of SATELLITE;   Confirmed
    wait for 0.5 s;                                                                   Confirmed
```

```
> GetValue analog_value_out3: 9.18
> Simulate Environment:: analog_value_out_4
> GetValue analog_value_out4: 0.81
> GetValue X_Axis: 4,995
```

SSO 1:	7	23	7. 23	Volts	Send SS1
SSO 2:	18	54	18. 54	Volts	Send SS2
SSO 3:	9	18	9. 18	Volts	Send SS3
SSO 4:	0	81	0. 81	Volts	Send SS4

🟦	System Element	🟩	Report Data
🟧	Activity	🟥	Event

Housekeeping Data

sun_vector_x_axis	4,995
sun_vector_y_axis	4,02
sun_vector_z_axis	11,65
analog_value_out_1	7.23
analog_value_out_2	18.54
analog_value_out_3	9.18
analog_value_out_4	0.81

Figure 6. STEPS's Graphical Interface.

V. Conclusions

This work represents a first effort to standardize INPE's test procedures with PLUTO language. A prototype was developed having a 'PLUTO Interpreter' with routines to execute a procedure and a 'SSM Instance' to manage a model. Both were applied to the presented case study. Communication mechanisms between interpreter and instanced model were developed to allow its communication with SUT and external equipment. Our goal is to follow with the STEPS development to create a full 'PLUTO Interpreter' and a 'SSM Manager' with GUIs to facilitate the preparation and to monitor the test procedures execution.

Acknowledgements

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References

[1]European Cooperation for Space Standardization (ECSS), "Space Engineering: Test and Operations Procedure Language", ECSS-E-ST-70-32C, ESTEC, The Netherlands, 31 July 2008.

[2]Fritz, Michael., Roeser, H-P., Eickhoff, J., Reid, S., "Low Cost Control and Simulation Environment for the 'Flying Laptop', a University Microsatellite", SpaceOps Conference, 25-30 April, Huntsville – Alabama, EUA, 2010.

[3]Adamson, K., Bargellini, P., Nogueira, T., Nett, H, Caspar, C., ADM-AEOLUS: Mission Planning Re-Use, Autonomy and Automation, SpaceOps Conference, 25-30 April, Huntsville – Alabama, EUA, 2010.

[4]European Cooperation for Space Standardization (ECSS), "Space Engineering: Ground Systems and Operations", ECSS-E-ST-70-31C, ESTEC, Netherlands, 31 July 2008.

[5]European Cooperation for Space Standardization (ECSS), "Space Engineering: Space system data repository", ECSS-E-TM-10-23A, ESTEC, The Netherlands, 25 November 2011.

[6]Croce, F., Simonic, A., ECSS-E-70-32 Test Platform and Applicability Area, SpaceOps Conference, 12-16 May, Heidelberg, Germany, 2008.

[7]Seymour, M. A., The PLUTO operations procedure language and its use for RADARSAT-2 mission operations, SpaceOps Conference, 17-21 May, Montréal, Canada, 2004.

[8]Koller, M., Reggestad, V., Adamson, K., Kay, R., "ESOC Earth Observation Missions and the Automation of Operational Routine Tasks", SpaceOps Conference, Huntsville – Alabama, EUA, 25-30 April 2010.