Proceedings International Seminar of Aerospace Science and Technology 17th SIPTEKGAN -2013, 25: 185-194

SOFTWARE ENGINEERING OF LAPAN SATELLITE AUTONOMOUS OPERATION ANDCONTROL

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Abstract

The number of passes will be a significant consequence for the operation of LAPAN A-2 satellites that have near-equatorial orbit. This is beneficial for mission operations, but also a challenge for the satellite operator to regulate the process of monitoring, control and data acquisition. Repetitive process of monitoring, control and data acquisition would be more efficient if it is done automatically. This paper will discuss the design, implementation and testing of LAPAN satellite system software automation. Requirements-based software design has been carried out and implemented starting from the level of modules up to the system level. Software testing results indicate there are 2 seconds differences in the performance of a data processing satellite telemetry already in orbit compare to test in the laboratory for 112 bytes telemetry data. As for the size of 213 bytes of data there is a difference of 3 seconds.

Key Words: ***A****utonomous Spacecraft Control, Software engineering*

1. Introduction

In order to continue the micro satellite program in Indonesia,LAPAN plans to build another satellite which called LAPAN-A2 and LAPAN-A3. LAPAN-A2 satellite is planned to be launched in the middle of 2014 as a piggyback on the launch of AstroSAT. LAPAN-A2 satellite will carry several payload such as analog video camera , digital camera, APRS (Automatic Packet Reporting System) , voice repeaters , and Automatic Identification System (AIS) .

The main difference betweenLAPAN-TUBSAT and LAPAN-A2 is the orbit type. LAPAN -TUBSAT orbiting in polar orbit while LAPAN-A2 will be orbiting in near - equatorial orbit with analtitude of 650 km. The other diffrence isthe mission operations of LAPAN-A2.The amount of contact time (pass) with ground stations in Indonesia region will be more often than LAPAN-TUBSAT. Aproximately there will be 14 passes per day. Telemetry data acquisition , analog video , digital images , and other payload shall be manage efficiently so that the process of data retrieval operations in accordance with the mission will not use a lot of human resources. Otonomousscenariobecomes a necessity to fulfill that requirement. LAPAN A-2 satellite which has near - equatorial orbit will give a significant consequence for the operation of the satellite.It is the number of passes that 7 times more than polar orbit . This is beneficial for mission operation, but also a challenge for the satellite operator to regulate the process of monitoring, control and data acquisition. Data acquisition process, monitoring, and control that repeatedly would be more efficient if used automation process . Telemetry data monitoring and data acquisition is a repeating cycle that the process can easily be automated. As with the control process that requires input parameters that vary from ADCS sensors and also the accurate calculation of output control parameters are also possible to be automated. So that the camera is always facing Earth satellite (nadir pointing) .

While the TTC ground station control and receiver can also be done centrally through the Monitoring& Control(M&C) server. All data status of each hardware TTC earth station and earth station receiver will be saved in G / S log parameter continously.Control and observation status of L / S / X band RF antenna made through L / S / X ACU system. As for the L / S / X baseband system is done directly by the M & C server through the ethernet port. Whereas for the hardware of TTC RF and baseband system will be carried out directly by the M&C server via com port or USB port. Medium hardware system that is not in the controller (such as RF SPDT Switch) will be made using a microcontroller which will interact with the M & C server through the ethernet port / USB .

1.1. Scope of The Problem

Monitoring and control process of LAPAN A-2 satellite which have near-equatorial[1]orbit require an autonomous ground control system. This system requires integrated ground station software which have function to acquire,monitor and analyze the real time telemetry data, and also to send command in order to response all mode of operation and condition. The software has to meet the minimum requirement in processing time of telemetry data and send command to response with necessary action/scenario. The objective of this research is to design, develop and test the LAPAN spacecraft autonomous software based on ground control.

2. Methode

The research Methodology used in conducting this study is:

- Literature of LAPAN A-2 and LAPAN-TUBSAT Satellite Control System
  - Literatureof spacecraft autonomous operation
  - Determination of Software Requirement
  - Determination of Software Specification
  - Software Design
  - Software Implementation
  - Telemetry and Command Database Implementation
  - Test, evaluation and Analysis

Location of this research and development activities was in LAPAN Satellite Technology Center. Rancabungur, Kabupaten Bogor , Indonesia.

3. Literatureof LAPAN A-2 and LAPAN-TUBSAT Satellite Control System

LAPAN-A2 satellite attitude control subsystem almost the same as LAPAN-TUBSAT which based on angular momentum management. LAPAN-A2 control system is done through actuator in the form of reaction wheel and magnetic torquers. Whereas for satellite attitude data is acquired from several sensor like Coarse sun sensor (using solar cell), star sensor (CCD and CMOS star sensor). Star sensors are used to get more accurate satellite attitude data, especially for momentum vector. Other than that gyro is used to determine satellite speed of rotation. Fig.1explain more detail information about attitude ,determination and control of LAPAN-TUBSAT satellite.

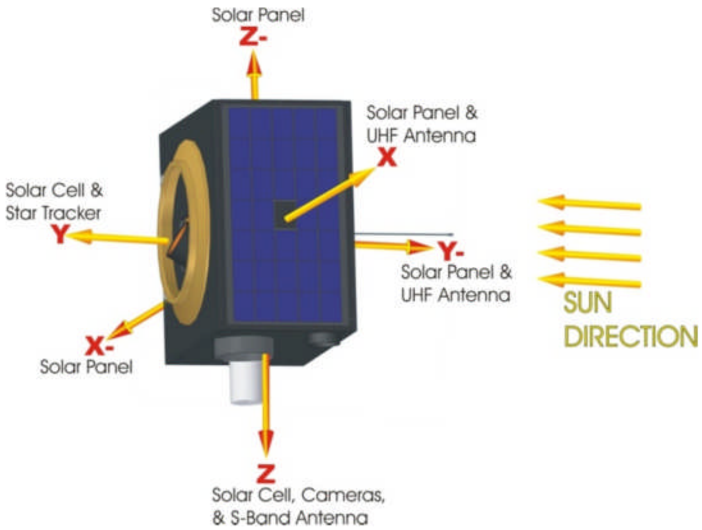

Fig. 1. LAPAN-TUBSAT Satellite ADCS Subsystem Configuration

Lapan-A2's Control Strategyis almost the same like LAPAN-TUBSAT' s control strategy. The main control strategy consist of 4 control strategy :

1. Hibernation/Momentum Bias Mode, where momentum angular is maintained at X-axis which perpendicular to the direction of orbit.In this mode the reaction wheel is set to absorp 90 % from momentum angular so that the spacecraft will rotate in the same direction of reaction whell.
2. Nadir Pointing Mode, where spacecraft or satellite is maintained at 3-axis stabilized and +Z axis is pointing to earth (nadir) along ground track. Satellite also has capability to point it's body to object outside ground track
3. Interactive Mode, where satellite/spacecraft has ability to rotate freely on each axis in order to get a target.
4. Tumbling Mode, where all satellite equipment are switched off except the OBDH and TTC.

Beside control strategy LAPAN-A2 and LAPAN-TUBSAT satellite also using magnetic torquesas an actuator along with reaction wheel. This equipment was integrated in all spacecraft axis. Coil Magnetic is used for generate magnetic dipole moments. That momen is used to compensate satellite residual magnetic fields or attitude drift which come from minor disturbance torques.

3.1. Literature of Spacecraft Autonomous Operation

There are two type of spacecraft autonomous system which can be implemented onboard, first type is adaptive type. The main objective of this autonomous type will always same (never be change) or fix during in orbit operation. Usually to reach the main goal/objective, this type will need several sequencetial actions or scenario which already defined previously. Basically all scenarios was define based on possible condition which may occurduring in orbit operation. If condition A occur then the response should be B, and if condition C occur then the response should be D. For example if On board computer having failure flag then the self check timer should on and check the onboard computer flag in 12 s. If in 12 s the failure flag still exist then the redundant on board computer should switch on.

The other type is independece type or usually called goal robustness. In this type, autonomous system has capability to create scenarios which never exist before. Those capability is based on artificial intelligence which included in mission operation. Mission can carry many objectives and can be change as per requirement and condition/problem which appears during mission lifetime. Integrated on board computer and TTC ground station are required to establish this autonomous type.Since at this time LAPAN satellite are not using integrated on board computer,integrated TTC ground station and also dont have any objectives which required rapid changes. The most convenient and less complicated is adaptive based on ground control command. It will only required an integrated ground station control software and database command.

4. Design Constraint of Autonomous Acquisition and Control LAPAN Satellite Software

Basically all software requirements and constraint accordance with equipment configuration requirements will be used. The constraint include, functionality, performance and technical. More details about LAPAN satellite autonomous software design constraint are shown Table 1 below :

Table 1.Constarint and Software requirement of LAPAN satellite Autonomous Operation and Control System Software

No	SubItem	Requirement	
1	Functionality	Software module made for autonomous telecommand transmission to all LAPAN's Satellite.	
		Software module made for autonomous telemetry data acquisition and check the health status of LAPAN satellite hardware and equipment.	
		Software Module made in accordance with communication and protocol requirements LAPAN-TUBSAT and LAPAN-A2 satellite	
		Software module made for autonomous control of Attitude Control Subsystem hardware LAPAN-A2 and LAPAN-TUBSAT satellite	
		Software Module use database as storage media for all equipment telemetry data of LAPAN-TUBSAT and LAPAN-A2Satellite.	
		Software Module have capability to display certain parameter which is desired from database log	
2	Performance	Minimum Telemetry Update rate	1s
		Number of Controlled Parameter	Same as Command
		Maximum number of Storage allocation	1 Terra byte
		Minimum number of Fields	12
3	Technical	Communication Protocol	Serial
		Baud rate	38400[3]
		Parity	No

4.1. Software Requirements of Flight Dynamic and ADCS Software

In order to achive the objective as an adaptive spacecraft autonomous control, its required to have flight dynamics an attitude control software as supporting system.Flight dynamics and ADCS software module requirements in details are shown Table 2 below:

Table 2.Flight dynamics and ADCS software module requirements

Parameter/Condition	Requirement
Time-Tag command Transmission	Software Modulehas capability to transmit time-tag command (Command Sequence) during satellite enter the ground station coverage
Satellite Scheduling Program	Software Modulehas capability to predictthe satellite passes in ground station coverage area.
Attitude Control TelemetryData -Gyro X,Y,Z - Wheel X,Y,Z	• Software Module has capability to transmit command for acquiring ACS Telemetry data • Software Module has capability to process received ACS Telemetry Data
Attitude Parameter Data from Star Sensor	• Software Module has capability to transmit command for acquiring Star sensor Telemetry data • Software Module has capability to process received star sensor Telemetry Data j

ACS equipments Status - Gyro - Wheel - Star Sensor - Magneto Coil	Software Module has capability to check ACS equipment status (Gyro,Wheel. Star Sensor and Magneto coil)
Switching Perangkat-perangkat ACS - Gyro - Wheel - Star Sensor - Magneto Coil	Software Module has capability to swicth on/off ACS equipment (Gyro,Wheel. Star Sensor and Magneto coil)
Attitude parameter calculation for point strategy	Software Module has capability to calculate attitude parameter in order to have certain earth pointing strategy.

4.2. Design and Implementation of Mission Planning & Command Interface Software Module

Software was developed using Visual basic 6.0 program with ADODC configuration for database application as per software requirement and constraint. Level-0 Data flow Diagram of this software module is shown in Fig. 2 below:

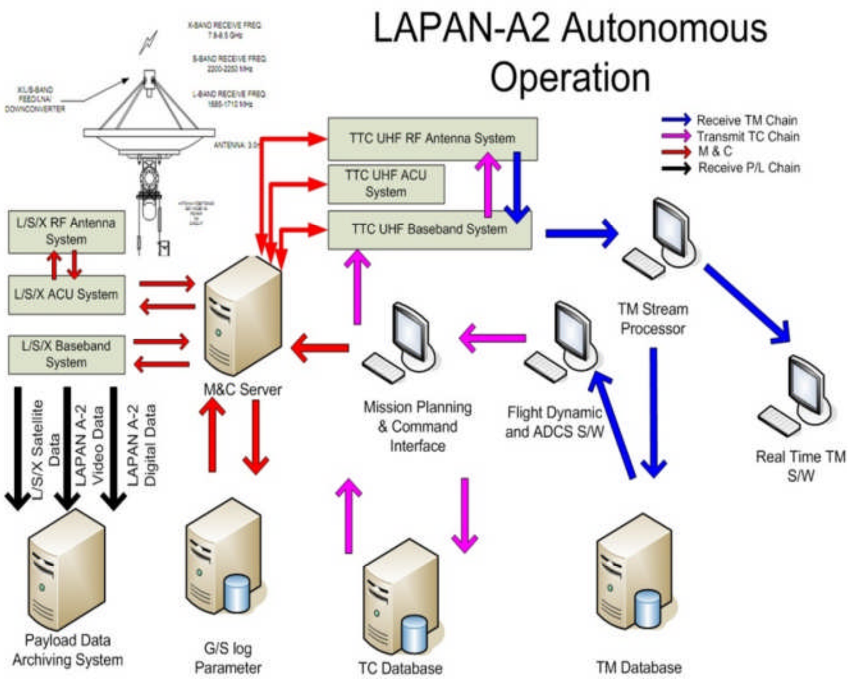

Fig. 2.Level-0 Data Flow Diagram LAPAN Autonomous Spacecraft Control

As shown above the autonomous process start from defining the operation plan through *Mission Planning & Command Interface* (MPCI). In this software module,operator task is only give input command or operation type to the system and those command will be transmited to the satellite when the satellite pass the ground station. Operation type can be telemetry data acquisiton, payload data acquisition, and other type of operation. After that the MPCI module will send a command to the *Monitoring & Control Server* (M&C Server) to make pre-pass necessary preparation for all TTC and receiving ground station equipments. After all ground station equipment are ready then MPCI will take the all command in MPCI list from telecommand database. When the time tag has the same value like current time then the command will be send to the satellite immediately via TTC baseband and RF system. After sending the telecommand then satellite will give response with sending requested telemetry data or acknowledge wheter the telecommand has reach destination . If the telemetry acquisition operation is performed then telemetry data will be processed by Telemetry Stream Processor (TMSP) software module. After that the processed telemetry data will be distributed to Real time Telemetry (RTM) software module and the other one will go to Telemetry Database archive. If payload data acquisition like camera or AIS are performed then there will be another supporting software module Flight dynamics & ADCS which have function to calculate the LAPAN-A2 control/attitude parameter. These parameters shall be send via telecommand in order to ensure that satellite in nadir pointing mode as per requirement.All payload data which acquired from satellite will through theL/S/X RF chain and baseband system then will recorded in data server called (Payload Data Archiving System: PDAS).

4.2.1. Schedule Plan Software Module

This software module was designed to send telecommand via ground station adapter hardware autonomously. Before send all the telecommand, operator has to fill the telecommand time of execution. This process was done by entering telecommand with telecommand time of execution to database table called schedule plan. This database table consist of several field such as : ID,Time Excecution,CMD ID,Description,Flag Check TM,Flag Check ID,St Index Add L Tele dan No of sets L Tele. Detail description of those fields are shown in Table 3 below.

Table 3. Database Field of Mision Plan with Description

No	Field	Description
1	ID	schedule plan ID.Every pass will be recorded into log files coincide with date, time and status (send/not send) of Schedule plan ID
2	Time Excecution	Time of telecommand excecution (Day/Month/YearandHour/minute/second)
3	Cmd ID	ID of eachtelecommand. This software is taking command from database command as per ID. So the database command will gives ID to each command. This to ensure the security level of this software. The idea was to localize the telecommand excecution only from one database center. Although operator which can accsess this software remotely cannot send telecommand to the satellite without having accsess to database command. Database command is protected using password and dedicated IP address
4	Flag Check TM	Sign to operator wheter telecommand that will be send require telemetry check response or not. The idea was to facilitate the operator with telemetry check which simultaneously generate another command if a important telemetry parameter has reach maximum or minimum limit. "1" means software will check required telemetry parameter (next field). The default value is "0" which means software only send the telecommand without check telemetry parameter.
5	Flag Check ID	The ID of telemetry parameter required to be check. In the telemetry database there are ID for each telemetry parameter.
6	Flag Check Value limit	The limit value of telemetry parameter which will be a reference for sending next telacommand. For example if the operator wants to check wheter satellite in latch-up condition or not, operator only send PCU TM telecommand and fill Field Flag Check TM with "1", then fill flag check ID with "27"and fill flag check value limit with200 .
7	St Index Add L Tele	Status of the telecommand wheter it is a telecommand for asking Long Telemetry or not
8	No of Sets of L Tele	Number of Long Telemetryset which will be sent for each transmission packet . Default value is 256 bytes

4.2.2. Schedule Plan Software Module Implementation and User Interface

Implementation and user interface of the schedule plan software module are shown in Fig. 3 below :

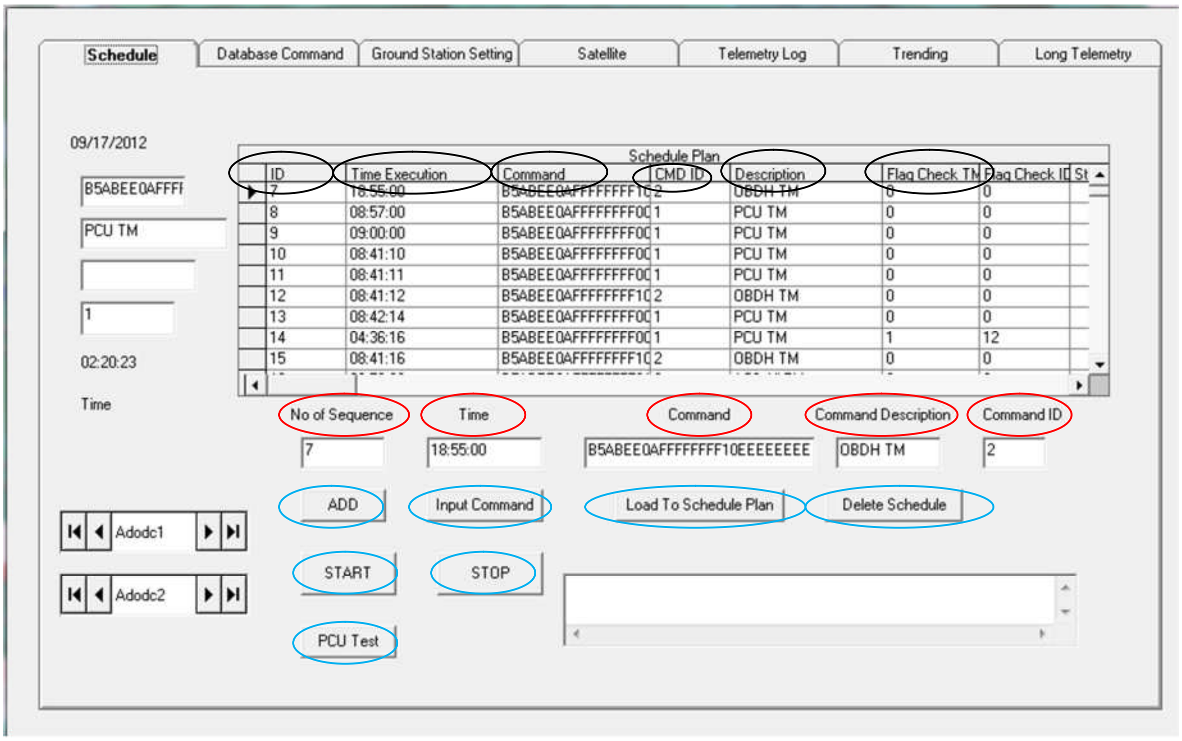

Fig.3.Mission Plan Software Module Display

As seen in figure 3 above is the display of schedule plan database with several input text which related with telecommand transmission process and telemetry data acquisition autonomous function. Black circle show all fields in the schedule plan database. Red circle show input text which need to be filled by operator and the blue circle show button for commands excecution to operate this software module.

4.2.3. Telemetry Log and Telemetry Stream Processor Software Module

After acquiring telemetry data the next process will be done by Telemetry stream Processor software module. Telemetry Data will be divided per channel, per parameter and also based on type of telemetri data such as (PCU TM,OBDH TM,Long Telemetry[4]). Each type of telemetrydata have diffrent type and format. If the total number of data acquired have same number as normal data then processed data will be archive in the telemetry log database. This database consist of several field such as ID, Date,Time, etc. Detail description of those fields are shown in Table 4 below

Table 4. Database Field of Mision Plan with Description

No	Field	Description
1	ID	Is a sequence of received Telemetry Data
2	Date	Day whenReceived Telemety Datawith format DD:MM:YYYY
3	Time	Time whenReceived Telemety Datawith format HH:MM:SS
4	Parameter	Object/Subsystem/Equipment measured (Temperature Sensor ,Voltage,current or digital sensor)
5	TM Value	Value of related parameter
6	Dimension	Dimensionof related parameter For example :mA , V, deg C dll
7	TM ID	Telemetry ID channel forrelated Telemetry data

4.2.4.Implementation and User Interface Telemetry Stream Processor and Telemetry Log Software Module

Implementation and user interface of the telemetry stream processor and telemetry log software module are shown in Fig.4 below .

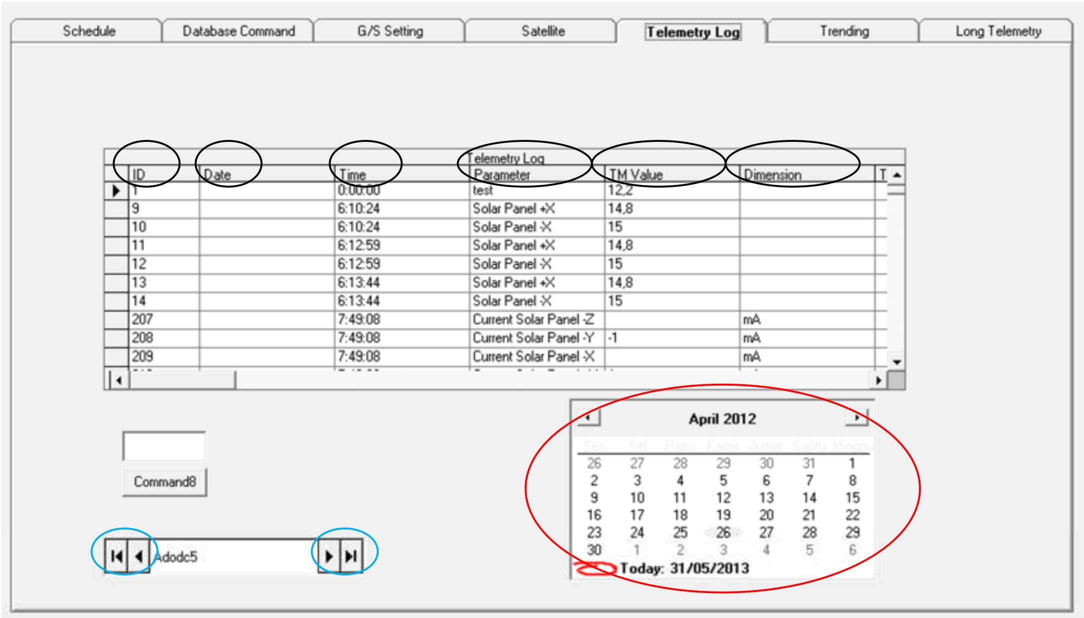

Fig.4.Telemetry Stream Processor Software Module Display

As shown in Fig. 4 above is the display of Telemetry Log database with calendar active-x control. Black circle show the fields in telemetry log database table. Red circle show the calender which used when sorting the telemetry data by date. Blue circle show the button for commands excecution to operate this software module.

4.2.5. DatabaseCommand Software Module

Beside Command Database, in this tab also consist of comand log database.This database will contain all telecommand status that have been sent which include date, hour,minute, and second. It also include command description, command ID (cmd ID) and command status.

4.2.6. Implementation and User InterfaceDatabase Command Software Module

Implementation and user interface of the Database Command software module are shown in Fig. 5 below .

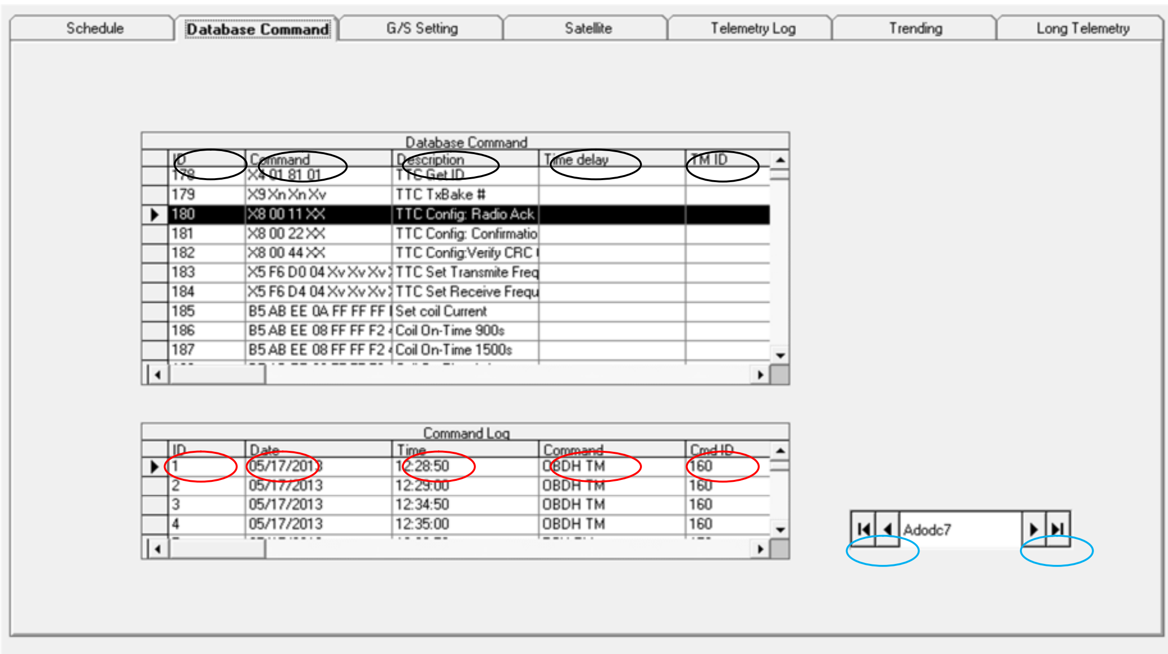

Fig.5.Database Command Software Module Display

As shown in figure 5 above is the display of Database command and command log of transmitted telecommand. Black circle show the fields in table of database command. Red circle show the command log database and blue circle show the button for commands excecution to operate this software module.

4.2.7. Functional and Performance Test of LAPAN Autonomous Spacecraft Operation Software

Software test of LAPAN Autonomous Spacecraft Operation Software consist of two type of test, first is functional test, and second is performance test. Functional test also consist of several sub module test like Interface test, Connection test, on the ground test, and final test is on orbit test.

Interface test was done using two type of UHF TTC radio. Radio which are used during this test are ICOM 910H[5]and YAESU FT847[6] . Test also done using each interface format for frequency tuning. As the result of interface test, the software was able to tune the frequency for all radio type (ICOM-910H and Yaesu FT-847).This feature will support the doppler frequency correction during pass automatically.

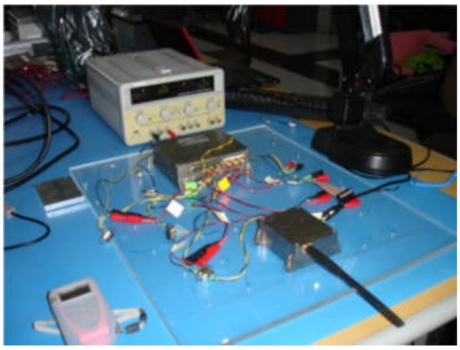

Fig.6a. Software Development Functional Test Using LAPAN-TUBSAT Engineering Model

Fig. 6b. Auto tuning Test of ICOM-910H radio

Connection Test was done using LAPAN-TUBSAT ground station adpter or modulator/demodulator. This test also using TM/TC standar protocol for LAPAN satellite. As the result of this test, the software was able to communicate with the modem at the baudrate 38400 bps.

Functional test using LAPAN-TUBSAT engineering model was conducted in order to show the performance of Autonomous Spacecraft Operation Software. The performance will be evaluated wheter its meet the software requirement or not. As the result of this test, the software was able to send telecommand ,receive telemetry and processed it autonomously. The time required to process the telemetry data was 1 second for PCU telemetry. And for OBDH Telemetry data it was required 3 second to process it.

Functional test using on orbit LAPAN-TUBSAT was conducted in order to show in orbit performance of Autonomous Spacecraft Operation Software. The performance will be evaluated wheter its meet the software requirement or not. As the result of this test, the software was able to send telecommand ,receive telemetry and processed it autonomously. The time required to process the telemetry data was 2 second for PCU telemetry. And for OBDH Telemetry data it was required 5 second to process it.

Result test of Doppler frequency calculation was done during in orbit test using LAPAN-TUBSAT satellite. The software was able to calculate doppler frequency and tune the radio autonomously. Calculation result of doppler frequency was almost as same as comercial software like NOVA for windows and Orbitron[7].

All operational activity of the software can be recorded automatically in the log files such as Command log, Telemetry log, Ground station log.

5. Result and Discussion

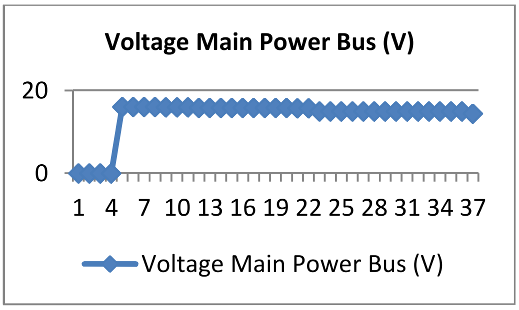

Fig.7a.Software Test Result Voltage Main Power Bus

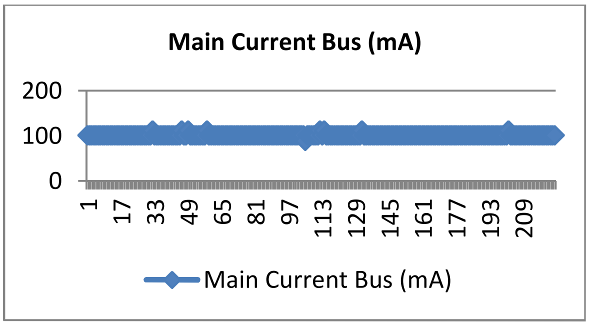

Fig.7b. Software Test Result Main Current Bus

Result shown in figure above are voltage and current of main power bus. This two parameter are required to analyze the

PCDH condition. If the voltage main power bus value go down below 12 V than it's require charging sequence and discharging is prohibited. The result also show that the voltage curve start at 0 V when the software still not calibrate with correct value. Whereas the main current bus is also one of three parameter which give operator sign that PCDH in healty condition or latch up. Above 200 mA it indicate the possible latch-up condition. This test also introduce this situation although with different limit value. During the test if the main current bus value is above 105 then the PCDH will generate OBC Telemetry. This test was succesfull without any correction from operator (run autonomously).

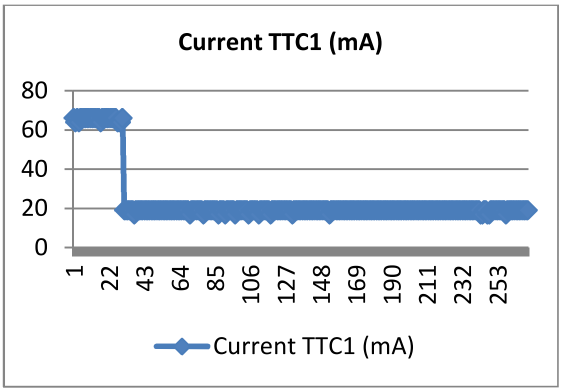

Fig.8a.Software Test Result TTC1 Current

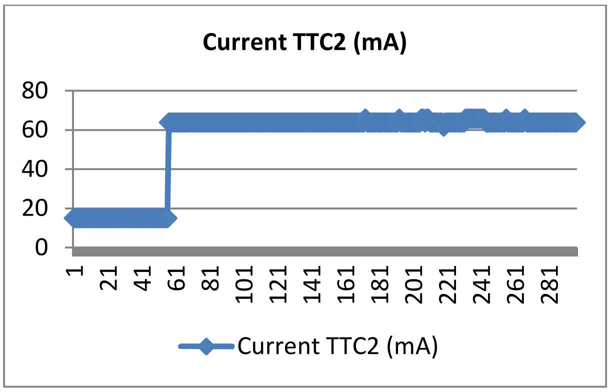

Fig.8b.Software Test Result TTC2 Current

Result shown in figure above are current of TTC1 and TTC2. This two TTC parameter are required to analyze the TTC Tranceiver condition. If the TTC currentvalue go down below 10mA than it's in OFF condition or fail. If TTC current value in the range from 12 – 20 mA than it's in receive mode or standby condition. If TTC current is increasing to 60 mA then it's in transmit mode. From figure above the conclusion are both TTC1 and TTC2 in good condition. The other things show from the result is when TTC1 is transmitting then TTC2 in standby mode and vice versa. This test was succesfull without any correction from operator (run autonomously).

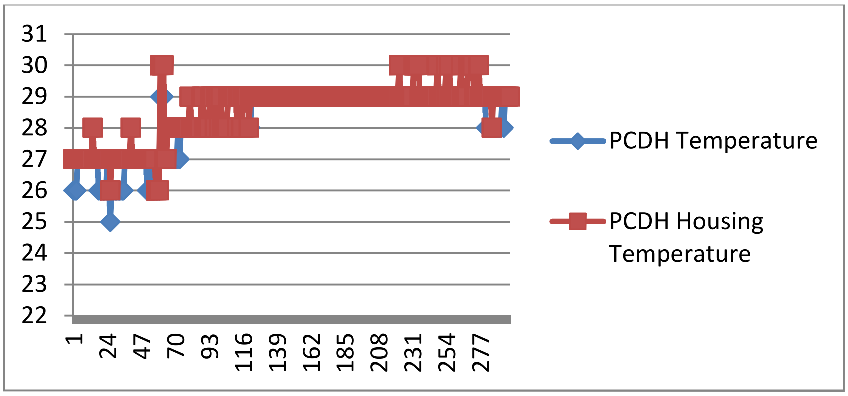

Fig.9.Software Test Result PCDH and PCDH Housing Temperature

Result shown in figure above are Temperature of PCDH and PCDH Housing. This two temperature parameter are required to analyze the PCDHwarning condition. If the PCDH temperature value go upabove 40 degree Celcius or go down below – 15 degree celcius then it's better not to operate the satellite. If that condition happen then software automatically disable the database command function. From figure above the conclusion are both Temperature still in normal operation range and have delta 1- 2 degree Celcius between the PCDH and PCDH Housing.

6. Conclusion

Functional test from sub module to system software, and functional test from on the ground to in orbit test was succsessfully conducted and evaluated. The result also show the performance has meet the minimum requirements. Inter connection performance between sub module has shown good result especially Mission plan module – Telemetry processor and Telemetry Log database also has been verified. There are differences between required time to process telemetry data acquired during on the ground test and in orbit test, 2 second for PCU telemetry data with total 112 byte. As for OBDH data which have 213 byte total data there is a difference 5 seconds. Suggestion for next test is use airbearing as a test media for attitude and control software module. This test also can be use for adding the test duration compare to in orbit test. The other suggestion is to use the software more frequent with varying the orbit path in order to know the character of required signal level to acquire valid telemetry data.

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Discussion

Question:

1. What kind of database was used? (M. ArifSaifudin, LAPAN)
2. Have the software been implemented in the real satellite operation?(M. ArifSaifudin, LAPAN)

Answer:

1. In this project we are using two well known Database Management Systems, first one is MySQL from Oracle and the other one is Microsoft Access from Microsoft. MySQL was used in the development of Mission Planning Software Module and Monitoring and control Software Module. Microsoft Access was used in the development of Mission Planning Software Module.
2. Yes this software has already been tested for real satellite operation. The test was done using LAPAN-TUBSAT satellite for several passes in Indonesia. The satellite operation test was conducted in Rancabungur TTC (Telemetry, Tracking Command) Ground station which located in Bogor.