Design of Antenna Tracking Software for MSC(Multi-Spectral Camera) Antenna Control

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Abstract

This paper shows the design concept of an ATS(Antenna Tracking Software) to control the movement of the MSC(Multi-Spectral Camera) antenna. The MSC has a two-axes directional X-band antenna for image transmission to KGS(KOMSAT2 Ground Station). The main objective of the ATS is to drive the APM(Antenna Pointing Mechanism) to the required elevation and the azimuth position according to an appropriate TPF(Tracking Parameter File). The ATS is implemented as one task of the SBC(Single Board Computer) software, which uses VxWorks as a real time OS. The ATS has several operational modes such as STANDBY mode, First EL mode, First AZ mode, Normal Operation mode, and so on. The ATS uses two PI controllers for the velocity and the position loop respectively, to satisfy the requirements specification. In order to show the feasibility of the described design concept, the various simulations and the experiments are performed under specific test configuration.

Keywords: ATS, MSC, SBC, X-band Antenna, Azimuth, Elevation

1. The Role of SBC in MSC

The MSC(Multi-Spectral Camera) is a space-borne payload system carried by a satellite, orbiting the earth in a given altitude, and providing aerial photography of selected legs along the satellite's track.

The MSC consists of the EOS(Electro-Optical Subsystem), the PMU and the PDTS(Payload Data Transmission Subsystem). The EOS is to obtain data for high-resolution images by converting incoming light into digital stream of pixel data. The PDTS stores and transmits these digital image data to the ground station through X-band antenna. The PMU performs electrical and software interfaces between the MSC and the spacecraft, and controls all the MSC subsystem by the ground station commands and reports all the SOH(State Of Health) and telemetry to the spacecraft. Fig.1 shows the MSC block diagram.

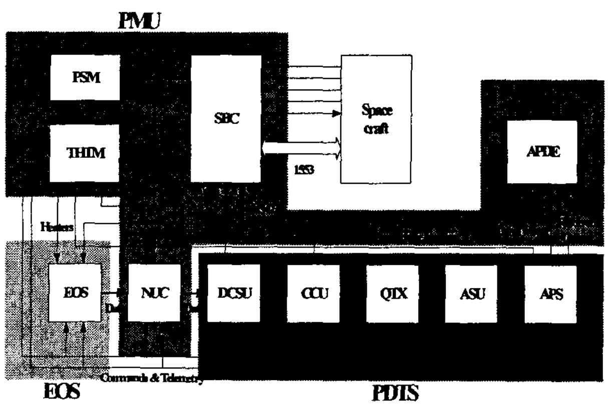

Fig.1. MSC System

As depicted in Fig.1, the SBC(Single Board Computer) in the MSC controls all the MSC units by means of receiving commands and data from the space craft via mil-std-1553B communication channel and distributing them to the proper unit at appropriate time via serial communication channel. In addition, the SBC is used to control the antenna movement for the image data transmission to ground station, which is performed by the ATS(Antenna Tracking Software).

2. Design of Antenna Tracking Software

The APS(Antenna Pointing System)'s concept is based on pitch over yaw – two axes gimbals. In principle, the azimuth and the elevation angles of the gimbals during transmitted depend on the satellite attitude, satellite location and ground station location. A TPF(Tracking Parameter File) is developed under these consideration by ground station. The TPF is prepared in advance by mission planning, and sent via S-band to the MSC payload. The X-band antenna gimbals are driven by the ATS according to the proper TPF. Fig.2 shows the operational concept for the APS.

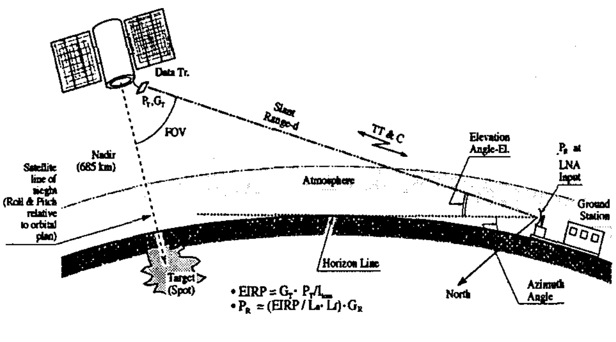

Fig.2. APS operation

2.1. ATS in SBC Software

The SBC software incorporates VxWorks as a real-time operating system in order to handle all the simultaneous activities. The SBC software consists of five main tasks and several modules to deal with controlling commands, data for imaging and all the state of health and telemetry data and to perform interface with the other MSC units. Five tasks have a different priority. And a message queue and a semaphore are used for the inter-task communication and the mutual exclusion in these tasks. The main structure of the SBC software is depicted in Fig.3.

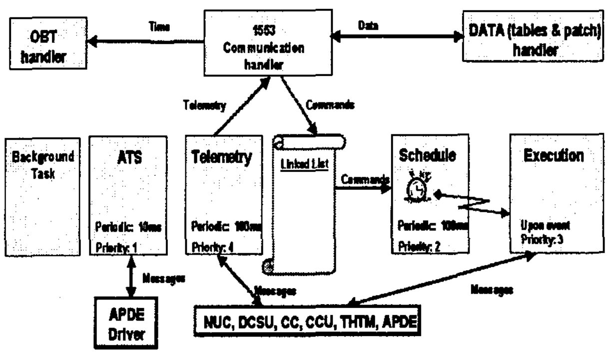

Fig.3. SBC Software Main Tasks

As described in Fig.3, most of commands and data come via mil-std-1553B communication channel and then stored in the command-linked list. The scheduler task monitors the commands linked list for a command to be executed. If a command has to be executed, it is being sent through a message queue to the execution task. The execution task invokes upon command arrival and activates the relevant function. The telemetry task gathers all the state of health data from all the units by receiving relevant message through serial communication channel. This task sends the telemetry data to the space craft every second according to the telemetry format table. The background task has lowest priority and performs the periodic BIT, and so on.

The ATS task is the most time critical task and has the highest priority. The ATS controls the X-band antenna both in elevation and in azimuth direction in order for PDTS to communicate with ground station. This task calculates the position of antenna and sends the PWM command to APDE(Antenna Positioning Derive

Electronics) through serial communication channel every 10 milliseconds. In order to calculate the next position of the antenna, the information about the position of satellite in the orbit, the attitude of satellite and the feedback value of current antenna position are required. These reflections should be considered in the TPF. The additional capability of the ATS is to gather and report the telemetry data, handle the tracking profile coefficients tables and control parameters and construct the tracing profile according to TPF. Fig.4 shows the relationship among the ATS, the APDE and the APM(Antenna Pointing Mechanism).

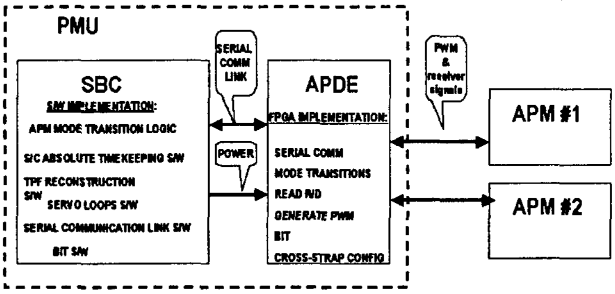

Fig.4. Antenna Positioning Servo System Block Diagram

2.2. ATS modes

The ATS has eight sub-modes of operation. In each mode excluding OFF mode, the ATS updates the telemetry data, and records ATS data into a cyclic buffer. After finishing the ATS activity it transfers to STANDBY mode.

2.2.1. OFF mode

This mode is the default mode when the PMU(Payload Management Unit) starts up. The ATS capabilities are idle in this mode.

2.2.2. STANDBY mode

This mode is a transit mode, so, all transitions have to be through this mode. In this mode each cycle a zero PWM message command is sent to the APM and ANT_RES(antenna resolve) message is read from the APM. After 2sec, the ATS disables the motor drivers in APDE.

2.2.3. FIRST_EL_OP mode

This mode is designed for first operation of the APM after antenna deployment to clear it from the mechanically locker. In this mode, the ATS controls the APM elevation axis to 15 degree at the velocity of 10 degree/sec. The AZ control loop is disabled in this mode.

2.2.4. FIRST_AZ_OP mode

This mode is also designed for first operation of the APM after antenna deployment to clear it from the mechanically locker. The initial condition of this mode is that EL angle is 15 degree. In this mode, the ATS controls the APM azimuth axis to do 15 rotations clock wise and 15 rotation counter clock wise at the velocity of 30 degree/sec. After finishing this operation, the ATS moves the EL, AZ motors to zero(0,0) position.

2.2.5. NORMAL_OP mode

Initial condition is AZ, EL motors are in zero(0,0) position. In this mode, the ATS moves the antenna in a predefined profile that is defined by a table coefficient. The coefficient table defines a polynomial in time-axis. The APS closes the control loop on the antenna position. In each cycle, the appropriate PWM message is sent and an ANT_RES message is read.

2.2.6. IBIT mode

In this mode, the APS sends several angles to APDE and gets the resolver's results. The control loop calculation and the motor drivers are disabled in this mode.

2.2.7. GROUND_TEST mode

This mode is for the APS testing and can be activate only on the ground. In this mode, the preprogrammed functions or A/D commands from the EGSE via an RS-422 channel are used as an input to the control loop.

2.2.8. IN_ORBIT_TEST mode

This mode is also for the APS testing. In this mode, the APS move the antenna in a predefined profile. The predefined profile is a result of several equations with several parameters in each equation. The ground station has the ability to choose one of the predefined equations and also to update the parameters.

Fig.5 shows the ATS mode transition diagram. As shown in this figure, transition from one mode to another is allowed via only STANDBY mode. The pyro ignition must be carried out by the PMU when the APS is at STANDBY mode. As long as the pyro is not released and FIRST_OP modes are not completed, the ATS can't leave STANDBY mode to NORMAL_OP mode or to IN_ORBIT_TEST mode.

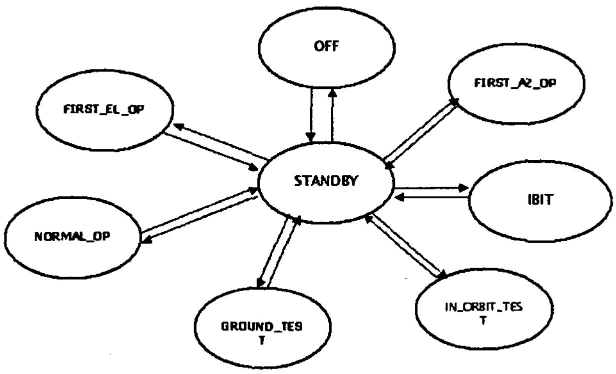

Fig.5. ATS Modes Transition Diagram

2.3. Antenna Control Loop

The azimuth and the elevation tracking commands shall be based on polynomial approximations of the predicted required tracking profiles, which is called TPF. This TPF shall be prepared at the ground station in advance, and sent to the spacecraft at least 1 pass before the pass of the relevant task. The SBC uses the TPF in order to reconstruct the required azimuth and the elevation angels of the APS at each control cycle during a transmission path. The reconstructed values shall be used as inputs to the antenna control loops. In order to achieve an overall error budget of 1.8 deg(3σ), the error between the position command and the antenna axis should be less than ±0.6°(3σ) for each axis separately. Table 1 describes the main property of the APM, which is termed as plant in these control loops.

Table 1. Main Property of APM

Property	Azimuth	Elevation
Range of Motion	360° cont.	0° ~ 113°
Max Moment of Inertia	11e-3[kg·m^2]	8e-3[kg·m^2]
Max. Angular Accl.	10°/sec^2	10°/sec^2
Max. Angular Vel.	10°/sec	10°/sec
Dynamic Fiction	40e-3[N·m]	14e-3[N·m]
Torsion Stiffness	6500[N·m/rad]	6500[N·m/rad]

Table 2 shows the error budget in case of normal profile dynamics. As described in this table, the error of antenna control loop should be within 6 degree for the each axis.

Table 2. Error budget in case of normal dynamics

Error source	Error budget(3σ)
RF beam calibration	< 0.5 deg.
Alignment assembly error	< 0.2 deg.
Thermal and vibration distortion	< 0.05 deg.
Satellite location error	< 0.05 deg.
Satellite altitude error:	
Azimuth error	< 0.08 deg
Elevation error	< 0.07 deg
Polynomial approximation	< 0.2 deg
Gimbal – Control error	< 0. 6 deg
Total RSS of random error components	0.64 deg
Total RSS of systematic error components	0.54 deg
Azimuth and Elevation entire peak error (each)	1.18 deg
Total pointing peak error	1.65 deg

The worst-case performance of the control loop is derived from the azimuth and the elevation commands, which are applying maximal angular velocity and maximal angular acceleration, yielded by the singular point algorithm that is designed to avoid gimbal lock while photographing the ground station. The velocity loop and the position loop are developed separately for the good antenna control. The velocity loop bandwidth is within 5 Hz, that of the position loop is within 1 Hz. Sampling frequency is up to 100 Hz in order to identify high frequency non-linear phenomena, such as friction and backlash, from current sampling. To satisfy these requirements, PI controllers are adopted for both control loop. Fig.6 and Fig.7 show two possible approximated control loop designs for one axis either azimuth or elevation

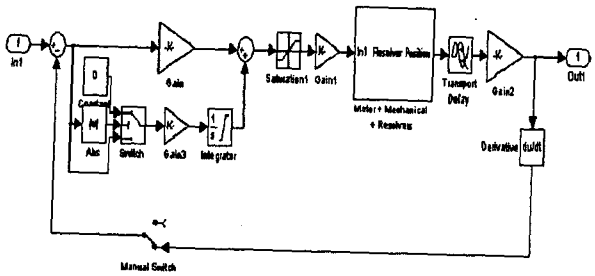

Fig.6. Velocity Loop Model

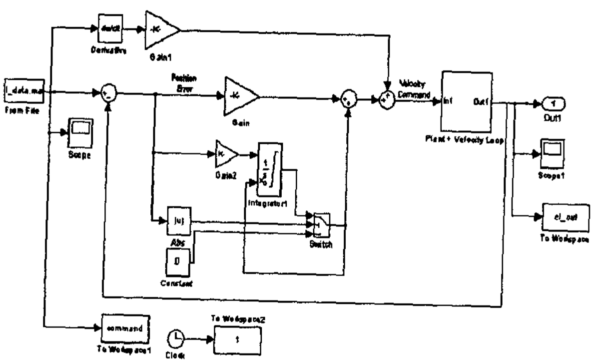

Fig.7. Position Loop Model

3. Integration and Test Results

Fig.8 describes the test set up for the X-band antenna control loop. This set up allows the integration of the design for APDE hardware, its FPGA design and APM, as well as the SBC software, which is simulated on a 486 PC with VxWorks OS, versus servo loops. This is especially important, since the entire servo system controlling the two axes of the APM includes real-time software running under VxWorks, while also the RS422 serial communication link(running at 65kBd) between the SBC simulator and APDE board. The ATS is being coded and downloaded from the S/W designer's PC to the SBC simulator, which communicates with the APDE board. The Test Equipment is equipped with dual A/D and D/A channels dedicated only to the integration process.

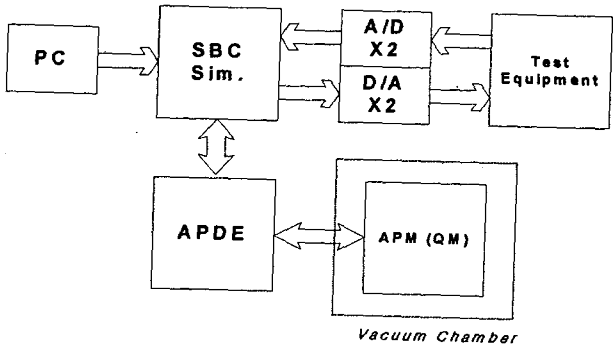

Fig.8. Integration Setup for ATS test

Fig.9 shows the multi-tasking result of SBC software. This figure shows that ATS is working rapidly with 10msec period and the highest priority.

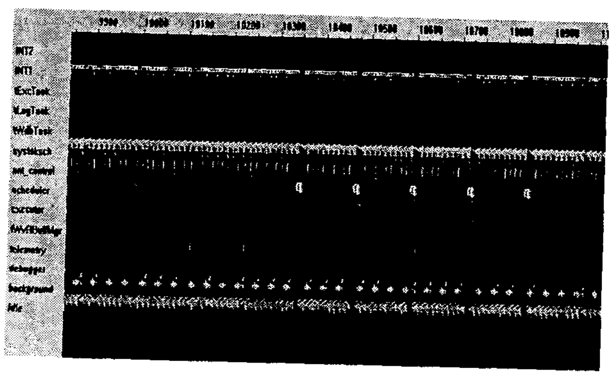

Fig.9. Multi-Tasking of SBC Software

In Fig.10 and Fig.11 shown are the APM azimuth and the elevation measured performance results, respectively, for a typical profile. As depicted these figure, the measured tracking error does not exceed 0.5 degrees for both axes.

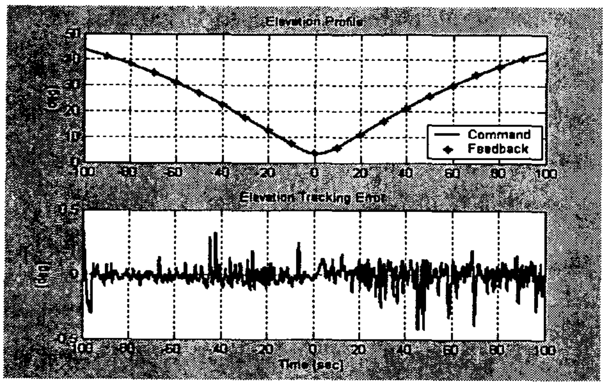

Fig.10. Measured Elevation Performance

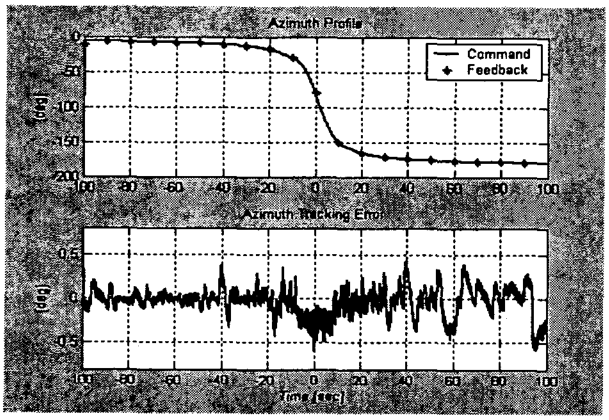

Fig.11. Measured Azimuth Performance

4. Conclusion

This paper shows the design concept of the ATS to control the movement of the MSC antenna. The main objective of the ATS is to drive the APM to the required elevation and azimuth position according to the appropriate TPF. The ATS is implemented as one task of the SBC software. In the SBC software, the ATS has the highest priority and works rapidly with 10msec period. Besides, the ATS has several operational modes, such as OFF mode, STANDBY mode, First EL mode, First AZ mode, Normal Operation mode, IBIT mode, Ground Test mode and In-Orbit mode. Two PI controllers are used for the velocity and the position control loop respectively. This paper tried to show the feasibility of the described design concept through the experiments, which are performed under specific test configuration. The test results show that this ATS is working well under the requirements specification.

Reference

[1] MSC SBC Software Requirement Specification.

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