The Specification and Subsystem Level Test of LAPAN-TUBSAT Star Sensor

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Abstract

The paper discuss about the specification and test of LAPAN-TUBSAT star sensor. The discussion includes the theoretical background of the subsystem, the subsystem design implementation on LAPAN-TUBSAT, as well as the subsystem level test.

1. Introduction

The attitude control of LAPAN-TUBSAT is based on angular momentum management. The attitude control system hardware consists of 3 reaction wheels placed orthogonally as satellite rotation actuator and angular moment absorber, 3 air coil type magneto-torquer as angular momentum generator/disipator, 3 gyros as angular rate sensor, 4 solar panel and 2 sun sensors as coarse attitude sensor and a star sensor as fine attitude sensor.

This paper focuses on the LAPAN-TUBSAT star sensor, which in the operation will be used to determine the satellite absolute attitude or the direction of its angular momentum.

Star sensor work in the principle of stellar navigation. That is, using the star position which is relatively fix (drift in the order of millions of years) in the sky to determine our pointing direction (attitude). Therefore, in order to perform stellar navigation one would need to be able to see star and compare the star configuration seen with star configuration a star map. A star sensor is equipped with 'digital camera', which take a picture of the stars and compare them with the stars catalog that its computer has to find out what stars that the camera saw. Knowing what stars configuration the camera saw the pointing direction of the star sensor can be calculated.

In the case of LAPAN-TUBSAT attitude acquisition and control operation, the pointing direction is expresses in Euler angle, since its physical meaning is easily determined. The angles in the system are called phi, theta, psi. Psi corresponds to the star angle (in star map) of right ascension, and theta corresponds to star angle of declination, while phi corresponds to the rotation of the sensor in the camera view's axis.

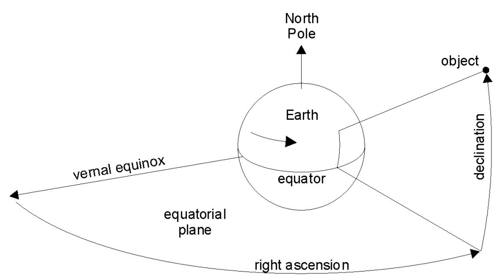

Figure 1. Star coordinate system

Performing a star navigation on space is easier than performing it on Earth, since the Earth surfaces rotate with respect to the star reference. Therefore, the coordinate system needs to be adjusted for star observer on Earth.

Earth rotated with respect to the inertial coordinate for 360 degree per 24 hours. From the earth, the Z axis of the inertial coordinate is defined as the line from the center of the Earth to the Polaris star. The line intersects the Earth's surface at the North Pole, which is also the axis in which the Earth rotates.

Coordinate in the star map is spherical system with axis called Right Ascension and Declination. Right ascension and declination are measured as if from the center of our Earth. As illustrated in figure 1, Right ascension is counted as distance (degree) from the vernal equinox, which is a point from Earth-center to sun-center at that moment around March 21.

For adjusting the coordinate system to observer on Earth, the coordinate elements should be computing in sidereal time. This sidereal time is based on the rotation of the Earth relative to the star and is defined as the HA (*Hour Angle*) of the vernal equinox, ♈. The local sidereal time is defined as local HA of ♈, LHA ♈, and sidereal time at Greenwich is defined as Greenwich HA of ♈, GHA ♈.

Sidereal time may also be determined from the HA and right ascension, RA, of any star. The RA of a star is azimuthal component of the star's position measured eastward from ♈.

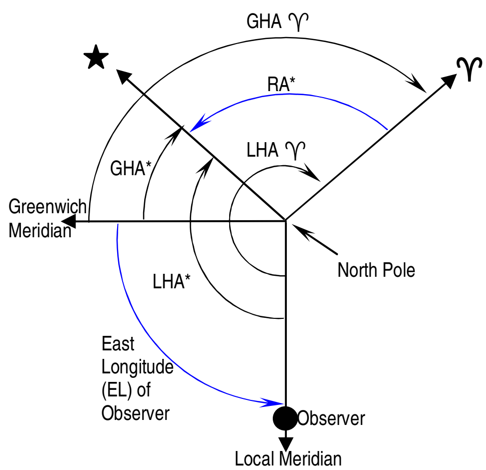

Figure2. Sidereal Time (View looking down on the Earth's North Pole)

The geometrical computations could be expressed in degree by equation below

GHA ♈= GHA* + RA* (1)

and

LHA ♈ = LHA* + RA* (2a)

LHA ♈ = GHA ♈+ EL (2b)

If the calculation is using mean solar time, Greenwich HA of ♈ also can be computed by

GHA ♈= GHA$♈_0$ +360.98564735.T (3)

Which is T referring to number of solar day after epoch.

2. LAPAN-TUBSAT Star Sensor

LAPAN-TUBSAT star sensor is a Vectronic STTO3. The star sensor is designed to provide fully autonomous attitude determination. In order to achieve this purpose, it integrates generally an image sensor to take picture from the sky and micro controller to processes and analyses this stellar information. The result of the processing is attitude parameter of the satellite in different format such as Euler Angle or Quaternion.

The specifications of this star sensor are listed below:

- 512 x 512 pixels radiation tolerant CMOS active pixels image sensor STAR 250
- 50 mm optics
- 14 bits analogue to digital converter
- 32 bit micro controller type Hitachi SH7045 for data processing and star recognition

Based on the mentioned hardware, and the star recognition software design, the star sensor performance are :

- field of view : 14^{o} x 14^{o}
- acquisition probability > 99,7% at angular rate < 0,6 ^{o}/s
- time to first acquisition: 900 ms
- update period : 4-8 Hz
- accuracy : X (optical axis) = 18 arcsec;
  Y/Z (imager axis) = 122 arcsec

The CMOS image sensor transform star images through the lens into analogue electrical information. The device is directly controlled by the Hitachi SH7045 microcontroller which also provides a possibility to influence the image generation such as adaptation of the exposure time or the analogue gain. The output of the CMOS sensor is converted to a digital signal before acquisition by the microcontroller.

In order to process the new acquired pattern data efficiently, a reference image already stored in memory to eliminate fixed pattern noise. It is known to be advantageous to compare the actual image with an up to date dark image to correct pixel-blemish and transients caused by radiation effects. This procedure however presumes that there is little coincidence between the actual image and the reference image i.e. the attitude of the spacecraft has slightly changed in the time between two subsequent images by at least $0,15^{o}$ (approximately 5 pixel) in the axes vertical to the optical axis and approximately 1^{o} along the optical axis. Bright stars provide clear advantage in the determination accuracy when calculating the center of intensity distribution. The imager and subsequent A/D conversion deliver 512 x 512 x 14 bits data for internal image processing by microcontroller. The coordinates of the brightest stars calculated by the microcontroller are based on the average value of all adjacent pixels, which belong to the same star. The star recognition is done by the microcontroller per comparison between the star database and the actual acquired star image.

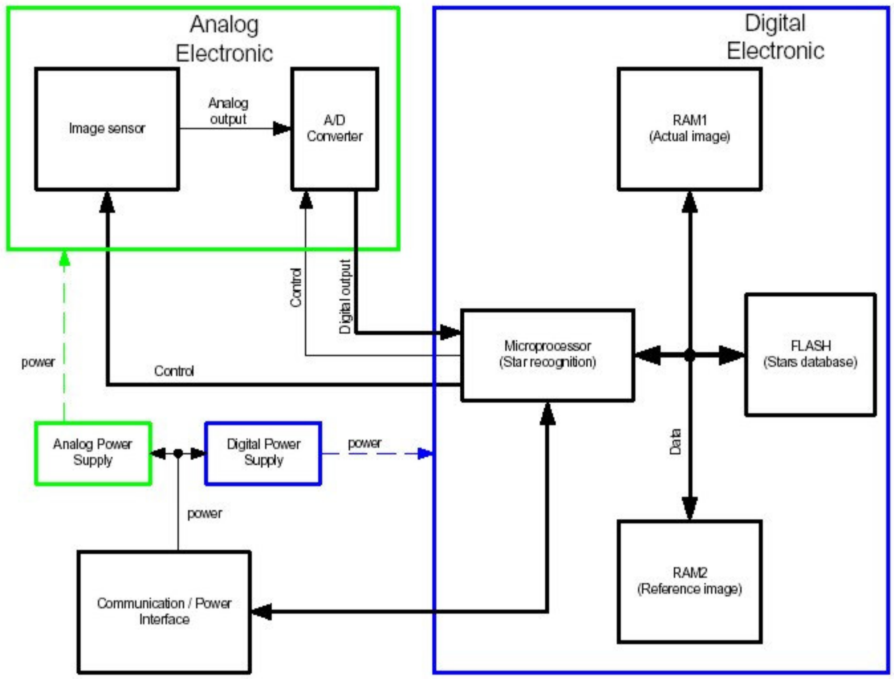

Figure 3. Schematic of the star sensor data structure

The operation modes of the star sensor are as follows :

1. First Acquisition Mode; After power on reset, the camera and all control variables are initialized and the star sensor turns automatically in a mode called First Acquisition Mode. In this mode the sensor performs one image of the sky and the whole data in the field of view of the star sensor is processed. The First Acquisition Mode is successfully passed over and the attitude of the satellite is known, the sensor turns automatically into a second mode, Tracking Mode.
2. Tracking Mode; In this mode the image sensor is continuously and completely read out (approximately every 250 ms). The image data is processed and reduced to star's coordinates with the corresponding magnitude by using a special technique, where frames around potential stars are defined. This technique, called frame technique, offers the advantage to process only predefined regions of interest susceptible to contain stars information instead of processing the whole read out data in sensor's field of view. The data processing in the Tracking Mode takes normally 100 ms to 150 ms depending on the number of detected stars. The rest of the time is reserved to process external commands. The star sensor stays in the Tracking Mode while the attitude of the satellite is successfully calculated. If the sensor is unable to recognize the current star pattern, it turns back into the First Acquisition Mode. After a successful completion of the First Acquisition Mode, the Tracking Mode will be activated again.

2.1. Hardware

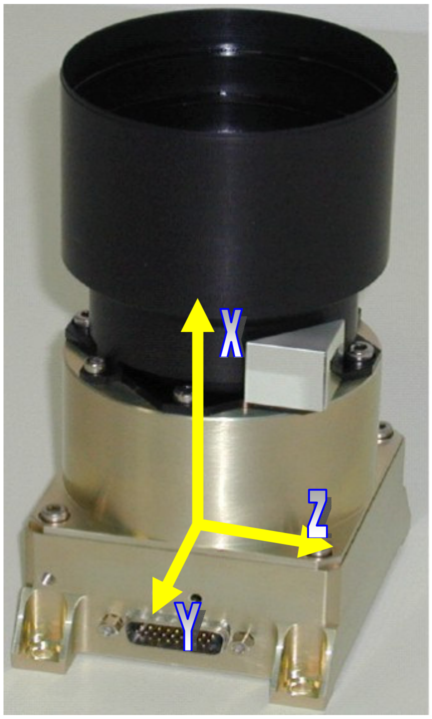

Figure 4. Star Tracker STT03 & its coordinates system

The electrical system of the star sensor consists of three different boards. The first board contains the data communication and power interface. It comprises two transceivers for communication and two DC-DC converters. The transceivers are directly connected to the microcontroller (second board) via pinhead interface. The unregulated input voltage is converted into two separated regulated voltages, one for analogue and the other for digital power supply. The power lines are distributed to the second board via another pinhead interface between the first and the second board.

The second board includes the microcontroller, the RAM memory and the flash memory. The RAM memory is divided in two equal parts. The first part is used to store the actual image data, while the second part contains a reference image. The digital board provides all the control signals for devices on the third board, which contains mainly analogue circuits like the CMOS image sensor and the analogue to digital converter. The power supply lines are lead through the second board.

The star sensor has an unregulated power input interface. The minimum and the maximum input voltage are 7,5 V and 18 V respectively. The unregulated input power is directly connected to two DC-DC converters, which deliver 6 V analogue and 5 V digital voltages respectively. The 6 V analogue voltages is further filtered and reduced to 5 V.

The star sensor has two serial data interfaces (RS 422) with the same properties. The first one is used for an asynchronous communication with a data rate of 38400 bps. The second communication interface is unused in then delivered configuration and could be used in a Hardware Triggered Mode or inside a bus communication.

The image sensor used for this star tracker is the STAR250, a radiation hard CMOS Active Pixel Sensor initially designed for application in Optical Inter-Satellite Link beam trackers, manufactured by Fillfactory.

2.2. Software

The software in the star sensor is divided into three parts.

1. The system routines: microcontroller initialization routines, routines for communication, routines for star sensor’s operation mode setting, etc.
2. Image sensor control routines for monitoring of the image acquisition operation
3. The image sensor data processing routines for star recognition operation

The software interface includes commands, which allow the remote control of the star sensor. The star sensor provides two types of command: low level commands and high level commands. The Low Level Commands are used for general memory read/write operation, while the High Level Commands are for specific device and function.

The communication is serial asynchronous and is usually initiated by the host computer. For each command, the host computer sends first the byte 0 of header and waits for its echo before sending the others seven bytes of the header and eventually data bytes. The star sensor receives the first byte and sends it back to the host computer before receiving the other seven bytes. Only the first byte of the header is always sent back by the star sensor. If the first byte is not sent back, the host shall abort the communication. The data transfer rate on the serial communication interface is 38400 bps.

There are four Low Level Commands; reset, execute, read data and write data. They are used for standards operations such us read data from a giving address or execute a subroutine at a particular address.

The high level commands are star sensor specific commands such as setting of operation mode. The high level command are for setting test mode, loading and reading star data, expose the imager, execute star recognition, making reference image, setting gain value and request telemetry.

3. Star Sensor Test

The objective of the test is to determine the health of a star sensor, two primary parameters are to be measured :

1. pointing validity
2. reading variation

The pointing validity of the sensor can be done using star simulator or by pointing the star to known direction and check the result. The reading variation test can be done by pointing the sensor to any constellation of stars and read the sensor's output several times for fixed interval of time.

The tests were done on a clear nights by pointing the star sensor to the sky from TU Berlin's ILR building (window or roof). The star sensor is connected to the PCDH and TTC, and the commanding was done via RF link (simulated ground station).

3.1. Pointing validity

As mention in the introduction, the calculation of theta depends on to the placement of the star sensor on the surface of the Earth, in this case is Berlin (52 N; 13,5 E). It is assumed that TU Berlin's ILR building is 5^o different from the true North. The test of FM star sensor uses the 30^o mounting block while the test of EM star sensor does not. The compilation of the result on the theta reading validity is as follows.

Table 1. Theta reading

STS	**FM**	**EM**	**FM**
test date	7/9/2004	10/3/2005	20/6/2005
Theta	77,35	51,75	39,67
expected	81	52	47
difference	3,65	0,25	7,33

The calculation of Psi, in addition to the placement of the star sensor on the surface of the Earth, also depend on the time (epoch) at which the test is conducted. The compilation of the result on the psi reading validity is as follows

Table 2. Psi reading

STS	**FM**	**EM**	**FM**
Test date	7/9/2004	10/3/2005	20/6/2005
lamda Berlin	285,48	121,887	237,459
Expected	285,48	121,887	286,46
Psi	280,00	123,00	290,00
difference	-5,48	1,11	3.54

3.2. Reading variation

Special procedure to test the star sensor reading variation is by using the boot program. The program imbedded in OBDH would set the sensor ON and command it to take attitude reading every 10 seconds for 6 minutes and then switch it OFF. The reading is stored in OBDH's RAM.

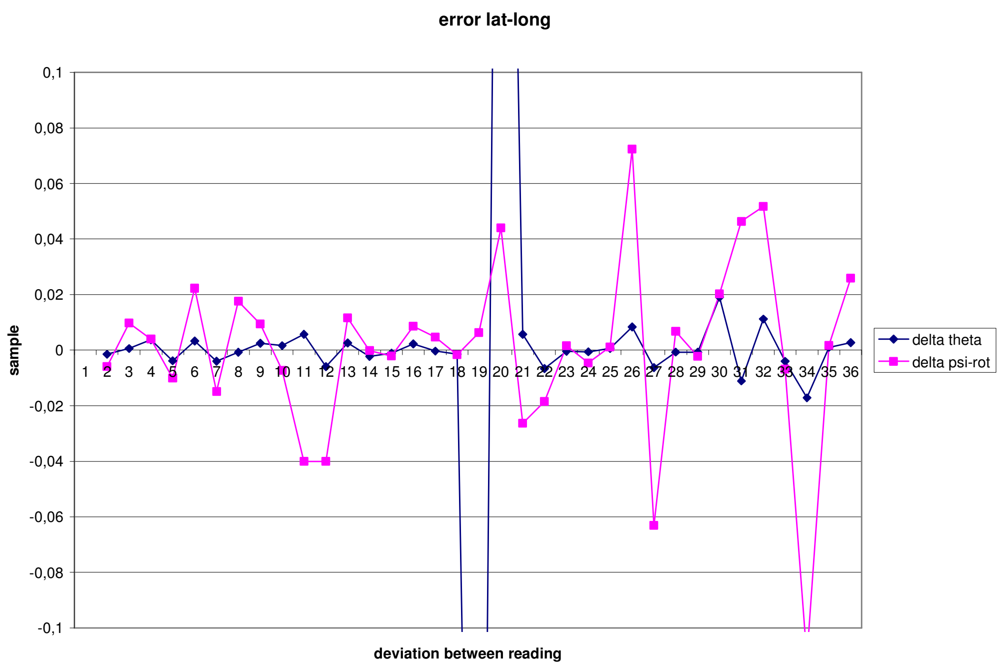

Figure 5. Boot program readings from September 2004 test

Figure 6. Reading variation from March 2005 test

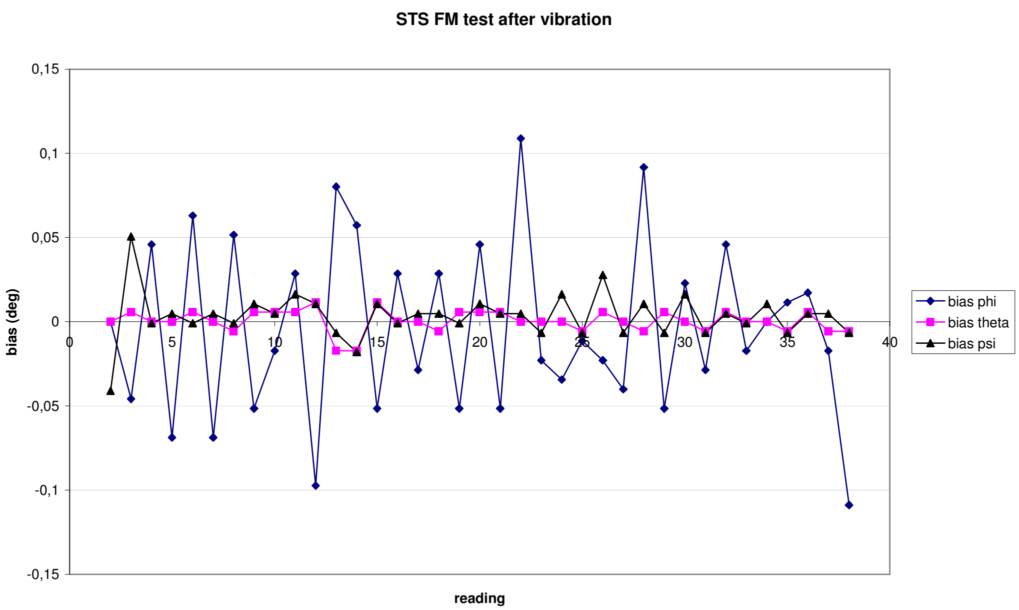

Figure 7. Reading variation from June 2005 test

The test results are shown in Figure 5-7. The average of reading deviation is shown in the table below.

Table 3. STS reading noise level (arcsec)

Test date	09/04	03/05	06/05
Right ascension	72	90	36
Declination	21,6	28	18
Rotation axis	54	172	162

4. Conclusions

The test result shows that the star sensor gives valid pointing. The inaccuracy in the reading is mainly due to the precision of the test set up.

The accuracy in star sensor's imager axis is better than in the vendor's specification. Meanwhile, in the optical axis is worse than in the vendor's specification.

To get test data more accurate, similar test can be recommended to be done with EM-star sensor. To check the STS performance during rotation, it is perform star reading test on a turntable.

The test results, as mention in the paper, will be used as reference for in orbit test later**.**

5. References

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