Algorithm Enhancement of STELLAR on LAPAN-A4 Satellite

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Abstract. The first LAPAN’s experimental star sensor has onboard on LAPAN-A3/LAPAN-IPB microsatellite that successfully launch on June, 6 2016. The second LAPAN’s experimental star sensor called STELLAR has scheduled to be onboard on LAPAN-A4 satellite. In orbit test of first star sensor provide conclusions. One of the conclusion is the radiation in space has an impact on star sensor performance. Many hot pixels or hotspots appear on CCD sensor temporarily that it causes a failure of star identification since the hotspots are fake stars. In order to solve this problem, an enhancement of algorithm is conducted. The enhancement aims to ignore the fake stars to proceed as stars candidate. This method selects a cloud pixel as star candidate and proceed only clouds pixel. The algorithm was tested and give more reliable result of star identification.

1. Introduction
Third satellite of LAPAN that is LAPAN-A3/LAPAN-IPB has successfully launch on June, 2016. Currently, the next satellite program that is LAPAN-A4 has been started. The main mission of LAPAN-A4 is intended for earth observation using optical imager. The imager are four bands multispectral medium resolution imager and high resolution imager developed by Satellite Technology Center LAPAN. Other missions are maritime traffic monitoring using space based Automatic Identification System (AIS) receiver and scientific mission using space based magnetometer. In addition to main mission, LAPAN-A4 has secondary mission that is technology demonstration of subsystem development. This mission is important to raise up the confidence of national capability in satellite’s subsystem development [1]. One of the subsystem is star sensor and it is the most accurate attitude sensor for satellite [2-5].

Figure 1. STELLAR on LAPAN-A3/LAPAN-IPB.
The star sensor developed by LAPAN called STELLAR (Star Sensor Experimental of LAPAN’s Laboratory). The first version of STELLAR has been flown on LAPAN-A3/LAPAN-IPB and the hardware is shown in figure 1. In despite of it is working well, the first in-orbit-test experience gives result that the sensor has much hotspots due to radiation in space since radiation damage in detectors is an issue for most space missions [6] and it has many effect on CCD performance [7]. The hotspots or hot pixels occurs on CCD causes the star identification algorithm failure. In order to manage these hotspots issue, the modification of star identification algorithm is introduced. This paper presents the enhancement star identification algorithm of STELLAR and also the test result to see the performance of algorithm.

2. Star Sensor Configuration and Algorithm
The STELLAR hardware design consists of a baffle, 16 mm lens, CCD camera, and Data Processing Unit (DPU). The baffle is highly important part of star sensor to control and reduce the stray light that causes reducing the image quality [8]. The baffle was designed to obviate the unnecessary light or stray light that hit the optical lens. The source of stray light may could be coming from the sun, moon, earth albedo, or other celestial objects. The software consists of the star identification algorithm and star database or star catalogue as reference. The camera is a monochrome CCD sensor and designed for industrial purpose. The sensor size is 1392 x 1040 pixel and power consumption is 3 Watts. The lens is also using commercial-off-the-shelf (COTS) component which has 16 mm of focal length. A 16 mm lens was selected to obtain wide field of view, therefore increasing the opportunity of number of stars captured by the camera. The DPU is the main computer of the star sensor where the algorithm and star catalogue have been implemented inside. The number of stars used in star catalogue is 800 stars which is extracted from SAO J2000 catalogue. The star catalogue is an optimized catalogue with the nearly uniform distribution over the celestrial sphere [9]. The specification of STELLAR is shown in table 1.

Table 1. Specification of STELLAR. [1]

| Parameter | Description |
|-----------|-------------|
| Sensor Type | CCD         |
| Sensor Size | 1392 x 1040 pixel |
| Focal length | 16 mm      |
| Update rate | 3 Hz        |
| FOV       | 31° x 23°   |
| Interface | RS422       |
| Power     | 3 W         |
| Voltage   | 15 V (nominal) |
| Mass      | 1.34 kg     |

Star identification algorithm is key of star sensor to determine the attitude. The work of algorithm is calculating the star position captured by sensor then compare with star database as known as star catalogue. Various novel algorithms are used and implemented such as star ID shortlisting technique [10], synthetic radial pattern [11], ellipticity pivot star method [12], hash table [13], OSP (ordered of set point pattern [14]. If the star pattern matches in the star catalogue, the identification process is successful. STELLAR uses the simplest algorithm to identify stars. The geometric method by using the angular distance has been implemented. In order to match the star pattern, it needs minimum three stars to construct a triangle. This method used in First Acquisition Mode which is the mode without any prior of attitude knowledge. The algorithm has an input data from the camera output. The camera was designed to send the brightest objects. Most star sensors have centroiding algorithm to estimate the centroid of star such as Gaussian Method [15-17]. It is used to handle the defocused problem or blurred condition due to satellite motion/maneuver [18]. STELLAR uses a simple method to estimate the...
centroid of star. It uses the brightest value of pixel as centroid of a star/object. The number of brightest objects is set to 30. As the camera imaging the stars, the output of camera is 30 brightest stars. Then the algorithm uses the three combination of these 30 stars to find the star pattern by calculate the angular distance separation between three stars and make fit with the star catalogue. The flowchart of the star identification algorithm is depicted in figure 2. The algorithm has a problem if mostly of 30 brightest stars are hotspots. The algorithm does not find the matching star pattern due to the hotspots were selected as star candidates.

![Flowchart of Star Identification Algorithm](image)

**Figure 2.** Flowchart of Star Identification Algorithm.
3. Methodology
Modification of the algorithm has been carried out by using the neighboring method or cloud detection method. This method avoids the single pixel as star candidate even though pixel magnitude has a high number. The algorithm works by detecting the two or more consecutive pixels in one column that has a high number of magnitudes.

3.1. Panorama Image
The modification algorithm uses panorama image as data input instead of 30 brightest objects. Panorama image consists only the respective maximum value (position and pixel value) of a line with a total number of lines is 1040. Position Pixel data is expressed in position (X,Y) and also the brightness (M_v) with 0 ≤ X ≤ 1391, 0 ≤ Y ≤ 1039, and 0 ≤ M_v ≤ 4095. Information for one pixel has 3 bytes and depicted is table 2.

| Byte 0 | Byte 1 | Byte 2 |
|--------|--------|--------|
| Y_0    | X_0    | M_v0   |
| ...    | ...    | ...    |
| Y_1039 | X_1039 | M_v1039|

Table 2. Data format of panorama image [19]

According to panorama image, the hotspots can be identified by pixel’s magnitude that occurs on the single pixel. Otherwise, the stars can be identified if the pixel has neighbours with high brightness value. Those cases can be illustrated in figure 3.

Figure 3. (a) Hotspot data and (b) stars data on panorama image
3.2. Cloud Base Algorithm

As shown in figure 3(b), the algorithm should identify those clouds in a panorama image data and ignoring the hotspot pixels. The method used is finding consecutive X position of two pixels then select the brightest pixel as star candidate. This procedure is carried out for 30 stars candidate to fulfill the 30 brightest stars. Afterward, the stars candidate array should be sorted with the brightest stars in the first position. This method will guarantee there is no hotspot on 30 brightest objects data. The flowchart algorithm is shown in figure 4.

![Flowchart of the modified algorithm](image)

Figure 4. Modification Algorithm Flowchart

4. Result and Discussion

Computer based simulation has been performed to test the algorithm. The panorama image data was obtained from STELLAR-1 on LAPAN-A3/LAPAN-IPB contained hotspots.

| Table 3. Data of 30 brightest objects before clouds finding (left) and after clouds finding (right) |
|---|---|---|
| y | x | m |
| 394 | 505 | 4095 |
| 968 | 450 | 3334 |
| 163 | 455 | 2562 |
| 469 | 311 | 2414 |
| 50 | 1055 | 1732 |
| 351 | 379 | 1582 |
| 904 | 962 | 1125 |
| 382 | 68 | 994 |
| 506 | 1055 | 949 |
| 575 | 194 | 766 |
| 779 | 136 | 683 |
| 287 | 349 | 558 |
| 471 | 1057 | 552 |
| 1008 | 539 | 551 |
| 1027 | 1097 | 535 |
| 57 | 1068 | 526 |
| 805 | 249 | 497 |
| 629 | 255 | 486 |
| 676 | 91 | 463 |
| 836 | 177 | 452 |
| 363 | 339 | 448 |
| 770 | 640 | 429 |
| 135 | 685 | 428 |
| 347 | 356 | 420 |
| 368 | 562 | 396 |

| x | y | m |
|---|---|---|
| 394 | 505 | 4095 |
| 469 | 311 | 2414 |
| 351 | 379 | 1582 |
| 904 | 962 | 1125 |
| 382 | 68 | 994 |
| 506 | 1055 | 949 |
| 575 | 194 | 766 |
| 779 | 136 | 683 |
| 287 | 349 | 558 |
| 471 | 1057 | 552 |
| 1008 | 539 | 551 |
| 1027 | 1097 | 535 |
| 57 | 1068 | 526 |
| 805 | 249 | 497 |
| 629 | 255 | 486 |
| 676 | 91 | 463 |
| 836 | 177 | 452 |
| 363 | 339 | 448 |
| 770 | 640 | 429 |
| 135 | 685 | 428 |
| 347 | 356 | 420 |
| 368 | 562 | 396 |
| 388 | 617 | 307 |
First, obtaining one sample of panorama image data from the star sensor, then applying the existing
algorithm to obtain 30 brightest objects. With the same panorama image, applying the cloud base
algorithm to get 30 brightest object as shown in table 3. Based on table 3 (left), the red color are the
hotspots which appear on the sensor. Then after applying the clouds finding, the hotspots were removed
from the data. Now, the input data is hotspot free and can be used for star identification process.

The real ground test with the real hardware was carried out. The specification of the hardware is
identical with the flight model on LAPAN-A3/LAPAN-IPB. The ground test was done to prove the
performance of the algorithm with the real stars. The test result is shown in figure 5, 6, and 7
respectively.

|       |       |       |
|-------|-------|-------|
| 803   | 700   | 379   |
| 175   | 141   | 377   |
| 202   | 248   | 375   |
| 133   | 284   | 368   |
| 325   | 344   | 370   |
| 771   | 513   | 305   |
| 702   | 556   | 290   |
| 648   | 684   | 286   |

|       |       |       |
|-------|-------|-------|
| 0.6   | 0.4   | 0.2   |
| 0.3   | 0.1   | 0   |

Figure 5. Right Ascension data compare with earth rotation

Figure 6. Declination data
According to test result presented in figure 5, 6, and 7, Rate of Right ascension is not quite different with the rate of earth rotation and also the Declination and Azimuth angle show stable value. The Right Ascension, Declination, and Azimuth have bias error of 0.008 deg, 0.006 deg, and 0.04 deg respectively.

5. Conclusion
The objective of this work was to enhance the algorithm of the star sensor developed by LAPAN (STELLAR) that will be onboard on LAPAN-A4 satellite. The enhancement of the algorithm has been performed and according to ground test, the algorithm has reliable performance for star identification to be applied in STELLAR. Further research, the radiation effect in space should be taken care to handle the hotspot issue occurs in CCD sensor.

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