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A Novel Gyro-less Tracking Method for Star Tracker

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Abstract

In this paper a new tracking method is presented, which is one of the most important and useful algorithms in the stat tracker normal mode. the developed algorithm is gyro less algorithm without need to angular speed information of satellite. The presented algorithm was realized and tested on the fabricated star tracker (ROJA1) in Nanoptronics research center located at faculty of electrical engineering, Iran University of Science and Technology.

Keywords: Star Tracker, Tracking, Star Sensor; Lost in Space, Attitude determination, Star Catalog, Satellite.

Introduction

Attitude determination is one of the most significant issues in Low Earth Orbit space missions. The star trackers are very accurate in this field. The star sensors have two main modes, which are:

✪ Lost in Space Mode
✪ Tracking Mode

Several approaches were studied to perform lost in space algorithm [1-5], but there are not enough published works for tracking mode [5]. Existing algorithms have been based on the speed information, acquired from gyro or satellite attitude determination system. In this paper a new technique is developed for tracking mode in which, there is no need for speed information. This technique causes reducing in cost, weight and also improves autonomous operation of star tracker.

The presented method is completely compatible with lost in space mode, such that it can work only with one common catalog for both lost in space and tracking modes, which needs less memory space. This algorithm was tested on the hardware and camera. The specifications of the camera and lost in space mode in this project are presented in following sections.

Star Tracker Hardware

Camera

The camera, was designed and fabricated in Nanoptronics research center, it design based on CMOS technology imaging sensor. The specifications of used sensor are:

Table 1: Star Tracker's Camera Specifications

Specification	Values
Detected Stars Range	2.5~6.9 Mv
Update Rate	4 Hz
Image Sensor	CMOS
Resolution	480×752 Pixels
Optical Format	1/3"
Angular Resolution	1.3 ×10-3 Degree
Focal Length	41.1 mm
Lens Aperture	30 mm
Actual FOV	7.56 Degree
Noise Equivalent Angle	0.00017 Degree

The used sensor has high quantum efficiency and the best sensitivity in the visible spectrum (class G2 stars). This sensor could identify the stars with magnitude less than 6.9.

We use an adaptive Magnitude threshold detection algorithm to detect the stars in the image [2]. And also we use a centroiding algorithm with the accuracy of better than 0.04 pixels for detected stars in the image.

Processing Units

ROJA1 processing Unit is based on ARM9® processor architecture with 400 MHz Clock frequency and 64 Mbytes memory. Processor module has

standard camera interface for communication with image sensor.

Catalogue Structure

We use the inter stars angle as main features for pattern recognition. we derive all inter stars angle for neighbor stars with magnitude less than 6.9 and located inside a cone with vertex angle of 2×FOV in HIPPARCOS catalog. Then angles between this star and its neighbors and related identifications number are stored in star tracker memory

The pointing vectors for each pair of stars are also stored according to Figure 1. If the angles between two stars were less than angular resolution of lens, only one of the stars chooses as base star.
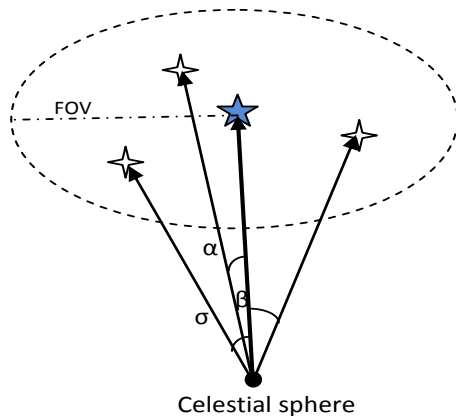

Figure 1. Neighbors star selected in the FOV

A part of the extracted catalog with stars of magnitude less than 6.9 (equal to 13000 stars) is shown in Table 2. The final size of extracted catalog is 38 Mbytes which contains 2 million combinations.

Table 2. A part of the extracted catalog

Inter Star Angel(deg)	Pivot Star ID	Pair Star
0.556483	3	19
6.395389	3	63
5.823231	3	119
3.522839	3	137
3.933105	3	254
3.348925	3	19
0.556483	3	63

Lost In Space Algorithm

Stars location in image plane should be transferred from image sensor coordinate system to 3-dimensional star tracker coordinate system, according to the focal length.

Four brightest stars is selected as pivot stars (pyramid algorithm, shown in Figure 2), and six angles between them is calculated. Mortari [4] has presented

an algorithm to prevent wrong star selection and time wasting, due to noise selection instead of a star. In this algorithm an intelligence method of star indexing is proposed.
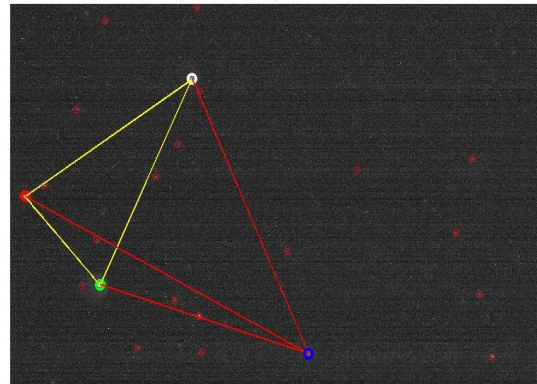

Figure 2. The extracted pyramid in real image

Now the existing star's ID in the image could be extracted using, K-Vector searching method [4],[1]. Then, related vectors in the reference coordinate will be extract from the catalog, based on detected stars from previous step. Therefore, attitude determination could be obtained.

Tracking Algorithm
Tracking Sequence

According to lack of satellite body speed information in this project, and also save the autonomy of the star tracker, a new tracking algorithm without need to speed information is developed and designed. sequence for tracking algorithm is as below:

1. All neighbors for detected stars (pivot star) will be extracted from the catalog.
2. The stars which are able to be in the image are determined, according to attitude determination in lost in space mode (or previous tracking step) and optical geometry of the star tracker. A window will be created surrounding each possible star. The dimensions of this window are relative to maximum angular velocity of the satellite and also relative to pixel to angle ratio.
3. A new image is captured from stars.
4. The new image is searched for a star in detecting window and center of the stars are obtained by using centroiding algorithm.
5. If the pivot star was also in the new image, the angles between this star and the other determined stars are calculated and if this calculated angle was in the measurement tolerance of the star tracker, the determined stars recognized as real star. If the pivot star

was not in the new image, one of the other stars is chose as the pivot star.

6. By using the detected stars pointing vector in body frame and pointing vector in reference frame in catalog, the attitude determination[3] is performed.
7. Steps 1 to 6 will be repeated.

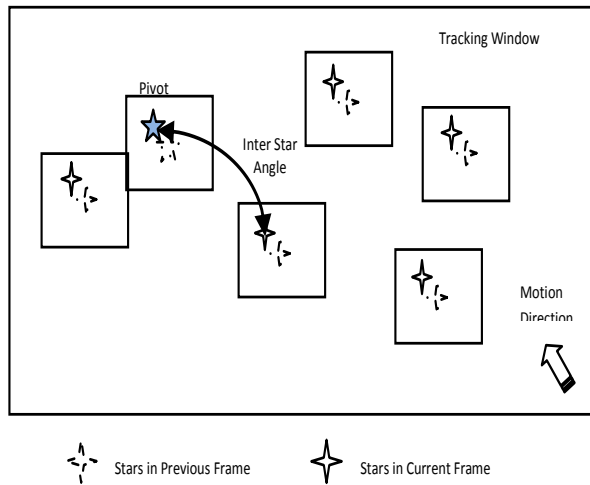Stars movement across the image and detecting windows is shown in Figure 3.

Figure 3. Stars movement across the image and windows

Detection Window

For determining the size of detecting window, at first transfer ratio between the angle and each pixel should be calculated from following equation:

$$\varepsilon = \frac{\text{Row Pixel}}{\text{FOV}_y} \qquad (1)$$

Then, with equation (2) the size of detecting window can be obtained:

$$w_{size} = \varepsilon \omega t_{samp} \qquad (2)$$

Where ω is angular velocity of the satellite and t_{samp} is sampling time or updating time of the star tracker image.

To limiting number of the stars which making a pair with pivot star, we will calculate four corner vectors of image sensor and the stars that able to be in image plane(Star Tracker field of view) will be specified based on following calculation.

According to Figure 4, four vectors of b1, b2, b3 and b4, which determine the coordinates of the four corners of the image are specified.
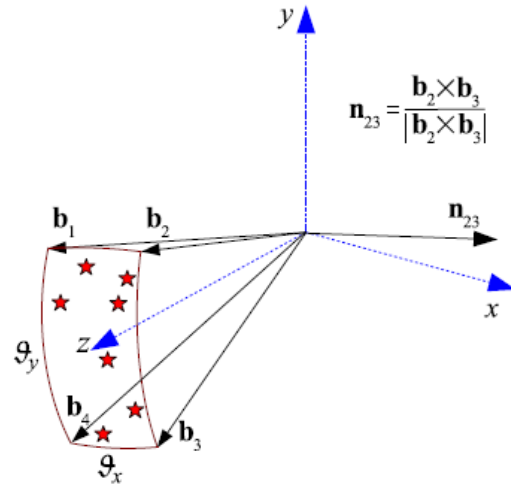

Figure 4. Characteristic vectors of the four corners of the sensor frame

The angle between star's pointing vector, b_k, and perpendicular vectors to each plane of the star tracker body is investigated to recognize if a specific star is in the FOV or not. It means if n_{ij} is perpendicular to the vectors of b_i and b_j or:

$$n_{ij} = \frac{(b_i \times b_j)}{\|(b_i \times b_j)\|} \qquad (3)$$

Then the star of b_k is in the FOV, if and only if

$$b_k^T n_{12} < 0, b_k^T n_{23} < 0, b_k^T n_{34} < 0, b_k^T n_{41} < 0 \qquad (4)$$

Perpendicular vectors to the star tracker body could be calculated, using attitude determination matrix. Using equation (4) and the stars catalog, the stars frame will be obtained in any desired time. Now if the pivot star was not in the image, another star chose as pivot star.

The detecting windows taken into account with center of detecting stars coordinate. After taking a new image, looking for stars will be performed only in the detecting windows area and if the new stars were detected, the center coordinates of them will be calculated. The angle between detected star and the pivot star is calculated and compared according to the catalog for verification. If the tolerance was acceptable the star is tracked.

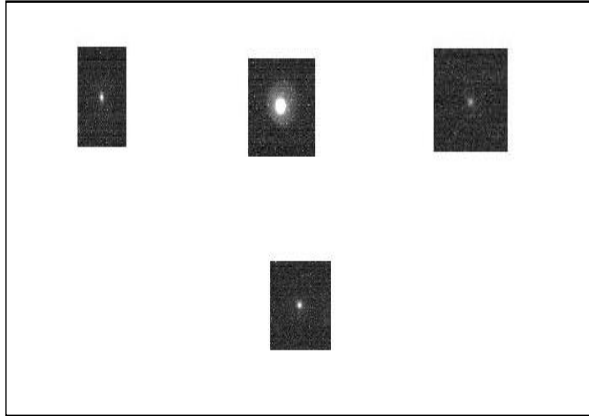In figure 5 you can see the detecting windows for real image.

Figure 5.   Real image of the stars in detecting windows

Test Result

The star tracker test was performed around the mountainous Desert area of NATANZ in central Iran. The fabricated photograph of designed star tracker, ROJA1, is shown in Figure 9. A part of star detecting algorithm results, using lost in space algorithm is shown in Table 3.

Table 3. A part of star detecting algorithm results (Test Date: Midnight of October 18, 2012)

Star ID1	Star ID2	Star ID3	Star ID4
10959	109556	110103	109972
2			
11538	116187	115806	115915
9			
15863	17358	16335	16826

Detected stars in the real image and its corresponding pyramid are shown in Figure 6.
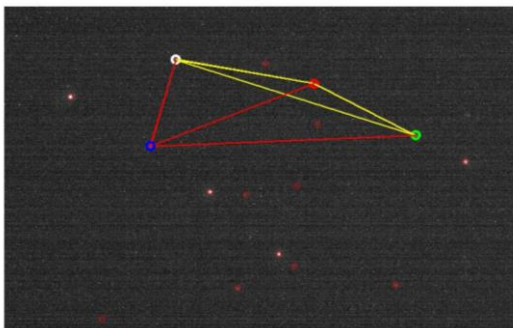

Figure 6.   Real image of the Detected stars

Cause of limitation of making perfect simulation of stars field in laboratory, Earth angular motion is used for verification of tracking algorithm. The result of test is illustrated in Figure 8 and Figure 9. Right ascension change rate is equal to 0.00455

deg/sec. the real earth Right ascension change rate is equal to 0.004166 deg/sec, then system error, is equal to:

$$\text{Angular Rate} = \frac{13.67 - 12.76}{200} = 0.00455$$

$$\text{deg}/_{\text{Sec}} \qquad (5)$$

$$\text{error} = 0.00455 - 0,004166$$
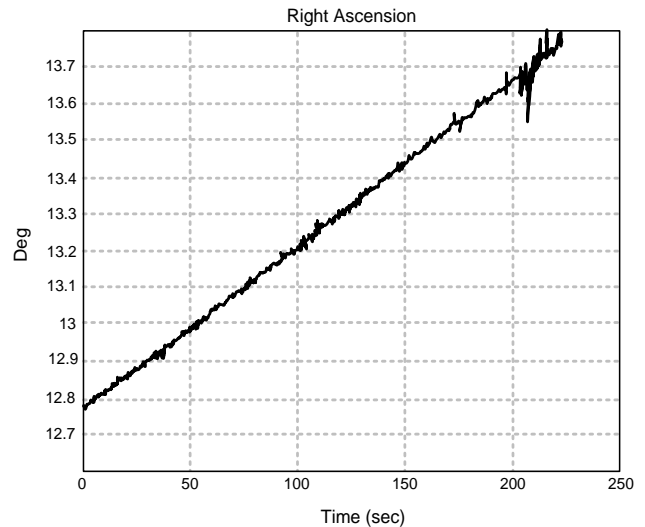$$= 0.000384 \, \text{deg}/_{\text{sec}} \quad (6)$$

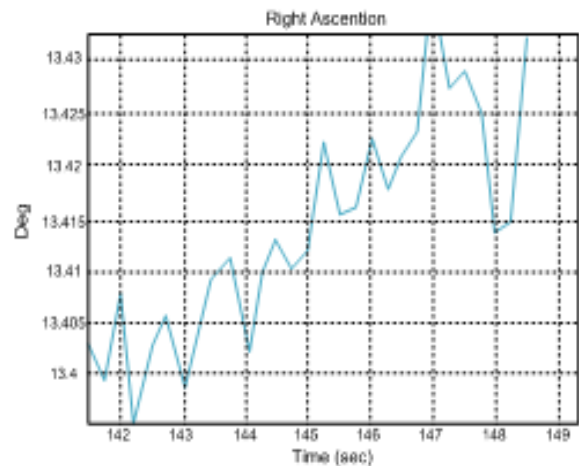**Figure 7. Earth right ascension change rate versus time.**

Figure 8. Earth Right Ascension Measurement uncertainty

Conclusion

A new gyro-less tracking method is presented, which leads faster and more accurate attitude determination. For verification the presented

algorithm was realized and tested on the fabricated star tracker (ROJA1) in Nanoptronics research center. The presented technique for tracking mode does not need speed information which causes reducing in cost, weight and also improves autonomous operation of star tracker from the satellite. The star tracker was tested the mountainous desert area. measured Earth Right ascension change rate is equal to 0.00455 deg/sec. the real earth Right ascension change rate is equal to 0.004166 deg/sec. the average of variation or measurement uncertainty is equal 0.005 degree or 18 arcsec. The fabricated star tracker test shows good performance which could be used in desired space missions.

Identification Algorithms,Journal of IEEE Transactions on Aerospace and Electronic Systems, Vol. 41, No. 4, 1246-1254, October 2005

Figure10. The fabricated Roja1 star tracker

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