Section
Satellite Communications, Navigation Systems and Technologies

A NEW FAST ALGORITHM FOR MICRO-SATELLITE ATTITUDE DETERMINATION BASED ON PANORAMIC ANNULAR LENS

Chen Lu, Wang Hao, Wang Bendong
Micro-Satellite Research Center, Zhejiang University, Hangzhou, China
E-mail:lynlur@163.com

Abstract: A new fast attitude determination algorithm based on panoramic annular lens has been developed. The panoramic annular lens is used as the static infrared sensor, which forms a large field of view to get the infrared image of the Earth. The algorithm of PAL projects the image points onto the virtual earth formatting a space circular loop. The points on this loop are used to construct the spatial vectors. Through the cross product of these spatial vectors, the micro-satellite direction vector can be estimated. This algorithm abandons the iterative process, which reduces the calculation time to meet the demand of rapid maneuver of micro-satellite.

Keywords: micro-satellite, attitude determination algorithm, static infrared earth sensor.

Introduction

Nowadays, the typical micro-satellite attitude determination algorithm of infrared earth sensors consists of Hough transformation and Least Squares fitting [1], and its iteration process is inevitable. Although the accuracy is increased, it takes a large amount of computation time and poses a serious problem for the rapid movement of micro-satellite [2–4]. In this research, a new attitude determination method of a panoramic annular lens (PAL) sensor has been developed which compensates the distortion and reduces the operation time. The PAL is used to construct the static infrared sensor, which forms a large field of view to get the infrared image of the earth. Then this algorithm projects the image points onto the virtual Earth, and the points are divided into different groups to construct the spatial vectors. Through the multiplication cross, a set of satellite direction vectors is obtained. The micro-satellite direction vectors are distributed normally, thus micro-satellite attitude angle can be estimated by the average number of direction vectors according to maximum probability. The experimental results show the improvement of new algorithm performance.

Spatial vector algorithm

The static infrared earth sensor testing system is shown in Fig.1. The PAL is used as the static infrared sensor [5, 6], which forms a large field of view to get the infrared image of the earth. Upper computer sends the rotation angle to the rotary table, and then the PAL obtains infrared earth images at different angles. Through the processing of DSP the infrared earth image data are transferred back to the upper computer.

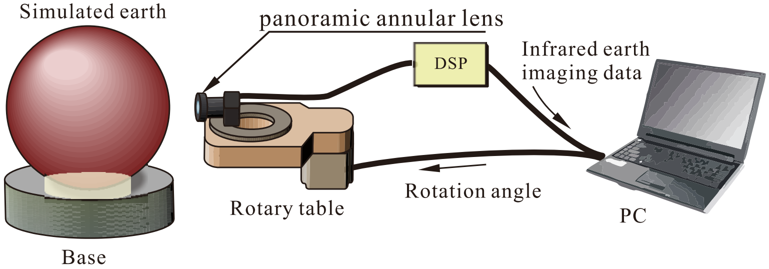

Fig.1. Static infrared earth sensor testing system.

The imaging principle of PAL sensor is

$$y = f \cdot \theta \tag{1}$$

The imaging of PAL sensor is positively correlated with angle θ. Therefore, no matter what direction the sensor moves, the earth imaging faces are the same, as shown in Fig.2.

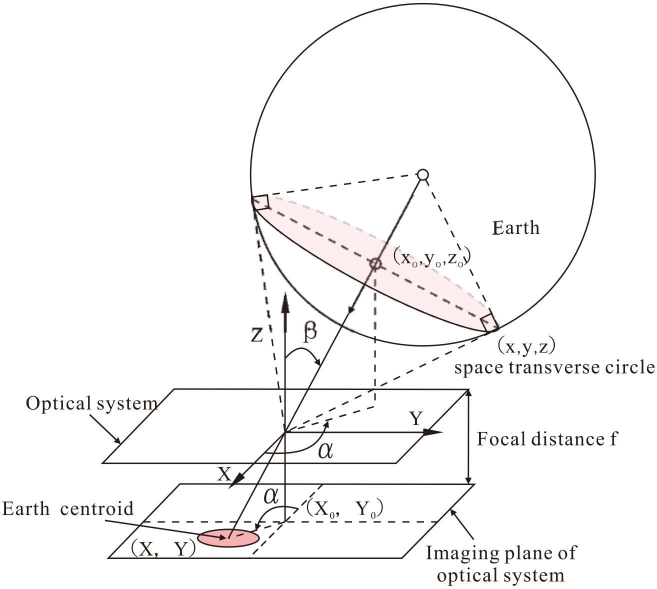

Fig.2. Diagrammatic sketch of PAL imaging.

The imaging point on the imaging plane of the optical system is (X, Y), and the goal of the system algorithm is to obtain β values by means of (X, Y).

According to the lens imaging formula (1) there is

$$\sqrt{X^2+Y^2} = f \cdot \theta \tag{2}$$

Then the relationship between the coordinate of imaging position and the three-dimensional direction of infrared imaging can be obtained.

$$x = R\sin(\theta)\frac{X}{\sqrt{X^2+Y^2}} \tag{3}$$

$$y = R\sin(\theta)\frac{Y}{\sqrt{X^2+Y^2}} \tag{4}$$

$$z = R\cos(\theta) \tag{5}$$

The mapping points of the optical imaging points (X, Y) to the sphere can be represented as points (x, y, z), and the mapping result is a cross section circle.

The space transverse circle is obtained from the distortion of the imaging point, as shown in Fig.3.

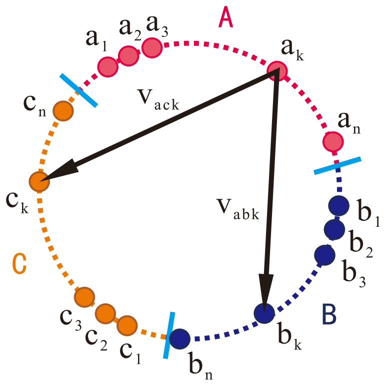

Fig.3. Space transverse circle.

The spatial transverse loop is mapped by the earth's infrared imaging points, and it can be divided into three parts A, B and C. Each part contains n image points, thus three parts can be represented as three sets A= $\{a_1,a_2,a_3\ldots a_n\}$, B= $\{b_1,b_2,b_3\ldots b_n\}$ and C= $\{c_1,c_2,c_3\ldots c_n\}$.

Three points a_k, b_k and c_k are selected from three sets, then we connect them together to get two vectors $\mathbf{v_{abk}}$ and $\mathbf{v_{ack}}$ called a spatial vector pair. There can be at least n spatial vector pairs, and they are in the same plane, and that is exactly the spatial transverse plane.

Vectors v_{abk} and v_{ack} are distributed in the same plane, and they are not on the same line. According to vector theory, we can get

$$D=\left\{\mathbf{d}\mid\mathbf{d_k}=\mathbf{v_{abk}}\times\mathbf{v_{ack}},\mathrm{k}=1,2\ldots\mathrm{n}\right\} \tag{6}$$

$\mathbf{d_k}$ is perpendicular to the plane of vectors $\mathbf{v_{abk}}$ and $\mathbf{v_{ack}}$, and that is the desired direction vector. In the same way, at least n directional vectors $\mathbf{d}\in D$ can be obtained, which are parallel to each other and perpendicular to the spatial transverse loop.

Then the angle β can be calculated

$$\mathrm{Bt}=\left\{\beta\mid\beta=\arccos\left(\frac{z_d}{|\mathbf{d}|}\right),\mathbf{d}=(x_d,y_d,z_d)\in D\right\} \tag{7}$$

But in fact, the result of distortion is that all the image points are not distributed in the same plane totally, which causes a little difference in angle β. And it is near normal distribution. In order to solve the problem, the angle β value of the maximum probability near the median is taken, and taking an average of them allows to estimate a more accurate angle β.

In order to obtain higher precision positioning, the traditional algorithm repeats the Hough transform and least squares fitting to remove the noise points. The k-th calculated distance between cross sectional and imaging center of sphere can be recorded as $r_{k.}$ Until the difference between r_k and r_{k-1} is less than the rated value, the iteration process stops and the corresponding β value is output. However, due to the Hough transformation, the least square method, and the iterative process, the calculation becomes pretty complicated, and usually consumes a large amount of time.

Experimental results and analysis

The t Actual measurement scene is shown in Fig.4. The turntable is rotated from -10 degrees to 10 degrees, and PAL takes infrared images of the earth at different angles.

Fig.4. Actual measurement scene.

The resulting data is processed by different algorithms. And the angle β between the image axis and the geocentric vector is obtained, as shown in Fig.5.

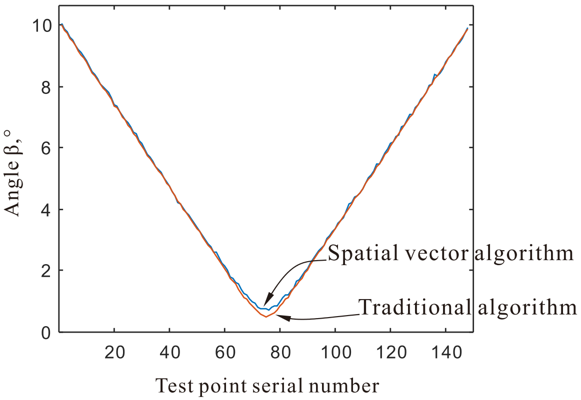

Fig.5. Angle β test results.

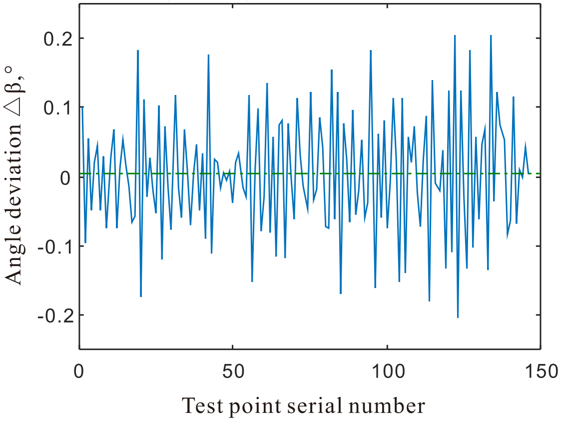

Fig.6. Angle deviation Δβ test results.

The experimental results show that the satellite attitude angles β derived from two algorithms are generally the same, and there is a small deviation near zero. Detailed performance comparisons are shown in the table 1

As shown in the Table 1, the accuracy of new algorithm is almost the same as traditional one, but the new algorithm can improve the efficiency up to nearly 94%.

Table 1. Results of convergence step length

Algorithm	**Average deviation, °**	**Standard variance**	**Computation time, second**
Traditonal	0.035	0.046	0.354
Spacial vector	0.024	0.082	0.018

Conclusions

This paper presents a new fast algorithm for micro-satellite attitude determination based on PAL. It was shown that the new fast algorithm, namely Spatial vector algorithm, discards the iterative process of the traditional algorithm, but calculates the attitude angle with the vector cross product. The experimental results show that the pose accuracy of this algorithm is about 0.03 degree, and it can improve the efficiency up to nearly 94%. This helps to achieve more accurate and rapid control of micro-satellites.

References

1. Shen G, Wang H, Guo Z, et al. Design of infrared static focal plane earth sensor for micro-satellite // Chinese Journal of Sensors & Actuators, 2012, 25(5):571-576.
2. Xin L I, Cui W N, Zhou S B. Wide Angle Attitude Measuring Model and Error Analysis of Static-infrared Earth Sensor // Infrared Technology, 2015, 37(1):73-77.
3. Zhang X L, Li F, Zhao J H. New Test System of Infrared Earth Sensor // Applied Mechanics & Materials, 2015, 789-790:536-539.
4. Harry Gross, Carol Bruegge, and Mark Helmlinger. Unattended Vicarious Calibration of a Low Earth Orbit Visible-Near Infrared Sensor // AIAA SPACE 2007 Conference & Exposition, AIAA SPACE Forum, doi.org/10.2514/6.2007-6088
5. Liu B, Meng L, Hua C. Sensitivity analysis of thermal design of infrared earth sensor for GEO satellites // Spacecraft Environment Engineering, 2013. 30(3):240-244.
6. Wang H, Xing F, You Z, et al. Study of high-precision earth sensor with triple-FOV // Instrumentation, 2014, 1(2):23-29.