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Technology for determining the local vertical of nanosatellite by processing videoimages of the Earth horizon

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Abstract: This paper describes the algorithm for determining the local vertical for nanosatellite, based on the sight of the horizon of the Earth in the visible wavelength range. The application of this algorithm will allow determining the direction of the local vertical to within 1 degree. The results of numerical experiments show that the proposed algorithm works in a wide range of orientation angles. The article also examines the semi-natural experiment to determine the pitch angle by processing the video coming from the camera. The experiment showed that the horizon sensor based on this algorithm would have an accuracy less than 1 degree in the area of ± 20 degrees pitch and ± 20 degrees yaw.

Keywords*:* nanosatellite, video navigation, the algorithm, image processing, attitude determination.

1. INTRODUCTION

Every year the number of nanosatellites is constantly increasing, so expands and the range of problems they can solve. One of this problems is the remote sensing of the earth. This problem requires the maintenance of a high-precision orientation of sensitive equipment relative to the local vertical. For example for a 500 km altitude orbit, 0.51 attitude control accuracy translates into approximately 4.5 km of spatial uncertainty on ground (Selva, D(2012)). Typically, this class of spacecraft has on-board inertial sensors that have integral error, so in solving problems of remote sensing, the role of non-inertial sensors, such as the horizon sensor, a star sensor, sun sensor is increasing. This article covers the creation of algorithm based on image processing of the Earth horizon. The purpose of the algorithm is to provide a direction vector of the local vertical by the analysis of two contemporary obtained images of Earth horizon.

The proposed algorithm is different from the known that the calculated vector is invariant to the horizontal displacement of the image and nanosatellite rotation around the longitudinal axis, and also does not depend on focal distance of the camera.

In the second part is a brief description of the algorithm, as well as technical systems on which it can be implemented.

In the third part describes the mathematical modeling of the algorithm and key results.

In the fourth part describes the conduct of the experiment and compare the data obtained from the simulation data.2.

2. ALGORITHM OF VIDEONAVIGATION AND HORIZON SENSOR DESIGN

2.1 Algorithm of videonavigation

The algorithm for determining the direction of the local vertical is as follows:

• The image obtained from the camera stands out the horizon line, which is a circular arc;

• Determine the center and the radius of the arc of a circle;

• Construct the line connecting the center of the resulting arc to the center of the frame;

• To construct the normal line;

• The same procedure is performed and the second camera;

• The cross product gives the desired normal vector direction of the local vertical in the associated coordinate system;

It should be noted that the line connecting the center of the arc resulting from the center of the frame is the trace of the plane that passes through the Earth's center, center of mass of the satellite and perpendicular to the plane of the camera frame. Thus the intersection of two such planes gives a line passing through the center of the Earth and the center of mass of the satellite, that is, the local vertical.

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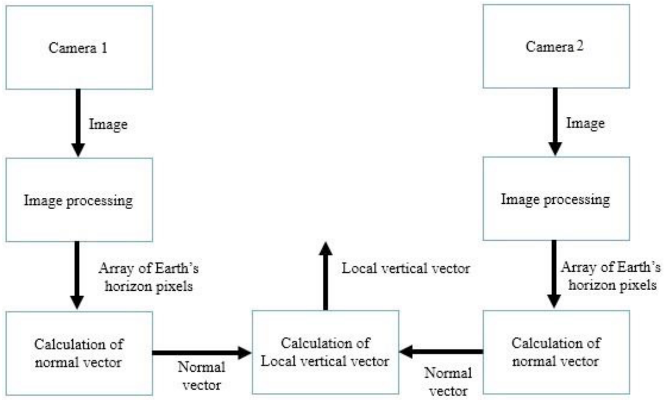

Fig. 1. Algorithm scheme

The input data for the calculation of the normal vector is an array of pixels, describing the border Earth - space, obtained by processing the image by Canny edge detector. At first arc selected three points - two outer points $P_1(x_1, y_1)$, $P_3(x_3, y_3)$, and one inner $P_2(x_2, y_2)$. Then the coordinates of the arc center are determined (x_c, y_c) and radius R_c (fig. 2)

$$m_a = y_2 - \frac{y_1}{(x_2-x_1)}, \tag{1}$$

$$m_b = y_3 - \frac{y_2}{(x_3-x_2)}, \tag{2}$$

$$x_c = \frac{m_a \cdot m_b \cdot (y_1-y_2) + m_b \cdot (x_1+x_2) - m_a \cdot (x_2-x_1)}{2 \cdot (m_a - m_b)}, \tag{3}$$

$$y_c = -\frac{1}{m_a} \cdot \left(x_c - \frac{x_1-x_2}{2}\right) + \frac{y_1-y_2}{2}, \tag{4}$$

$$R_c = \sqrt{(x_c + x_2)^2 + (y_c + y_2)^2}, \tag{5}.$$

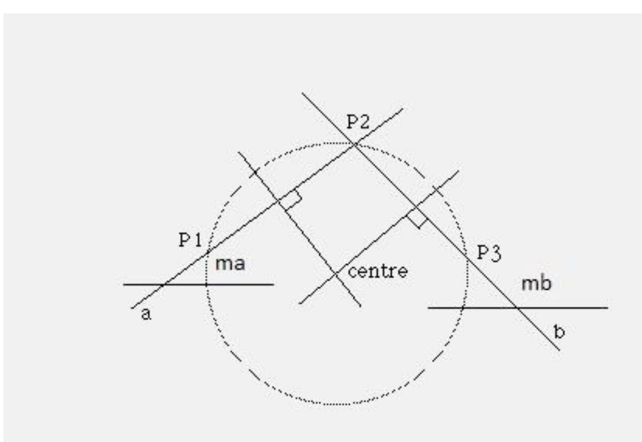

Fig. 2. Determination of the center.

After that, you need to connect the center of the arc to the center of the frame with a line, which is described by the equation:

$$y = kx + m \tag{6}$$

Where *k* and *m* coefficients that are calculated according to the formulas:

$$k = \frac{y_k - y_c}{x_k - x_c} \tag{7}$$

$$m = y_c - \frac{y_k - y_c}{x_k - x_c} \cdot x_c \tag{8}$$

Transform equation (6) to the form $A(x - x_0) + B(y - y_0) = 0$, where A and B - of the vector perpendicular to a given line that you want to find. To find A and B equate $x_0 = x_c$, $y_0 = y_c$ and form a system of linear equations

$$\begin{cases} A(x_1 - x_c) + B(y_1 - y_c) = 0 \\ A(x_2 - x_c) + B(y_2 - y_0) = 0 \end{cases} \tag{9}$$

where (x_1, y_1) и (x_2, y_2) - the coordinates of two random points, calculated according to the formula 6).

2.2 Horizon sensor design

Prospective embodiment of the system is shown on Figure 3. It is a device consisting of a photodetector and a circuit board with onboard computing device. The photodetectors are positioned so that their sight axis perpendicular to each other and lie in a plane orthogonal to the longitudinal axis of the nanosatellite to acquire images in the associated with the satellite coordinate system.

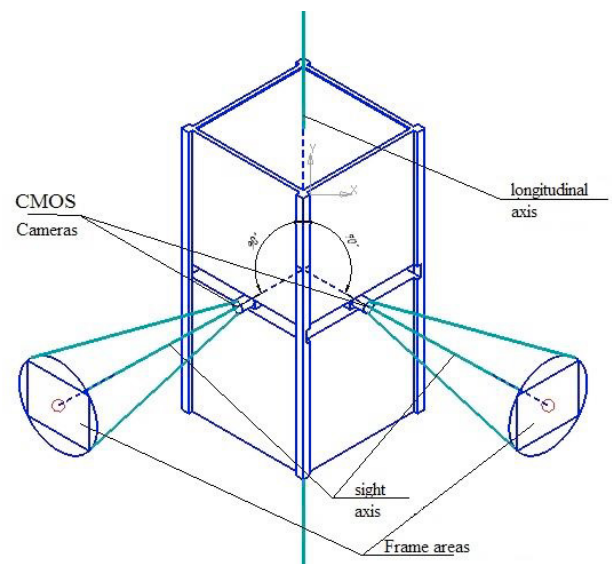

Fig. 3. Horizon sensor design.

3. SIMULATION OF THE ALGORITHM

The nanosatellite is located at orbit with altitude H above the Earth. Accepted assumption that the Earth is a sphere, described by the equation:

$$x^2 + y^2 + z^2 = R^2 \tag{10}$$

At the nanosatellite are located two identical photodetectors which receive two simultaneous snapshots of the Earth horizon. Axis sight unit vector is describing photodetectors, and (in the geocentric coordinate system), respectively. Snapshots have a resolution $n \times m$ of pixels.

The projection of the Earth's horizon to the plane of the photodetector is an arc of a circle, which is described by parametric equations: