ON-BOARD ALGORITHM FOR NANOSATELLITE ORIENTATION AND STABILIZATION SYSTEM

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Now the nanosatellites of CubeSat standard are widely-spread. At the Samara State Aerospace University work on developing of the such nanosatellite is in progress. The main objectives of the nanosatellite are its motion dynamics studying and orientation and stabilization algorithm workout, using the built-in measuring and actuating means which are a part of on-board modules: the three-axis magnetometer placed on the on-board computer; Sun sensors, the angular-rate sensors placed on solar battery panels; magnetic coils.

The limitations imposed by accepted structure of measuring and actuating means, and also the on-board computer performances, form rigid requirements of the orientation and stabilization algorithm computing complexity. As the nanosatellite will be orientated along the vector of orbital motion rate, the spatial orientation determination problem is reduced to a problem of nanosatellite longitudinal axis orientation determination, i.e. determination of pitch angle (ϑ) and yaw angle (ψ), and the problem of controlling is reduced to a problem of dual-channel controlling.

In solving the formulated problems the frames of references shown in Fig.1 are used [1]. The axes of orbital frame of reference $OX_gY_gZ_g$ with the origin in the centre of mass O of the moving nanosatellite are directed as follows: OY_g is along the radius-vector $\vec{\rho}$ from center of Earth to the nanosatellite center of mass, OX_g is perpendicular to OY_g, in the plane of orbit and directed along the flight direction, OZ_g is along the bi-normal to the orbit and build the right frame of reference with other two axes. The body frame of reference is chosen in such a way that its axes coincided with the main central axes of inertia of the nanosatellite. The origin of the body frame $OXYZ$ is located in the nanosatellite centre of mass; OX is directed forward along the NS longitudinal axes, OY is placed in the NS plane of symmetry and is directed upward along the normal, OZ build the right frame of reference with other two axes.

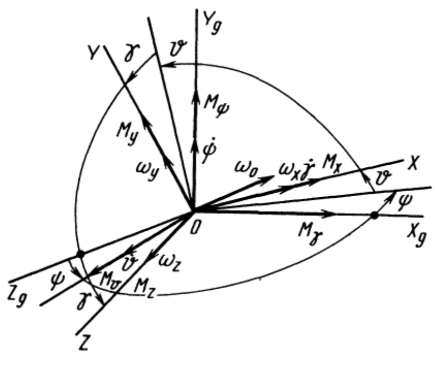

Fig. 1 – The scheme of rotation angles in going from the orbital to the body frame of reference

The scheme of solving the formulated problems is shown in Fig. 2.

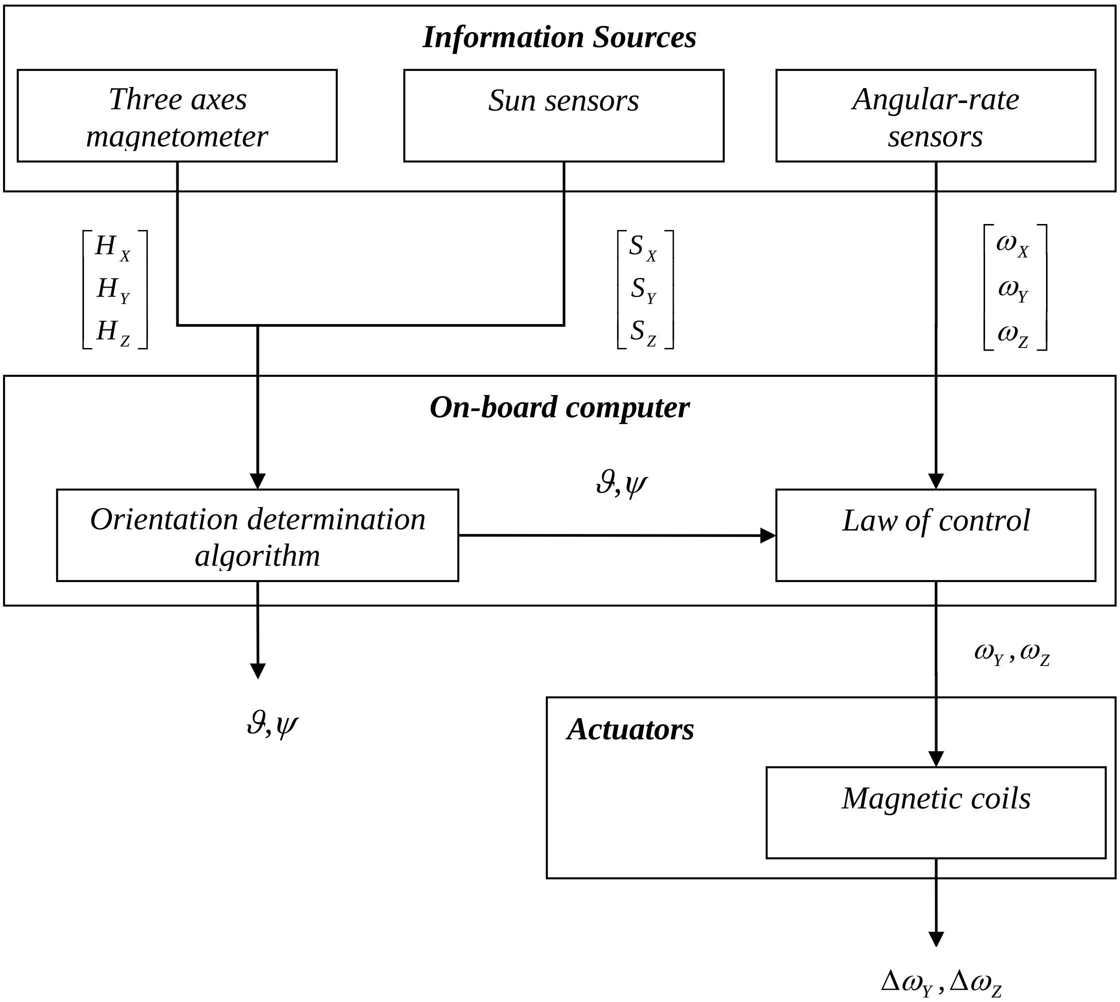

Fig. 2 – The scheme of solving the formulated problems

In fig. 2 the following designations are accepted:

$[H_X \quad H_Y \quad H_Z]^T$ - the components of Earth magnetic vector;

$[S_X \quad S_Y \quad S_Z]^T$ - the components of current vector from the solar battery panels; $[\omega_X \quad \omega_Y \quad \omega_Z]^T$ - the projections of the nanosatellite momentary angular rate;

$\Delta\omega_Y, \Delta\omega_Z$ - the change of the values of the projections of the nanosatellite angular rate after the control input.

As the orientation determination algorithm the two-vector algorithm of the nanosatellite angular location determination is chosen [2]. There are the components of the **S** and **H** vectors in the body and orbital frames of reference at every moment. They are connected by the following relations:

$$\begin{vmatrix} S_X \\ S_Y \\ S_Z \end{vmatrix} = \mathbf{A}\begin{vmatrix} S_{Xg} \\ S_{Yg} \\ S_{Zg} \end{vmatrix}; \quad \begin{vmatrix} H_X \\ H_Y \\ H_Z \end{vmatrix} = \mathbf{A}\begin{vmatrix} H_{Xg} \\ H_{Yg} \\ H_{Zg} \end{vmatrix}. \tag{1}$$

The transfer matrix from orbital to body frame of reference is presented as follows:

$$\mathbf{A_1} = \begin{bmatrix} \cos\psi\cos\vartheta & -\sin\vartheta & -\sin\psi\cos\vartheta \\ -\sin\gamma\sin\psi + \cos\gamma\cos\psi\sin\vartheta & \cos\gamma\cos\vartheta & -\sin\gamma\cos\psi - \cos\gamma\sin\psi\sin\vartheta \\ \cos\gamma\sin\psi + \sin\gamma\cos\psi\sin\vartheta & \sin\gamma\cos\vartheta & \cos\gamma\cos\psi - \sin\gamma\sin\psi\sin\vartheta \end{bmatrix} \tag{2}$$

The unit axes are

$$\mathbf{p}=\mathbf{H};\quad \mathbf{q}=\frac{\mathbf{H}\times\mathbf{S}\times\mathbf{H}}{|\mathbf{H}\times\mathbf{S}|};\quad \mathbf{r}=\frac{\mathbf{H}\times\mathbf{S}}{|\mathbf{H}\times\mathbf{S}|}. \tag{3}$$

The transfer matrices $\mathbf{M_1}$, $\mathbf{M_2}$ from secondary frame of reference *Opqr* to orbital and body frame of reference relatively are

$$\mathbf{M}_1^{\mathrm{T}}=\frac{1}{|\mathbf{H}\times\mathbf{S}|}\begin{vmatrix} H_X|\mathbf{H}\times\mathbf{S}| & H_Y|\mathbf{H}\times\mathbf{S}| & H_Z|\mathbf{H}\times\mathbf{S}| \\ S_X-H_X(\mathbf{H},\mathbf{S}) & S_Y-H_Y(\mathbf{H},\mathbf{S}) & S_Z-H_Z(\mathbf{H},\mathbf{S}) \\ H_YS_Z-H_ZS_Y & H_ZS_X-H_XS_Z & H_XS_Y-H_YS_X \end{vmatrix};$$

$$\mathbf{M}_1^{\mathrm{T}}=\frac{1}{|\mathbf{H}\times\mathbf{S}|}\begin{vmatrix} H_{Xg}|\mathbf{H}\times\mathbf{S}| & H_{Yg}|\mathbf{H}\times\mathbf{S}| & H_{Zg}|\mathbf{H}\times\mathbf{S}| \\ S_{Xg}-H_{Xg}(\mathbf{H},\mathbf{S}) & S_{Yg}-H_{Yg}(\mathbf{H},\mathbf{S}) & S_{Zg}-H_{Zg}(\mathbf{H},\mathbf{S}) \\ H_{Yg}S_{Zg}-H_{Zg}S_{Yg} & H_{Zg}S_{Xg}-H_{Xg}S_{Zg} & H_{Xg}S_{Yg}-H_{Yg}S_{Xg} \end{vmatrix}. \tag{4}$$

Using matrices $\mathbf{M_1}$ and $\mathbf{M_2}$, let's find the transfer matrix from orbital to body frame of reference. The result is

$$\mathbf{A}_2=\mathbf{M}_1\mathbf{M}_2^{\mathrm{T}} \tag{5}$$

The angles ϑ,ψ are found using the matrices $\mathbf{A}_1$ and $\mathbf{A}_2$ by well-known trigonometric relations.

In this problem as the control object appears the model of nanosatellite angular motion [1]:

$$\begin{cases} I_x\dot{\omega}_x-(I_y-I_z)\omega_y\omega_z=-M_{x\text{у}}+M_{x\text{в}} \\ I_y\dot{\omega}_y-(I_z-I_x)\omega_x\omega_z=-M_{y\text{у}}+M_{y\text{в}} \\ I_z\dot{\omega}_z-(I_x-I_y)\omega_x\omega_y=-M_{z\text{у}}+M_{z\text{в}} \end{cases} \tag{6}$$

where $\begin{bmatrix}I_X & I_Y & I_Z\end{bmatrix}^T$ - the main central moments of inertia about the relative axes, $\begin{bmatrix}M_{x\text{у}} & M_{y\text{у}} & M_{z\text{у}}\end{bmatrix}^T$ and $\begin{bmatrix}M_{x\text{в}} & M_{y\text{в}} & M_{z\text{в}}\end{bmatrix}^T$ - the projections of controlling and disturbing moments on the relative axes.

As the controlling moment let's take the moment from magnetic coils [3]:

$$\mathbf{M}_{\mathbf{у}}=\mathbf{L}\times\mathbf{H} \tag{7}$$

where $\mathbf{L}$ - the dipole moment of the magnetic coil.

In general the disturbing moment could be written as follows [3]:

$$\mathbf{M}_{\mathbf{в}}=\mathbf{M}_{\mathbf{г}}+\mathbf{M}_{\mathbf{а}}+\mathbf{M}_{\mathbf{с}}+\mathbf{M}_{\mathbf{м}} \tag{8}$$

where $\mathbf{M}_{\mathbf{г}},\mathbf{M}_{\mathbf{а}},\mathbf{M}_{\mathbf{с}},\mathbf{M}_{\mathbf{м}}$ - the vectors of disturbing moments of gravity, aerodynamics, solar radiation pressure and from the Earth magnetic field relatively. In solving the formulated problems we will take into account only gravitational and aerodynamic disturbing moments.

The anticipated accuracy of solving the problems: in the nanosatellite orientation determination problem it will be 10°; in the nanosatellite orientation control problem it will be ± 5°.

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References

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