Optimizing the Spacecraft Guidance Laws at the Earth Optoelectronic Observation*

Ye.I. Somov *, **S.A. Butyrin** *, **A.V. Butko** *

* *Samara Scientific Center, Russian Academy of Sciences (RAS),*
3a Studenchesky Lane, Samara 443001 Russia
(e-mail: e_somov@mail.ru)

Abstract: Obtained in the space photos a ground resolution depends on a spacecraft (SC) spatial angular motion during optoelectronic survey. The paper examines case of optimal equalization of an image longitudinal velocity in the focal plane of telescope and tackles the problem of defining initial azimuth of the scanning survey under the condition of minimizing quadratic functional of image cross velocity values on the left and right edges of the CCD linear array. Results of a simulated survey of random surface object are presented, and the change of initial azimuth value for various survey angles within the swath is examined. The paper presents a brief description of developed software for designing the space telescope characteristics and gives recommendations for its application.

Keywords: spacecraft, guidance, optoelectronic observation, optimization

1. INTRODUCTION

Resolution of onboard telescope depends to a big extent on a remote sensing SC's spatial angular motion along the survey route. To obtain a high quality image it is reasonable to calculate the image longitudinal velocity (ILV) V_y^i in a telescope focal plane (Butyrin, 2007). It
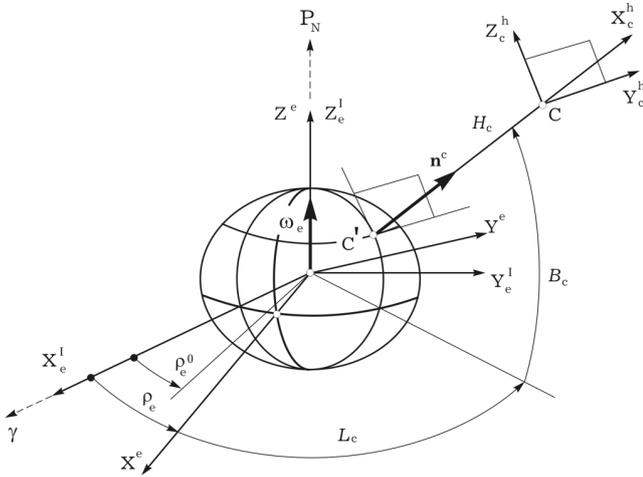

Fig. 1. The bases $\mathbf{I}_\oplus$, $\mathbf{E}_e$ and $\mathbf{E}_e^h$

is also necessary that for an image cross velocity (ICV) V_z^i the condition $|V_z^i| \leq V_d^i$ was fulfilled, where V_d^i is a constant value. Non-fulfillment of this condition may lead to a blurred image due to a disturbed process of charge accumulation in the CCD array. In object survey (short en-route way) the only free parameter is the survey azimuth A_0 which considerably affects the ICV on the edges of linear array of optoelectronic converters (OECs) by the CCD matrices.
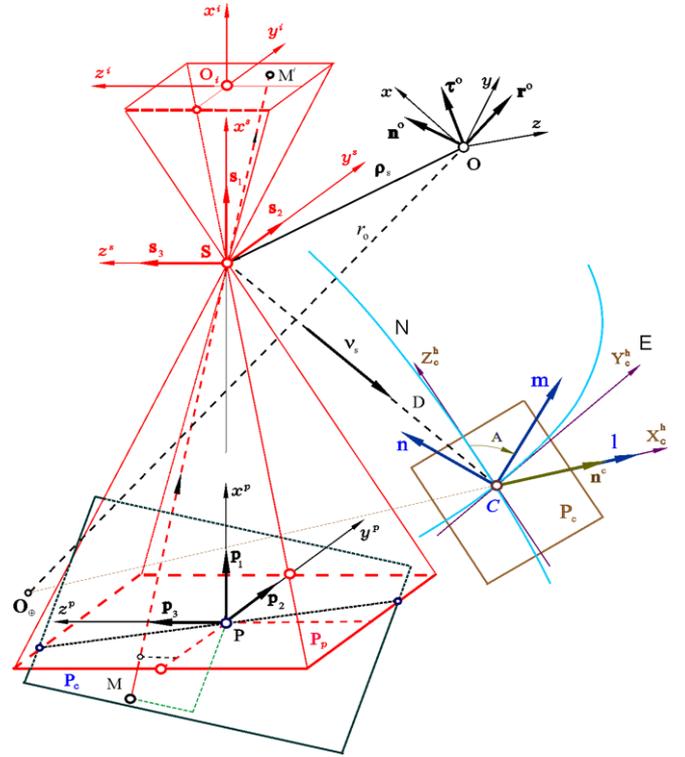

Fig. 2. The reference frames

2. THE PROBLEM STATEMENT

We use the following bases and reference frames:

- the inertial reference frame (IRF) $\mathbf{I}_\oplus = \{\mathbf{i}_1, \mathbf{i}_2, \mathbf{i}_3\}$ $(O_\oplus X_e^I Y_e^I Z_e^I)$ of the present time, Fig. 1;
- geodesic Greenwich reference frame (GRF) $\mathbf{E}_e$ $(O_\oplus X^e Y^e Z^e)$ which is rotated with respect to the IRF by angular rate vector $\boldsymbol{\omega}_\oplus \equiv \boldsymbol{\omega}_e = \omega_\oplus \mathbf{i}_3$, see Fig. 1;
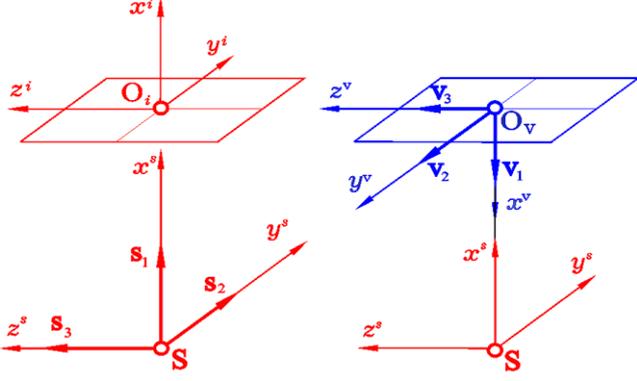
Fig. 3. The bases $\mathcal{S}$, $\mathcal{F}$ and $\mathbf{V}$

- the geodesic horizon reference frame (HRF) $\mathbf{E}_e^h$ ($C\,X_c^h Y_c^h Z_c^h$) with origin in a point C and ellipsoidal geodesic coordinates altitude H_c, longitude L_c and latitude B_c : axis $C\,X_c^h$ is the local vertical, axes $C\,Y_c^h$ and $C\,Z_c^h$ lie in the local horizon plane and directed to local East (E) and local North (N), respectively, Fig. 1 and Fig. 2;
- the body reference frame (BRF) $\mathbf{B} = \{\mathbf{b}_1, \mathbf{b}_2, \mathbf{b}_3\}$ ($Oxyz$) with origin in the SC mass center O;
- the orbit reference frame (ORF) $\mathbf{O} = \{\boldsymbol{\tau}^o, \mathbf{r}^o, -\mathbf{n}^o\}$ ($Ox^o y^o z^o$): axis Oy^o lies in the orbit radius and axis Oz^o points in the negative direction of the orbit normal, see Fig. 2;
- the optical telescope (sensor) reference frame (SRF) $\mathcal{S} = \{\mathbf{s}_1, \mathbf{s}_2, \mathbf{s}_3\}$ (S $x^s y^s z^s$) with origin in point S – the center of optical projection, see Fig. 2 and Fig. 3;
- the image field reference frame (FRF) $\mathcal{F}$ ($O_i x^i y^i z^i$) with origin in center O_i of the telescope focal plane $y^i O_i z^i$, Fig. 3;
- the visual (sighting) reference frame (VRF) $\mathbf{V} = \{\mathbf{v}_1, \mathbf{v}_2, \mathbf{v}_3\}$ ($O_v x^v y^v z^v$) with origin in center O_v of main OEC linear array, see Fig. 3.

The BRF attitude with respect to the IRF is defined by quaternion $\boldsymbol{\Lambda}_I^b \equiv \boldsymbol{\Lambda} = (\lambda_0, \boldsymbol{\lambda})$, $\boldsymbol{\lambda} = \{\lambda_1, \lambda_2, \lambda_3\}$. The BRF attitude with respect to the ORF is determined by Euler-Krylov angles in the sequence of turns around x-axis (roll angle γ), y-axis (yaw angle ψ) and z-axis (pitch angle θ) by the SC body reference frame. Let vectors $\boldsymbol{\omega}(t)$, $\mathbf{r}(t)$ and $\mathbf{v}(t)$ are standard denotations of the SC body vector angular rate, the SC mass center's position and progressive velocity with respect to the IRF.

For simplicity we assume that the SC mass center (O) is the same as optical projection center (S). Axis $O_i x_i$ direction coincides with that of axis $O_v x_v$, e.g. the units $\mathbf{s}_1$ and $\mathbf{v}_1$ are opposite, see Fig. 3. The central linear array with l general length lies in the VRF axis $O_v z^v$ symmetrically to point O_v. Basically, the ILV should be constant along the entire length of the OEC linear array, i.e. $V_y^i(0, z^i) = W_y^i = \text{const} \ \forall \ z^i \in [-l/2, l/2]$. However this condition cannot be strictly fulfilled since the image longitudinal velocity is not linearly related to the coordinates of focal plane points.

Let's introduce notations V_z^{i-} and V_z^{i+} for image cross velocity on the left and right edges of the central linear OEC array, respectively. The problem consists in finding the optimal azimuth of a space survey A_0^o which determines

the minimum of the functional
$$F = (V_z^{i+})^2 + (V_z^{i-})^2 \Rightarrow \min_{A_0} \qquad (1)$$
within permissible angles of the SC attitude relative to the orbital reference frame (ORF).

3. PRINCIPLE RELATIONS

Analytic matching solution have been obtained for problem of the SC angular guidance at a spatial course motion. The solution is based on a vector composition of all elemental motions in the GRF $\mathbf{E}_e$ using next reference frames: the HRF $\mathbf{E}_e^h$, the SRF $\mathcal{S}$ and the FRF $\mathcal{F}$ (Somov, 2008). Vectors $\mathbf{r}(t)$ and $\mathbf{v}(t)$ are presented in the GRF $\mathbf{E}_e$:
$$\mathbf{r}^e = \mathbf{T}_I^e\, \mathbf{r}; \qquad \mathbf{v}^e = \mathbf{T}_I^e\, (\mathbf{v} - [\omega_\oplus \mathbf{i}_3 \times] \mathbf{r}),$$
where matrix $\mathbf{T}_I^e = [\rho_e(t)]_3$ and angle $\rho_e(t) = \rho_e^0 + \omega_\oplus(t - t_0)$, see Fig. 1. Vectors $\boldsymbol{\omega}_e^s$ and $\mathbf{v}_e^s$ are defined as
$$\boldsymbol{\omega}_e^s = \{\omega_{ei}^s\} = \mathbf{T}_b^s(\boldsymbol{\omega} - \tilde{\boldsymbol{\Lambda}} \circ \omega_\oplus \mathbf{i}_3 \circ \boldsymbol{\Lambda}); \quad \mathbf{v}_e^s = \tilde{\boldsymbol{\Lambda}}_e^s \circ \mathbf{v}_o^e \circ \boldsymbol{\Lambda}_e^s,$$
where $\boldsymbol{\Lambda} = \boldsymbol{\Lambda}_I^b$; $\boldsymbol{\Lambda}_e^s = \boldsymbol{\Lambda}_e^I \circ \boldsymbol{\Lambda}_I^b \circ \boldsymbol{\Lambda}_b^s$ and $\dot{\boldsymbol{\Lambda}}_e^s = \boldsymbol{\Lambda}_e^s \circ \boldsymbol{\omega}_e^s / 2$, and constant matrix $\mathbf{T}_b^s$ and quaternion $\boldsymbol{\Lambda}_b^s$ represent the telescope fixation on the SC body.

For any observed point C the oblique range D is analytically calculated as $\mathrm{D} = |\mathbf{r}_c^e - \mathbf{r}^e|$. If orthogonal matrix $\mathbf{C}_h^s \equiv \tilde{\mathbf{C}} = \|\tilde{c}_{ij}\|$ defines the SRF $\mathcal{S}$ attitude with respect to the HRF $\mathbf{E}_e^h$, then for any point $\mathrm{M}(\tilde{y}^i, \tilde{z}^i)$ at the telescope focal plane $y^i O_i z^i$ (see Fig. 2) the components $\tilde{V}_y^i(\tilde{y}^i, \tilde{z}^i) = \dot{\tilde{y}}^i$ and $\tilde{V}_z^i(\tilde{y}^i, \tilde{z}^i) = \dot{\tilde{z}}^i$ of normed vector by an image motion velocity are appeared as
$$\begin{bmatrix} \dot{\tilde{y}}^i \\ \dot{\tilde{z}}^i \end{bmatrix} = \begin{bmatrix} \tilde{y}^i & 1 & 0 \\ \tilde{z}^i & 0 & 1 \end{bmatrix} \begin{bmatrix} q^i \tilde{\mathrm{v}}_{e1}^s - \tilde{y}^i\,\omega_{e3}^s + \tilde{z}^i\,\omega_{e2}^s \\ q^i \tilde{\mathrm{v}}_{e2}^s - \omega_{e3}^s - \tilde{z}^i\,\omega_{e1}^s \\ q^i \tilde{\mathrm{v}}_{e3}^s + \omega_{e2}^s + \tilde{y}^i\,\omega_{e1}^s \end{bmatrix}. \qquad (2)$$
Here normed focal coordinates $\tilde{y}^i = y^i / f_e$ and $\tilde{z}^i = z^i / f_e$, where f_e is the telescope equivalent focal distance; function $q^i \equiv 1 - (\tilde{c}_{21}\tilde{y}^i + \tilde{c}_{31}\tilde{z}^i)/\tilde{c}_{11}$, and vector of normed SC's mass center velocity have the components $\tilde{\mathrm{v}}_{ei}^s = \mathrm{v}_{ei}^s / \mathrm{D}$, $i = 1 \div 3$. For given normed image longitudinal velocity
$$\tilde{\mathrm{W}}_y^i \equiv \mathrm{W}_y^i / f_e = -\tilde{\mathrm{W}}_y^s \equiv -\mathrm{W}_y^s / \mathrm{D} = \text{const}$$
at conditions
$$\tilde{V}_y^i(0,0) = \tilde{\mathrm{W}}_y^i; \quad \tilde{V}_z^i(0,0) = 0; \quad \partial \tilde{V}_y^i(0,0)/\partial \tilde{z}^i = 0,$$
a calculation of vector $\boldsymbol{\omega}_e^s$ is carried out by the relations
$$\omega_{e1}^s = -\tilde{\mathrm{v}}_{e2}^s \tilde{c}_{31}/\tilde{c}_{11}; \quad \omega_{e2}^s = -\tilde{\mathrm{v}}_{e3}^s; \quad \omega_{e3}^s = -\tilde{\mathrm{W}}_y^i + \tilde{\mathrm{v}}_{e2}^s. \qquad (3)$$
By numerical solution of the quaternion differential equation $\dot{\boldsymbol{\Lambda}}_e^s = \boldsymbol{\Lambda}_e^s \circ \boldsymbol{\omega}_e^s / 2$ with regard to (3) one can obtain values $\boldsymbol{\Lambda}_{e\,s}^s \equiv \boldsymbol{\Lambda}_e^s(t_s)$ for the discrete time moments $t_s \in \mathrm{T}_n \equiv [t_o^n, t_f^n]$ with period T_q, $s = 0 \div n_q$, $n_q = T_n / T_q$ when initial value $\boldsymbol{\Lambda}_e^s(t_o^n)$ is given. If discrete values $\boldsymbol{\Lambda}_{e\,s}^s$ and $\boldsymbol{\omega}_{e\,s}^s$ are known then further solution is based on elegant extrapolation of values $\boldsymbol{\sigma}_{es}^s = \boldsymbol{\lambda}_{es}^s/(1 + \lambda_{0\,es}^s)$ by the vector of Rodrigues' modified parameters and values $\boldsymbol{\omega}_{es}^s$ of the angular rate vector. The extrapolation is carried out by these two sets of n_q coordinated 3-degree vector splines with analytical obtaining a high-precise approximation of the SRF $\mathcal{S}$ guidance motion with respect to the GRF $\mathbf{E}_e$. In result one can obtain the vector of image velocity at any point $\mathrm{M}(\tilde{y}^i, \tilde{z}^i)$ into the telescope focal plane for any $t \in \mathrm{T}_n$ by calculation (2).
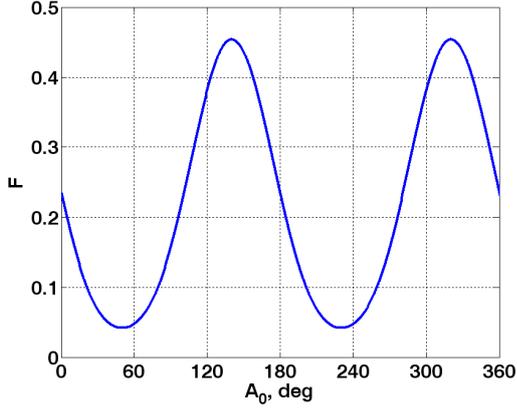
Fig. 4. Two minimums case for functional

The normed image cross velocity along the central linear OEC array have the form

$$\tilde{V}_z^i(0, \tilde{z}^i) = \tilde{z}^i(q_z^i \tilde{v}_{e1}^s + \tilde{z}^i \omega_{e2}^s) + q_z^i \tilde{v}_{e3}^s + \omega_{e2}^s,$$

where $q_z^i \equiv 1 - \tilde{z}^i(\tilde{c}_{31}/\tilde{c}_{11})$. Taking into account $\omega_{e2}^s = -\tilde{v}_{e3}^s$ because of condition (3) one can obtain the elegant formula

$$\tilde{V}_z^i(0, \tilde{z}^i) \equiv \tilde{z}^i\left(\tilde{v}_{e1}^s - \frac{\tilde{c}_{31}}{\tilde{c}_{11}}\tilde{v}_{e3}^s\right) - (\tilde{z}^i)^2\left(\tilde{v}_{e3}^s + \frac{\tilde{c}_{31}}{\tilde{c}_{11}}\tilde{v}_{e1}^s\right).$$

Normed focal z-coordinates of the left and right edges for the central linear OEC array have the presentation $\tilde{z}^{i-} = -l/(2f_e)$ and $\tilde{z}^{i+} = l/(2f_e)$, therefore

$$V_z^{i-} = f_e \tilde{V}_z^i(0, \tilde{z}^{i-}); \quad V_z^{i+} = f_e \tilde{V}_z^i(0, \tilde{z}^{i+}). \quad (4)$$

Analytical method for defining initial value A_0 for calculation of the ILV V_y^i and the ICV V_z^i involves trigonometric functions, vector products and the solution of scalar quadratic equation. Analytical calculations give very complex nonlinear dependence of the ILV V_y^i and the ICV V_z^i via initial azimuth A_0. Analytical condition of optimization leads to the necessity of numerical solution of nonlinear transcendental equation $\partial F/\partial A_0 = 0$ relative to the initial azimuth A_0. Research proved practical efficiency of a simple approximate computer-oriented optimization.

4. NUMERICAL OPTIMIZATION METHOD

Approximate computer algorithm for optimizing the index (1) of the initial azimuth A_0 consists next steps:

1. Begin the pitch angle θ cycle with $\delta\theta$ increment
2. Begin the roll angle γ cycle with $\delta\gamma$ increment
   For observed point C there are calculated vectors $\mathbf{r}^e$, $\mathbf{v}^e$ and the oblique range D along unit $\boldsymbol{\nu}$ on the telescope line-of-sight (Fig. 2) via the angles θ and γ, and also quaternion $\boldsymbol{\Lambda}_e^s$ for value $A_0 = 0$
3. Begin the azimuth angle A_0 cycle with δA_0 increment
   3.1. Calculation of matrix $\mathbf{C}_h^s \equiv \tilde{\mathbf{C}}$ from known A_0
   3.2. Calculation of the ICV on left (V_z^{i-}) and right (V_z^{i+}) ends of the OEC linear array by relation (4)
   3.3. Calculation of the functional (1)
4. Accumulation of the functional value base via azimuth
   End of initial azimuth A_0 values cycle
5. Numerical definition of minimums for functional (1) via azimuth A_0
   End of the roll angle γ cycle
   End of the pitch angle θ cycle
6. Accumulation and analysis of minimums base in pitch and roll angles function.
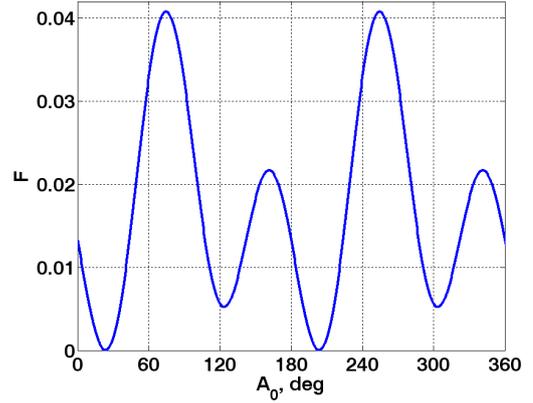

Fig. 5. Four minimums case for functional

5. OPTIMIZATION RESULTS

Below we give an example of survey optimization at the following parameters: circular orbit with altitude 600km and inclination 60°, the telescope equivalent focal length $f_e = 10$m, the OEC linear array length $l = 0.4$m; given ILV $W_y^i = 60$mm/s, the angle range $\theta, \gamma \in [-30°, 30°]$.

Analysis of obtained results allows to make the following conclusion: functional $F(A_0)$ can have 2 or 4 minimums, moreover two minimums correspond to 180° values A_0^o. Fig. 4 and Fig. 5 show the behavior of functional $F(A_0)$ values for the SC attitude angles with respect to the ORF, namely in Fig. 4 values $\theta = +5°, \gamma = -5°$, and in Fig. 5 values $\theta = 0°, \gamma = -5°$. Fig. 6 and Fig. 7 represent the optimal azimuth surface for given range of pitch and roll angles variation.
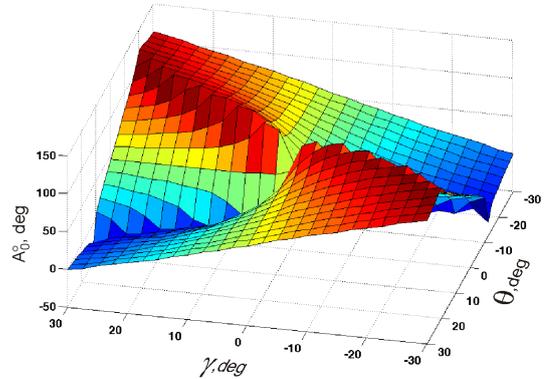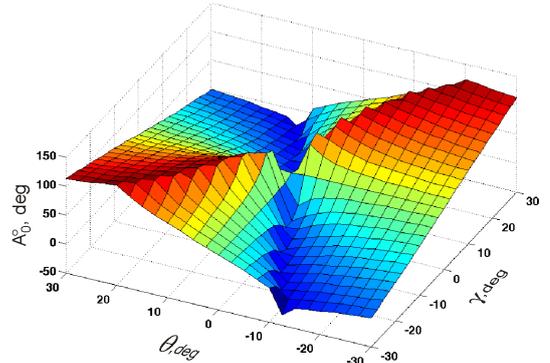

Fig. 6. Optimal azimuth surface, view 1

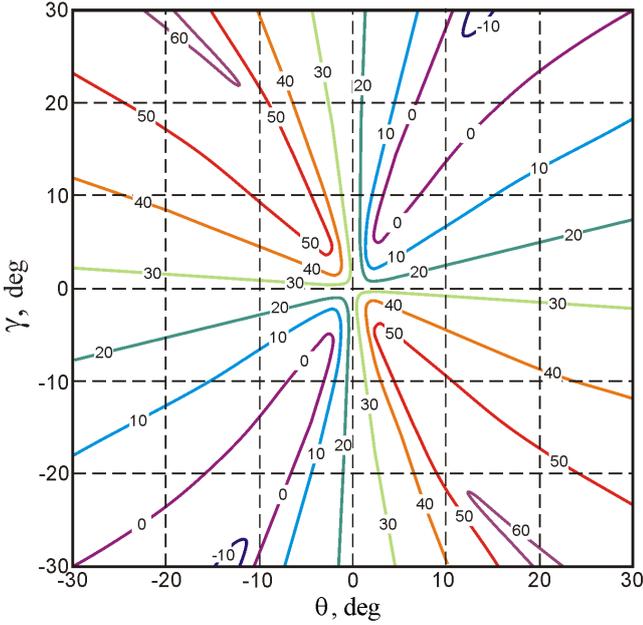Fig. 7. Optimal azimuth surface, view 2

Fig. 8. Level lines for optimal azimuth surface

Fig. 8 shows the lines of equal levels of optimal azimuth corresponding to the first minimum of the functional. It follows from these figures that when pitch and roll angle change in the first and third quadrants of their variation plane, optimal values of the survey initial azimuths lie within $[-10°, 26°]$, and when these angle change in the second and fourth quadrants of the plane – initial azimuths lie within $[26°, 60°]$. The results of nomogram in Fig. 8 are applicable for cases when the vector in horizon plane at survey azimuth angle to meridian plane has a positive projection on flight direction. Otherwise when projection of this vector is negative it is necessary to use the second minimum corresponding to azimuths that differ from the first one by $180°$.

As it can be seen from Figs. 4 & 5 maximums and minimums of the functional F (1) differ considerably which allows to conclude that only surveys at close to optimal azimuths are possible. Thus, with 32 accumulation increments in CCD matrix as is the case under consideration, permissible the ICV $V_d^i = 0.6$mm/s and pitch angle $\theta = 0$ the survey at random azimuth is impossible because when azimuth values correspond to maximum of the functional F, condition $|V_z^i| \le V_d^i$ will not be fulfilled.

6. SOFTWARE COMPLEX

Presented software complex is intended for the development of functional requirements to the gyrodine control systems of pointing the Earth survey spacecraft allowing to find the factors affecting the SC design characteristics to the greatest extent (Somov et al., 2008). The software can be used

- for evaluating the methods of guidance and optoelectronic survey optimization,
- for the comparison of various alternatives of onboard equipment,
- for forming the requirements to gyro moment cluster (GMC) and measuring instrument.

Along with this, software complex enables to perform simulation and analysis of space systems including several Earth survey spacecraft, relay satellites and ground based infrastructure, and detailed analysis of the performance characteristics for each observation satellite for the purpose of solving target problems. Complex logic includes dialogue monitor, simulation, analysis and synthesis subsystems and results recording auxiliary sub-system. Complex operation is controlled by hierarchical menu system. Input data for complex operation are the parameters of space system including the SC orbit parameters, measuring and special-purpose instruments characteristics, the SC and the GMC's gyrodine parameters, the SC operation modes with the list of restrictions, preset characteristic packages of space system quality and optimization criteria. Software complex output is represented by cartography based survey routes, tables and diagrams of the SC and the GMC's gyrodine coordinates change with time, observation instruments characteristics, achieved quality and optimization criteria.

6.1 Simulation Subsystem

Simulation subsystem includes the following components:

- *the Earth model*: shape, physical and geometrical characteristics of ground objects;
- *the SC structural model*: vehicle's reference frames, geometrical and inertia characteristics of the structure, characteristics of telescopes, actuators, measuring instruments, restrictions;
- *the SC ballistic model*: parameters used for computation of the SC's mass center motion, standard computation cases;
- *the SC orbit motion*: reference frames, the Earth observation schemes, computation methods of the SC route motions and rotation maneuvers, object survey and stereo routes, ground areas;
- *the environment models*: parameters and calculation methods of underlying surface illumination, the Sun altitude, background characteristics of underlying surface in various bands of electromagnetic spectrum, cloudiness etc. ;
- *the SC interaction models*: spacecraft population in space system, interaction with relay satellites and ground based receiving stations;
- *optical path models*: parameters and methods of scanning process, calculation models of image velocity in telescope focal plane and in the CCD arrays, resolution etc.;
- *target scenery*: parameters and data bases of standard problems and observed objects on the Earth surface specifying priorities.

6.2 Analysis and Synthesis Subsystem

The subsystem performs the following functions:

- displaying the Earth surface maps with inserted objects required for the accomplishment of complex mission (coastline, country borders, rivers, big cities etc.) and adjustment opportunity (projection, removal and addition of objects, coloration etc.);
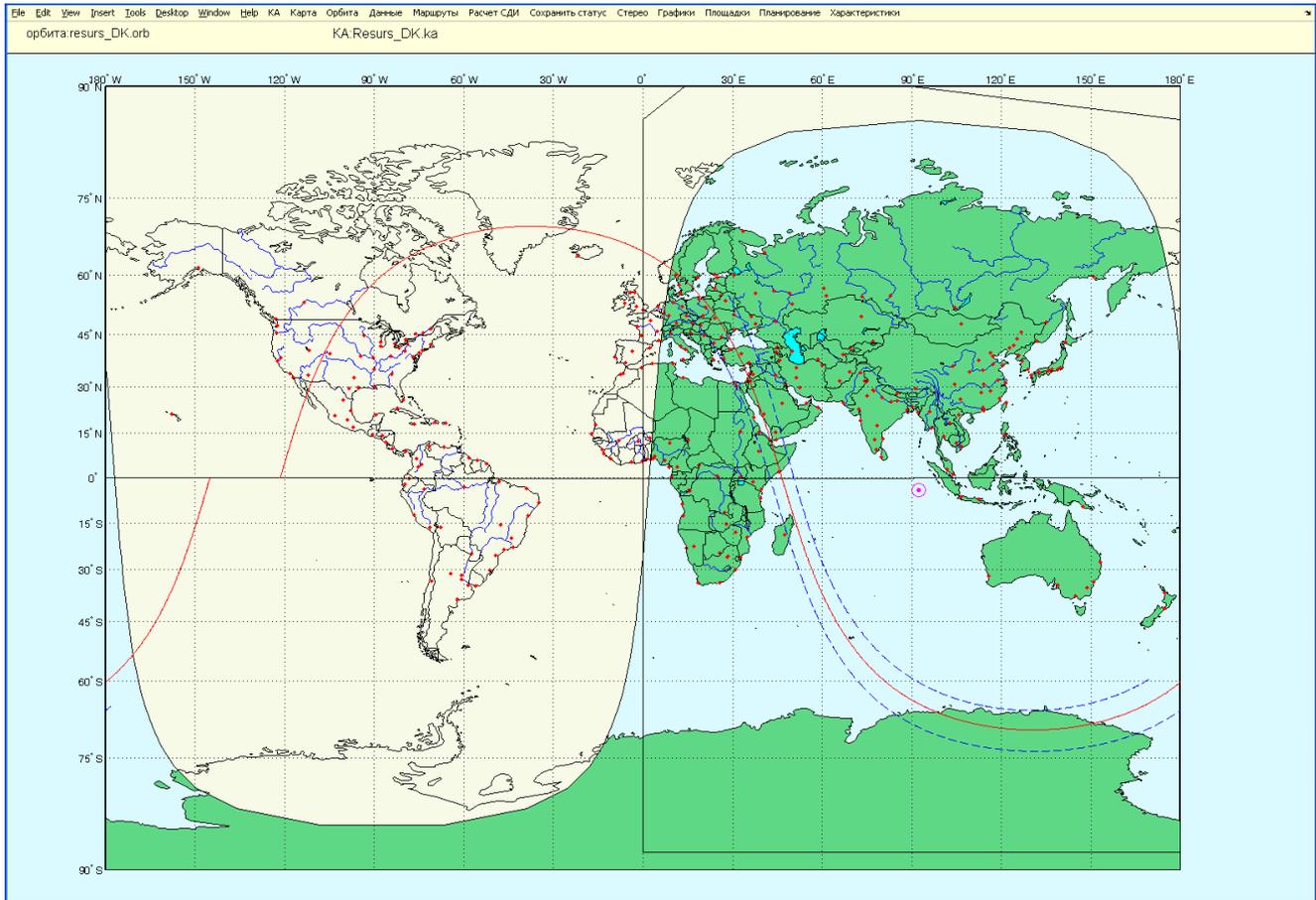- displaying the orbit and spacecraft flight route, swath, illumination;

Fig. 9. Main Dialogue Window

- computation and display of the SC orbital motion parameters: coordinates and linear velocities of the SC mass center changing with time, nominal and osculating elements of the orbit;
- computation and display of the SC motion during mission task fulfillment: flight altitude, azimuth range to an object; status vector of observation perspective; orientation angles in the ORF, traverse point coordinates; azimuth from object point to sub-satellite point; instantaneous route azimuth etc.;
- the SC status vector parameters at routes and rotational maneuvers: quaternions, angular rate vectors, accelerations and derived accelerations;
- check of preset angular rate feasibility with available the GMC resources with account of a probable accumulated angular momentum of mechanical system and a restrictions' fulfillment in details for each gyrogine into the GMC;
- analysis of transient processes in the SC attitude control system during the programmed angular motion with determination of the guaranteed damping time of the SC resilient members;
- calculation and display of the Sun elevation over the horizon in observation point, visibility and direction to receiving station and other spacecraft etc.;
- calculation of image velocity in given points of focal plane and obtained linear ground resolution;
- calculation of mission efficiency by frequency criteria (frequency of watched object entry into the SC coverage zone in various flight conditions);

- calculation of mission efficiency by performance (number of objects and earth surface that can be "pictured" by spacecraft in one pass (day, year);
- calculation of mission efficiency by operability (time characteristics related to observation planning, sending task order on board spacecraft, target approach time, entry into radio visibility zone etc.);
- comparative analysis of space system alternatives by various quality criteria;
- synthesis of space system and its functioning process, optimization of ballistic construction of the orbital group;
- justification of space system tactical and technical requirements with optimal planning of onboard equipment programs.

6.3 Interactive Environment and Application Examples

Main dialogue window of software system is shown in Fig. 9 with upper menu, geographic map, sub-satellite track, swath, circle of illumination. Dialogue with the user is enabled in emerging windows. Data input and environment setting for storage in status file are made for each spacecraft – menu "Store status" in Fig. 9. Hereafter data of each spacecraft and environment can be loaded simply by selecting the required status file.

Menu "Spacecraft" is intended to enter characteristics of the SC's GMC. In particular, the following data will be entered: inertia tensor of the SC body, characteristics of the SC resilient members, restrictions for rate and

acceleration of the SC body, number of gyrodines and their layout in the GMC, angular momentum of each gyrodine and restrictions on angular rate and acceleration with respect to the axis of its suspension. Basic data of optical track of special equipment (telescope, CCD matrix), measuring equipment (star trackers, angular rate vector instrument) and measuring subsystems (strapdown inertial system with astronomical correction) etc.

Fig. 10. Target Locations for Planning Object Survey

Fig. 11. Stereo Photography Scene Display

Menu "Map" is applied for setting the map including special cylindrical, conical or azimuth projections, geographical point in the line of sight, and altitudes. Map colors can also be adjusted, so that it can display coastline, rivers and lakes, country borders, big city centers etc.

Menu "Orbit" allows to calculate the SC orbital motion or upload a pre-computed orbit. Computation is made with a preset time increment for the required number of passes. Initial conditions of the SC orbital motion shall be set in the form of coordinates and in osculating orbit elements with account of given number of geopotential harmonics.

Fig. 12. Site Survey Display

Menu "Routes" is intended for calculation and display on the map survey tracks and line of sight trace on the earth surface. If planned routes cannot be realized due to imposed restrictions, the user will see appropriate diagnostic messages.

Menu "Planning" is intended to enter target locations and opens access to data base of standard problems and surveyed objects.

Menu "Characteristics" allows to calculate mission efficiency by various quality criteria.

A visual example of target location scene and solving the problem of object survey planning by performance criteria is presented in Fig.10 showing flight track, swath limits and line of sight direction in object mapping. An example of stereo photography is shown in Fig. 11, non-overlapping bands are shown in a different color. The site survey display is presented in Fig. 12.

7. CONCLUSION

Initial azimuth was determined for scanning survey of ground based objects of small extension with equalization of the ILV in the focal plane of telescope based on minimization of quadratic functional of the ICV on the left and right edges of the OEC linear array. Changes of optimal initial azimuth for various survey angles within the swath were studied. A brief description of special software system and recommendations for its application were presented.

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