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MODELING COMPLEX FOR STUDIES OF METHODICAL AND INSTRUMENTAL ERRORS OF THE STRAPDOWN INERTIAL NAVIGATION SYSTEM

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Abstract*—To study the accuracy characteristics, a strapdown inertial navigation system is represented as a set of kinematic equations and equations of a mathematical model of the Earth. Based on the mathematical model in the Matlab-Simulink package, a modeling complex was created, consisting of subsystems of the reference and studied navigation system, subsystems of the reference and simplified model of the Earth and a subsystem of primary information sensors. In navigation subsystems, kinematic equations of inertial navigation algorithms are solved, and matrices of direction cosines are formed. In the subsystems of the Earth model, the parameters of the Earth's spheroid and the acceleration of gravity are calculated. The sensor models are developed based on the characteristics of low-cost microelectromechanical sensors. The purpose of the study was to assess methodological and instrumental errors as the difference in the dead reckoning signals of the flight navigation parameters of the reference and studied navigation systems. Methodological errors of the system are played up by simplifications of the parameters of the earth's spheroid, and instrumental errors are caused by errors in inertial sensors.*

Index Terms—Strapdown inertial navigation system; reference system; inertial sensors; terrestrial spheroid; methodological and instrumental errors.

I. INTRODUCTION

The strapdown inertial navigation system (SINS) generates the main navigation parameters obtained by the dead reckoning method, that is, by continuously integrating signals corresponding to aircraft accelerations. Acceleration information comes from accelerometers located on board of the aircraft. The procedure for integrating vector quantities, which are accelerations and velocities of the aircraft, is ensured by reproducing the corresponding coordinate system on board of the aircraft.

Inaccuracies in the reproduction of the coordinate system, in particular the model of the earth's spheroid, or simplification of the equations of the dynamics of aircraft motion in the gravitational field of the rotating Earth cause errors in the calculation of flight’s navigation parameters. However, basically, SINS errors are determined by errors of inertial sensors [1]. That is why while designing SINS it is necessary to reduce the magnitude of the instrument errors in the primary information sensors.

But for unmanned aerial vehicles (UAVs), SINS sensors are usually chosen to be small and inexpensive, and microelectromechanical sensors (MEMS sensors) almost completely meet these requirements [3], however, the accuracy characteristics of these sensors leave much to be desired.

Therefore, complex navigation systems are used as UAV navigation systems, most often these are inertial satellite navigation systems. The high accuracy of navigation measurements of satellite navigation systems (SNS), on the one hand, the information content, autonomy and reliability of navigation definitions of inertial navigation systems, on the other, naturally determined this integration. The subsystem for combining SINS and SNS is implemented in an integration circuit (usually a Kalman filter unit) [2]. This scheme estimates the position and speed of UAV, and this data can come not only to consumers, but also to the delay and phase tracking blocks of SNS receivers.

When designing rough SINS based on MEMS sensors, the problem arises of developing SINS operation algorithms, the methodological errors in the calculation of navigation parameters of which corresponded to the calculation errors caused by the primary information sensors. The assessment of SINS errors is carried out through mathematical modeling, which is why the development of a computer model of SINS and a comparative assessment of its methodological and instrumental errors is a very urgent task.

II. Problem Statement

The object of the study is the algorithms of SINS operation and its primary information sensors.

The subject of the study is the computer-mathematical model of SINS and its accuracy characteristics that depend on methodological errors of SINS algorithms and instrumental errors of primary information sensors.

The purpose of the work is to develop a mathematical and computer model of a SINS for evaluation of its methodological and instrumental errors.

III. Problem Solution

We will use the trihedron denoted *NHE* as the navigation triangle.

Let's choose the following direction of the *NHE* axes (Fig. 1).

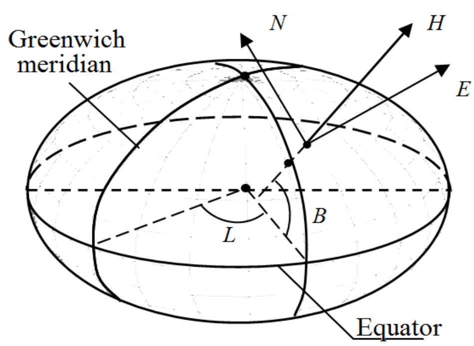


Fig. 1. Coordinate system, used in SINS algorithms: *OH* – coincides with the vertical; *ON*–tangent to the meridian; *OE*- forms the right triangle

In SINS algorithms, dynamic and kinematic equations are usually distinguished. Dynamic equations implement a three-component SINS scheme, in which the geographical coordinates *L*, *B*, *H* are determined by integrating equations of the form:

$$\dot{L} = \frac{V_E}{(R_2 + H)\cos B},$$
$$\dot{B} = \frac{V_N}{R_1 + H},$$
$$\dot{H} = V_H,$$

where V_N, V_E are northern and eastern projections of the path velocity (projections on the axes of *NHE* coordinate system (Fig. 1); R_1, R_2 are two radius of curvature of the Earth's spheroid (ellipsoid of rotation); R_1 is the radius of curvature of meridional intersection of the ellipsoid (HN plane); R_2 is the radius of curvature of the ellipsoid section by the *HE* plane (plane of the first vertical). Radii of curvature are defined as:

$$R_1 = \frac{a\left(1-e^2\right)}{\left(1-e^2\sin^2 B\right)^{\frac{3}{2}}}, \quad R_2 = \frac{a}{\sqrt{1-e^2\sin^2 B}},$$

where a is large semi-axis of the ellipsoid (a = 6378388 m); e is the eccentricity of the ellipsoid ($e^2 = 6{,}73\cdot 10^{-3}$); H is the flight altitude.

Functions $\left[1/(R_1+H)\right]$ and $\left[1/(R_2+H)\right]$ with accuracy to members of the order of smallness 10^{-5} can be represented as follows:

$$\frac{1}{R_1+H} = \frac{1}{a}\left[1 - e^2 - \frac{H}{a} - \frac{3}{2}e^2\sin^2 B - 2e^2\frac{H}{a} + 3e^2\frac{H}{a}\sin^2 B + \left(\frac{H}{a}\right)^2 + e^4\left(1 - 3\sin^2 B + \frac{3}{8}\sin^4 B\right)\right],$$
$$\frac{1}{R_2+H} = \frac{1}{a}\left[1 - \frac{H}{a} - \frac{1}{2}e^2\sin^2 B + \left(\frac{H}{a}\right)^2 + e^2\frac{H}{a}\sin^2 B + e^4\left(\frac{1}{4}\sin^2 B - \frac{3}{8}\right)\sin^2 B\right].$$

If you save only terms of order of smallness 10^{-2} in the formulas $\left[1/(R_1+H)\right]$, $\left[1/(R_2+H)\right]$, they will take the form:

$$\frac{1}{R_1+H} \approx \frac{1}{a}\left[1 - e^2 - \frac{H}{a} - \frac{3}{2}e^2\sin^2 B\right],$$
$$\frac{1}{R_2+H} \approx \frac{1}{a}\left[1 - \frac{H}{a} - \frac{1}{2}e^2\sin^2 B\right].$$

The use of such simplifications leads to methodological errors in the calculation of navigation parameters.

The components of the air craft's path velocity V_L, V_N, V_H are obtained by integrating the projections of accelerometer signals, excluding the Carioles acceleration and gravity acceleration components:

$$\dot{V}_E = a_E - \left(V_N\omega_{H_\Sigma} - V_H\omega_{N_\Sigma}\right) + g_E,$$
$$\dot{V}_H = a_H - \left(V_E\omega_{N_\Sigma} - V_N\omega_{E_\Sigma}\right) + g_H,$$
$$\dot{V}_N = a_N - \left(V_H\omega_{E_\Sigma} - V_E\omega_{H_\Sigma}\right) + g_N,$$

where a_E, a_H, a_N are projections of aircraft imaginary acceleration, measured by accelerometers, on the axis of the navigation triangle; g_E, g_H, g_N are projections of the acceleration vector of the weight force, which take into account the acceleration of the earth's gravity and the acceleration caused by the centrifugal force of inertial and associated with the rotation of the Earth; components in brackets–projection of the Carioles principle on the axis of the navigation trihedron; $\omega_{E_\Sigma}, \omega_{H_\Sigma}, \omega_{N_\Sigma}$ are projections of the angular velocity of the navigation triangle relative to inertial space, which take into account the projections of the angular velocity of the Earth's rotation $\Omega_E, \Omega_H, \Omega_N$ and the components of the relative angular velocity of the navigation triangle caused by the movement of the aircraft relative to the Earth ω_{E_V}, ω_{H_V}, ω_{N_V} :

$$\omega_{N_\Sigma} = \omega_{N_V} + 2\Omega_N, \quad \omega_{H_\Sigma} = \omega_{H_V} + 2\Omega_H,$$
$$\omega_{E_\Sigma} = \omega_{E_V} + 2\Omega_E.$$

In turn, the components of the relative angular velocity of the navigation trihedron and the Earth's rotation speed are determined by the following relations:

$$\omega_{E_V} = -\frac{V_N}{R_1 + H} = -\dot{B}, \quad \omega_{HV} = \frac{V_E}{R_2 + H}\,\mathrm{tg}B = \dot{L}\sin B,$$
$$\omega_{N_V} = \frac{V_E}{R_2 + H} = \dot{L}\cos B,$$
$$\Omega_N = \Omega_{\text{Earth}}\cos B, \quad \Omega_H = \Omega_{\text{Earth}}\sin B, \quad \Omega_E = 0,$$

here Ω_{Earth} is angular velocity of the Earth's rotation ($\Omega_{\text{Earth}} = 7.27\cdot10^{-5}$).

A deterministic mathematical model of the acceleration of gravity exists only for the normal component of the gravity field, which corresponds to a terrestrial ellipsoid with a uniform distribution of masses in the volume of this figure. The gradient of this field at any point belonging to the surface of the ellipsoid is directed along the normal to it and is located in the plane of the meridional section. Since the aircraft location point does not belong to the Earth's surface, strictly speaking, the gradient vector of the normal gravity field at this point will not be directed along the normal line lowered from it to the surface of the Earth's ellipsoid (*ON* axis). At the same time, this vector will be located in the meridian plane of point *O*, that is, in the *NOH* plane.

Then, using the potential function of the normal gravity field of the Earth's spheroid, with an accuracy of terms of the order of smallness 10^{-5} the ratios for the projections of the components of the gravity field $\overline{g}$ are as follows:

$$g_E = 0,$$
$$g_N = \frac{1}{2}g\left[\frac{H}{a}\left(e^2 - 5q\right) + qe^2\sin^2 B\right]\sin 2B,$$
$$g_H = -g\Bigg\{1 - 2\frac{H}{a} - \left(e^2 + 2q - 3\frac{H}{a}\right)\frac{H}{a} + \left[\frac{1}{2}\left(5q - e^2\right) - \frac{1}{8}e^4 + \frac{17}{18}qe^2 + \left(3e^2 - 5q\right)\frac{H}{a}\right]\sin^2 B - \frac{1}{2}qe^2\sin^4 B + \frac{1}{16}e^2\left(\frac{1}{2}e^2 - 7q\right)\sin^2 2B\Bigg\},$$

where g = 9.78049 m/s^2 is the accele1ration of the force of gravity at the equator; q = 0.00346775 – the ratio of the centrifugal force, caused by the rotation of the Earth, to the force of gravity at the equator.

With an accuracy of the order of smallness of 10^{-4} the ratios for the projections of components of the gravity field $\overline{g}$ are somewhat simplified:

$$g_E = 0,$$
$$g_N = g\sin 2B + \frac{5}{2}q\sin^2 B\frac{H}{a}\left(\frac{e^2}{2} - 2q\right),$$
$$g_H = -g\Bigg[1 - \frac{e^2}{2}\sin^2 B + \frac{3}{2}q\sin^2 B + e^4\left(-\frac{1}{8}\sin^2 B + \frac{1}{32}\sin^2 2B\right) + e^2 q\left(-\frac{17}{28}\sin^2 B - \frac{5}{16}\sin^2 2B\right) + \frac{H}{a}e^2\left(3\sin^2 B - 1\right) + \frac{Hq}{a}\left(-1 - 6\sin^2 B\right) - 2\frac{H}{a} + 3\frac{H^2}{a^2}\Bigg].$$

And with an accuracy of the order of smallness of 10^{-2}, they look simple:

$$g_E = 0, \quad g_N = 0,$$
$$g_H = -g\left(1 + 5.2884\cdot10^{-3}\sin^2 B\right)\cdot\left[1 - \frac{2H}{a}\left(1 - e\,\sin^2 B\right)\right].$$

Projections a_E, a_H, a_N of the aircraft imaginary acceleration on the axis of the navigation trihedron *LRΦ* are calculated from the readings of the accelerometers from the *XYZ* coordinate system connected to the aircraft using direction cosine matrix **B**:

$$\begin{bmatrix} a_N \\ a_H \\ a_E \end{bmatrix} = \mathbf{B}\begin{bmatrix} a_{x_{AC}} \\ a_{y_{AC}} \\ a_{z_{AC}} \end{bmatrix}.$$

Matrix **B**, which defines the transformation of vectors from the coordinate system associated with the aircraft – *OXYZ* to the navigation – *ONHE*, has the form:

$$\mathbf{B}=\begin{bmatrix} \cos\psi\cos\vartheta & \begin{matrix}\sin\psi\sin\gamma-\\ -\cos\psi\sin\vartheta\cos\gamma\end{matrix} & \begin{matrix}\sin\psi\cos\gamma+\\ +\sin\psi\cos\vartheta\sin\gamma\end{matrix} \\ \sin\vartheta & \cos\vartheta\cos\gamma & -\cos\vartheta\sin\gamma \\ -\sin\psi\cos\vartheta & \begin{matrix}\cos\psi\sin\gamma+\\ +\sin\psi\sin\vartheta\cos\gamma\end{matrix} & \begin{matrix}\cos\psi\cos\gamma-\\ -\sin\psi\sin\vartheta\sin\gamma\end{matrix} \end{bmatrix}.$$

Direction cosine matrix **B** can be obtained as a result of solving the generalized Poisson equation based on information on the aircraft angular velocity relative to the inertial ω_{AC} and the angular velocity of the navigation coordinate system relative to the inertial space ω_{NHE}, which takes into account the angular velocity of the Earth's rotation and the angular velocity due to the aircraft flight around the spherical Earth:

$$\dot{\mathbf{B}}=\mathbf{B}\,\omega_{\mathbf{AC}}-\omega_{NHE}\mathbf{B},$$

where

$$\omega_{\mathrm{AC}}=\begin{bmatrix} 0 & -\omega_{z_{\mathrm{AC}}} & \omega_{y_{\mathrm{AC}}} \\ \omega_{z_{\mathrm{AC}}} & 0 & -\omega_{x_{\mathrm{AC}}} \\ -\omega_{y_{\mathrm{AC}}} & \omega_{x_{\mathrm{AC}}} & 0 \end{bmatrix},$$

$$\omega_{NHE}=\begin{bmatrix} 0 & -(\omega_{E_V}+\Omega_E) & (\omega_{H_V}+\Omega_H) \\ (\omega_{E_V}+\Omega_E) & 0 & -(\omega_{N_V}+\Omega_N) \\ -(\omega_{H_V}+\Omega_H) & (\omega_{N_V}+\Omega_N) & 0 \end{bmatrix},$$

$\omega_{x_{\mathrm{AC}}}$, $\omega_{y_{\mathrm{AC}}}$, $\omega_{z_{\mathrm{AC}}}$ are aircraft angular velocities relative to the connected axes, measured by angular velocity sensors.

The elements of matrix **B** determine the aircraft orientation angles: roll γ, pitch ϑ, yaw (course) ψ, for example:

$$\psi=-\mathrm{arctg}\left(\frac{b_{31}}{b_{11}}\right),\ \gamma=\mathrm{arctg}\left(\frac{-b_{23}}{b_{22}}\right),$$

$$\vartheta=\arcsin(b_{21}).$$

The study of the proposed algorithms of the integrated system was carried out using the Simulink the visual modeling software, which is part of the universal mathematical programming package Matlab. The block diagram of the model of the single simulation complex is shown in Fig. 1a.

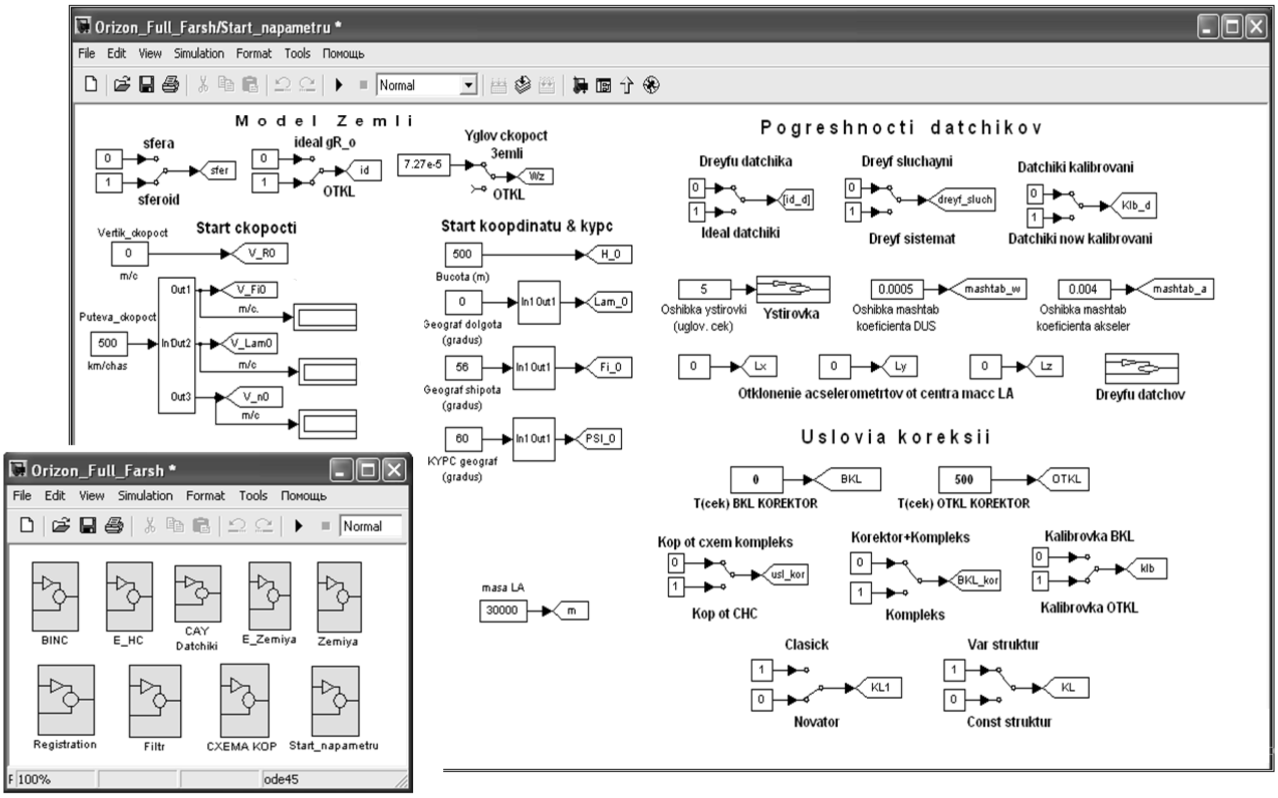


Fig. 1. The block diagram of the model of the single simulation complex

During the modeling, subsystems of the reference navigation system "E_HC" were created, which, in turn, if the output signals are noisy, can be used as a model of the satellite navigation system and the researched "SINC". Also, subsystems of the Earth model (reference "E_Zemlya" and simplified

"Zemlya"), subsystem of the CAY and primary data sensors "CAY-Datchiki" were created. The combination and correction algorithms were implemented in the subsystems "Filter" and "Diagram kop". In addition, the Registration" simulation results registration subsystem and a subsystem for setting the modeling parameters (initial conditions) "Start_napametru" were created.

Mathematical models of the reference navigation system, as well as the researched SINS, were built according to the hierarchical principle. In particular, the "SINC" subsystem consists of the following subsystems: "Acceleration", "Yglov Ckopocti", "Ckopocti", "Koopdinatu".

In these subsystems, individual kinematic equations of the SINC algorithm are solved, and the direction cosine matrix B is formed. Since the SINC algorithms do not contain methodological errors associated with simplifications (except for the Earth model), the E_NS subsystem, which models the reference navigation system, completely duplicates the SINC subsystem.

The Earth model subsystems calculate the components of the Earth's angular velocity, calculate its radius of curvature and acceleration of the gravity force, and the Earth can be represented by a sphere or a spheroid; as rotating or non-rotating. These changes are made from the "Start_napametru" subsystem (see Fig. 1b).

From the "Start_napametru" subsystem, the following are entered into the simulation program:

– initial coordinate values:

- altitude H_0 in meters;
- geographical longitude λ_0 and latitude φ_0 in degrees;
- the initial value of the geographic course ψ_{M0} in degrees.

– initial flight speed values:

- vertical speed V_{R0} (m/s);
- ground speed V (km/hour).

The switches in the "Earth_Model" group change the parameters of the "Zemliya" subsystem. The switches "sfera-spheroid" and "Yglov ckopoct Zemli" change the parameters of calculations of the Earth's surface curvature radius, and also simulate its rotation. Turning the "idealg R_o OTKL" switch to the "idealg R_o" position ensures that the acceleration component of the gravity force is generated in the same wayin "Zemiya" and "E_Zemiya" subsystems. Otherwise, the difference in the form of writing this component results in a difference in the fourth character.

"CAY-Datchiki" subsystem consists of sub-blocks "DYCu", "Akselerometr», and "CAY_LA".

The outputs of the "DYCu" and "Akselerometr" sub-blocks are signals measured by sensors of the reference navigation system and SINS. Moreover, error signals in the form of deterministic, systematic drift components or random components can be superimposed on the signals of SINS sensors. The formation of the error signals components is carried out from the subsystem "Start_napametru" by the group of switches "Pogreshnocti datchikov".

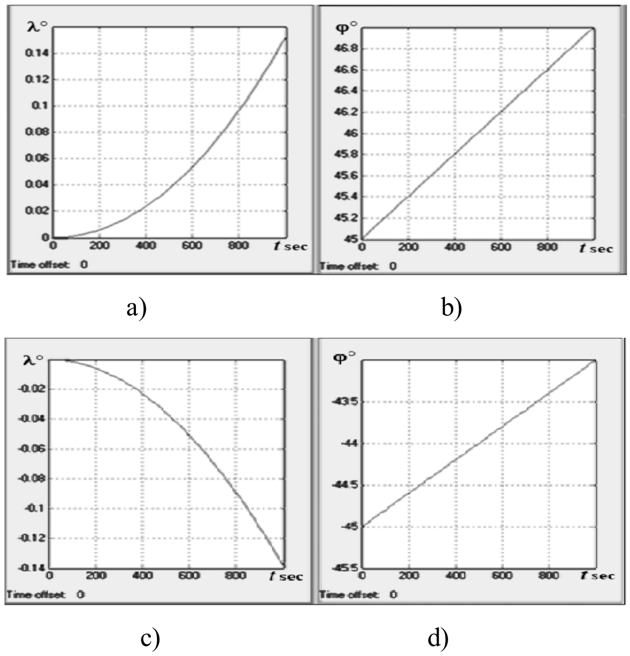


Fig. 2. Modeling the movement of an object along the meridian in the Earth's gravitational field

During these studies, in the "Start_napametru" block, the geographical heading was set equal to 0°, and the initial latitude was set first in the southern and then in the northern hemisphere. In the subsystem "CAY_LA", the stabilization of the component of the aircraft's ground speed along the axes of the navigation triangle was disabled.

When moving along the equator, the Carioles forces change the trajectory of the body in a slightly different way. This fact was also studied in order to assess the adequacy of the SINS navigation computer algorithms.

When moving to the west, the body is pressed against the Earth by the Carioles force (Fig. 3a), and when moving to the east, it goes up (Fig. 3b). During these experiments, the altitude stabilization was disabled.

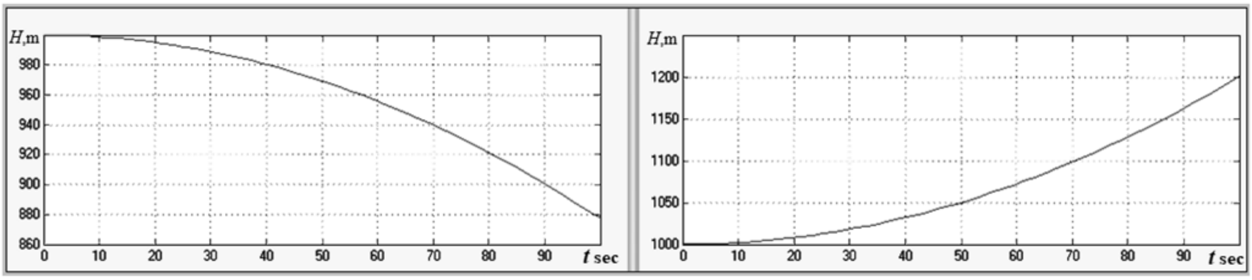
Other factors confirming the correctness of the SINS algorithms can be checked. For example, by disabling the stabilization of the angular position, one can observe the imaginary departure of the accompanying trihedron in heading, roll and pitch relative to the navigation one. For the initial value of the geographic latitude 45° and the initial geographic heading 45°, the imaginary departure of the aircraft along angular coordinates is shown in the oscillograms of Fig. 4.

In the theory of inertial navigation systems, it is proved that horizon contours essentially model the so-called Schuler pendulum. To confirm this fact, which proves the adequacy of the SINS algorithms, additional studies were conducted.

During these studies, the "CAY_LA" subsystem included invariant stabilization of all parameters of the aircraft motion.

For the purpose of purity of the experiment, in the "Start_napametru" block, the initial latitude was set to zero, the geographical heading to 90° (strictly along the equator), and the flight speed to zero. The influence of the drift to the longitude in accelerometer (Fig. 5a) and the drift of the pitch angular velocity sensor (Fig. 5b) on the error of the longitude calculation $\Delta\lambda$ (in meters) was studied.

The modeling results fully confirm the theoretical statements. In particular, for one-component SINS, the coordinate determination error, caused by accelerometer Δa, varies with the period of the Schuler pendulum. The error, caused by angular velocity sensor error, excluding the component that varies with the Schuler period, has a component that grows proportionally with time.



a) b)

Fig. 3. Modeling the movement of an object in the Earth's gravitational field along equator

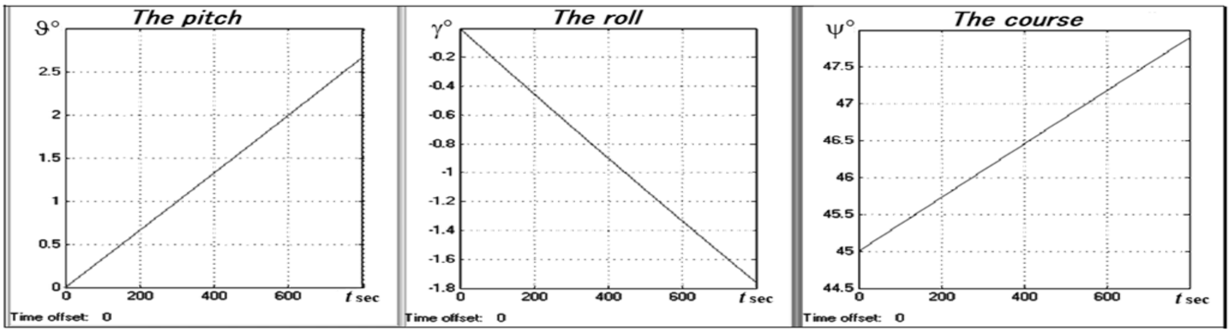


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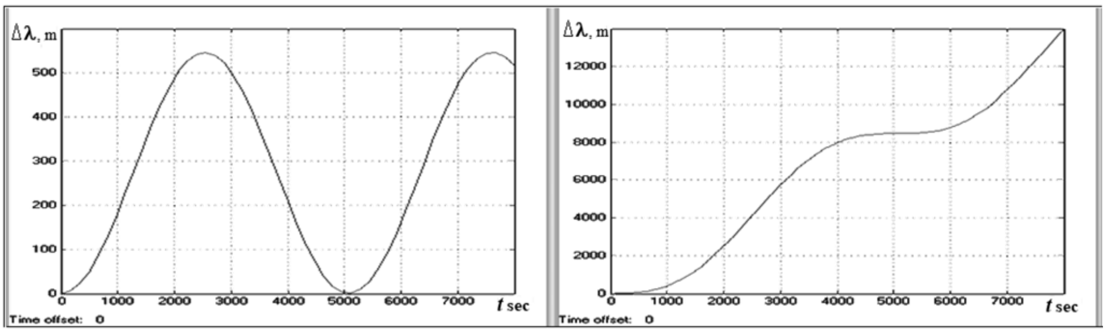
Fig. 4. The imaginary departure of the accompanying trihedron by course, roll and pitch relative to the navigational one



a) b)

Fig.5. The influence of the errors of inertial sensors on the error of coordinate calculation

In addition to the adequacy checks, at this stage, methodological errors of SINS related to the possibility of presenting the Earth model in the form of a sphere were investigated. The results of the research during the flight in the middle latitudes, where the maximum coordinate calculation errors are expected, are presented in oscillograms. Figure 6(a, b) shows the changes in coordinate calculation errors in meters, and Fig. 7(a – c) show the errors of the angular orientation parameters in degrees.

Studies have shown that the maximum errors in calculating coordinates for two hours of flight do not exceed ± 100…150 m, and errors in determining the angular orientation parameters are thousandths of a degree, which is quite acceptable for navigation systems of this class.

The biggest problems in SINS arise from the instability of the vertical channel. For example, differences in the calculation of the acceleration vector of the force of gravity in the SINS model and the reference navigation model, which differ in fourth decimal place (10^{-4}) lead to an error avalanche in the calculation of navigation parameters. This fact is illustrated in the oscillograms (errors in calculating longitude and latitude in meters in Fig. 8(a, b); pitch, heading and roll errors in degrees in Fig. 9(a – c). In two hours of flight, the error in coordinates reaches 40...160 km, and in angular coordinates 3°.

A radical solution to the problem of instability of the vertical channel of the SINS is possible only with the use of an external, albeit rather crude, corrector, for example, a barometric meter of vertical speed and altitude (from the airborne signal system).

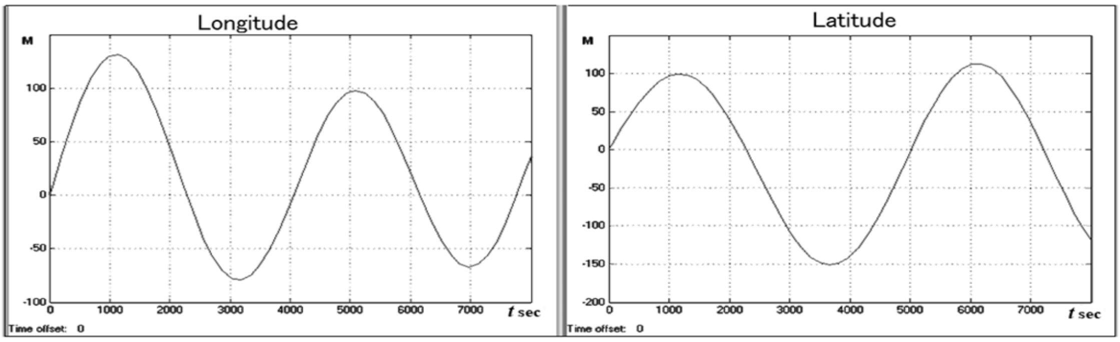


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Fig. 6. Influence of inertial sensor errors on the error of coordinate calculation

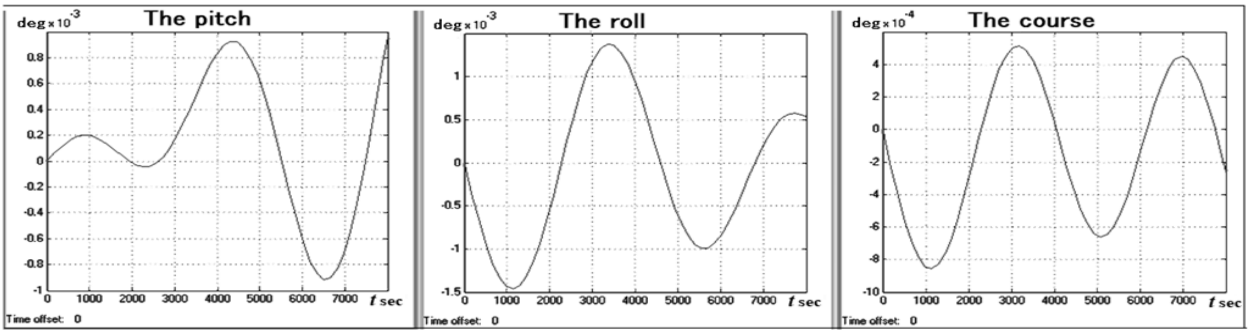

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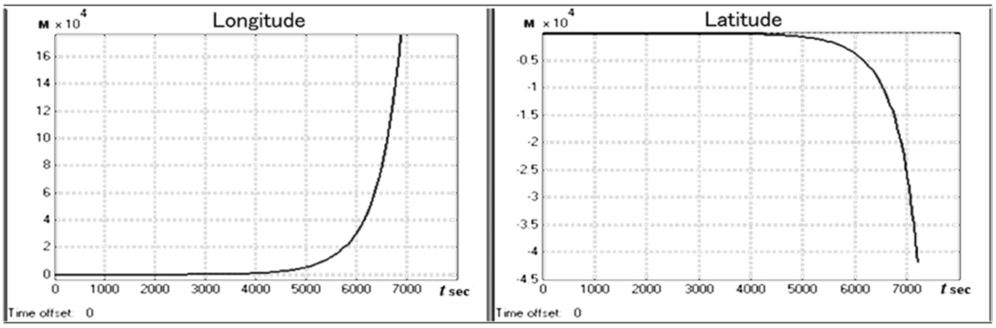
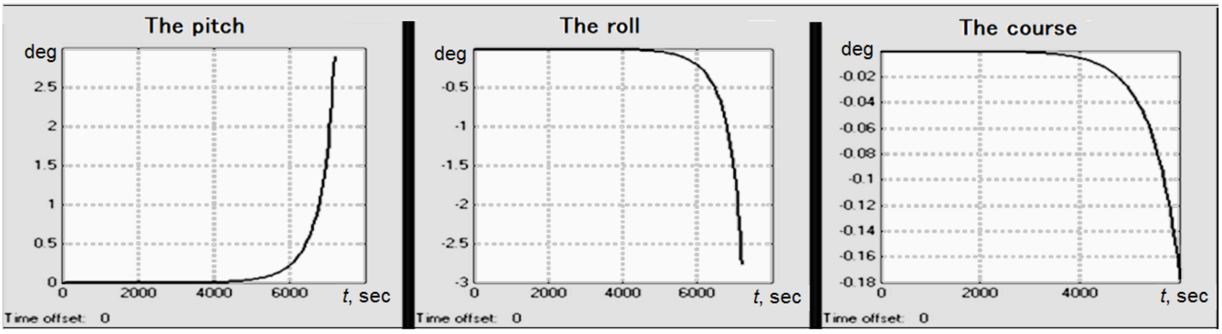
Fig. 7. Influence of inertial sensor errors on the calculation errors of angular orientation parameters



a) b

Fig. 8. The impact to differences in the calculation of force of gravity acceleration vector on coordinates calculation error



a) b) c)

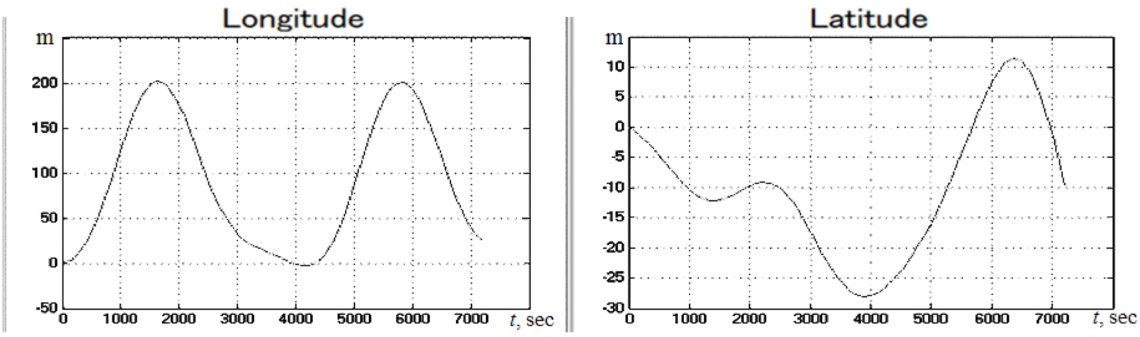
Fig. 9. The impact of simplifications in calculations of gravity force vector acceleration on the angular orientation error

This approach to the construction of the SINS algorithm was studied at the stage of preliminary modeling. During the research, some improvements were made to the SINC subsystem to enable the connection of a barometric corrector.

Connecting the corrector in the SINS algorithms is done with the "BKL КОРРЕКТОР" switch.

In this case, in the SINS algorithms, the vertical speed and altitude signals are generated as signals of the reference navigation system, and the error correctors "play along" the constant and variable components. During the research, the error of the barometric altimeter was form as a constant component with a value of 25 m, which was combined with a component that slowly changed with a frequency of 0.003 rad/s and amplitude of 5 m.

The results of the study is of the SINS algorithms with an external corrector are presented in the oscillograms (Fig. 10a and b).



a) b)

Fig. 10. The impact of differenced in calculations of gravity force vector acceleration on coordinates calculation error

Under similar modeling conditions to the previous ones, this correction reduces the error in the coordinates of longitude λ and latitude φ to 200…300 m. The errors in calculating the angular orientation parameters are reduced by about three orders of magnitude. However, the methodological errors of SINS in calculating angular coordinates even before correction meet the requirements for similar navigation systems. Naturally, the error in calculating coordinates in this case will depend on the errors of the external corrector.

Initial parameters (errors of primary data sensors and flight conditions) in modeling can vary: average, high and low latitudes; flight direction (along and across the meridian; along the direction of Earth rotation and against it, etc.).

The developed models and their simulation results were compared with real test results of the strapdown gyro vertical СБКВ-П2А [3] and confirmed their validity. This allows us to recommend the developed computer models of AINS for comparative evaluation of its methodological and instrumental errors at the stage of designing the navigation system of an unmanned aerial vehicle. The modeling complex can also be used for experimental testing of innovative algorithms of satellite and inertial navigation system data integration.

IV. CONCLUSIONS

The modeling complex implemented in MATLAB-Simulink allows solving the problem of designing algorithms for SINS operation, the methodological errors of calculation of navigation parameters of which, in particular, simplification of the parameters of the earth spheroid, would correspond to the calculation errors caused by errors of primary information sensors. The calculation errors of navigation parameters in the modeling complex are formed as differences in signals of the reference and the studied navigation systems. The modeling can vary: medium, high and low latitudes; altitude and flight direction (along and a cross the meridian; along the direction of Earth's rotation and against it).

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М. К. Філяшкін, О. І. Смірнов. Моделюючий комплекс для дослідження методичних та інструментальних похибок безплатної інерційної навігаційної системи

Під час дослідження точнісних характеристик безплатформна інерціальна навігаційна система представляється як сукупність кінематичних рівнянь та рівнянь математичноїмоделі Землі. На основі такої математичної моделі в пакеті Matlab-Simulink створено моделюючий комплекс, що складається із субсистем еталонної та досліджуваної навігаційної системи, субсистем еталонної та спрощеної моделі Землі та субсистем датчиків первинної інформації. У навігаційних субсистемах розв‘язуються кінематичні рівняння алгоритмів інерціальної навігації, а також формуються матриці напрямних косінусів. У субсистемах моделі Землі обчислюються параметри земного сфероїда та прискорення сили тяжіння. Моделі датчиків розроблені з урахуванням характеристик недорогих микроэлектромеханических датчиків. Метою дослідження була оцінка методичних та інструментальних похибок як різниц сигналів числення навігаційних параметрів польоту еталонною та досліджуваною навігаційними системами. Методичні похибки підігрувалися спрощеннями параметрів земного сфероїда, а інструментальні помилками інерційних датчиків.

Ключові слова: безплатформна інерційна навігаційна система; еталонна система; інерційні датчики; земний сфероїд; методичні та інструментальні похибки.

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Напрям наукової діяльності: комплексна обробка інформації в пілотажно-навігаційних комплексах, автоматизація та оптимізація керування повітряними суднами на різних етапах польоту.
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