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ALGORITHM OF THE SEMI-ANALYTIC TYPE INERTIAL NAVIGATION SYSTEM WITH THE CORRECTION OF THE PARAMETERS OF ABSOLUTE MOVEMENT IN THE GEOGRAPHICAL SYSTEM OF COORDINATES

PUSANALĪTISKA TIPA INERCIĀLA NAVIGĀCIJAS SISTĒMAS ALGORITMS ĢEOGRĀFISKAJĀ ATSKAITES SISTĒMĀ AR KOREKCIJU PĒC ABSOLŪTĀS KUSTĪBAS PARAMETRIEM

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Geographical system of coordinates NEH is connected to the Earth surface. Axis N and E located in the plane of local horizon. Axis N is directed to the North Pole of the Earth. Axis E is directed to the East and perpendicular to the N axis. Axis H directed as a vertical to the place. The system of coordinates is realized by gyro-stabilized platform, on which the sensors of primary information of navigation system are fitted.

In order to get the algorithm of the semi-analytic type INS with the correction of the parameters of absolute movement functioning in the geographical system of coordinates it is necessary to project the vector equation of relative velocity changes on the axis's of the geographical system of coordinates:

$$\frac{d\vec{U}}{dt} = \vec{\alpha}_{acc} - \left(\vec{\Omega}_{SC} \times \vec{V}_a\right) - \frac{d\vec{V}_e}{dt}, \tag{1}$$

$$\vec{V}_a = \vec{U} + \vec{V}_e; \ \vec{V}_e = \vec{V}_3 = \vec{\Omega}_3 \times \vec{R}_3; \ \vec{\Omega}_{SC} = \frac{\vec{V}_a}{R_3},$$

where:

$\vec{\alpha}_{acc}$ is a vector of the output signal of the accelerometer,

$\vec{V}_a$ is a vector of the absolute velocity of movement,

$\vec{V}_e$ is a vector of the carrying velocity,

$\vec{U}$ is a vector of relative velocity,

$\vec{\Omega}_3$ is a vector of the angular velocity of rotation of the Earth,

$\vec{V}_3$ is a vector of the linear velocity of rotation of the Earth,

$\vec{\Omega}_{SC}$ is a vector of the angular velocity of the geographical system of coordinates rotation.

The vector of the linear velocity of the earth's movement V_3, directed by the E axis. The vector of the relative velocity of the aircraft movement has projections on all axes of the geographical system of coordinates. According to that projections of the vector of the absolute movement velocity $\vec{V}_a$ on the axes of the geographical system of coordinates will be determined as follows:

$$V_{aE} = V_3 + U_E\,;\; V_{aN} = U_N\,;\; V_H = U_H\,. \tag{2}$$

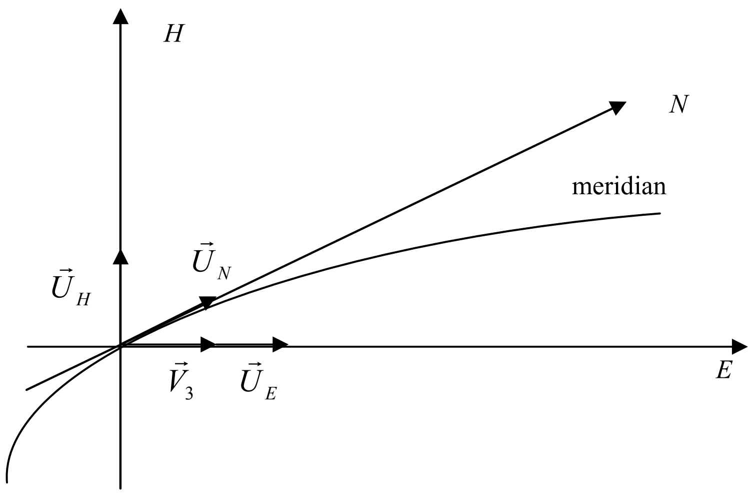

Fig. 1. Components of relative speed

The geographical system of coordinates is the moving reckoning system in the world absolute space. Geographical system of coordinates rotating with the angular velocity Ω_{SC}, that depends from absolute movement velocity of the aircraft. North component of the absolute velocity V_{aN} will produce the east component of *the angular velocity of movement of the* system of coordinates: $\Omega_{SCE} = -\dfrac{V_{aN}}{R_3}$. The East component of absolute velocity V_{aE} will produce angular velocity of movement of the system of coordinates $\Omega_{SCj3} = \dfrac{V_{aE}}{R_3 \cos\varphi}$, which has a components by both *N axis* (Ω_{SCN}) and *H axis* (Ω_{SCH}). The projections of vector of angular velocity of syst6em of coordinates $\vec{\Omega}_{SC}$ on their axes will be determined as follows:

$$\Omega_{SCN} = \Omega_{SCj3} \cdot \cos\varphi = \frac{V_{aE}}{R_3};$$

$$\Omega_{SCH} = \Omega_{SCj3} \cdot \sin\varphi = \frac{V_{aE}}{R_3} tg\varphi; \tag{3}$$

$$\Omega_{SCE} = -\frac{V_{aN}}{R_3},$$

where: φ is a latitude angle.

In the equation (1) the member $\frac{d\vec{V}_e}{dt}$ determined as the value changes of the vector $\vec{V}_3$. At the movement of the aircraft by the meridian (when latitude angle φ changes) will change vector's $\vec{V}_3(\Delta\varphi)$ value. Let's find out the value of the vector $\vec{V}_3$ changes:

$$\Delta V_3 = V_{32} - V_{31} = \Omega_3 R_3 \cos\varphi_2 - \Omega_3 R_3 \cos\varphi_1 = \Omega_3 R_3 \cos\varphi_2 - \Omega_3 R_3 \cos(\varphi_2 - \Delta\varphi) =$$

$$= \Omega_3 R_3 \cos\varphi_2 - \Omega_3 R_3 \cos\varphi_2 \cos\Delta\varphi - \Omega_3 R_3 \sin\varphi_2 \sin\Delta\varphi = \Omega_3 R_3 \cos\varphi_2 - \tag{4}$$

$$- \Omega_3 R_3 \cos\varphi_2 - \Omega_3 R_3 \sin\varphi_2 \cdot \Delta\varphi = -\Omega_3 R_3 \sin\varphi_2 \cdot \frac{U_N \Delta t}{R_3}.$$

From the equation (4) we will get the value of the differential $\frac{d\vec{V}_e}{dt}$:

$$\left|\frac{d\vec{V}_e}{dt}\right| = \left|\lim_{\Delta t \to 0} \frac{\Delta\vec{V}_3}{\Delta t}\right| = -\Omega_3 U_N \sin\varphi_2. \tag{5}$$

The differential $\frac{d\vec{V}_e}{dt}$ has a projection $\Delta\vec{V}_3(\Delta\varphi)$ only by axis *E* of geographical system of coordinates:

$$\frac{dV_e}{dt} = \frac{dV_{eE}}{dt} = -\Omega_3 U_N \sin\varphi_i, \tag{6}$$

where: φ_i – current value of the latitude angle.

When we found separate components in equation (1), now we can calculate projection of the vectors multiplication $(\vec{\Omega}_{SC} \times \vec{V}_a)$ on axis's of geographical system of coordinates. Projections of the vectors multiplication $(\vec{\Omega}_{SC} \times \vec{V}_a)$ on axis's *N, E, H* will be equal:

$$(\vec{\Omega}_{SC} \times \vec{V}_a)_{1N} = V_{aE}\Omega_{SCH} + V_{aH}\Omega_{SCE},$$

$$(\vec{\Omega}_{SC} \times \vec{V}_a)_{1E} = V_{aN}\Omega_{SCH} + V_{aH}\Omega_{SCN}, \tag{7}$$

$$(\vec{\Omega}_{SC} \times \vec{V}_a)_{1H} = V_{aE}\Omega_{SCN}.$$

Now if we will collect all components of equation (1) by the appropriate axes, will get the full algorithm of Inertial Navigation System operating in geographical system of coordinates with the correction by the absolute movement parameters:

$$\frac{dU_N}{dt} = \alpha_{accN} - V_{aE}\Omega_{SCH} - V_{aH}\Omega_{SCE},$$

$$\frac{dU_E}{dt} = \alpha_{accE} + V_{aN}\Omega_{SCH} - V_{aH}\Omega_{SCN} + \Omega_3 U_N \sin\varphi,$$

$$\frac{dU_H}{dt} = \alpha_{accH} - q - V_{aE}\Omega_{SCN},$$

$$V_{aE} = V_3 + U_E;\ V_{aN} = U_N;\ V_H = U_H;\ V_3 = \Omega_3 R_3 \sin\varphi, \tag{8}$$

$$\Omega_{SCN} = \frac{V_{aE}}{R_3};\ \Omega_{SCE} = -\frac{V_{aN}}{R_3};\ \Omega_{SCH} = \frac{V_{aE}}{R_3} tg\varphi;$$

$$S_N = \int_0^t U_N dt;\ S_E = \int_0^t U_E dt;\ H = \int_0^t U_H dt,$$

$$\varphi = \varphi_0 + \frac{S_N}{R_3};\ U_N = \int_0^t \frac{dU_N}{dt} dt;\ U_E = \int_0^t \frac{dU_E}{dt} dt;\ U_H = \int_0^t \frac{dU_H}{dt} dt.$$

Without a vertical channel the algorithm of the semi-analytic type Inertial Navigation System, which operating in geographical system of coordinates with the correction by the absolute movement parameters:

$$\frac{dU_N}{dt} = \alpha_{accN} - V_{aE}\Omega_{SCH};\ \frac{dU_E}{dt} = \alpha_{accE} + V_{aN}\Omega_{SCH} + \Omega_3 U_N \sin\varphi;$$

$$U_N = \int_0^t \frac{dU_N}{dt} dt;\ U_E = \int_0^t \frac{dU_E}{dt} dt;$$

$$V_{aE} = V_3 + U_E;\ V_{aN} = U_N;\ V_3 = \Omega_3 R_3 \sin\varphi; \tag{9}$$

$$\Omega_{SCN} = \frac{V_{aE}}{R_3};\ \Omega_{SCE} = -\frac{V_{aN}}{R_3};\ \Omega_{SCH} = \frac{V_{aE}}{R_3} tg\varphi;$$

$$S_N = \int_0^t U_N dt;\ S_E = \int_0^t U_E dt;\ \varphi = \varphi_0 + \frac{S_N}{R_3}.$$

Developed algorithm contains less number of operations *(23)* in comparison with classical variant of *INS (39*). This will cause the decreasing of the number of the structural technical elements and therefore increasing of the reliability of the INS operation.

Conclusions

The algorithm of an inertial system in geographical system of coordinates is developed, where correction implements on parameters of motion in the absolute space.

The developed algorithm contains smaller number of operations concerning classical version.

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Trifonova-Bogdanova T., Trifonovs-Bogdanovs P., Fetisovs D. Pusanalītiska tipa inerciāla navigācijas sistēmas algoritms ģeogrāfiskajā atskaites sistēmā ar korekciju pēc absolūtās kustības parametriem

Pusanalītiskā tipa inerciālā navigācijas sistēma, kas strādā pēc ģeogrāfiskās koordinātu sistēmas, tiek raksturota ar divkāršu gaisa kuģa lidojuma parametru pārveidošanu. Sākumā no mērāmajiem absolūtajiem parametriem pāriet uz relatīvajiem parametriem. Pēc tam no relatīvajiem parametriem atkārtoti tiek formulēti absolūtie parametri. Šie absolūtie parametri turpmāk tiek izmantoti iekšējās inerciālās navigācijas sistēmas korekcijai. Tādā veidā daļēji analītiskā tipa inerciālās navigācijas sistēmā, kas strādā pēc ģeogrāfiskās koordinātu sistēmas, norisinās divkāršā gaisa kuģa lidojuma parametru pārveidošana. Tas noved pie liekiem struktūras sarežģījumiem un pie tā, ka kļūst nepieciešams ieviest papildus sastāvdaļas inerciālās navigācijas sistēmas struktūrā. Optimizācijai ir izstrādāts jauns pusanalītiskā tipa algoritms inerciālajām navigācijas sistēmām, kas darbojas pēc ģeogrāfiskā kursa. Korekcijas algoritms tiek izstrādāts pēc absolūtās kustības parametriem. Piedāvātais algoritms, kas strādā pēc ģeogrāfiskās koordinātu sistēmas, satur mazāk sastāvdaļu inerciālās navigācijas sistēmā salīdzinājumā ar klasisko analogu.

Trifonova-Bogdanova T., Trifonovs-Bogdanovs P., Fetisovs D. Algorithm of the semi-analytic type inertial navigation system with the correction of the parameters of absolute movement in the geographical system of coordinates

The semi-analytic type inertial navigation system, which operates in geographical coordinate system, performs dual conversion of parameters of motion of flying vehicle. In the beginning, the measured (absolute) parameters are converted to relative parameters. Then the absolute parameters are obtained from these relative parameters again. These absolute parameters are used for internal correction of inertial navigation system. Thus the dual conversion of flying vehicle flight parameters is performed in semi-analytic type inertial navigation system. These conversions led to sophistication of operational algorithm and as a result there are additional functional elements of the system. For optimization of structure of semi-analytic type inertial navigation system, the algorithm should include correction elements of parameters of motion in the absolute space. The new algorithm of optimization of semi-analytical type inertial navigation system, which operates in geographical coordinate system, is developed. Optimization is performed using absolute flight parameters of flying vehicle. Offered algorithm consists of smaller functional element number in comparison with classical algorithm.

Трифонова-Богданова Т., Трифонов-Богданов П., Фетисов Д. Алгоритм инерциальной навигационной системы полуаналитического типа в географической системе координат с коррекцией по параметрам абсолютного движения

Инерциальная навигационная система полуаналитического типа, работающая в географической системе координат, характеризуется двойным преобразованием параметров движения воздушного судна. В начале от измеряемых абсолютных параметров переходят к относительным параметрам. Затем из относительных параметров вновь формируются абсолютные параметры. И эти абсолютные параметры используются для внутренней коррекции инерциальной навигационной системы. Таким образом, в структуре инерциальной навигационной системы полуаналитического типа осуществляется двойное преобразование параметров полета воздушного судна. Это дает излишнее структурное усложнение и приводит к появлению дополнительных составных частей в структуре инерциальной навигационной системы. Разработан новый алгоритм оптимизации инерциальной системы полуаналитического типа в географической системе координат. Операции по коррекции алгоритма производились по параметрам абсолютного движения. Предлагаемый алгоритм содержит меньше составных частей инерциальной навигационной системы, работающей в географической системе координат, по сравнению с классическим аналогом.