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OPTIMIZATION OF ALGORITHM OF AN INERTIAL SYSTEM OF THE SEMI-ANALYTICAL SCHEME

INERCIĀLAS SISTĒMAS PUSANALĪTISKA TIPA ALGORITMA OPTIMIZĀCIJA

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The classical semi-analytic type INS variant is characterized by double transformation of movement parameter information. Sensors of primary information (accelerometer) take the parameters of absolute movement. First transformation of information in the calculations is made in acceleration level. Transition from absolute movement parameters to parameters of relative movement is performed in the calculation chain. The second conversion of movement parameter information is performed in INS correction chains. There is transition in opposite direction – from relative movement parameters to absolute movement parameters. Such double transition of movement kinematic components is not optimal from the point of view of operation amount minimizing in the INS algorithm. The minimizing of operation numbers in the navigation system algorithm increases the reliability of its function.

Considering that accelerometers and control gyros of semi-analytic type INS are working in space of absolute movement parameters, it is useful to make correction in the system on these parameters only.

For evolution of semi-analytic type INS algorithm with correction on absolute movement parameters only, let's look through kinematics of a complex movement. From aircraft movement kinematics follows that its absolute movement velocity V_a is sum of relative movement velocity U and transfer movement velocity V_e:

$$\vec{V}_a = \vec{U} + \vec{V}_e . \tag{1}$$

The frame of reference, where the semi-analytic type INS operates, is connected with earth's ground. In that case equation (1) can be expressed as sum of components on axes of ground coordinate system *KLN*:

$$\vec{V}_a = (\vec{k}U_k + \vec{l}\,U_l + \vec{n}U_n) + (\vec{k}V_{ek} + \vec{l}\,V_{el} + \vec{n}V_{en}) , \tag{2}$$

where: k, l, n – unit vectors of ground coordinate system;
U_k, U_l, U_n – projections of relative velocity on ground coordinate system axes;
V_{ek}, V_{el}, V_{en} – projections of transfer movement velocity on ground coordinate system axes.

Accelerometer measures the change of aircraft movement absolute velocity:

$$\vec{a}_{aks} = \vec{a}_a = \frac{d\vec{V}_a}{dt} = \frac{d\vec{V}}{dt} = \frac{d\vec{V}}{dt} + \frac{d\vec{V}_e}{dt} \tag{3}$$

Considering (2), expression (3) can be written in following way:

$$\begin{aligned}\vec{a}_{aks} &= \left(\vec{k}\frac{dU_k}{dt}+\vec{l}\frac{dU_l}{dt}+\vec{n}\frac{dU_n}{dt}\right)+\left(\frac{d\vec{k}}{dt}U_k+\frac{d\vec{l}}{dt}U_l+\frac{d\vec{n}}{dt}U_n\right)+\\ &+\left(\vec{k}\frac{dV_{ek}}{dt}+\vec{l}\frac{dV_{el}}{dt}+\vec{n}\frac{dV_{en}}{dt}\right)+\left(\frac{d\vec{k}}{dt}V_{ek}+\frac{d\vec{l}}{dt}V_{el}+\frac{d\vec{n}}{dt}V_{en}\right).\end{aligned} \tag{4}$$

The first item in expression (4) is relative acceleration:

$$\vec{k}\frac{dU_k}{dt}+\vec{l}\frac{dU_l}{dt}+\vec{n}\frac{dU_n}{dt}=\vec{a}_r=\frac{d\vec{U}}{dt}. \tag{5}$$

The third item in expression (4) is portable acceleration component, which describes the change of transfer velocity value:

$$\vec{k}\frac{dV_{ek}}{dt}+\vec{l}\frac{dV_{el}}{dt}+\vec{n}\frac{dV_{en}}{dt}=\vec{a}_k=\frac{d\vec{V}_e}{dt}. \tag{6}$$

Let's transform the second and the fourth item of expression (4):

$$\begin{aligned}&\left(\frac{d\vec{k}}{dt}U_k+\frac{d\vec{l}}{dt}U_l+\frac{d\vec{n}}{dt}U_n\right)+\left(\frac{d\vec{k}}{dt}V_{ek}+\frac{d\vec{l}}{dt}V_{el}+\frac{d\vec{n}}{dt}V_{en}\right)=\\ &=\frac{d\vec{k}}{dt}\left(U_k+V_{ek}\right)+\frac{d\vec{l}}{dt}\left(U_l+V_{el}\right)+\frac{d\vec{n}}{dt}\left(U_n+V_{en}\right)=\\ &=V_{ak}\left(\vec{\Omega}_{sk}\times\vec{k}\right)+V_{al}\left(\vec{\Omega}_{sk}\times\vec{l}\right)+V_{an}\left(\vec{\Omega}_{sk}\times\vec{n}\right),\end{aligned} \tag{7}$$

where: Ω_{sk} – angular velocity of coordinate system *KLN*;
V_{ak}, V_{al}, V_{an} – components of absolute velocity on coordinate system *KLN* axes.

Further transformation of expression (7) gives:

$$\begin{aligned}&V_{ak}\left(\vec{\Omega}_{sk}\times\vec{k}\right)+V_{al}\left(\vec{\Omega}_{sk}\times\vec{l}\right)+V_{an}\left(\vec{\Omega}_{sk}\times\vec{n}\right)=\\ &=\vec{\Omega}_{sk}\times\left(V_{ak}\cdot\vec{k}+V_{al}\cdot\vec{l}+V_{an}\cdot\vec{n}\right)=\vec{\Omega}_{sk}\times\vec{V}_a=\vec{a}_e.\end{aligned} \tag{8}$$

This is the component of absolute acceleration which occurs because of the change of aircraft velocity direction, when a movement of reference frame exists.

The expression of accelerometer output signal, considering all the transformations, will be as follows:

$$\vec{a}_{aks}=\vec{a}_a=\vec{a}_r+\vec{a}_e+\vec{a}_k=\frac{d\vec{V}}{dt}+\left(\vec{\Omega}_{sk}\times\vec{V}_a\right)+\frac{d\vec{V}_e}{dt}. \tag{9}$$

In this equation, considering the task conditions, transfer velocity V_e is linear velocity of a point on earth's ground, over which in the given moment the aircraft is located:

$$\vec{V}_e=\vec{V}_z=\vec{\Omega}_z\times\vec{R}_z, \tag{10}$$

where: Ω_z – angular velocity of earth's rotation.

Angular velocity of earth's coordinate system rotation depends on earth's rotation velocity and relative velocity of aircraft:

$$\vec{\Omega}_{sk} = \frac{\vec{V} + \vec{V}_z}{R_z} = \frac{\vec{V}_a}{R_z} . \tag{11}$$

From expressions (9), (10), (11) of aircraft complex movement kinematics we can obtain semi-analytic type INS algorithm with correction on absolute movement parameters:

$$\frac{d\vec{U}}{dt} = \vec{a}_{aks} - \left(\vec{\Omega}_{sk} \times \vec{V}_a\right) - \frac{d\vec{V}_e}{dt}; \;\; \vec{\Omega}_{sk} = \frac{\vec{V}_a}{R_z};$$

$$\vec{V}_a = \vec{U} + \vec{V}_e; \;\; \vec{V}_e = \vec{V}_z; \;\; \vec{V}_z = \vec{\Omega}_z \times \vec{R}_z . \tag{12}$$

This algorithm allows composing the structural scheme of semi-analytic type INS for operation with given (geographical or ortodrome) coordinate system.

Conclusion

The algorithm of an inertial system of the semi-analytical scheme 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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Trifonovs-Bogdanovs P. Inerciālas sistēmas pusanalītiska tipa algoritma optimizācija

Pusanalītiskā tipa inerciālā navigācijas sistēma tiek raksturota ar divkāršu gaisa kuģa lidojuma parametru pārveidošanu. Sākumā no izmērāmajiem absolūtajiem parametriem pāriet uz relatīvajiem parametriem. Informācija par relatīvajiem parametriem tiek nosūtīta gaisa kuģa apkalpei. Pēc tam no relatīvajiem parametriem atkārtoti tiek formulēti absolūtie parametri. Šie absolūtie parametri tiek turpmāk izmantoti iekšējās inerciālās navigācijas sistēmas korekcijai. Tādā veidā pusanalītiskā tipa inerciālās navigācijas sistēmā norisinās divkāršā gaisa kuģa lidojuma parametru pārveidošana. Tā rodas lieki struktūras sarežģījumi, kas noved pie tā, ka ir nepieciešams ievest papildus sastāvdaļas inerciālās navigācijas sistēmas struktūrā. Ir izstrādāts jauns algoritms pusanalītiskā tipa inerciālās navigācijas sistēmas optimizācijai. Korekcijas algoritms tiek izstrādāts pēc absolūtās kustības parametriem. Piedāvātais algoritms sastāv no mazāka sastāvdaļu skaita, salīdzinājumā ar savu klasisko analogu.

Trifonov-Bogdanov P. Optimization of algorithm of an inertial system of the semi -analytical scheme

The semi-analytic type inertial navigation 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 is developed. Optimization is performed using absolute flight parameters of flying vehicle. Offered algorithm consists of smaller functional element number in comparison with classical analogue.*

Трифонов-Богданов П. Оптимизация алгоритма инерциальной системы полуаналитического типа
Инерциальная навигационная система полуаналитического типа характеризуется двойным преобразованием параметров движения воздушного судна. В начале от измеряемых абсолютных параметров переходят к относительным параметрам. Информация об относительных параметрах посылается экипажу воздушного судна. 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. Операции по коррекции алгоритма производились по параметрам абсолютного движения. Предлагаемый алгоритм содержит меньше составных частей, по сравнению со своим классическим аналогом.