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DATA WARE OF AIRCRAFT AUTOMATED CONTROL USING GLOBAL NAVIGATION SATELLITE SYSTEMS

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The variant of information maintenance of aircraft's automatic control using satellite navigation system for providing landing approach and landing has been considered in this research. Calculation ratios for definition of coarse deviations have been given. Error statistics of determination of deviations have been investigated.

Keywords: information maintenance, automatic control, aircraft, GNSS

Introduction

To ensure the tasks of aircraft navigation and control it's necessary to have the following information: parameters of the aircraft mass center movement; aircraft motion relative to its center of mass; aircraft motion relative to landmarks. Sensors of required information are radio navigation, inertial and in the last decades satellite navigation.

Instrumental landing system (ILS) assumes presence at airport of ground complex equipment, which includes on-course and glide-path beacons, and airborne on-course and glide-path radio receivers. Ground radio beacons set no perturbed flight trajectory that occurred due to intersection of radio signal zones of on-course and glide-path beacons in space. Aircraft deviation from the reference trajectory is fixed by on-course and glide-path radio receivers.

There are regulated procedures of precision landing by Category I at presence of correspondent GNSS equipment. Procedure of precision landing using GNSS is designated as GLS. Flight trajectory according to GLS is defined in other manner that with ILS. Data defining flight trajectory are transmitted by GBAS to aircraft through digital communication line as FAS data blocks. Airborne GNSS equipment using geometric relationships calculates trajectory parameters and determines guidance parameters similarly to other landing systems, ILF for example.

Problem statement

It's necessary to consider variant of aircraft guidance to the landing decision point by itinerary way using GNSS airborne equipment [1] and estimate error parameters of aircraft deviation from the reference point.

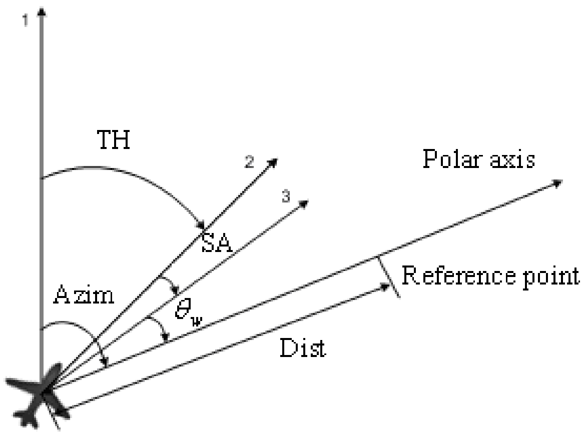
Data ware creation

Let's suppose, there is an airborne navigation GNSS receiver. It provides setting of the following parameters:

- coordinates X_s, Y_s, Z_s of aircraft center of mass (in geocentric coordinate system X, Y, Z);
- ellipsoid geographic coordinates of aircraft center of mass: θ (latitude) and λ (longitude);
- ground speed vector $VG\,[VG_x, VG_y, VG_z]$.

Coordinates of reference point in geocentric coordinate system X_z, Y_z, Z_z are transmitted from ground station of outside pilot. There is possible variant when coordinates X_z, Y_z, Z_z are known a priory.

Let's consider variant of data ware for aircraft automated control organization. As a basis itinerary way of aircraft guidance to the reference point is taken, scheme of which is depicted at fig. 1 [1].



Scheme of itinerary way of aircraft guidance to the reference point: 1 – North Direction (*N*); 2 – vector of aircraft ground speed; 3 – projection of vector *W* of aircraft ground speed – *V*; TH – true heading; SA – slip angle (кут зносу); Dist – distance from aircraft mass centre to the reference point; Azim – azimuth of polar axis; θ_w – angle between polar axis and *W*.

For determination of angle deviation θ_w in topocentric coordinate system O_t, X_t, Y_t, Z_t with start point at the aircraft mass centre let's perform following transformations.

Let's transfer line between points (X_s, Y_s, Z_s) and (X_z, Y_z, Z_z) from geocentric to topocentric coordinate system through transfer of geocentric coordinate system at point O_t and rotations relative to axes X_t, Y_t, Z_t [1].

Coordinates of transferred line (as a vector) are calculated in the following way:

$$R_x = \sin\theta\cos\lambda\, rx + \sin\theta\sin\lambda\, ry - \cos\theta\, rz;$$

$$R_y = -\sin\lambda\, rx + \cos\lambda\, ry;$$

$$R_z = \cos\theta\cos\lambda\, rx + \cos\theta\sin\lambda\, ry + \sin\theta\, rz,$$

where $[rx, ry, rz] = [X_s - X_z, Y_s - Y_z, Z_s - Z_z]$.

For transferring vector *W* it's enough to perform three rotations:

$$V_x = \sin\theta\cos\lambda W_x + \sin\theta\sin\lambda W_y - \cos\theta W_z;$$

$$V_y = -\sin\lambda W_x + \cos\lambda W_y;$$

$$V_z = \cos\theta\cos\lambda W_x + \cos\theta\sin\lambda W_y + \sin\theta W_z.$$

Azimuth, elevation and angle α, that equals sum of true heading and slip angle, are calculated as:

$$А_{зт} = \mathrm{arctg}\left(-\frac{R_y}{R_x}\right);$$

$$U_m = \arcsin\left(\frac{R_z}{R}\right);$$

$$\alpha = \mathrm{arctg}\left(-\frac{V_y}{V_x}\right),$$

where $R = \sqrt{R_x^2 + R_y^2 + R_z^2}$.

Angle θ_w equals:

$$\theta_w = А_{зт} - \alpha.$$

Distance

$$Д_{зт} = \sqrt{(X_s - X_z)^2 + (Y_s - Y_z)^2 + (Z_s - Z_z)^2}.$$

Motion control is performed by aircraft guidance, which keeps equality $\theta_w = 0$ at condition, that $Д_{зт} \neq 0$, and $\theta_w < 90°$.

Mathematical modeling

For errors' calculation of $А_{зт}$ and $Д_{зт}$ parameters determination mathematical modeling has been performed. Initial data: coordinates X_z, Y_z, Z_z і X_s, Y_s, Z_s, θ_s, λ_s. Aircraft is at the same longitude with ground control station at distance of 30 km and angle $3°$. Errors of coordinates calculation are set as random variables with normal distribution with parameters *md*, *sd* for Cartesian and *ms*, *ss*, for polar coordinates. Mathematical expectations *mD*, *mA* and standard deviations *sD*, *sA* of distance and azimuth are calculated for 50000 samples. It's supposed that *ms* = *md* = 0. Simulation results are represented at tab. 1.

Data analysis from the table shows:

- mean square error of distance calculation is in proportion to mean square error of Cartesian coordinates measurement by means of GNSS;
- mean square error of azimuth calculation depends on error of polar coordinates calculation and almost doesn't depend on the error of Cartesian coordinates measurements;
- at errors of Cartesian coordinates measurement *sd* = 3 m and polar coordinates calculation *ss* = 0,005 rad mean square error of distance between reference point and aircraft equals to 4,2 m, azimuth – $2\cdot10^{-3}$ rad, that allows considering this way of automated control for aircraft landing task solution.

Conditional accuracy of coordinates' determination is obtained using modern navigation receivers in a standard mode. Differential mode of navigation allows receiving increased accuracy that corresponds to the last column at tab. 1. As it's seen from the above mentioned equations, error of angle θ_w calculation is 1.4 times bigger than azimuth calculation error.

Such control can be used for automated aircraft landing system. At foreseen place of landing reference station is placed that transmits on board through connection line coordinates X_s, Y_s, Z_s (point of landing or decision making) and differential corrections. Parameters θ_w and $Д_{зт}$ are calculated for aircraft and then transmitted to the system of automatic control that includes all necessary circuits of dynamic system correction, servomotors and feedbacks.

When aircraft approaches to the decision taking point control is passed to ground operator or to the control landing program.

Landing control program it's possible to construct, for example, by method of automatic landing control at exponential aligning trajectory [3]. Landing trajectory is described by differential equation:

$$T \cdot \dot{H} + H = H_{ac},$$

where T – constant; H_{ac} – asymptote to exponential; H – aircraft altitude above landing area.

Altitude determination accuracy is an essential task for this method realization. Therefore accuracy of altitude determination is investigated by simulation according to the following equation:

$$H = R\sin(U_m).$$

Simulation results are represented at tab. 2, where *mH* – mathematical expectation, *sH* – root mean square errors of *H* calculation, m.

Table 1

Statistics of $А_{зт}$ and $Д_{зт}$ parameters calculation errors

sd , m	20	10	5	5	3	3	1
ss, rad	0,05	0,05	0,05	$5 \cdot 10^{-3}$	0,05	0,005	0,005
mA, rad	$3 \cdot 10^{-5}$	$-3 \cdot 10^{-4}$	$-3 \cdot 10^{-4}$	-10^{-5}	$-2 \cdot 10^{-6}$	$3 \cdot 10^{-6}$	$2 \cdot 10^{-6}$
sA , rad	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
mD, m	-0,2	-0,2	0,01	0,03	0,02	0,04	0,01
sD, m	28	14	7	7	4,2	4,2	1,4

Table 2

Statistics of altitude calculation errors

sd, m	5	5	5	3	3	1	1
ss, rad	$5 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-10}$	$5 \cdot 10^{-4}$	$5 \cdot 10^{-6}$	$5 \cdot 10^{-4}$	$5 \cdot 10^{-6}$
mH, m	0,02	-0,08	-0,03	0,02	-0,02	0,02	0,02
sH, m	15,4	7,3	7,2	15,4	4,2	13,7	1,4

As it's seen from tab. 2 for obtaining accuracy of altitude calculation of 1.4 m, it's necessary to ensure accuracy of navigation parameters determination by GNSS not less than 1 m at all axes. It causes the necessity of differential mode apply. For obtaining better accuracy, interference immunity, availability and reliability it's recommended to integrate GNSS with inertial navigation system.

Conclusions

Recent studies have shown that data ware of aircraft automated control system at the basis of standard airborne navigation equipment and differential mode of GNSS according to its accuracy allows performing aircraft landing, especially for unmanned aerial vehicles.

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