The theta-theta channel functioning algorithm synthesis of the data measuring system for the maneuvering aircraft with consideration to its dynamic and kinematic characteristics

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Abstract. The state and observation models considered both kinematic and dynamic aircrafts parameters should be applied for the electronic navigation aids accuracy increasing issue of the air-traffic control system data measuring. In contrast to current air-traffic control system kinematic and dynamic parameters summarizing allows to describe the aircrafts movement model more adequate. In the study the theta-theta (t-t) navigation channel functioning algorithm of the air-traffic control system data measuring constructed by the kinematic and dynamic parameters correlation principle was developed and tested.

1. Introduction

The accuracy, stability and antijam performance response of the data measuring systems (DMS) for air-traffic control (ATC) depends on the aircraft manoeuvring at the airport operating zone. During the such aircraft manoeuvres as banking, turn and etc., the classic Kalman filters of the t-t channels (t-tCh) tends to divergence resulted in violent increasing of the azimuth (az-el-range) estimation error due to complex kinematic aircraft parameters - function (both angles and angular rate) [1, 2].
For the modern DMS ATC the t-tCh state model is based on the hypothesis of the aircraft movements with either a constant speed or a constant acceleration. According to [2], in this case the significant azimuth (az-el-range) estimation errors are appeared at the aircraft manoeuvres, which are inadequate to the current ATC system requirements at the safe flight number increasing controlled by an air traffic manager.
The synthesis of DMS ATC principles with both kinematic and dynamic aircraft parameters analysis is offered for the its path estimation. The information about kinematic and dynamic aircraft parameters can be acquired by an electric communication system in the airport area directly from the airborne sensors monitoring the aircraft flight parameters [2, 3, 4]. This technique can allow to choose the model of the t-tCh system more correctly. It should be stressed that in the current functional t-tCh algorithms of DMS, the data from the airborne sensors is not used.

2. Selection and justification system models

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It is known that the Zinger's state model is applied at the algorithm development of electric communication DMS system where the acceleration is simulated by the stationary process for the all possible aircraft paths [2, 5]. The Zinger's model of t-tCh system is:

- the state model

$$\varepsilon_a(k) = \varepsilon_a(k-1) + \omega_{\varepsilon_a}(k-1)T + 0{,}5a_{\varepsilon_a}(k-1)T^2; \tag{1}$$

$$\omega_{\varepsilon_a}(k) = \omega_{\varepsilon_a}(k-1) + a_{\varepsilon_a}(k-1)T; \tag{2}$$

$$a_{\varepsilon_a}(k) = (1-\alpha_a T)a_{\varepsilon_a}(k-1) + \xi_a(k-1); \tag{3}$$

- the observation model

$$\varepsilon_{ai}(k) = \varepsilon_a(k) + \xi_{a_i}(k). \tag{4}$$

In the (1) – (4) equations): α_a – manoeuvring time constant; ξ_a – the statistic white with R_a dispersion; T – discretisation interval (range); k – time discrete number; ξ_{a_i} – centralized discrete white noise of azimuth measuring with known R_{a_i} dispersion.

Providing the acceleration in (1) - (4) system model is constructed considered the manoeuvring time constant characterized various aircraft paths, the formed filter is optimal for different paths in general but not for the particular aircraft monitoring. According to the Zinger's model analysis result [2] the estimation of azimuth ε_a, angular rate speed ω_{ε_a} and angular acceleration in azimuth a_{ε_a} are correct if the aircraft is flying with either the constant rate or acceleration. At the aircraft manoeuvring the standard deviation estimation by azimuth for the both (1) and (2) models is increased in 3…4 times. It is the prohibitive value for DMS ATC. Moreover, the phase coordinates during the aircraft manoeuvring are nonlinear as the result of varied angular acceleration in azimuth according to the both type and manoeuvre stage at to separated path parts. Due to static character of the Zinger's model there are some problems at the law definition of the angular acceleration variation: aimed to the advanced parameters determination of the t-tCh DMS ATC, the aircraft acceleration characterization at the manoeuvring must be accurate [2].

The aircraft manoeuvring is characterized by both their kinematic (θ and φ – aircraft flight-path angles for the vertical and horizontal planes; γ_v – flight path bank angle) and dynamic (n_x – thrust load factor, n_y – vertical load factor, n_z – lateral acceleration) parameters. This information can be applied to the t-tCh in azimuth model construction for the aircraft azimuth definition in relation to the DMS ATC. Such the t-tCh in azimuth model can be presented as:

- the state model:

$$\varepsilon_a(k+1) = \varepsilon_a(k) + \omega_{\varepsilon_a}(k)T + 0{,}5a_{\varepsilon_a}(k)T^2; \tag{5}$$

$$\omega_{\varepsilon_a}(k+1) = \omega_{\varepsilon_a}(k) + a_{\varepsilon_a}(k)T; \tag{6}$$

$$a_{\varepsilon_a}(k+1) = a_{\varepsilon_a}(k) + \xi_a(k); \tag{7}$$

- the observation model:

$$\varepsilon_{ai}(k+1) = \varepsilon_a(k+1) + \xi_{\varepsilon_{ai}}(k+1); \tag{8}$$

$$\begin{aligned} a_{\varepsilon_{ai}}(k+1) = \operatorname{arctg}\Bigg(\Bigg(\Bigg(\Big(g\Big(&\big(\sin\varphi(k)\sin\theta(k) - \cos\varphi(k)\sin\theta(k)\big)\times \\ &\times\big(n_y(k)\cos\gamma_v(k) - n_z(k)\sin\gamma_v(k)\big) + n_x(k)\cos\theta(k)\times \\ &\times\big(\cos\varphi(k) - \sin\varphi(k)\big) + \big(\sin\varphi(k) + \cos\varphi(k)\big)\times \\ &\times\big(n_y(k)\sin\gamma_v(k) + n_z(k)\cos\gamma_v(k)\big)\Big)\Big)^2 - \\ &-\big(a_{lv}(k)\cos\varepsilon_{\text{в}}(k)\big)^2\Bigg)^{0,5}\Bigg)\Bigg/\big(D(k)\cos\varepsilon_{\text{в}}(k)\big)\Bigg) + \xi_{a_i}(k). \end{aligned} \tag{9}$$

where ξ_{a_i} – discrete centralized Gaussian noise of the acceleration measuring with R_{a_i} known dispersion; g – downward acceleration; D – line-of-sight distance, determined by the DMS RDR; θ, φ – banking and turning aircraft angles; $\varepsilon_{\text{в}}$ – elevation; a_{lv} – aircraft acceleration at the line-of-sight distance, determined by the distance measurement channel RDR.

3. The functioning algorithm of azimuth measuring device

Using the Kalman's filter [6, 7], both the state (5) - (7) and the observation model (8)- (9), we can determine the t-tCh functioning algorithm in azimuth aimed to the phase coordinates in azimuth ε_{aes}, angular rate $\omega_{\varepsilon_{a\,es}}$ and angular acceleration in azimuth $a_{\varepsilon_{a\,es}}$:

$$\varepsilon_{aes}(k+1) = \varepsilon_{ae}(k+1) + \mathrm{K}_{F11}(k+1)\Delta\varepsilon_a(k+1) + \mathrm{K}_{F12}(k+1)\Delta a_{\varepsilon_a}(k+1); \tag{10}$$

$$\omega_{\varepsilon_{a\,es}}(k+1) = \omega_{\varepsilon_{a\,e}}(k+1) + \mathrm{K}_{F21}(k+1)\Delta\varepsilon_a(k+1) + \mathrm{K}_{F22}(k+1)\Delta a_{\varepsilon_a}(k+1); \tag{11}$$

$$a_{\varepsilon_{a\,es}}(k+1) = a_{\varepsilon_{a\,e}}(k+1) + \mathrm{K}_{F31}(k+1)\Delta\varepsilon_a(k+1) + \mathrm{K}_{F32}(k+1)\Delta a_{\varepsilon_a}(k+1); \tag{12}$$

$$\varepsilon_{ae}(k+1) = \varepsilon_{aes}(k) + \omega_{\varepsilon_{a\,es}}(k)T + 0{,}5a_{\varepsilon_{a\,es}}(k)T^2; \tag{13}$$

$$\omega_{\varepsilon_{a\,e}} k+1) = \omega_{\varepsilon_{a\,es}}(k) + a_{\varepsilon_{a\,es}}(k)T; \tag{14}$$

$$a_{\varepsilon_{a\,es}}(k+1) = a_{\varepsilon_{a\,es}}(k); \tag{15}$$

$$\Delta\varepsilon_a(k+1) = \Delta\varepsilon_{ai}(k+1) - \Delta\varepsilon_{ae}(k+1); \tag{16}$$

$$\Delta a_{\varepsilon_a}(k+1) = a_{\varepsilon_{a\,i}}(k+1) - a_{\varepsilon_{a\,e}}(k+1). \tag{17}$$

4. Azimuth measuring device simulation and examination

The basic technique of real aircraft azimuth accuracy definition is computer simulation modelling. At the simulation procedure the resultant dynamic and fluctuation errors are defined for all conceivable application conditions as well as the filter divergence potentiality at the phase coordinates estimation procedure at the "Landing" manoeuvre [2].

Herein, at the modelling the input (from the measuring devices) signals simulation is performed as the changeable values of both relative true azimuth (figure 1) and the true angular azimuth rate in line-of-sight distance (figure 2) at the "Landing" aircraft manoeuvre. The observation noises $\xi_{\varepsilon_{ai}}$ and a_{ε_a} are determined by the random data generators. The simulated signals operating is carried out according to the (10)-(17) algorithm.

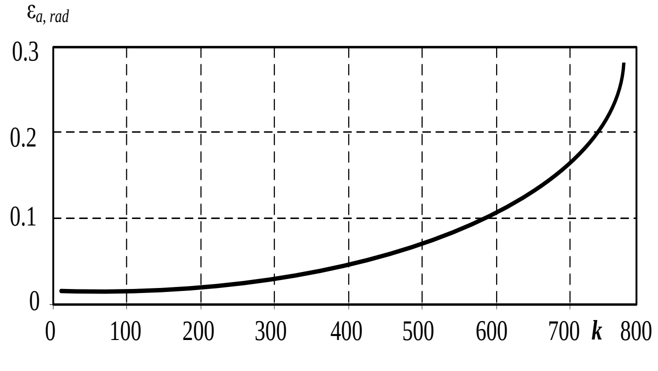

Figure 1. The line-of-sight distance azimuth dependence in time

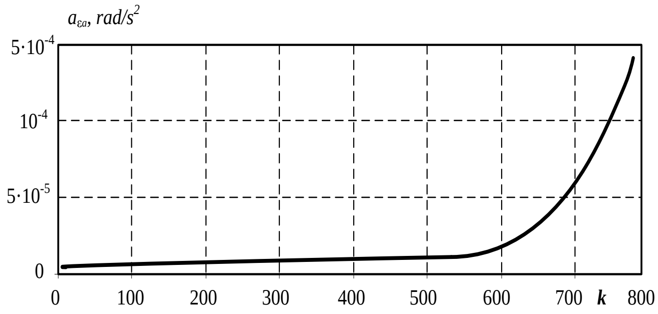

Figure 2. The line-of-sight distance angular azimuth rate dependence in time

According to figures 1-2, the both azimuth ε_a and angular azimuth rate a_{ε_a} are nonlinear functions in time that is not considered by the current DMS ATC techniques (by both the state and observation models). Consequently, the kinematic and dynamic aircraft parameters absence in the modelling procedure decreases the phase t-tCh coordinates accuracy.

In the study the real accuracy was estimated by the standard deviation of ε_a, ω_{ε_a} and a_{ε_a} values [1, 8]. The modeling was performed for two models of t-tCh in azimuth. The first t-tCh model is based on the both state and observation Zinger's model of relative aircraft movement (1)-(4). In the second model the developed model (5)-(9) is applied considered both kinematic and dynamic parameters detected by DMS from the aircraft side).

The average standard deviations time-dependence graphs of azimuth filtration ε_a, angular azimuth rate ω_{ε_a} and angular azimuth acceleration a_{ε_a} estimation in line-of-sight distance between t-tCh DMS and the aircraft are presented in figures 3-5.

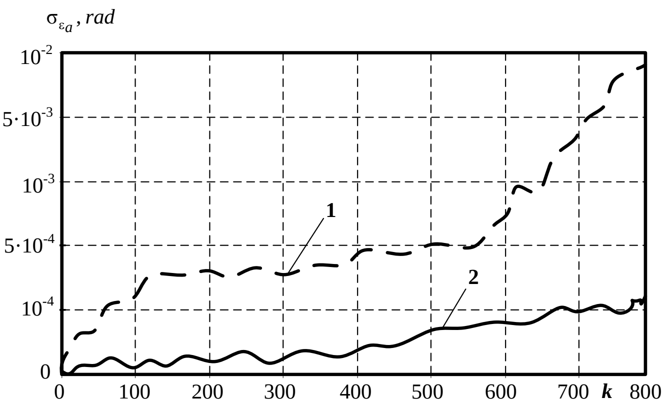

Figure 3. The average standard deviation of the azimuth

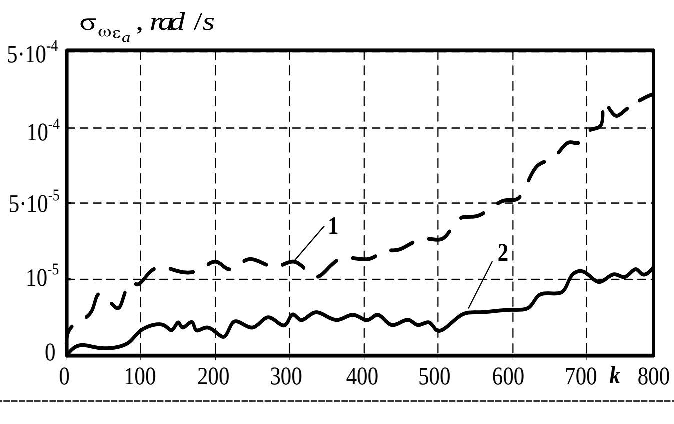

Figure 4. The average standard deviation of the angular azimuth rate

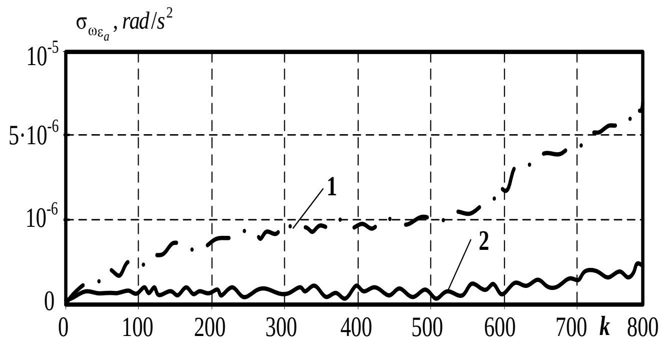

Figure 5. The average standard deviation of the angular azimuth acceleration

As it is clear from figures 3-5, during the “Landing” aircraft manoeuvre, the ε_a, ω_{ε_a} and a_{ε_a} average standard deviations are less provided that the developed model is applied (curve 2) in contrast to the Zinger’s model (curve 1). Therefore, the developed t-tCh model (10)-(17) taking to account both the kinematic and dynamic parameters can update the aircraft handling in the airport areas. So, in particular the improving accuracy can allow to increase the acceptance ATC rate accompanied with possibility reservation of aircraft safe operating area crossing.

Due to such information sources in the developed observation t-tCh model as:

- the aircraft azimuth is measured by RDR;
- the angular azimuth acceleration is determined by indirect assay considered both kinematic and aircraft dynamic parameters detected by DMS ATC throw the data transmission systemы;

this technique can increase DMS immunity at the RDR channel interference. Providing that direct-noise background effect presence the RDR capability the measured azimuth data will not present in the observation equation, but the angular azimuth acceleration data in the equation allows to significantly increase the developed filter memory time in comparison to Zinger’s model one. Due to this he next changeover to the pursuit behavior mode is simplified after either the noise action or no-signal RDR mode ends.

Conclusion

The simulation results analysis of the presented t-tCh functioning algorithm in azimuth terms proved that accuracy increasing of the average standard deviations estimation of the azimuth filtration ε_a, angular azimuth rate ω_{ε_a} and angular azimuth acceleration a_{ε_a} in line-of-sight distance between t-tCh DMS and the aircraft in 3…4 times higher in case of both kinematic and dynamic parameters considering in comparison to the Zinger’s filter mainly due to angular acceleration more accurate description in the state and observation model.

So, the developed t-tCh functioning algorithm in azimuth terms allows update the aircraft handling in the airport areas as well as to increase the acceptance ATC rate accompanied at least up to 80% at the possibility reservation of aircraft safe operating area crossing

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