ACCURANCY AND RESISTANCE OF THE RADIONAVIGATION DISTANCE METER AGAINST CHAOTIC IMPULSE INTERFERENCE WHEN USING BINARY CARRIER SIGNALS

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Abstract

I present one of the methods of assessment of accuracy and resistance to interference of a distance - measuring channel of radionavigation system of near-navigation. By using computer technology, the method enables us to determine the potential but also the real error measuring the distance of the flying object by radionavigation distance meter.

Keywords

chaotic impulse interference, non-linear filtration

1. Introduction

Increased requirements to increase quality of information transmission in very unfavourable noise conditions with strong interference (e. g. in space communications or in special military applications) makes it necessary to search for new wans to improve wireless electronic systems. In the last 50th years, new systems with spread spectrum systems started be in a used.

It is interesting for us, if it is possible, to increase the accuracy and resistance of the radionavigation distance meter (RDM) which operates in conditions of chaotic impulse interference using binary carrier signals obtained on the base of Walsh functions (WF).

2. Task Formulation

The input of the radionavigation distance meter receiver in time interval of (0,t) this signal $\mu(t)$ is as an additive mixture of $S_w(x,t)$ effective signal and of NY(t) chaotic impulse interference and n(t) wide range interference:

$$\mu(t) = S_w(x,t) + NY(t) + n(t). \qquad (1)$$

We carry out a formal change in relation (1):

$$S(t) = S_w(t) + NY(t).$$

We express the $\mu(t)$ random process in the signal processor input of the navigation device as an additive mixture of the S(t) signal and n(t) white noise:

$$\mu(t) = S(t) + n(t).$$

$S_w(.)$ symbol in equation (1) means the continuous or discrete n-th Walshian signal (WS).

Wide-band interference n(t) is approximated by means of Gaussian noise with known statistic characteristic [1]:

$$E(n(t)) = 0;\ E(n(t_1)\ .\ n(t_2)) = N_0/2\ .\ \delta(t_2 - t_1); \qquad (2)$$

where N_0 is an intensity of the n(t) process.

We will simulate a chaotic impulse interference (CHII) as a double component Markov process, whereby it is assumed that both components are independent [2]:

$$NY(t)=u(t).NY_i(t), \quad i = 1,2. \qquad (3)$$

We can approximate a CHII discreet component by a $NY_i(t)$ discreet Markov process that accidentally takes the value of $NY_1(t)=A$ or $NY_2(t)=0$. The transition probabilities of these states:

$$p_{ij}(t_0,\ t)=P\{\ NY(t) = NY_j/\ NY(t_0) = NY_i\ \}, \quad i,j = 1,2;$$

are given by differential equations in the following form:

$$dp_{11}(t_0,t)/dt = -h.p_{11}(t_0,t) + \mu_f.p_{12}(t_0,t),$$

$$dp_{12}(t_0,t)/dt = -\ \mu_f.p_{12}(t_0,t) + h.p_{11}(t_0,t), \qquad (4)$$

with given initial conditions

$$p_{ij}(t_0,\ t) = \{\ NY_j\ \};\ j = 1,\ 2,$$

where 1/h and μ_f are standard parameters of CHII,representig a mean length and a mean frequency of interference impulses. The parameters of CHII h^{-1} and μ_f are accidental quantities arranged according to an exponential law.

The process u(t) can be simulated by a sub-harmonic incidental process what we assume to be normal, stationary and close range about:

$$u(t) = U(t).\cos[\Omega_0.t - \Phi_n(t)],$$

or

$$u(t) = U_C(t).\cos\Omega_0.t + U_S(t).\sin \Omega_0.t,$$

where

$$U_C(t) = U(t).\cos \Phi_n(t);\ U_S(t) = U(t).\sin \Phi_n(t);$$

U(t) - amplitude of process u(t); Ω_0 - mean frequency of interference spectrum; U(t), $\Phi_n(t)$ - slowly change functions in comparison with cos Ω_0t.

Let aprior process models $U_S(t)$ and $U_C(t)$ are expressed:

$$dU_C(t)/dt = -\tau_u . U_C(t) + (2.\tau_u.\sigma_{uc}^2)^{1/2}.\ n_{uc}(t), \quad (5)$$

$$dU_S(t)/dt = -\tau_u . U_S(t) + (2.\tau_u.\sigma_{us}^2)^{1/2}.\ n_{us}(t), \quad (6)$$

where τ_u^{-1} is time of correlation of processes $U_C(t)$ and $U_S(t)$; $n_{uc}(t)$, $n_{us}(t)$ - independent white Gaussian noise with known statistical characteristics:$E(n_{uc}(t)) = E(n_{us}(t)) = 0$;

$$E\{n_{uc}(t_1).n_{uc}(t_2)\}=1.\delta(t_2-t_1);$$

$$E\{n_{us}(t_1).n_{us}(t_2)\}=1.\delta(t_2-t_1).$$

The effective Walshian signal (WS) $S_w(X,t)$ RDM will be created by means of a dual pulse with a code interval of κ_k. Individual pulses will be considered to be a realization of WF length T_w, with T_w equaling to WS period. In accordance with [3], it is to be expressed as a sequence of pulses of quasi rectangular form:

$$\beta_n(t) = h_n(t) - h_n(t - \kappa_e). \quad (7)$$

$$h_n(t) = \begin{cases} EXP[(-4\ln 2/\kappa_f^2).(t- \kappa_f/2)^2];\ t\le \kappa_f/2; \\ 1;\ \kappa_f/2 < t \le \kappa_e - \kappa_f/2; \\ EXP[(-4\ln 2/\kappa_f^2).(t- \kappa_e + \kappa_f/2)^2];\ t\le \kappa_f/2; \\ \quad t\le \kappa_e-\kappa_f/2 \end{cases} \quad (8)$$

where $\kappa_f/2$, κ_p-length of increased (decreased) edge and flat pulse part; $\kappa_e= \kappa_f + \kappa_p$ -length of elementary pulse WS. When modulating the WS time position, RDM measure signal is to be expressed in following form:

$$S_w(X,t)= \sum_{r=0}^{\infty}\sum_{k=0}^{L_0-1} A_C(t).Wal_{no}\{T_{wo};k/2^m\}.EXP[(-4\ln 2/\kappa_f^2).$$
$$.(t- \kappa_f/2 - r.T_i - t_z - k.T_{wo}/L_o + \kappa(t) - 2D(t)/c)^2] +$$
$$+\sum_{r=0}^{\infty}\sum_{k=0}^{L_0-1} A_C(t).Wal_{no}\{T_{wo};k/2^m\}.\quad EXP[(-4\ln 2/\kappa_f^2).$$
$$.(t- \kappa_f/2 - r.T_i - t_z - \kappa_k - k.T_{wo}/L_o + \kappa(t) - 2D(t)/c)^2], \quad (9)$$

where $t\le \kappa_f/2$; when expressing $S_w(.)$ for t greater than κ_e-$\kappa_f/2$, correlations of (7) and (8) must be expressed; A(t) - pulse amplitude. Further, we assume that A(t) = Ao = const. $Wal_{no}\{.\}$ - elements of n-th Walshian function on the base of which the signal is created;

m =] $\log_2$ n [+ 1 - number of Walshian function diade; $L_o = 2^m$ - time base WF; r - pulse number of response; T_i - interrogation pulsesťperiod; t_z - signal lag in transponder circuits; κ_k - code interval; D(t) - inclinated distance of flying object (FO) from overground responser.

To compare the results of this work (e. g. with [1]), signal parameters (9) will be equal:

$$T_{wo} = 1{,}0\ \mu s\ ;\ n_o = 1937;\ \kappa_e = 5{,}16.10^{-10}\ s;$$

$$f_{wo} =](n+1)/2[\ /\ T_{wo}$$ - WS frequency; $\Omega_0=f_{wo}$.

3. Parameters Models of Effective Signal

Accuracy measurement of an effective parameter signal is influenced upon by frequency instability of the supporting generator RDM which is manifested by occasional changes of time signal position $\kappa(t)$:

$$\kappa(t) =\kappa_o+ M_t.L(t), \quad (10)$$

where κ_o - time signal position without undesirable information L(t); M_t-time modulation coefficient. Undesirable information L(t) will be modelled in accordance with relation (10). If it is true that:

$$\kappa(t) - \kappa_o = M_t.L(t) = \kappa_D(t) \quad (11)$$

and

$$M_t.\sigma_{lt} = \sigma_t, \quad (12)$$

where σ_{lt}, σ_t - medium quadratic deviations of processes L(t) and $\kappa(t)$. Then $\kappa_D(t)$ model will be expressed as:

$$d\kappa_D(t)/dt= -\Gamma_t.\kappa_D(t) + (2.\Gamma_t.\sigma_t^2)^{1/2}.n_t(t),\ \kappa_D(t_o)=\kappa_{DO}, \quad (13)$$

where $n_t(t)$ - is a white Gaussian noise with zeroing mean and intensity equal to 1; κ_D - change of time position WS in consequence of interference; Γ_t -coefficient characterized spectrum wide of process fluctuation κ_D.

The motion of the navigation object considers the dynamic model reflecting the process of the real motion of the navigation object [1], [2]:

$$dD(t)/dt = V(t) = V_f(t) + V_0;\qquad D(t_0) = D_0;$$

$$dV_f(t)/dt = a(t);\qquad V_f(t_0) = V_{f0}$$

$$da(t)/dt = - \alpha.a(t) - \beta.V_f(t) + (2.\ \alpha.\sigma_a^2)^{1/2}.n_a(t);$$
$$a(t_0) = a_0,$$

$$dV_0/dt = 0;\qquad V_0(t_0) = V_{00}, \quad (14)$$

where $V_f(t)$ - fluctuation part of the radial component of track velocity; $V_0 = E\ \{V(t)\}$ - mean of velocity $V_{TD}(t)$; α, β are variable coefficients characterised spectral density of acceleration random changes which are determined by a fluctuation component of wind velocity, object type and conditions of its movement; $\sigma_a^2 = E\{a^2(t)\}$ - variance of acceleration fluctuation which is dependent upon atmosphere turbulence capacity, motor thrust fluctuation, etc; $n_a(t)$ - is a white Gaussian noise with zeroing mean and intensity equal to 1; The meaning and calculations of model coefficients of flying object movement (14) are stated in literature [2].

4. Algoritms of Optimum Filtering

From equations (2-14) it can be seen that seven-component status vector:

$$X^T = [D, V_f, a, T_{wo}, \kappa_D, U_c, U_s], \quad (15)$$

is corresponding with systems of differential equations:

$$dX/dt = F*X + G*N_x(t); \quad X(t_0) = X_0. \quad (16)$$

Matrix F and G of (7x7) dimension consist of non-zero elements:

$$f_{12} = f_{23} = 1;\ f_{32} = -\beta;\ f_{33} = -\alpha;\ f_{55} = -\Gamma_t;$$

$$f_{66} = f_{77} = -\tau_u;$$

$$g_{33} = (2.\alpha.\sigma_a^2)^{1/2};\ g_{55} = (2.\Gamma_t.\sigma_t^2)^{1/2}.$$

$$g_{66} = (2.\tau_u.\sigma_{uc}^2)^{1/2};\ g_{77} = (2.\tau_u.\sigma_{us}^2)^{1/2}. \quad (17)$$

When calculating the matrix elements F and G, it is assumed that the $S_w(.)$ signal period is known.

$N_x = [0, 0, n_a, 0, n_t, n_{uc}, n_{us}]^T$ - a white Gaussian noise vector of zero mean value and of an intensity equal to one.

In paper [2] it is demonstrated that with synthesis of an optimum receiving device for signal processing created on the base of Walshian functions, it is possible to use the methods of optimum non-linear filtration. Then, in accordance with equations (4 -16), algoritms of optimum non-linear filtration of pulse signals RD have got a form:

$$d\overset{*}{X}/dt = F.\overset{*}{X}(t) + K(t).F_1(\overset{*}{X},t).\frac{2}{N_o}.[\mu(t) - S(\overset{*}{X},t)],$$

$$\overset{*}{X}(t_0) = X_0; \quad (18)$$

$$dK(t)/dt = F.K(t) + K(t).F^T + Q - K(t).\frac{2}{N_o}.F_k(\overset{*}{X},t).K(t),$$

$$K(t_0) = K_0, \quad (19)$$

where matrix

$$F_1(\overset{*}{X},t) = [dS(\overset{*}{X},t)/d\overset{*}{X}_1, 0,0,0, dS(\overset{*}{X},t)/d\overset{*}{X}_5, 0,0], \quad (20)$$

matrix

$$F_k(\overset{*}{X},t) = \begin{bmatrix} \left(\dfrac{dS(\overset{*}{X},t)}{d\overset{*}{X}_1}\right)^2 & \Lambda & \dfrac{d^2S(\overset{*}{X},t)}{d\overset{*}{X}_1\, d\overset{*}{X}_7} \\ M & O & M \\ \dfrac{d^2S(\overset{*}{X},t)}{d\overset{*}{X}_1\, d\overset{*}{X}_7} & \Lambda & \left(\dfrac{dS(\overset{*}{X},t)}{d\overset{*}{X}_7}\right)^2 \end{bmatrix} \quad (21)$$

The * symbol indicates the signal measured parameter.

Equations (18) and (19) determine the structure, accuracy and resistance to interference of sub optimum RDM which has the best precision characteristics (independent of the simplifications accepted by deriving relations (18) and (19)). By means of calculation according to relation (19) and by the substitution of the covariance matrix of aposterior errors of signal parameters filtration (9) K(t) in equation (18), it is possible by using a computer to simulate a distance - measuring process of FO from RDM by means of a sub optimum receiver.

The simulation enables us to find out the dependence of RDM characteristics on the change of input signal parameters, of wide - spectrum fluctuation disturbance and of flight dynamics of FO. The results of the simulation can be used in the practical construction of RDM.

5. The Results of the Simulation of the Process of Distance-Measuring D(t) by Means of a Subotimum RDM

The simulation of the process of measuring the distance D(t) by means of a suboptimum RDM according to algorithms (18) and (19) was perform by a computer, type PC using the method RUNGE - KUTTA. Some results of the simulation are given in Fig.1-8.

Matrix K(t) after standardization contains elements $\delta_{ij} = K_{ij}*\sigma_i^{-1}*\sigma_j^{-1}$, where σ_i, σ_j - a priori variance of signal parameters (9);

$i \in \{1,2,......,7\}$; $j \in \{1,2,.....,7\}$.

The initial conditions for matrices K(t) have the form:

$\delta_{ii}=1$; $\delta_{ij}=0$;

In the calculations, the parameters of a random process model X(t) where selected in accordance with [1], [2] and have the following values:

$m=0,1\ s^{-1}$; $\alpha=0,479\ s^{-1}$; $\beta=3.49*10^{-2}\ s^{-2}$; $\sigma_i=2,7\ m.s^{-1}$; $\Omega_0=f_{wo}$; $b=3,49*10^{-1}$; $\sigma_t = 3.10^{-10}s$; $T_i= 30,0\ s^{-1}$; $T_w = 1.10^{-6}\ s$; $\Gamma_t = 10^{-3}s^{-1}$; $\sigma_D=15,0\ m$; $\sigma_V=1,0\ m*s^{-1}$; $\sigma_a=1,0\ m*s^{-2}$; $\kappa_f=2.10^{-10}$- $4.10^{-10}s$; $\mu_f=3,0.10^3s^{-1}$; $h=3,3.10^3s^{-1}$; $\tau_u=3000\ s^{-1}$;

Matrix elements $F_1(.)$ and $F_k(.)$ were calculated regarding to relations (20) and (21) and method of mentioned work [2].

The ratio of useful signal to noise was of the range 40-100. The initial conditions for state vector:

$X^T = [1.10^5; 2;5 ; 1.10^{-6} ; 0;0;0]$; $V_o=340$ m.s^{-1}.

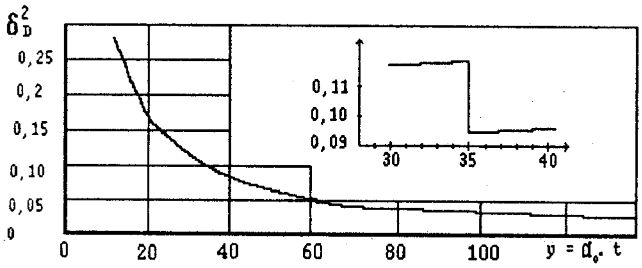

Fig. 1

Fig.1 shows the dependence of mean value of the aposterior standardised variance $\delta_D^2(t)$ the errors of measurement of oblique distance of FO from radionavigation distance meter D(t) in dimensionless time $y = \alpha_0 * t$, where $\alpha_0 = 300$ s^{-1}. The ratio of useful signal (S/N) to noise was equal 90. It follows from the graf that $\delta_D^2(t)$ in transition mode depends on the received pulse quantity of the land transponder of RDM. The more response pulses are received, the better is the potential measuring accuracy of process D(t). Approximately within 0.4 s the transffering process is terminated practically and potential accuracy of RDM for S/N = 90 is equal to: $K_{DD} = 4.5$ m^2. In the case of effective-signal absence in receiver input, so in accordance with algorithms (18) and (19) the receiver performs extrapolation of D(t) distance.

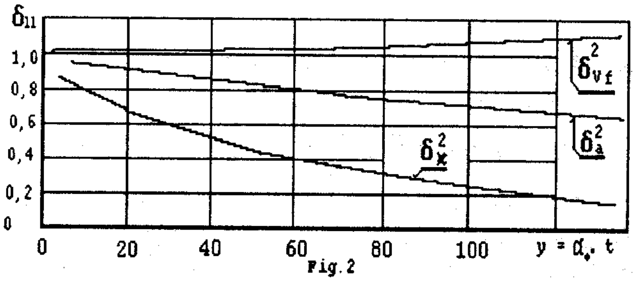

Fig. 2

Filtration error of processes $V_f(t)$, a(t) is illustrated in figure No.2. From this diagram it results that character of processes D(t), a(t) and $\kappa_D(t)$ is the same. In the case of effective-signal absence in receiver input, so the $\delta_D^2(t)$ variance of filtration error will be higher in consequence of fluctuation and inaccuracy of filtration process $\kappa_D(t)$ because $\delta\kappa_D$ is distinct from zero (figure 3.4.).

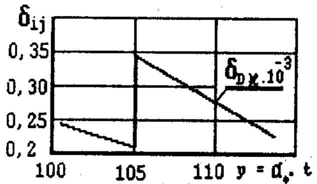

Fig. 3

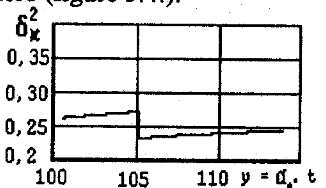

Fig. 4

Measure accuracy of D(t) and length of transferring process is depended upon ration S/N in the receiver input (figure 5, 6) and length of leading edge of elementary pulse WS (figure 7).

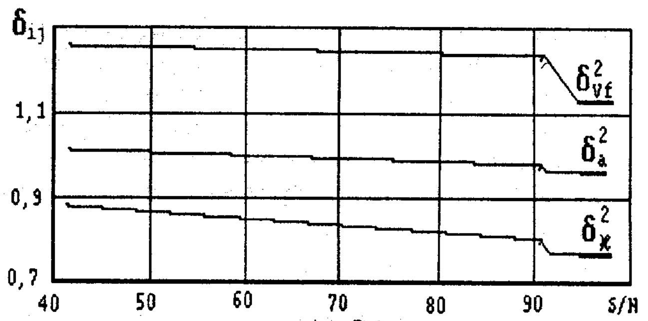

Fig. 5

If ratio S/N is changed in the range from 40 - 90 so the influence of CHII on precision of measuring the distance is lowered. If S/N is magnified 1,8 times, cross correlation coefficient δ_{DUC} is lowered 1,7 times and measuring error of distance dD(t) is lowered 1,3 times.

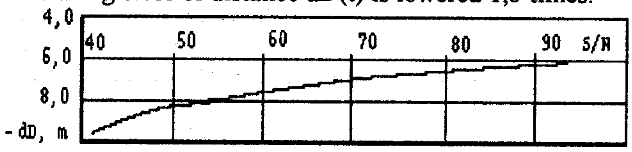

Fig. 6

When increasing κ_f by 1.7 multiple, D(t) measurement accuracy will be reduced by 1.75 multiple. The cross correlation coefficient δ_{DUC} increased 1,25 times.

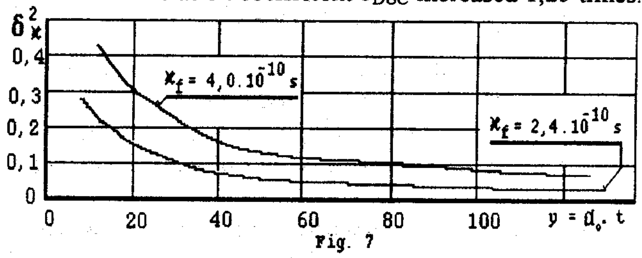

Fig. 7

The precision of navigational parameter filtration

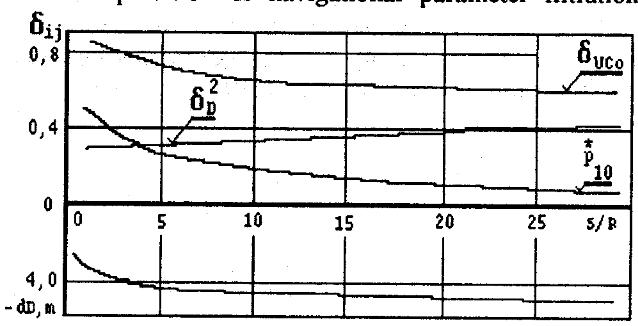

Fig. 8

suggested by RDM depends on the ratio of CHII output to noise R/N. (Fig. 8).

If the ratio R/N is changed from 5 to 25 a measuring error of distance is magnified 1,2 times and that is expressed by the fact that RDM is, to a certain degree, resistant to interference. The magnifying of the ratio R/N improves the characteristics of a receiver in compensation of CHII (curve p_{10}). The simulating confirmed that the change of an output signal ratio to an interference output in the range from 8 to 3 did not nearly change the characteristics of a radionavigation distance meter.

Further real accuracy of measuring of process D(t) by means of radionavigation distance meter was verified through simulation. The results of the simulation of the measurement process D(t) by a quasi-optimum RDM the functional connection of which is determined by algorithms

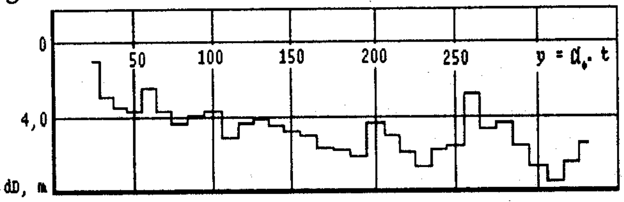

Fig. 9

(18) and (19), are given in Fig.9, where dD = D(t) - $\overset{*}{D}$ (t).

Under simulation, the proportion signal/noise at the receiver input was equal to 90.0. The simulation of RDM receiver activity confirmed its functionality. Absolute error of distance measure D(t) was in range of 2 up to 10 m. Mean error deviation of measurement D(t) was equal to 8.7 m which is less than distance measuring error RDM which is used at aviation operation management.

6. Conclusion

Results of calculations of potential accuracy by means of modelling the distance measurements FO from RDM D(t) by suboptimal receiver RDM regarding to algorithms (18) and (19) prove that usage of digital measuring signals in wireless navigation makes possible significant increase of accuracy and resistance of such wireless navigation systems against interference. When comparing the accuracy of proposed RDM (σ_D = 8.7 m) with contemporaneously used RDM of TACAN/DME type (σ_D = 100 m) or proposed RDM published in [1], [2] (σ_D =141 m) so it is obvious that to improve the accuracy of RDM with usage of binary signals is evident.

This requires the usage of high-stabile managing generators with designing these systems (df/f) $\approx 10^{-10}$. Further problems of binary signal usage will be designing the suitable receiving and transmitting aerials.

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