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Synthesis of receiver with multiplex synchronization in satellite navigation systems

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User apparatuses and used algorithm for processing of received navigation signal proves to be important for accurate positioning of the satellite navigation systems. The receiver based upon an algorithm of Kalman filtration with multiplex synchronization [1] provides higher accuracy characteristics in comparison with one which carries out measurement of time delays only by "envelope" (range-finder code). The increase of accuracy is achieved owing to the more complete use of information contained in the received radio-signal.

For synthesis of such receiving set a frame of reference O_0XYZ is chosen with origin O_0 which is fixed with respect to the Earth. This coordinate system is described in [1]. On board a mobile object the signals emitted from four emmission sources are observed. The coordinates of the emission sources are known $X_k(t)=(x_k(t),y_k(t),z_k(t)),\ k=\overline{1,4}$.

The state vector $\lambda^T=(x,V_x,y,V_y,z,V_z,\Delta,V_\Delta)$ includes: the coordinates of the mobile object — x,y,z; Δ — the scale disagreement of the mobile object with respect to the system time; V_x,V_y,V_z,V_Δ — the respective velocities of x,y,z and Δ.

For using the multiplex synchronization method (the method of additional variable) an additional variables vector $T_d^T=(T_{d1},T_{d2},T_{d3},T_{d4})$ is introduced for the signals from the four emission sources. T_{d1},T_{d2},T_{d3} and T_{d4} are the time delays of high frequency filling of received signals from the separate emission sources respectively. Then the vector state λ is expanded to the new state vector $\lambda_d^T=\{\lambda^T,T_d^T\}$ [1, 2].

The observation equation is given by [1—3]

(1) $$\xi(t)=s(t,\lambda_{d\nu})+n(t),\ t\in(t_\nu,t_{\nu+1});$$

(2) $$s\left(t,\lambda_\nu,T_{d\nu}\right)=\sum_{k=1}^{4} f_k\left[t-T_k\left(\lambda_\nu\right)\right]\cos\left[\omega_0\left(t-T_{dk\nu}\right)\right]$$

where $\lambda_{d\nu}^T=\left\{\lambda_\nu^T,T_{d\nu}^T\right\}$; $T_{d\nu}=T_d\left(t_\nu\right)$; $t_\nu=\nu T$; $f_k\left(t-T_k(\lambda)\right)$ is a radio-signal envelope from the k-th emission source; $\omega_0=2\pi f_0$ is the circular frequency of the high-frequency filling; $T_k(\lambda)=\tau_k(X)+\Delta$ is the arrival time of the signal from the k-th emission source; $\tau_k(X)$ is the real time of the signal delay from the k-th emission source [1]; $n(t)$ is a white Gaussian noise whose characteristics are described in [1].

The amplitudes of received signals from the different emission sources in the zone of radio-visibility are assumed to be equal. The state vector λ can be described through Gaussian diffusion Markov process which satisfies the system of stochastic differential equations that is shown in [1]. The matrices of the drift coefficients and the diffusion coefficients and the noise vector are also shown in [1].

The expanded Kalman filter state equation is given by [1—3]

(3) $$\hat{\lambda}_{d(\nu+1)}=\tilde{\lambda}_{d(\nu+1)}+\frac{2}{N}R_{\nu+1}\int_{t_\nu}^{t_{\nu+1}}\xi(t)\frac{\partial s\left(t,\tilde{\lambda}_{d(\nu+1)}\right)}{\partial\lambda_d}dt$$

where $\tilde{\lambda}_{d(\nu+1)}=\Phi_d\hat{\lambda}_{d\nu}$ is a vector of the state prediction; Φ_d is the state transition matrix for sampling interval (T) [1];

$$\hat{\lambda}_{d\nu}^T=\left\{\hat{\lambda}_\nu^T,\hat{T}_{d\nu}^T\right\};\ \hat{\lambda}_\nu^T=\left\{\hat{x}_\nu,\hat{V}_{x\nu},\hat{y}_\nu,\hat{V}_{y\nu},\hat{z}_\nu,\hat{V}_{z\nu},\hat{\Delta}_\nu,\hat{V}_{\Delta\nu}\right\};$$

$$\hat{T}_{d\nu}^T=\left\{\hat{T}_{d1\nu},\hat{T}_{d2\nu},\hat{T}_{d3\nu},\hat{T}_{d4\nu}\right\};$$

$$R_\nu=\begin{vmatrix}R_{\lambda_\nu} & R_{\lambda T_{d\nu}}\\ R_{T_d\lambda_\nu} & R_{T_{d\nu}}\end{vmatrix};\ R_{\lambda T_{d\nu}}=R_{T_d\lambda_\nu}^T.$$

The above equation describes the algorithm of expanded Kalman filter which gives optimum receiving of signals and filtration of the parameters. An optimum system for processing of the received signals will be synthesized with the help of this equation.

From (2) for $\frac{\partial s\left(t,\tilde{\lambda}_{d(\nu+1)}\right)}{\partial\lambda}$ and $\frac{\partial s\left(t,\tilde{\lambda}_{d(\nu+1)}\right)}{\partial T_d}$ it is obtained

$$\frac{\partial s\left(t,\tilde{\lambda}_{d(\nu+1)}\right)}{\partial\lambda}=\left|\frac{\partial s_1\left(t,\tilde{\lambda},\tilde{T}_{d1}\right)}{\partial\lambda};\frac{\partial s_2\left(t,\tilde{\lambda},\tilde{T}_{d2}\right)}{\partial\lambda};\frac{\partial s_3\left(t,\tilde{\lambda},\tilde{T}_{d3}\right)}{\partial\lambda};\frac{\partial s_4\left(t,\tilde{\lambda},\tilde{T}_{d4}\right)}{\partial\lambda}\right|;$$

$$\frac{\partial s\left(t,\tilde{\lambda}_{d(\nu+1)}\right)}{\partial T_d}=\left|\frac{\partial s_1\left(t,\tilde{\lambda},\tilde{T}_{d1}\right)}{\partial T_d};\frac{\partial s_2\left(t,\tilde{\lambda},\tilde{T}_{d2}\right)}{\partial T_d};\frac{\partial s_3\left(t,\tilde{\lambda},\tilde{T}_{d3}\right)}{\partial T_d};\frac{\partial s_4\left(t,\tilde{\lambda},\tilde{T}_{d4}\right)}{\partial T_d}\right|;$$

where

$$(4)\qquad \frac{\partial s_k\left(t,\widetilde{\boldsymbol\lambda}_{\nu+1},\widetilde{T}_{dk(\nu+1)}\right)}{\partial\boldsymbol\lambda}=\frac{\partial s_k\left(t,\widetilde{\boldsymbol\lambda}_{\nu+1},\widetilde{T}_{dk(\nu+1)}\right)}{\partial T_k(\boldsymbol\lambda)}\,\frac{dT_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)}{d\boldsymbol\lambda}$$

$$=-\frac{\partial f_k\left(t-T_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)\right)}{\partial t}\cos\left[\omega_0\left(t-\widetilde{T}_{dk(\nu+1)}\right)\right]\frac{dT_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)}{d\boldsymbol\lambda};$$

$$(5)\qquad \frac{\partial s_k\left(t,\widetilde{\boldsymbol\lambda}_{\nu+1},\widetilde{T}_{dk(\nu+1)}\right)}{\partial \boldsymbol{T}_d}=\frac{\partial s_k\left(t,\widetilde{\boldsymbol\lambda}_{\nu+1},\widetilde{T}_{dk(\nu+1)}\right)}{\partial T_{dk}}\,\frac{d\widetilde{T}_{dk(\nu+1)}}{d\boldsymbol{T}_d}$$

$$=\omega_0 f_k\left[t-T_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)\right]\sin\left[\omega_0\left(t-\widetilde{T}_{dk(\nu+1)}\right)\right]\frac{d\widetilde{T}_{dk(\nu+1)}}{d\boldsymbol{T}_d}.$$

The state equation takes the form

$$(6)\quad \hat{\boldsymbol\lambda}_{\nu+1}=\widetilde{\boldsymbol\lambda}_{\nu+1}+\frac{2}{N}\int_{t_\nu}^{t_{\nu+1}}\left[\boldsymbol{R}_{\lambda(\nu+1)}\frac{\partial s\left(t,\widetilde{\boldsymbol\lambda}_{d(\nu+1)}\right)}{\partial\boldsymbol\lambda}+\boldsymbol{R}_{\lambda T_d(\nu+1)}\frac{\partial s\left(t,\widetilde{\boldsymbol\lambda}_{d(\nu+1)}\right)}{\partial \boldsymbol{T}_d}\right]\xi(t)\,dt;$$

$$(7)\quad \hat{\boldsymbol{T}}_{d(\nu+1)}=\hat{\boldsymbol{T}}_{d(\nu+1)}+\frac{2}{N}\int_{t_\nu}^{t_{\nu+1}}\left[\boldsymbol{R}_{T_d\lambda(\nu+1)}\frac{\partial s\left(t,\widetilde{\boldsymbol\lambda}_{d(\nu+1)}\right)}{\partial\boldsymbol\lambda}+\boldsymbol{R}_{T_d(\nu+1)}\frac{\partial s\left(t,\widetilde{\boldsymbol\lambda}_{d(\nu+1)}\right)}{\partial \boldsymbol{T}_d}\right]\xi(t)\,dt.$$

From (4 ÷ 7) it follows

$$(8)\qquad \hat{\boldsymbol\lambda}_{\nu+1}=\widetilde{\boldsymbol\lambda}_{\nu+1}+\sum_{k=1}^{4}\frac{2}{N}\left\{-\boldsymbol{R}_{\lambda(\nu+1)}\frac{\partial T_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)}{\partial\boldsymbol\lambda}\right.$$

$$\times\int_{t_\nu}^{t_{\nu+1}}\frac{\partial f_k\left(t-T_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)\right)}{\partial t}\cos\left[\omega_0\left(t-\widetilde{T}_{dk(\nu+1)}\right)\right]\xi(t)\,dt$$

$$\left.+\boldsymbol{R}_{\lambda T_d(\nu+1)}\frac{\partial\widetilde{T}_{dk(\nu+1)})}{\partial\boldsymbol{T}_d}\omega_0\int_{t_\nu}^{t_{\nu+1}}f_k\left(t-T_k\left(\widetilde{\boldsymbol\lambda}_{\nu+1}\right)\right)\sin\left[\omega_0\left(t-\widetilde{T}_{dk(\nu+1)}\right)\right]\xi(t)\,dt\right\};$$

$$(9)\quad \hat{T}_{d\,(\nu+1)} = \tilde{T}_{d\,(\nu+1)} + \sum_{k=1}^{4} \frac{2}{N} \left\{ -R_{T_d \lambda\,(\nu+1)} \frac{\partial T_k(\tilde{\boldsymbol{\lambda}}_{\nu+1})}{\partial \boldsymbol{\lambda}} \right.$$

$$\times \int_{t_\nu}^{t_{\nu+1}} \frac{\partial f_k(t - T_k(\tilde{\boldsymbol{\lambda}}_{\nu+1}))}{\partial t} \cos\left[\omega_0\left(t - \tilde{T}_{dk\,(\nu+1)}\right)\right] \xi(t)\, dt$$

$$\left. + R_{T_d\,(\nu+1)} \frac{\partial \tilde{T}_{dk\,(\nu+1)}}{\partial T_d} \omega_0 \int_{t_\nu}^{t_{\nu+1}} f_k(t - T_k(\tilde{\boldsymbol{\lambda}}_{\nu+1})) \sin\left[\omega_0\left(t - \tilde{T}_{dk\,(\nu+1)}\right)\right] \xi(t)\, dt \right\}.$$

The algorithm of expanded Kalman filter (3) can be represented in the following form

$$(10)\quad \begin{cases} \hat{\boldsymbol{\lambda}}_{\nu+1} = \tilde{\boldsymbol{\lambda}}_{\nu+1} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_k} B_k + \Gamma_{\lambda T_{dk}} B_{dk}\right) \\ \hat{T}_{d(\nu+1)} = \tilde{T}_{d(\nu+1)} + \sum_{k=1}^{4}\left(\Gamma_{T_d \lambda_k} B_k + \Gamma_{T_{dk}} B_{dk}\right), \end{cases}$$

where

$$(11)\quad \Gamma_{\lambda_k} = R_{\lambda(\nu+1)} \frac{\partial T_k\left(\tilde{\boldsymbol{\lambda}}_{\nu+1}\right)}{\partial \boldsymbol{\lambda}};$$

$$(12)\quad \Gamma_{\lambda T_{dk}} = R_{\lambda T_d\,(\nu+1)} \frac{\partial \tilde{T}_{dk(\nu+1)}}{\partial T_d};$$

$$(13)\quad \Gamma_{T_d \lambda_k} = R_{T_d \lambda(\nu+1)} \frac{\partial T_k\left(\tilde{\boldsymbol{\lambda}}_{\nu+1}\right)}{\partial \boldsymbol{\lambda}};$$

$$(14)\quad \Gamma_{T_{dk}} = R_{T_d(\nu+1)} \frac{\partial \tilde{T}_{dk(\nu+1)}}{\partial T_d};$$

$$(15)\quad B_k = -\frac{2}{N} \int_{t_\nu}^{t_{\nu+1}} \xi(t) \frac{\partial f_k\left(t - T_k\left(\tilde{\boldsymbol{\lambda}}_{\nu+1}\right)\right)}{\partial t} \cos\left[\omega_0\left(t - \tilde{T}_{dk(\nu+1)}\right)\right] dt;$$

$$(16)\quad B_{dk} = \omega_0 \frac{2}{N} \int_{t_\nu}^{t_{\nu+1}} \xi(t) f_k\left(t - T_k\left(\tilde{\boldsymbol{\lambda}}_{\nu+1}\right)\right) \sin\left[\omega_0\left(t - \tilde{T}_{dk(\nu+1)}\right)\right] dt.$$

The analytical expressions of the correlation integrals B_k and B_{dk} of the signals received from NAVSTAR system at multiplex synchronization are represented in [4, 5].

The following recursion algorithm is obtained by passing from the vector equations (10) to scalar ones.

$$\hat{x}_{\nu+1} = \hat{x}_\nu + \Phi_{12}\hat{V}_{x\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{1k}} B_k + \Gamma_{\lambda T_{d1k}} B_{dk}\right);$$

$$\hat{V}_{x(\nu+1)} = \Phi_{12}\hat{V}_{x\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{2k}} B_k + \Gamma_{\lambda T_{d2k}} B_{dk}\right);$$

$$\hat{y}_{\nu+1} = \hat{y}_\nu + \Phi_{34}\hat{V}_{y\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{3k}} B_k + \Gamma_{\lambda T_{d3k}} B_{dk}\right);$$

$$\hat{V}_{y(\nu+1)} = \Phi_{44}\hat{V}_{y\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{4k}} B_k + \Gamma_{\lambda T_{d4k}} B_{dk}\right);$$

$$\hat{z}_{\nu+1} = \hat{z}_\nu + \Phi_{56}\hat{V}_{z\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{5k}} B_k + \Gamma_{\lambda T_{d5k}} B_{dk}\right);$$

$$\hat{V}_{z(\nu+1)} = \Phi_{66}\hat{V}_{z\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{6k}} B_k + \Gamma_{\lambda T_{d6k}} B_{dk}\right);$$

(17)

$$\hat{\Delta}_{\nu+1} = \hat{\Delta}_\nu + \Phi_{78}\hat{V}_{\Delta\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{7k}} B_k + \Gamma_{\lambda T_{d7k}} B_{dk}\right);$$

$$\hat{V}_{\Delta(\nu+1)} = \Phi_{88}\hat{V}_{\Delta\nu} + \sum_{k=1}^{4}\left(\Gamma_{\lambda_{8k}} B_k + \Gamma_{\lambda T_{d8k}} B_{dk}\right);$$

$$\hat{T}_{d1(\nu+1)} = \hat{T}_{d1\nu} + \Phi_{92}\hat{V}_{x\nu} + \Phi_{94}\hat{V}_{y\nu} + \Phi_{96}\hat{V}_{z\nu} + \Phi_{98}\hat{V}_{\Delta\nu} + \sum_{k=1}^{4}\left(\Gamma_{T_d\lambda_{1k}} B_k + \Gamma_{T_{d1k}} B_{dk}\right);$$

$$\hat{T}_{d2(\nu+1)} = \hat{T}_{d2\nu} + \Phi_{10,2}\hat{V}_{x\nu} + \Phi_{10,4}\hat{V}_{y\nu} + \Phi_{10,6}\hat{V}_{z\nu} + \Phi_{10,8}\hat{V}_{\Delta\nu} + \sum_{k=1}^{4}\left(\Gamma_{T_d\lambda_{2k}} B_k + \Gamma_{T_{d2k}} B_{dk}\right);$$

$$\hat{T}_{d3(\nu+1)} = \hat{T}_{d3\nu} + \Phi_{11,2}\hat{V}_{x\nu} + \Phi_{11,4}\hat{V}_{y\nu} + \Phi_{11,6}\hat{V}_{z\nu} + \Phi_{11,8}\hat{V}_{\Delta\nu} + \sum_{k=1}^{4}\left(\Gamma_{T_d\lambda_{3k}} B_k + \Gamma_{T_{d3k}} B_{dk}\right);$$

$$\hat{T}_{d4(\nu+1)} = \hat{T}_{d4\nu} + \Phi_{12,2}\hat{V}_{x\nu} + \Phi_{12,4}\hat{V}_{y\nu} + \Phi_{12,6}\hat{V}_{z\nu} + \Phi_{12,8}\hat{V}_{\Delta\nu} + \sum_{k=1}^{4}\left(\Gamma_{T_d\lambda_{4k}} B_k + \Gamma_{T_{d4k}} B_{dk}\right),$$

where $\Gamma_{\lambda_{ik}}$ is computed from (11), $\Gamma_{\lambda T_{dik}}$ — from (12) $\left(i = \overline{1,8}; k = \overline{1,4}\right)$, $\Gamma_{T_d\lambda_{jk}}$ — from (13), $\Gamma_{T_{djk}}$ — from (14) $\left(j = \overline{1,4}\right)$.

Having found the filtered estimate vectors $\hat{\boldsymbol{\lambda}}_{\nu+1}, \hat{\boldsymbol{T}}_{d(\nu+1)}$ on every step $(\nu+1)$, the time delays of the envelopes of the signals from the separate emission sources are computed

$$\boldsymbol{T}\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) = \begin{vmatrix} T_1\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) \\ T_2\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) \\ T_3\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) \\ T_4\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) \end{vmatrix},$$

by using the following interrelations

$$(18)\quad \left| \begin{array}{l} T_1\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) = c^{-1}\left[\left(\hat{x}_{\nu+1} - x_1\right)^2 + \left(\hat{y}_{\nu+1} - y_1\right)^2 + \left(\hat{z}_{\nu+1} - z_1\right)^2\right]^{1/2} + \hat{\Delta}_{\nu+1} \\ T_2\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) = c^{-1}\left[\left(\hat{x}_{\nu+1} - x_2\right)^2 + \left(\hat{y}_{\nu+1} - y_2\right)^2 + \left(\hat{z}_{\nu+1} - z_2\right)^2\right]^{1/2} + \hat{\Delta}_{\nu+1} \\ T_3\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) = c^{-1}\left[\left(\hat{x}_{\nu+1} - x_3\right)^2 + \left(\hat{y}_{\nu+1} - y_3\right)^2 + \left(\hat{z}_{\nu+1} - z_3\right)^2\right]^{1/2} + \hat{\Delta}_{\nu+1} \\ T_4\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right) = c^{-1}\left[\left(\hat{x}_{\nu+1} - x_4\right)^2 + \left(\hat{y}_{\nu+1} - y_4\right)^2 + \left(\hat{z}_{\nu+1} - z_4\right)^2\right]^{1/2} + \hat{\Delta}_{\nu+1}. \end{array} \right.$$

After the estimates $T_r\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right), \left(r = \overline{1,4}\right)$ are obtained, an operation is carried out aiming at finding how many whole periods $k^*_{r(\nu+1)}$ of the carrier frequency with period $T_0 = 1/f_0$ are necessary to minimize the expression $\left\{\hat{T}_{dr(\nu+1)} + k_{r(\nu+1)}T_0 - T_r\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right)\right\}$, i.e. the estimate $k^*_{r(\nu+1)}$ is found by the rule

$$(19)\qquad k^*_{r(\nu+1)} = \min_k{}^{-1}\left|\hat{T}_{dr(\nu+1)} + k_{r(\nu+1)}T_0 - T_r\left(\hat{x}_{\nu+1}, \hat{y}_{\nu+1}, \hat{z}_{\nu+1}, \hat{\Delta}_{\nu+1}\right)\right|.$$

So a decision is taken that the time delay of the signal from the r-th emission source is

$$(20)\qquad T^*_{r(\nu+1)} = \hat{T}_{dr(\nu+1)} + k^*_{r(\nu+1)}T_0.$$

In this way the lack of uniqueness in measuring the time delay by the high frequency filling is removed. On the other side the higher accuracy of these measurements is used. This concept is a typical one for **the systems with multiplex synchronization (SMS)** [3–8].

A final step of the recursion algorithm is the determining of the corrected estimates $x^*_{\nu+1}, y^*_{\nu+1}, z^*_{\nu+1}, \Delta^*_{\nu+1}$ of the coordinates of the mobile object and disagreement of its scale with respect to the system time. For this purpose the system of nonlinear equations (sphere equations) must be solved

$$
(21)\quad
\begin{cases}
T^*_{1(\nu+1)} = c^{-1}\left[\left(x^*_{\nu+1} - x_1\right)^2 + \left(y^*_{\nu+1} - y_1\right)^2 + \left(z^*_{\nu+1} - z_1\right)^2\right]^{1/2} + \Delta^*_{\nu+1} \\
T^*_{2(\nu+1)} = c^{-1}\left[\left(x^*_{\nu+1} - x_2\right)^2 + \left(y^*_{\nu+1} - y_2\right)^2 + \left(z^*_{\nu+1} - z_2\right)^2\right]^{1/2} + \Delta^*_{\nu+1} \\
T^*_{3(\nu+1)} = c^{-1}\left[\left(x^*_{\nu+1} - x_3\right)^2 + \left(y^*_{\nu+1} - y_3\right)^2 + \left(z^*_{\nu+1} - z_3\right)^2\right]^{1/2} + \Delta^*_{\nu+1} \\
T^*_{4(\nu+1)} = c^{-1}\left[\left(x^*_{\nu+1} - x_4\right)^2 + \left(y^*_{\nu+1} - y_4\right)^2 + \left(z^*_{\nu+1} - z_4\right)^2\right]^{1/2} + \Delta^*_{\nu+1}.
\end{cases}
$$

Fig. 1 represents the structural scheme of this recursion algorithm (11 ÷ 21). The receiving set is composed of four (number of the emission sources) **time discriminators** and **processor** for forming estimates of the parameters λ^*_ν. On the base of the results of the estimate of the parameters λ and the known coordinates of the emission sources — $x_k, y_k, z_k, \left(k = \overline{1,4}\right)$ the current values of the time delays of the supporting signals are formed in the **discriminators**: by range-finder code $T_k\left(\tilde{\lambda}_{\nu+1}\right)$ and by carrier frequency — $\tilde{T}_{dk(\nu+1)}$. A mixture $\xi(t)$ of an useful signal and noise is received at the input of the **discriminators.** From each **discriminator** two digital signals B'_k and B'_{dk} enter the **processor**. These signals are associated with B_k and B_{dk} through the following interrelations

$$B_k = -\frac{2}{N} B'_k;\ B_{dk} = \frac{2}{N}\omega_0 B'_{dk}.$$

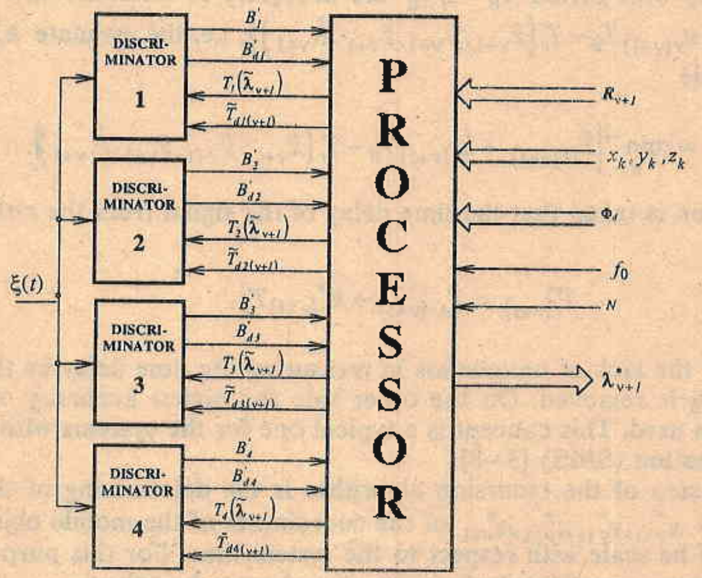

Fig. 1. Structural scheme of the synthesized SMS

The discriminators are analog devices. The initial analog signals B'_k and B'_{dk} by means of analog to digital converter are transformed in digital and enter the **processor** where they are processed by means of the represented recursion algorithm.

For carrying out the computing procedures in **the processor** the following data are passed: components of the matrix $\boldsymbol{R}_{\nu+1}$; coordinates of the k-th emission source — $x_k, y_k, z_k, (k = \overline{1,4})$; components of the state transition matrix $\boldsymbol{\Phi}_d$; carrier frequency f_0 of the signal at which the optimum processing is carried out; spectral density N of the noise at the receiver's input.

The synthesized receiver represents an optimal system with multiplex synchronization. It is constructed on the base of nonlinear filter with four inputs.

In the receiver an estimate of the time disagreement $\hat{\Delta}(t)$ is done, which is used for filtration of the error obtained owing to the instability of the frequency of the **supporting generator** in receiver of the satellite navigation system. This completely corresponds to the concept of quasi-ranging method [3, 9]. With high stability of the supporting generator the time of disagreement $\Delta(t_\nu)$ is slowly varying value in comparison with the errors of the coordinates estimate of the mobile object — x_ν, y_ν, z_ν. Therefore, it could be determined with higher accuracy owing to the accumulation of the observations. Thus the accuracy of the system is expected to be close to the accuracy of the ranging system [3], i.e. when $\Delta(t_\nu) = 0$. It is researched and it is proved, that the concept of the quasi-ranging method is optimum one for whatever deviations $\Delta(t_\nu)$, and not only for very small ones or very slow ones [3]. The structure of the synthesized receiver (Fig. 1) has some differences from the known devices which using quasi-ranging method. Usually availability of autonomous systems for tracking the arrival moment of the signals from the different emission sources is supposed. The estimates of the time delays of the signals (by range-finder code — $\hat{T}_{k(\nu+1)}$ and by carrier frequency — $\hat{T}_{dk(\nu+1)}$) are used by the systems for tracking $\boldsymbol{\lambda}$. In the synthesized receiving set (Fig. 1) there are no separate systems for tracking the time delays of the signals. An integrated closed system exists for tracking of the parameters $\boldsymbol{\lambda}$ by which the time delays of the signals from the corresponding emission sources by envelope and by carrier are computed.

The synthesized navigation system with multiplex synchronization allows normal working and unessential decreasing of the accuracy when there is loss of signal from one emission source for determinate time. The positioning error will be increased owing to the lack of observation of the disagreement Δ of the **supporting generator**. In this case three-coordinate navigation will be carried out by means of ranging method with receiving of signals from three emission sources.

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Синтез на приемно устройство с обединена синхронизация в спътникови навигационни системи

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(Резюме)

Синтезирано е оптимално устройство за приемане и обработка на спътникови навигационни сигнали. С негова помощ се определят координатите и параметрите на движение на подвижен обект (ПО) по квазидалекомерен метод. Синтезираният навигационен приемник представлява система с обединена синхронизация. Обработката на радионавигационните сигнали се извършва по алгоритъм на оптимална филтрация. В синтезираното устройство, прилагащо метода на обединена синхронизация, се използва информацията за времезакъсненията на далекомерния код и високочестотното запълнение. Квазидалекомерното радионавигационно устройство отчита разсъгласуването на еталонния генератор на борда на ПО спрямо системното време.