UDC 631.315:629.783

L. V. Aniskevych,
F. M. Zakharin

DATA FUSION ALGORITM OF UNMANNED GROUND VEHICLE

State research institute of Aviation, Kyiv, l-anisk@mail.ru

The method of processing navigation information from heading-speeding and satellite navigation systems for unmanned ground vehicle is offered. Such method envisages the evaluation of corrections to the meterages of course and speed sensors by the iteration algorithm of nonlinear regression, and also evaluation of coordinates and accurate determination of corrections to the meterages of sensors with the use of generalized discrete filter.

Keywords: unmanned ground vehicle, navigation system, iteration algorithm, nonlinear regression, correction and extrapolation of coordinates.

Reliable navigation information is necessary to land mobile objects (for example, unmanned ground vehicles) performing complicated technological operations. Nowadays there are numerous technical feasibilities to navigate the vehicles [1].

In order to control motion of the vehicle on the reference trajectory it is necessary to determine parameters of object motion taking into account accuracy and reliability of data involving coordinates, speed and spatial orientation of the vehicle. Onboard navigation system and certain algorithms for calculating navigation information are necessary to address this goal.

As a rule, onboard navigation system integrates two and more navigation subsystems (fig. 1).

The structure of the onboard navigation system includes:

– heading-speeding subsystem (HSS), which includes speed sensor for measuring current ground speed, and heading sensor;

– differential global positioning system (DGPS).

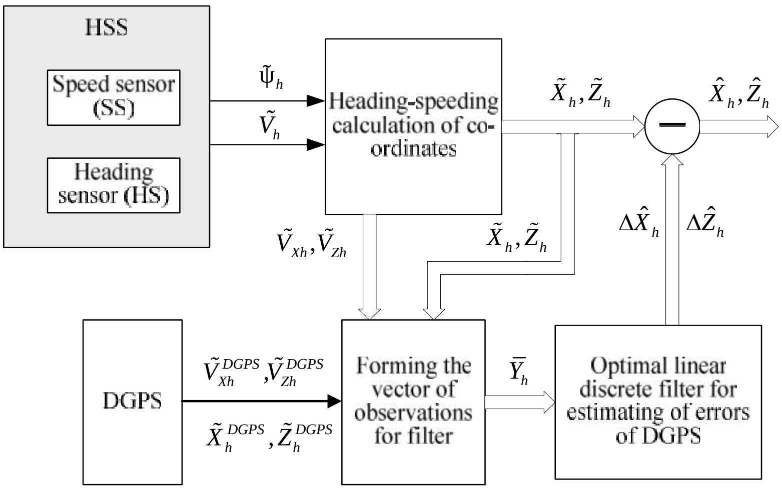

Fig. 1. Block diagram of the known method of complex processing of navigation information from HSS and DGPS

Accuracy of navigation system functionality depends on the method of calculating complex navigation information.

The method based on difference measurements (estimation differences of navigation parameters which are outputs of HSS and DGPS) is often employed [2].

Such method of processing navigation information from HSS and DGPS is in the evaluation of HSS errors with the use of current information about speed from DGPS by the linear discrete filter and proper correction of HSS in relation to determination of vehicle centre-of-mass coordinates.

The drawback of such method is possible violation of linear model character of navigation system errors evaluation with simultaneous errors growth in coordinates calculation.

The other drawback of the known method of processing navigation information is the low integration level (integration takes place at the level of the systems: HSS and DGPS), and also ignoring dynamic properties of the vehicle navigation parameters.

The task of removal of the noted disadvantages and of increasing of the spatial accuracy of calculation of coordinates and vehicle kinematics parameters is marked. Eliminating such disadvantages is required to increase the spatial accuracy of coordinates calculation and vehicle kinematics parameters.

To implement the method of calculation navigation information it is suggested [3] to use the block of estimating of corrections to the meterages of speed and heading sensors with the help of iteration algorithm of nonlinear regression. In addition, the block of corrections for the estimation of coordinates and for the sensors meterage and covariance matrix of errors with the next extrapolation of coordinates estimation and covariance matrices of errors on one step is used (fig. 2).

The method of processing of navigation information provides, at every discrete K-th step of calculating information from DGPS about the vehicle speed components with the help of special procedure of nonlinear regression, calculation of estimations of corrections to the meterages of heading sensor $\delta\hat{\psi}_K$ and values of scale factor of speed sensor $\Delta\hat{\delta}_K$. The meterages of DGPS receiver for components of speed can be shown by the following expressions:

$$\begin{aligned}\tilde{V}_{Xh}^{DGPS} &= \tilde{V}_h(1+\Delta\delta_p)\cos(\tilde{\psi}_h+\delta\psi_p)+\eta_{V_{Xh}};\\ \tilde{V}_{Zh}^{DGPS} &= \tilde{V}_h(1+\Delta\delta_p)\sin(\tilde{\psi}_h+\delta\psi_p)+\eta_{V_{Zh}},\end{aligned} \tag{1}$$

where $\Delta\delta_p$ and $\delta\psi_p$ – are amendments to the meterages of speed and heading sensors; $\eta_{V_{Xh}}$ and $\eta_{V_{Zh}}$ – are random disturbances which are conditioned by the random error terms of DGPS and also speed and heading sensors.

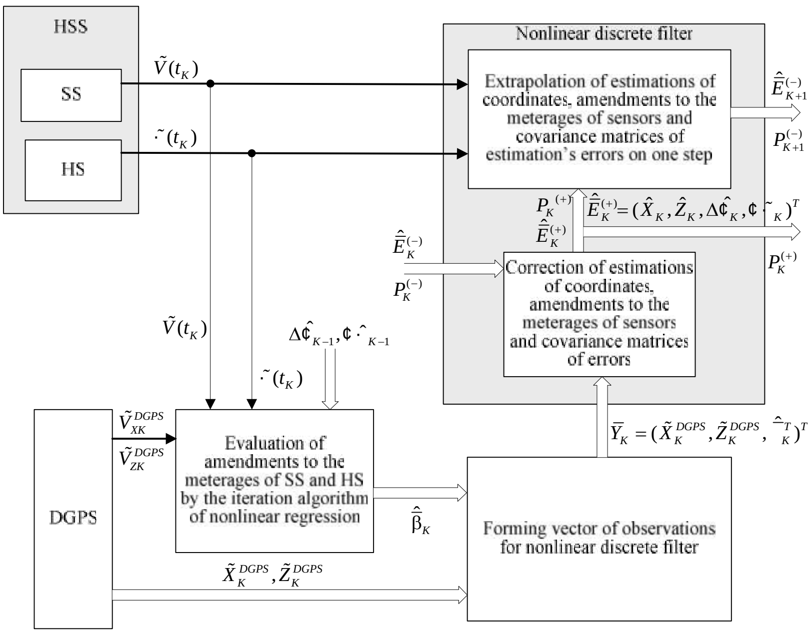

Fig. 2. Scheme of the offered method of processing of navigation information

Based on equations (1) the vector model of nonlinear regression:

$$\overline{Y}_K = \overline{h}(\overline{\beta}, \overline{\gamma}_K) + \overline{\eta}, \tag{2}$$

where $\bar{Y}_K = (\tilde{V}_{XK}^{DGPS}, \tilde{V}_{ZK}^{DGPS})^T$ – is vector-column of the current measurements of speed components by DGPS; $\bar{\beta} = (\Delta\delta_p, \delta\psi_p)^T$ – is vector-column of amendment to the meterages of heading and speed sensors; $\bar{\gamma}_K = (\tilde{V}_K, \tilde{\psi}_K)^T$ – is vector-column of current meterages of course and speed sensors; $\bar{h}(\bar{\beta}, \bar{\gamma}_K) = (X_K, Z_K, \tilde{V}_K(1+\Delta\delta_p)\cos(\tilde{\psi}_K + \delta\psi_p),\ \tilde{V}_K(1+\Delta\delta_p)\sin(\tilde{\psi}_K + \delta\psi_p))^T$; $\bar{\eta}$ – is vector of random disturbances in equalization of nonlinear regression, that conditioned by the random errors of DGPS in measuring of components of vehicle speed and by the random components of errors of heading and speed sensors.

The estimations of amendment vector $\bar{\beta}$ of corrections to the meterages of heading and speed sensors on the every *K-th* step of navigation information processing is suggested to get by the generalized nonlinear regressive procedure as Gauss-Newton in form [4]:

$$\hat{\bar{\beta}}_{K_{i+1}} = \hat{\bar{\beta}}_{K_i} + \lambda\Gamma_{iK}^{\oplus}[\bar{Y}_R - \bar{h}(\hat{\bar{\beta}}_{K_i}, \bar{\gamma}_K)],\ i = 0,1,2,...,i_{\max} \quad (3)$$

where $\Gamma_{iK} = \dfrac{\partial\bar{h}(\hat{\bar{\beta}}, \bar{\gamma}_K)}{\partial\hat{\bar{\beta}}_{li}}$; $\oplus$ – is character of operation of matrix pseudorotation; λ – is parameter of iteration step; $i_{\max}$ – is maximal number of iteration that is set.

The initial values of component of vector of corrections on the first step of processing of navigation information are set to zero (at K=1). The initial values of estimations of vector of corrections for the steps when K>1 are taken from a previous step (K-1) as the results of evaluation of vector of corrections.

Expressions for matrices Γ_{iK} and $\Gamma_{iK}^{\oplus}$ in procedure (3) have the following form:

$$\Gamma_{iK} = \tilde{V}_K \begin{pmatrix} \cos(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) & -(1+\Delta\hat{\delta}_{iK})\sin(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) \\ \sin(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) & (1+\Delta\hat{\delta}_{iK})\cos(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) \end{pmatrix}; \quad (4)$$

$$\Gamma_{iK}^{\oplus} = \frac{1}{\tilde{V}_K(1+\Delta\hat{\delta}_{iK})} \times \begin{pmatrix} (1+\Delta\hat{\delta}_{iK})Cos(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) & (1+\Delta\hat{\delta}_{iK})Sin(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) \\ -Sin(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) & Cos(\tilde{\psi}_K + \delta\hat{\psi}_{iK}) \end{pmatrix}. \quad (5)$$

On every *K-th* step of processing of navigation information, except for the evaluation of corrections to the meterages of sensors with the help of procedure (3), the estimations of current positions of vehicle centre-of-mass and the estimations of corrections $\Delta\delta_K, \delta\psi_K$ to the meterages of sensors are also received. For implementation of the last operation the procedure of the generalized discrete filtering is performed. To do last the correction of estimations of vehicle coordinates and corrections to the meterages of sensors is executed only at the presence of current information about the position and speed from DGPS, and the operation of extrapolation of estimations of coordinates at every processing step is executed by formulas for the heading-speeding calculation of coordinates with taking into account the current values of estimations of corrections to the meterages of speed and heading sensors.

The state vector for generalized discrete filter can be determined as:

$$\bar{E}_K = (X_K, Z_K, \Delta\delta_P, \delta\psi_P)^T \quad (6)$$

where $X_K, Z_K, \Delta\delta_P, \delta\psi_P$ are the amendment values of coordinates and corrections to the meterages of sensors.

The discrete model of state vector evolution is calculated according to the formula:

$$\bar{E}_{K+1} = \bar{f}(\bar{E}_K) + B_{1K}\bar{\varepsilon}_{1K} + B_{2K}\bar{\varepsilon}_{2K} \quad (7)$$

where $\bar{\varepsilon}_{1K}$, $\bar{\varepsilon}_{2K}$ – are 4-dimentional vectors-columns of the uncorrelated random disturbances with the zero mean values and single variances – that are vectors of “white” noise;

$$B_{1K}=\begin{pmatrix}0&0&0&0\\0&0&0&0\\0&0&\sigma_{\xi\delta_V}&0\\0&0&0&\sigma_{\xi\Delta\psi}\end{pmatrix}\Delta T^{\frac{1}{2}};$$

$$B_{2K}=\begin{pmatrix}\sigma_{V_d}\cos\tilde{\psi}_K & -\delta_\psi\tilde{V}_{Z_K}\Delta T & 0 & 0\\ \sigma_{V_d}\sin\tilde{\psi}_K & \delta_\psi\tilde{V}_{X_K}\Delta T & 0 & 0\\ 0&0&0&0\\0&0&0&0\end{pmatrix}\Delta T^{\frac{1}{2}};$$

$\sigma_{\xi\delta_V}$, $\sigma_{\xi\Delta\psi}$ – are the set parameters that characterize the small changes (random changes) of bias errors δ_V and $\Delta\psi$ in time; $\tilde{V}_{X_K}=\tilde{V}_{\kappa}\cos\tilde{\psi}_K$; $\tilde{V}_{Z_K}=\tilde{V}_{\kappa}\sin\tilde{\psi}_K$.

Vector-function $\bar{f}(\bar{E}_K)$ is

$$\bar{f}(\bar{E}_K)=\bar{E}_K+\begin{pmatrix}\tilde{V}_K(1+\Delta\delta_{PK})\cos(\tilde{\psi}_K+\delta\psi_{PK})\\ \tilde{V}_K(1+\Delta\delta_{PK})\sin(\tilde{\psi}_K+\delta\psi_{PK})\end{pmatrix}. \tag{8}$$

The vector of observations for the generalized discrete filter is expressed by:

$$\bar{Y}_K=(\tilde{X}_K^{CHC},\tilde{Z}_K^{CHC},\hat{\bar{\beta}}_K^T)^T, \tag{9}$$

where $\hat{\bar{\beta}}_K$ – is the estimations vector of corrections to the sensors meterages which are taken by procedure of nonlinear regression (3).

The vector of observations $\bar{Y}_K$ corresponds to the formula:

$$\bar{Y}_K=\bar{E}_K+D_{1K}\bar{\varepsilon}_{1K}+D_{2K}\bar{\varepsilon}_{2K}. \tag{10}$$

In expression (7) the matrices D_{1K} and D_{2K} are the following:

$$D_{1K}=\frac{\sigma_{Vc}}{\tilde{V}_K}\begin{pmatrix}0&0&0&0\\0&0&0&0\\ Cos(\tilde{\psi}_K+\delta\hat{\psi}_{PK}) & Sin(\tilde{\psi}_K+\delta\hat{\psi}_{PK}) & 0 & 0\\ -Sin(\tilde{\psi}_K+\delta\hat{\psi}_{PK}) & Cos(\tilde{\psi}_K+\delta\hat{\psi}_{PK}) & 0 & 0\end{pmatrix}; \tag{11}$$

$$D_{2K}=\begin{pmatrix}0&0&\sigma_{Rc}&0\\0&0&0&\sigma_{Rc}\\ \frac{\sigma_{Vd}}{\tilde{V}_K}&0&0&0\\0&\sigma_{\psi d}&0&0\end{pmatrix}. \tag{12}$$

The procedure of the generalized discrete filtering (evaluation of vector $\bar{E}_K$), which corresponds to the model (7) and in accordance to the observations in form (9) is characterized by the formulas (5) of correction of vector $\hat{\bar{E}}_K^{(-)}$ estimations and by the covariance matrix of errors of estimation $P_K^{(-)}$ which is performed under conditions of position-speed information from DGPS:

$$\hat{\bar{E}}_K^{(+)} = \hat{\bar{E}}_K^{(-)} + P_K^{(-)} Q_\gamma^{\oplus} (\bar{Y}_K - \hat{\bar{E}}_K^{(-)}); \tag{13}$$

$$P_K^{(+)} = P_K^{(-)} - P_\gamma Q_\gamma^{\oplus} P_\gamma^T, \tag{14}$$

where $Q_\gamma = P_K^{(-)} + D_{1K} D_{1K}{}^T + D_{2K} D_{2K}{}^T$;

$P_\gamma = B_{1K} D_{1K}{}^T + B_{2K} D_{2K}{}^T + P_K^{(-)}$; $\oplus$– operation symbol of matrix pseudorotation.

Operation of extrapolation $\hat{\bar{E}}_K^{(+)}$ and $P_K^{(+)}$, that is executed at each step of processing navigation information, is expressed by:

$$\hat{\bar{E}}_{K+1}^{(-)} = f(\hat{\bar{E}}_K^{(+)}); \tag{15}$$

$$P_{K+1}^{(-)} = \Phi_K P_K^{(+)} \Phi_K{}^T + B_{1K} B_{1K}^T + B_{2K} B_{2K}^T, \tag{16}$$

where $\Phi_K = \begin{pmatrix} 1 & 0 & \tilde{V}_{X_K} \Delta T & -\tilde{V}_{Z_K} \Delta T \\ 0 & 1 & \tilde{V}_{Z_K} \Delta T & \tilde{V}_{X_K} \Delta T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$ is transitional matrix.

The offered method of processing of navigation information is characterized by the high level of integration of onboard navigation subsystems (integration takes place at the level of primary information sensors), that enables to increase the convergence speed of estimated corrections to the sensors meterages and estimations of vehicle coordinates. Because of that, high accuracy of estimating vehicle navigation parameters by minimizing the cost of equipment and computing operations is provided.

Thus the offered method of processing navigation information does not need using the linear model of heading-speeding subsystem errors evolution in time, allows increasing the level of integrating subsystems, and (taking into account dynamic properties of navigation parameters of vehicle), as a result, improves navigation of vehicle on the reference trajectory.

References

1. *Ricket T. D., Ams J. D.* Future navigation Needs in Agriculture. Proceeding of the 60-th Annual Meeting of Institute of Navigation. USA, Ohio 7-9 June, 2004.
2. *Соловьев Ю. А.* Спутниковая навигация и ее приложения / Ю. А. Соловьев. М.: Эко-Трэнд, 2003. – 325 с.
   [*Solov’ev Ju. A.* Satellite navigation and its applications / Ju. A. Solov’ev. M.: Eko-Trend, 2003. – 325 p.] (in Russian).
3. *Пат. № 69393* Україна. Спосіб комплексної обробки навігаційної інформації / Л. В. Аніскевич, Д. Г. Войтюк, Ф. М. Захарін; опубл. 25.04.2012. Бюл. № 8.

[*Utility* model patent Ukraine, № 69393. A method of processing complex navigational information / L. V. Aniskevich, D. G. Vo'tjuk, F. M. Zakharin. opubl. 25.04.2012. Bjul. № 8] (in Ukrainian).

4. *Захарин Ф. М.* Методы и алгоритмы прикладного анализа / Ф. М. Захарин. Вып. 2. Статистическая фильтрация. – К.: КВВАИУ, 1978. – 148 с.
   [*Zakharin F. M.* Methods and algorithms of applied analysis / F. M. Zakharin. Vol. 2. Staticticheskaya filtratsiya. – K.: KVVAIU, 1978. – 148 p.] (in Russian).
5. *Липцер Р. Ш.* Статистика случайных процессов. Нелинейная фильтрация и смежные вопросы / Р. Ш. Липцер, А. Н. Ширяев. – М.: Наука, 1974. – 696 с.
   [*Liptser R. Sh.* Statistics of random processes. Nonlinear filtering and related matters / R. Sh. Liptser, A. N. Shirjaev. – M.: Nauka, 1974. – 696 p.] (in Russian).

Л. В. Аніскевич, Ф. М. Захарін

Спосіб комплексної обробки інформації для безпілотного наземного апарата

Представлено новий спосіб обробки навігаційної інформації від курсо-швидкісної і супутникової навігаційних систем для безпілотних апаратів наземного базування. Такий спосіб передбачає оцінювання поправок до показників датчиків курсу і швидкості за допомогою ітераційного алгоритму нелінійної регресії, а також оцінювання координат і уточнення оцінок поправок до показників датчиків з використанням узагальненого дискретного фільтру.

Л. В. Анискевич, Ф. М. Захарин

Способ комплексной обработки информации для беспилотного наземного аппарата

Представлен новый способ обработки навигационной информации от курсо-скоростной и спутниковой навигационных систем для беспилотных аппаратов наземного базирования. Такой способ предусматривает оценивание поправок к показаниям датчиков курса и скорости с помощью итерационного алгоритма нелинейной регрессии, а также оценивания координат и уточнения оценок поправок к показаниям датчиков с использованием обобщенного дискретного фильтра.