Oleg Dmitriev[1]
Nadiia Kushnerova[2]
Stanislav Profatilov[3]

DEVELOPMENT OF WAYS OF INCREASING THE RELIABILITY OF THE INTEGRATED COMPLEX OF SATELLITE AND INNERATION NAVIGATION SYSTEMS

Flight Academy of the National Aviation University
1, Dobrovolskogo str., Kropyvnytskyi, 25005, Ukraine
E-mails: [1]dmitronik70@i.ua; [2]nadiiakushnerov@gmail.com; [3]stanislav.profatilov@gmail.com

Abstract

Purpose: *is an analysis of methods and models for ensuring the functions of controlling the integrity of the GNSS and functional diagnostics of the INS in flight conditions, as well as developing an algorithm for monitoring the integrity of the GNSS and controlling the correct functioning of it.* ***Methods****: methods of the theory of optimal estimation, the theory of probability and the theory of random processes.* ***Results****: The analysis of factors influencing the quality of autonomous monitoring of the integrity of the satellite radionavigation system and analysis of possible ways to increase reliability and integrity were carried out. An algorithm for monitoring the integrity of the GNSS and controlling the correct functioning of the INS has been developed.* ***Discussion:*** *Based on the results of the study it is proposed to develop mathematical complex, which allows to conduct a complete cycle of simulation of the algorithm at a given stage of flight of the aircraft using existing groupings of spacecraft, as well as experimental navigation data of the GNSS and the INS, registered during the flights.*

Keywords: functional diagnostics; inertial system; integration; integrity; satellite system

1. Introduction

The article is devoted to research and analysis of the methods of joint processing of navigation data obtained from satellite and inertial navigation systems (INS) in order to increase the reliability of autonomous integrity control and verify the correct functioning of the INS in the conditions of the flight of the aircraft. Also, in this article an algorithm for monitoring the integrity of the GNSS is presented.

When flying along the route, the acceptable levels of error detection are quite high, which may facilitate the use of the global navigation satellite system (GNSS) as the main navigation tool. In the case of an non-precision approach, the integrity requirement is significantly increased and control parameters that are calculated by the built-in algorithm can exceed the margin of error, which can lead to the loss of accessibility of integrity assessment functions (GNSS).

Significantly improve the performance of built-in monitoring of the system is possible not only through functional additions, but also at the expense of other on-board navigation systems, namely the INS.

In this article an analysis of the autonomous control of the integrity of satellite navigation systems is carried out and on its basis the creation of an integrity control algorithm for the GNSS and the INS, which will allow detection, localization and elimination of abnormal measurements, as well as conduct functional diagnostics of the INS during flight performance.

2. Analysis of latest research and publications

Thanks to the widespread use of satellite navigation technology, the integrity of navigation systems is becoming an important issue, especially for improving safety on aviation. [1 – 3]. Receiver autonomous integrity monitoring (RAIM) is an important technology developed to evaluate and maintain the integrity of the GPS system.

The main requirements for the autonomous monitoring of integrity are set out in the main guidance documents [4, 5]. According to these

requirements, the satellite receiver indicator should form control parameters that will allow to conclude that the requirements for the integrity of the navigation system for the given phase of the flight of the aircraft are met and to issue warning signals.

The high efficiency of RAIM depends on a sufficient number of visible satellites and their geometric configuration. Usually, RAIM availability requires at least five satellites. In addition, the level of protection defined by the geometric configuration must be less than the warning threshold.

Unfortunately, at the landing and landing stage, errors and obstacles can lead to a loss of signal. In this case, the performance of the detection of defects RAIM sharply reduced [6 - 8].

The loss of functions for assessing the integrity of a satellite radio-navigation system may also arise due to insufficient redundancy of measurements, with the adverse mutual geometry of the working constellation of navigational satellites and high errors in measurements [9].

The search for algorithms for monitoring the integrity of the GNSS with the use of navigation information is devoted in works [10 – 12]. However, the approaches proposed in these works to the development of integrity monitoring in integrated systems do not provide an assessment of the work of the INS in terms of ensuring an adequate level of reliability of its functioning.

3. Research tasks

The purpose of this research is to develop ways to increase the continuity of the navigation function with the GNSS - INS complex at the landing stage. To achieve this goal, it is necessary to analyze the factors that influence the quality of autonomous integrity monitoring, the GNSS and develop possible ways to increase the reliability of the functions of the integrity assessment of the INS, namely, the algorithm for monitoring the integrity of the GNSS and controlling the correct functioning of the INS.

4. Development of the algorithm for monitoring the integrity of the GNSS and controlling the correct functioning of the INS

The basic requirements for a satellite system are the provision of the necessary values of accuracy, integrity, continuity and accessibility.

The aim of using RAIM technologies is the determination of the presence of abnormal errors and their exclusion using the measurements themselves. The solution to this problem has become possible due to the excess of measurements.

The task of close integration of the INS and the GNSS arises in the development of advanced navigational systems. The peculiarity of the problem of close integration is the possibility of obtaining integrated solutions with a small number of visible navigational satellites when autonomous positional and high-speed satellite navigation solutions are impossible.

The INS / GNSS integrated navigation system combines the benefits and compensates for the disadvantages inherent in each system separately.

As noted above, the approaches to the development of integrity monitoring in integrated systems do not provide an assessment of the work of the INS in terms of its correct functioning [10 - 12].

Methods for detecting errors in the INS can use quantitative models, qualitative models and retrospective data [13 – 19]. In the presence of an analytical model of the technological process, methods based on quantitative models are used. These include: the use of analytical or hardware redundancy, the construction of verification equations. Qualitative description of the technological process uses methods based on non-numerical models. These include the use of a directed graph, a failure tree, and a model of "common sense."

For many processes, the analytical description is not defined, and the qualitative representation is rather cumbersome, in which case retrospective data on the technological process are used. For this case, the following diagnostic methods are needed that would allow information from the retrospective data array. Such methods are divided into numeric and non-numeric. Non-numerical methods include the use of expert systems and qualitative analysis of trends. By numerical methods - the use of statistical methods, the use of neural networks [18].

For hardware redundancy, methods based on merging data [20, 21] are used with procedures such as the method of reducing uncertainty. In methods based on analytical redundancy, additional values of process variables are obtained using various process models. The most commonly used Kalman filters, Luenberger's supervisors, verification equations, artificial neural networks, Bayesian trust networks. An overview of such methods is presented in papers [17 – 19, 22, 23].

The use of verification equations is based on checking the "integrity" of the model with the measured values of inputs and outputs. Testing equations are considered in documents [19, 20].

To detect malfunctions that may lead to a failure, an oriented graph is used. The direction of the arcs of the graph is determined from the top-cause to the vertex-

consequence. Each vertex corresponds to the deviation of the variable from the value in normal operation. Using the oriented graph to detect deviations in the system is considered in [24].

The failure tree is widely used in the analysis of reliability and safety of systems. The tree of failure is a logical tree, through which it is possible to trace the path from failure to its possible consequences. The principle of the structure of the tree failure is considered in the paper [18].

Methods based on the analysis of retrospective data are divided into two classes: numerical and non-numeric methods. Non-numerical methods include the use of expert systems and qualitative analysis of trends. To numerical ones - use of neural networks, discriminant analysis, analysis of main components, etc.

When using expert data systems, error searches are initially performed [25]. In case of failure, the relevant part of the retrospective data is transmitted for analysis by the expert. The expert formulates the rules describing the failure, its cause, the failure relationship with the value of the process parameter. Rules are entered into the expert system and in the future used to process the current data on the progress of the technological process. To the disadvantages of the expert system it is necessary to include the narrowness of the possibilities of the area of use, as well as the difficulties in interviewing the expert.

Qualitative trend analysis is the construction of a trend description using a pre-selected set of primitives [13, 18]. For example, the trend area can be described as a triple number, including: the inclination of the tangent to the trend at two critical points and the straight line connecting these points. The presence of a failure gives rise to specific primitive configurations, which are used to identify the pattern recognition method.

The principal component method is used to reduce the dimension and is described in [18].

The problem of detecting a failure can be considered as a classification problem, for which the discriminant function is used. A set of values of the parameters of the technological process at each instant represents a point in the n-dimensional space. With the help of a pre-built discriminant function, you can recognize the points that correspond to the failure. The disadvantage of this approach is the need to construct discriminatory functions, as well as the fact that in most cases it is difficult to obtain an error-free classification.

When detecting a refusal by searching for previously defined signs it is possible to use methods of pattern recognition. The most simple methods are based on distance calculation. Each sign corresponds to a point in the multidimensional space of signs. Metric detection methods are based on a quantitative estimate of the proximity between these points. Different distances are used to estimate proximity [14].

Distance diagnostic methods are divided into two groups: diagnostics from distance to the standard and diagnostics from distance to plural. In the method of the standards, the ratio of the represented sign to one of the n states is carried out at the smallest distance to the standard, which takes as a characteristic typical for this state. When diagnosing distance to a plural, the distance from the reference is taken into account, and the distance from the point x to all points of the set with the given state.

As a sign of a gradual failure, a change in the trend of the variable of the technological process can be used. Under real conditions, the trend may be hidden by interferences, which makes it hard to detect such a change. It is necessary to use methods of allocation of trends. These methods include current smoothing, exponential smoothing, and the estimation of polynomial trends [26].

One of the methods for estimating a trend that takes into account the observation of different weights is the exponential mean [27]. In the exponential average weight of past observations decreases the more, the further they are from the moment of evaluation. With a sufficiently large remoteness from observation time, the value of a line does not affect the assessment of the trend. In practice, for the description of the trend most often used is the simplest two-parameter model, described in [27].

The problem of evaluating the integrity of the integrated GNSS – INS system can be considered using general theory methods called "detection of abnormal measurements" or functional diagnostics of dynamical systems [28].

Functional diagnostics examines the principles, methods and devices for evaluating technical objects in order to increase the efficiency and quality of the work of the systems being studied. The main task of functional diagnostics is to identify the technical state of an object that is being checked during its work at the given time in terms of the correctness of the functions performed on it [28].

The methods of this scientific direction are increasingly used, due to the growing demands on the quality and reliability of complex technical systems, such as navigation systems installed on board of an aircraft.

According to [28], in diagnosis, it is possible to solve three types of tasks: checking the correctness, efficiency and correct functioning of the system.

Inspection of serviceability and performance can not be carried out in the conditions of flight performance, since it is proposed to conduct a complete set of tests to assess the technical condition of the object in all modes of operation.

Verifying the correct functioning of the system requires less costs. It runs in the operating mode and evaluates the system at a given time. The conduct of such verification is appropriate for dynamic objects, including the integrated navigation system GNSS – INS.

At the same time, the diagnostic tasks distinguish between control tasks (detecting the fact of failure) and diagnostics (localization of the defect).

Thus, the purpose of the functional control of the GNSS – INS complex is to monitor the integrity of the GNSS and to control the correct functioning of the INS. At the same time, the principle of analytical redundancy is based on the control of the integrity of the GNSS, and the diagnostic features (the characteristics of the object necessary to determine its technical condition) are formed on the basis of measurements of both navigation systems. This will increase the reliability of the autonomous control of integrity and verify the correct functioning of the INS in the conditions of the flight of the aircraft.

Figure 1 shows an example of a model for assessing the integrity of the GNSS -INS system during the flight.
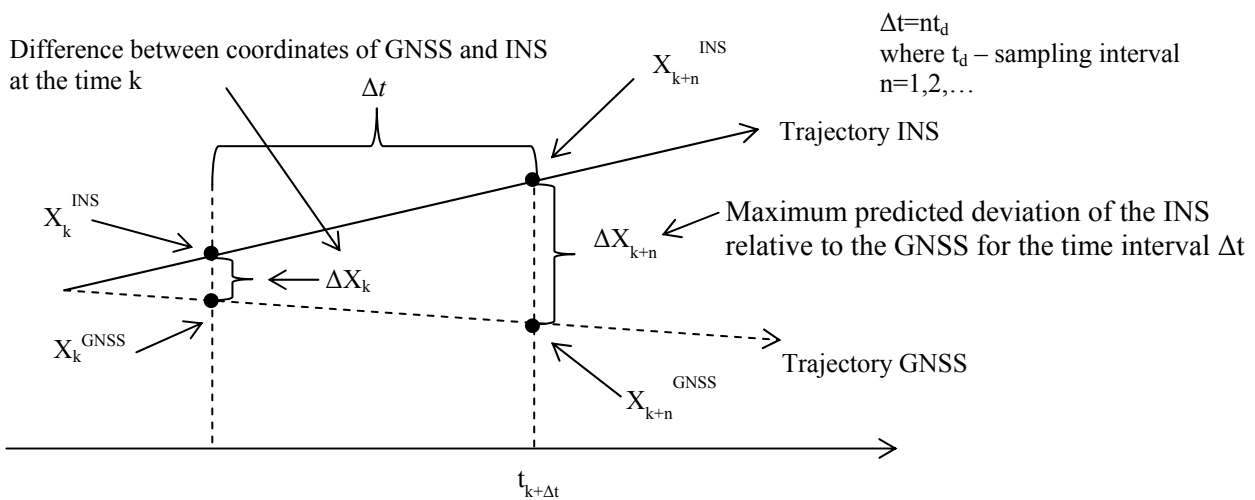

Fig. 1. Model for assessing the integrity of the *GNSS* – INS system during the flight.

The difference in velocities Δv, which are determined by the *GNSS* and the INS, can be used as an object of observation with optimal linear filtration. The algorithm for estimating the integrity of the *GNSS* – INS complex will be constructed on the basis of the processing of the value Δv.

Let's take a look at the work of the algorithm (Fig. 2).

At the time of the regular work of all satellites of the working constellation and the INS, the difference in velocities Δv, measured in the *GNSS* v_k^{GNSS} indicator and the inertial system v_k^{INS} at the time t_k, is formed.

$$\Delta v_k = v_k^{GNSS} - v_k^{INS} \qquad (1)$$

The value Δv_k enters the Kalman filter, at the filter output, an optimal linear estimate $\Delta \hat{v}_k$ is observed. The presence of the value $\Delta \hat{v}_k$ allows us to find an optimal estimate of velocity $\hat{v}_k$ by measuring two navigation sensors according to the expression

$$\hat{v}_k = v_k^{INS} + \Delta \hat{v}_k \text{, where}$$

$$\hat{v}_k = \begin{bmatrix} \hat{V}_k^N \\ \hat{V}_k^E \end{bmatrix}, \quad \Delta \hat{v}_k = \begin{bmatrix} \Delta \hat{V}_k^N \\ \Delta \hat{V}_k^E \end{bmatrix}, \quad v_k^{INS} = \begin{bmatrix} V_{N_k}^{INS} \\ V_{E_k}^{INS} \end{bmatrix} \qquad (2)$$

where, V_N, V_E is the northern and eastern component of the velocity vector in the axes of the accompanying triangular.

Optimal coordinate estimation $\hat{x} = \left[\hat{\phi}_k, \hat{l}_k \right]^T$ can be found by numerical integration (calculating coordinates) [29]:
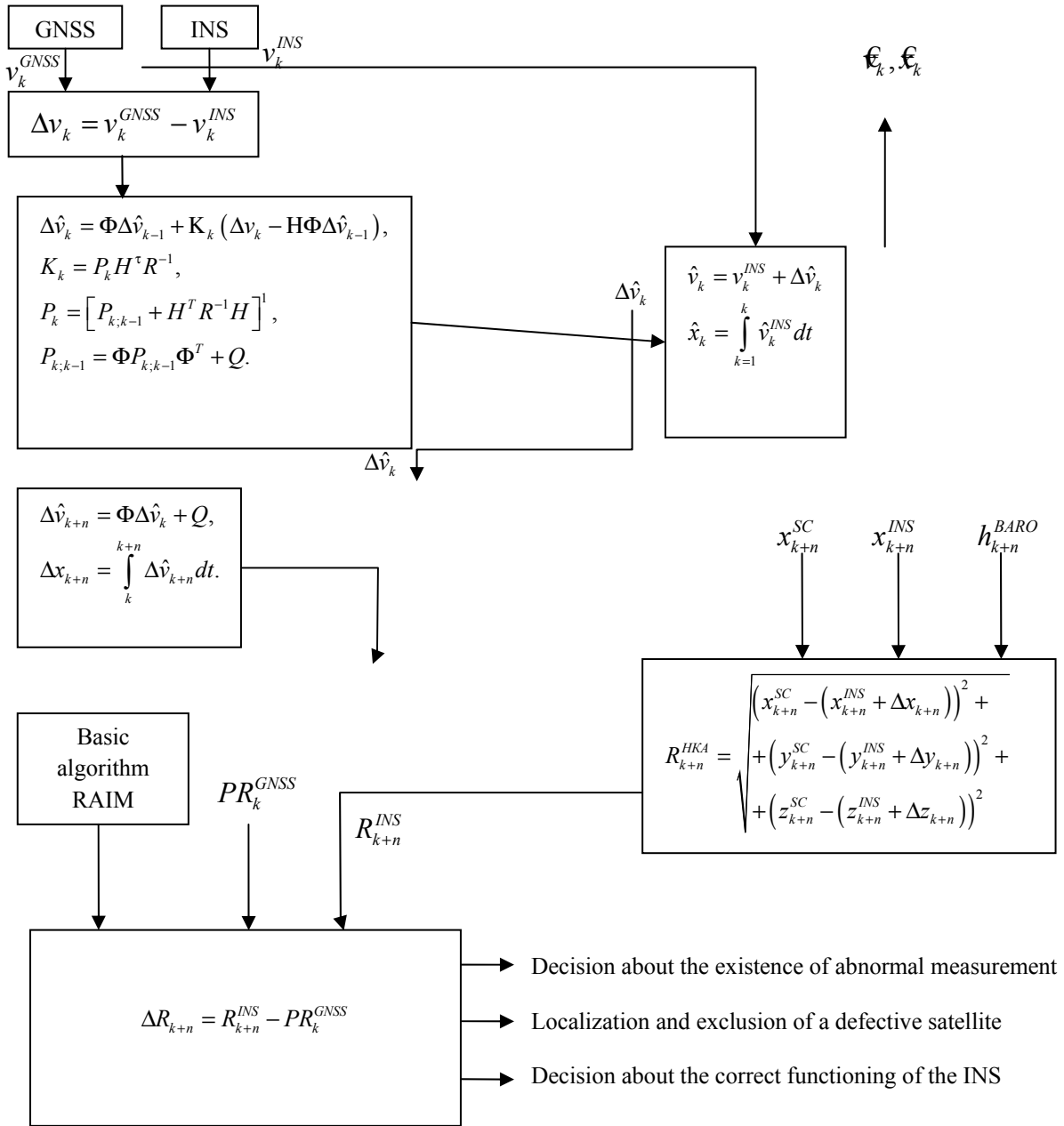
Fig. 2. Algorithm for monitoring the integrity of the *GNSS* and controlling the correct functioning of the INS

At the time of the regular work of all satellites of the working constellation and the INS, the difference in velocities Δv, measured in the *GNSS* v_k^{GNSS} indicator and the inertial system v_k^{INS} at the time t_k, is formed.

$$\Delta v_k = v_k^{CHC} - v_k^{IIHC} \qquad (1)$$

The value Δv_k enters the Kalman filter, at the filter output, an optimal linear estimate $\Delta \hat{v}_k$ is observed. The presence of the value $\Delta \hat{v}_k$ allows us to find an optimal estimate of velocity $\hat{v}_k$ by measuring two navigation sensors according to the expression $\hat{v}_k = v_k^{INS} + \Delta \hat{v}_k$, where

$$\hat{v}_k = \begin{bmatrix} \hat{V}_k^N \\ \hat{V}_k^E \end{bmatrix}, \quad \Delta\hat{v}_k = \begin{bmatrix} \Delta\hat{V}_k^N \\ \Delta\hat{V}_k^E \end{bmatrix}, \quad v_k^{INS} = \begin{bmatrix} V_{N_k}^{INS} \\ V_{E_k}^{INS} \end{bmatrix} \quad (2)$$

where, V_N, V_E is the northern and eastern component of the velocity vector in the axes of the accompanying triangular.

Optimal coordinate estimation $\hat{x} = \left[\hat{\phi}_k, \hat{l}_k\right]^T$ can be found by numerical integration (calculating coordinates) [29]:

$$\hat{\phi}_k = \phi_{k-1} + \sum_{k=1}^{N} \frac{\hat{V}_k^N}{M}(t_k - t_{k-1}),$$

$$\hat{\lambda}_k = \lambda_{k-1} + \sum_{k=1}^{N} \frac{\hat{V}_k^E}{N\cos(\hat{\phi}_k)}(t_k - t_{k-1}),$$

$$M = (a + H)\frac{1 - e^2}{\left(1 - e^2\sin^2(\hat{\phi}_{k-1})\right)^{3\backslash 2}}, \quad (3)$$

$$N = (a + H)\frac{1}{\sqrt{\left(1 - e^2\sin^2(\hat{\phi})\right)}},$$

where M and N are the radius of curvature of the meridian and the first vertical, H is the flight altitude of the aircraft, and *a* is the large half-axis of the ellipsoid of the Earth.

Found an estimate $\Delta\hat{v}_k$ enters the prediction block, which represents a open Kalman filter. In the forecast block, this value is extrapolated to the time point $t_{k+\Delta t}$, where $\Delta t = n t_d$, t_d – sampling step, *n* is the number of samples taken during the extrapolation interval Δt:

$$\Delta v_{k+n} = \Phi\Delta\hat{v}_k + Q \quad (4)$$

The magnitude Δv_{k+n} represents the predicted difference between the measurements of the speed of the *GNSS* and the INS. An equivalent difference in coordinates can be found by numerically integrating the resulting vector Δv_{k+n}. The corresponding expressions (3) are written as:

$$\Delta\phi_{k+n} = \sum_{i=1}^{\Delta t = n\cdot t_d} \frac{\Delta V_{k+i}^N}{M} t_d,$$

$$\Delta\lambda_{k+n} = \sum_{i=1}^{\Delta t = n\cdot t_d} \frac{\Delta V_{k+i}^N}{N\cos(\hat{\phi}_k)} t_d, \quad 5)$$

$$\Delta x_{k+n}^{INS} = \begin{bmatrix} \Delta\phi_{k+n} \\ \Delta\lambda_{k+n} \end{bmatrix}.$$

5. Conclusions

The proposed concept for monitoring the integrity of the GNSS and assessing the correct functioning of the INS involves the parallel work of the basic RAIM algorithm and the developed algorithm for monitoring the integrity of the *GNSS* and control the correct functioning of the INS, built on the basis of the processing of navigation data of the GNSS and the INS. This approach ensures an increase in the continuity of the implementation of the navigation functioning with the GNSS – INS complex.

References

1. Vision-Aided RAIM: A New Method for GPS Integrity Monitoring in Approach and Landing Phase:Article / [Li Fu and et al.]. – SENSORS ISSN 1424-8220, 2015. – P. 20.

2. Jun Wang. Rover Autonomous Integrity Monitoring of GNSS RTK Positioning Solutions with Multi Constellations: Article / Jun Wang, YanmingFeng, Charles Wang. – Cooperative Research Centre for Spatial Information, Queensland University of Technology : Savannah International Convention Center, Savannah, Georgia, 2009. – P.12.

3. Integrity monitoring algorithms for airport surface movement / [Wolfgang Schuster and et al.]. – Journal GPS Solutions. Volume 16 Issue 1, January 2012. – Pages 65 – 75.

4. Doc 9849, Global Navigation Satellite System (GNSS) Manual DOC-09849-003-01-E-P. 3rd edition, 2017.International Civil Aviation Organization. Approved by the Secretary General and published under his authority

5. Performance-based. Navigation (PBN). Manual. Third Edition — 2008. Doc 9613. AN/937. International Civil Aviation Organization. Approved by the Secretary General and published under his authority

6. Abidat A. The study of RAIM performance by simulation: Des. Manuf. / Abidat A., Li C., Tan, Z. Comput.-Aided Draft., 2006. – Pages 58–64.

7. Prediction and analysis of GBAS integrity monitoring availability at LinZhi airport / Wang Z. [et al.]. – GPS Solut. 2014. – Pages 27–40.

8. A new differential positioning method using modulation correlation of signals of opportunity / [Webb T et al]. – In Proceedings of the IEEE/ION Position Location and Navigation Symposium (PLANS), Indian Wells, CA, USA, 4–6 May 2010. – Pages 972–981.

9. Performance Analysis of Constrained Loosely Coupled GPS/INS Integration Solutions /

Gianluca Falco [et al]. – SENSORS ISSN 1424-8220, 2012.– P. 25.

10. Mathieu J. Integrity Risk of Kalman Filter-Based RAIM : Article / Mathieu Joerger, Boris Pervan. – Illinois Institute of Technology, 2011. – P. 12.

11. Yuanxi Yang. GNSS receiver autonomous integrity monitoring (RAIM) algorithm based on robust estimation: Original research article / Yuanxi Yang, JunyiXu. – Geodesy and Geodynamics Volume 7, Issue 2, March 2016, Pages 117-123.

12. Demidov O.V. The task of close integration of GLONASS and GPS systems with inertial systems of different accuracy classes: the dissertation of the candidate of technical sciences: 01.02.01 \ DemidovO.V. – Moscow, 2009. – 139 p. (in Russian)

13. Ignatyev A.A. Fundamentals of technical diagnostics of automated systems of mechanical engineering. / A.A. Ignatyev, Y.S. Philipov. Saratov: SSTU, 2001.68 p. (in Russian)

14. Iydu K.A. Reliability, control and diagnostics of computers and systems. / K.A. Iydu. M.: high school, 1989. 216 p. (in Russian)

15. Frank P.M. Fault Diagnosis in Dynamic Systems Using Analytical and Knowledge-based Redundancy - A Survey and Some New Results. / P.M. Frank // Automatica, vol. 26, No. 3, 1990. P.459-474.

16. Isermann R. Process Fault Diagnosis Based on Dynamic Models and Parameter estimation methods. / R. Isermann, R.J. Patton, P.M. Frank, R.N. Clark. New York: Prantice Hall, 1989, 300 p.

17. Venkatasubramanian V. A Review of Process Fault Detection and Diagnosis. / V. Venkatasubramanian, R. Rengaswamy, S.N. Kavuri, K. Yin. // Computers and Chemical Engineering, 2003, No. 27. P. 327-346.

18. Willsky A. A Survey of Design Methods for Failure Detection in Dynamic Systems. / A. Willsky//Automatica, 1976, No. 12. P.601-611.

19. Gertler J. Fault Detection and Isolation Using Parity Realtions. / J. Gertler // Control Engineering Practice, 1997, vol. 5, No. 5. P.653-661.

20. Lee J.S. Multiple Sensor Fusion Based on Moфhological Processing. / J.S. Lee. // Proceeding of SPIE - The International Society for Optical Engineering, 1988. P.94-100.

21. Basseville M. Detection of Abrupt Changes: Theory and Application./ M. Basseville, I.V. Nikiforov. New York: Prentice Hall PTR, 1997. 447 p.

22. Gustaffson F. Adaptive filtering and change detection. / Gustaffson F. New York: John Wiley & Sons, 2000. 500 p.

23. Chang C. On-Line Fault Detection Using Signed Directed Graph. / C Chang, C Yu. // Industrial Engineering Chemical Research, 1995, No. 29. P. 1290-1299.

24. Kramer M.A. Malfunction Diagnosis Using Quantitative Models with nonbooleanReasoning in Expert Systems. /M.A. Kramer. //AIChE Journal, 1995, No. 33, P. 130-140.

25. Bolshakov A.A. Methods for processing multidimensional data and time series. / A.A. Bolshakov, R.N. Karimov. М.:Горячаялиния - Телеком, 2007. 522 p. (in Russian)

26. Bolshakov A.A. Methods of information compression. / A.A. Bolshakov, R.N. Karimov. Saratov, 1991. 88 p. (in Russian)

27. Mich'eleBasseville, Igor V. Nikiforov. Detection of Abrupt Changes: Theory and Applications, Prentice-Hall – Englewood Cliffs, N.J., 1993.

28.Kharin E. G., Comprehensive processing of information on the navigation systems of aircraft: The experience of many years. pract. application: Textbook. allowance / E.G. Harin; SPBUHSS "Flight - research institute named after M.M. Gromov", Moscow. avia. in-t (state technical university). M.: Publ. MAI, 2002. - 259 p. : pic., grafs. 20 cm; ISBN 5-7035-2563-7

О.М. Дмітрієв[1], Н.І. Кушнєрова[2], С.С. Профатілов[3]
Розроблення шляхів підвищення надійності інтегрованого комплексу супутникових та інерційних навігаційних систем
Льотна академія Національного авіаційного університету, вул. Добровольского, 1., м. Кропивницький, 25005, Україна
E-mails: [1]dmitronik70@i.ua; [2]nadiiakushnerov@gmail.com; [3]stanislav.profatilov@gmail.com

Мета: аналіз методів та моделей забезпечення функцій контролю цілісності СНС та функціонального діагностування ІНС в умовах польоту, а також розробці алгоритму моніторингу цілісності СНС та

контролю правильності її функціонування. **Методи дослідження**: методи теорії оптимального оцінювання, метод теорії вірогідності та теорії випадкових процесів. **Результати:** Проведено аналіз факторів, які впливають на якість роботи автономного моніторингу цілісності супутникової радіонавігаційної системи та аналіз можливих шляхів підвищення надійності та цілісності. Представлено алгоритм моніторингу цілісності СНС та контролю правильності функціонування ІНС. **Обговорення:** На основі підсумків дослідження пропонується розбити прикладний математичний комплекс, що дозволяє проводити повний цикл моделювання роботи алгоритму на заданому етапі польоту повітряного судна при використанні існуючих угрупувань космічних апаратів, а також експериментальних навігаційних даних СНС та ІНС, зареєстрованих в ході польотів.

Ключові слова: інерційна система; інтеграція; супутникова система; цілісність; функціональне діагностування

О.Н. Дмитриев[1], Н.И. Кушнерова[2] , С.С. Профатилов[3]

Разработка путей повышения надежности интегрированного комплекса спутниковых и инерциальных навигационных систем
Летная академия Национального авиационного университета, ул. Добровольского, 1., 25005, г. Кропивницкий, Украина
E-mails: [1]dmitronik70@i.ua; [2]nadiiakushnerov@gmail.com; [3]stanislav.profatilov@gmail.com

Цель: анализ методов и моделей обеспечения функций контроля целостности СНС и функционального диагностирования ИНС в условиях полета, а также разработке алгоритма мониторинга целостности СНС и контроля правильности ее функционирования. **Методы: исследования**: методы теории оптимального оценивания, метод теории вероятностей и теории случайных процессов. **Результаты:** проведен анализ факторов, влияющих на качество работы автономного мониторинга целостности спутниковой радионавигационной системы и анализ возможных путей повышения надежности и целостности. Представлен алгоритм мониторинга целостности СНС и контроля правильности функционирования ИНС. **Обсуждение:** на основе итогов исследования предлагается разбить прикладной математический комплекс, позволяющий проводить полный цикл моделирования работы алгоритма на заданном этапе полета воздушного судна при использовании существующих группировок космических аппаратов, а также экспериментальных навигационных данных СНС и ИНС, зарегистрированных в ходе полетов.

Ключевые слова: инерционная система; интеграция; целостность; спутниковая система; функциональное диагностирование

Dmitriev Oleg (1970). PhD.
Head of the Department of flight operations, aerodynamics and flight dynamics, the Flight Academy of the National Aviation University.
Education: Kharkov Higher Military AviationSchoolofPilots(1991), National Defence AcademyofUkraine (2004).
Publications: 22.
E-mail: dmitronik70@i.ua

Kushnerova Nadiia (1989). PhD.
Head of the Department of Aeronavigation.
Education: Flight Academy of the National Aviation University (2012).
Publications: 27
E-mail: nadiiakushnerov@gmail.com

Profatilov Stanislav (1995).
Education: Flight Academy of the National Aviation University (2018).
E-mail: stanislav.profatilov@gmail.com