ISSN 1813-1166 print
ISSN 2306-1472 online

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
National Aviation University

PROCEEDINGS

of the National Aviation University

Scientific journal * 4 times a year * Established in November 1996

4 (73) 2017

KYIV

Proceedings of the National Aviation University, N 4 (73), 2017

http://jrnl.nau.edu.ua/index.php/visnik/

Journal Scope: *Proceedings of the National Aviation University* Scientific Journal is intended for publishing original research papers in English presenting results of experimental and theoretical studies in the air transport field. Our journal represents the following fields of research: aerospace systems for monitoring and control; modern aviation and space technology; airports and their infrastructure; information technology; environment protection; chemmotology and chemical technology; biotechnology; transport technologies; economic development strategy; professional education; law.

History: The Scientific Journal *Proceedings of the National Aviation University* was founded in 1996. The first volume of the Scientific Journal was published under the title Proceedings of the Kyiv International University of Civil Aviation in 1998. Since 2001 the Scientific Journal has been issued under the title Proceedings of the National Aviation University. Scientific journal "Proceedings of the National Aviation University" is referred to Ukrainian professional and scientific publications in the field of Engineering, Chemical (Ecological Safety) and Pedagogical Sciences.

Abstracts & Indexing: EBSCO, Google Scholar; Directory of Open Access Journals (DOAJ); CrossRef, Russian Science Citation Index (Elibrary.ru); Chemical Abstracts Service (CAS); Index Copernicus International (IC), WorldCat; DRIVER; Academic Journals Database, Simple Search Metadata (SSM); the Vernadsky National Library of Ukraine; Scientific and Technical Library of the National Aviation University; Bielefeld Academic Search Engine (BASE); Ulrichsweb global serials directory; Directory of Research Journal Indexing (DRJI); Journal TOCs; SHERPA/RoMEO; Journal Finder University Libraries, Sjournals, Universal Impact factor, Research Bible, Periodicos.capes.gov.br.

Certificate of State Registration KV 5091 of 28 April 2001.

Approved for publication and distribution via the Internet by the Academic Council of the National Aviation University (Minutes 13 of 20 December 2017).

Submissions: All submissions should be made online at the Proceedings of the National Aviation University (http://jrnl.nau.edu.ua/index.php/visnik/author). Complete guidelines for preparing and submitting a manuscript to this Scientific Journal are provided at the Scientific Journal website.

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Kosmonavta Komarova avenue 1
Kyiv, Ukraine, 03680
Phone: +38044 408 24 29
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CONTENTS

AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

1. Volodymyr Kharchenko, Valeriy Konin, Tetiana Olevinska
A*ircraft Navigation Efficiency Improving During Landing Using Satellite Navigation System*..... 8

2. Volodymyr Kharchenko, Denys Matiychyk
Mathematical Model of Unmanned Aerial Vehicle Control in Single Control Channel..... 18

3. Volodymyr Kharchenko, Alexander Kukush, Iurii Chyrka
Simple Objects Detection and Recognition by the Probabilistic Approach 24

4. Volodymyr Kharchenko, Valeriyan Shvets,
Pulse Characteristics of Network Satellite Systems Adaptive Antenna for Assessing Correlation Interference Matrix 30

5. Svitlana Pavlova, Dmytro Voloshenyuk
Method of Aircraft Landing by Curvilinear Glide Paths within the Boundary Trajectories..... 36

6. Olha Sushchenko
Simulation of Precision Attitude and Heading Reference System Perturbed by Environmental Disturbances 44

7. Mykhailo Matiychyk, Natalya Suvorova, Dmytro Tereshchenko, Ievgen Plakhotniuk, Kateryna Trachuk
Influence of Icing on Aircraft Performance of Unmanned Aerial Vehicle M-10-2 "Око"..... 52

8. Alexander Lysenko, Olena Tachinina
Method of Path Constructing of Information Robot on The Basis of Unmanned Aerial Vehicle..... 60

MODERN AVIATION AND SPACE TECHNOLOGIES

9. Tatiana Udartseva
Raising Level of Flight Safety during Agricultural-Air Works..... 68

BIOTECHNOLOGY

10. Oksana Kryvosheyeva, Katerina Garkava, Larysa Natrus
Influence of Microdose of Fatty Acids of Citrullus Colocynthis Extracton Lipoproteids of Rat Blood with Diabetes Mellitus Type 1..... 74

11. Ludmila Kosogolova, Bogdana Polishchuk, Iryna Kryvutenko, Kateryna Yablonska, Zoriana Romanova, Olena Hurska
The Optimizing the Extraction Process of Biologically Active Substances Obtained from Dandelion Leaves (Taraxacum Officinale Wigg) 81

12. Taras Dvoretskij, Vyacheslav Kukhtin
The Technology of the New Instrumental Estimation Method of the Vegetation Cover Microclimatic Characteristics 88

13. Svitlana Gorobets, Oksana Gorobets, Oleksandr Medviediev, Liubov Kuzminykh
The Role of Pathogenic Microorganisms in the Accumulation of Biogenic Magnetic Nanoparticles in Lung Tissues 96

PROFESSIONAL EDUCATION

14. Liliya Korol
Peculiarities of Classifying Aviation Engineers According to Their Specialities in Great Britain.....102

Instructions for Authors 107

AEROSPACE SYSTEMS FOR MONITORING AND CONTROL

UDC 629.7.052
DOI: 10.18372/2306-1472.73.12165

Volodymyr Kharchenko[1]
Valeriy Konin[2]
Tetiana Olevinska[3]

AIRCRAFT NAVIGATION EFFICIENCY IMPROVING DURING LANDING USING SATELLITE NAVIGATION SYSTEM

National Aviation University
Kosmonavta Komarova Avenue 1, 03680, Kyiv, Ukraine
E-mails: [1]kharch@nau.edu.ua; [2]konin2v@gmail.com; [3]olevinska-ans@yandex.ru

Abstract

Purpose: *Two algorithms have been considered in this article. Both of them make possible to improve aircraft navigation efficiency during landing by satellite navigation system signals. The first algorithm describes creation of two reference planes in space using measured coordinates of four points on the runway and the subsequent calculation of the aircraft horizontal and vertical angular deviation from these planes. The second algorithm describes an autonomous integrity control in the aerodrome area when four satellites are visible.* ***Methods:*** *methods of experiment planning, analytic geometry and linear algebra have been used.* ***Results:*** *obtained a new experimental data.* ***Discussion:*** *The results of experimental research of the first algorithm showed the principal possibility of deviation calculation in this way. It is shown that implementation of this technology will make it possible to increase the efficiency of small aircrafts navigation during landing at aerodromes and landing areas that are currently not equipped with radio equipment for instrument landing. The results of research of the second algorithm showed that it allows reducing the number of satellite navigation system failures and also enhances navigation efficiency. These results can be used in the aerospace sector for reducing the number of small aircraft non-flying periods.*

Keywords: aircraft landing; global navigation satellite system; instrument landing; integrity; navigation efficiency; precise landing.

1. Introduction

Small aircraft is in demand in many branches of the national economy - forestry, agriculture, firefighting, etc. The leading role is played by small aviation in the training of flight crew members. Low requirements to the quality and geometric dimensions of the runway allow small aircraft to have a wide geography of flights and to carry out promptly. But since flights are performed mainly on unequipped airfields, this imposes significant restrictions during landing.

Landing of the aircraft is a decrease along a rectilinear trajectory inclined to the horizon at an angle of 2.5-3.5 ° (for mountain airodromes this value can reach 5 °). Currently, at most classified and unclassified aerodromes for small aircrafts the visual landing is usually performed. This, along with the implementation of VFR (visual flight rules) flights, avoids unnecessary costs for aerodrome radio equipment, certification of the air fleet for instrumental flights and air navigation services. However, VFR flight and visual landing have significant restrictions on meteorological conditions, which lead to frequent downtimes. The equipment of airfields and landing areas with means ensuring vertical and horizontal guidance of aircraft would significantly reduce the number of non-flying weather conditions and increase the efficiency of the use of the air fleet. Obviously, the use of the radio-navaid system like Instrument Landing System (ILS) for this purpose is inadvisable due to the high cost of its installation (at least $ 800,000) and maintenance (about 10% of the installation cost annually), as well as the long duration of the deployment process. The problem can be solved by guiding the aircraft by the signals of satellite navigation systems.

2. Analysis of latest research and publications

The Global navigation satellite system (GNSS) technologies are being rapidly introduced in all industries where the time and coordinates detection is needed. The European Agency for GNSS periodically publishes detailed reports about the development, production, use of satellite navigation devices and the elemental base for their creation. A fragment from one of these reports [1] is shown in Fig. 1. It concerns the distribution of services between different categories of GNSS users.

GNSS technologies are practically not applied in Ukrainian aviation despite their proved economic and technical attractiveness. One of the reasons is the lack of a regulatory framework. Some economic and technical aspects of the effectiveness of GNSS technologies for navigation in Ukrainian aviation were considered in [2 - 5].

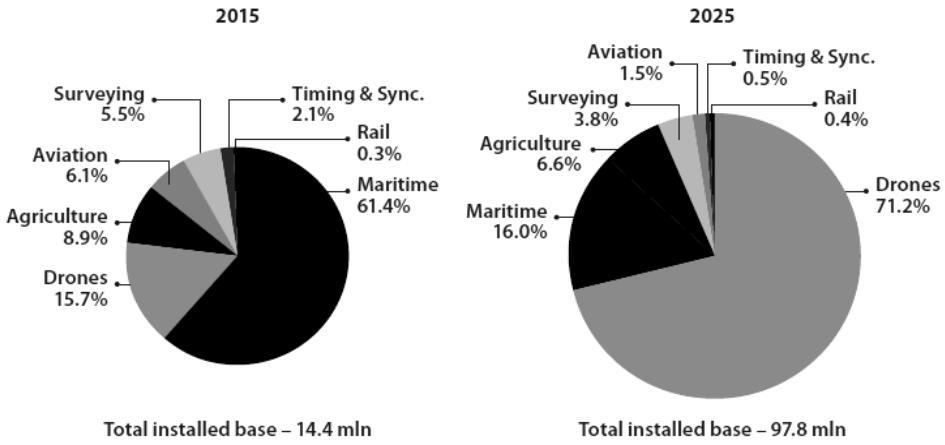


Fig. 1. Distribution of services between different categories of GNSS users.

The GNSS Guide [6] emphasizes that states implementing satellite navigation technologies in aviation take responsibility for safety at all stages of the flight and provide supervision and control of satellite signals in space. The wide-scale implementation of GNSS should be preceded by the development of the operational concept (CONOPS) and a detailed business case that takes into account interests of all stakeholders. In particular, the advantages, costs and benefits of using space and terrestrial functional additions (SBAS and GBAS), dependent surveillance systems (ADS-B/C). The document [7] outlines some of Ukraine's intentions to implement GNSS technologies. However, they have a very general nature and outline only strategic goals.

3. Research tasks

The research task is to develop ways of increasing aircraft navigation efficiency during landing using satellite system signals. For this purpose, it is necessary to develop an aircraft guidance technique during landing and an algorithm for ensuring the navigation field integrity.

4. The solution of the problem

To provide aircraft guidance, the coordinates of some points on the runway have to be measured and a block of relevant data has to be transmitted to the aircraft, allowing the formation of reference surfaces and calculating the deviations of the aircraft from these surfaces. The data block can also be pre-entered into the on-board computer database. One of the algorithms for deviations calculating is considered in [8]. To determine the spatial position of the runway and reference planes, it is necessary to measure the three-dimensional coordinates of four points on the runway (Fig. 2).

The point L is set at the intersection of the central axis of the runway and its landing threshold. The point T is set directly above the point L at the desired height of the aircraft flying above the threshold of the runway. Point P (the point at which the glide path is projected) is selected on the central axis of the runway in such a way that allows to set the glide path slope angle within acceptable limits. The point K is selected at the edge of the runway in such a way that the segment PK is perpendicular to the axis of the runway and parallel to its ends. In contrast to the methods for aircraft deviations calculating presented earlier by Rockwell Collins [9] and The Boeing Company [10], the presented method allows defining the reference surfaces in space as intersecting planes, which greatly simplifies calculations.

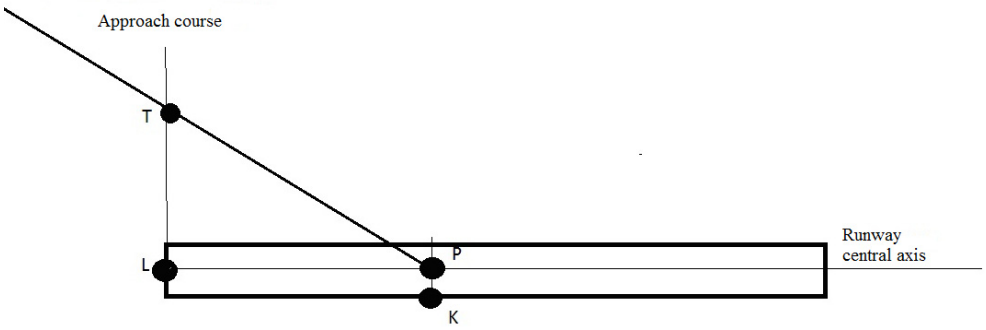


Fig. 2. Illustration of the selection of 4 points on the runway

The equation of a plane in space can be defined as follows [11]:

$$\begin{vmatrix} x-x_1 & y-y_1 & z-z_1 \\ x_2-x_1 & y_2-y_1 & z_2-z_1 \\ x_3-x_1 & y_3-y_1 & z_3-z_1 \end{vmatrix} = 0 \qquad (1)$$

In the equation (1) $(x_1\ y_1\ z_1)$, $(x_2\ y_2\ z_2)$, $(x_3\ y_3\ z_3)$ are the coordinates of points which are not lying on the same line. The determinant of the third order of the square matrix is found according to the rule of Sarrus.

As a result, we obtain the equation of the plane in the form $Ax + By + Cz + D = 0$. The course plane is given by the coordinates of the points T, L, P, the plane of the glide path is given by coordinates of the points K, P, T. The on-board GNSS receiver measures its own coordinates (x, y, z) and substitutes them into the plane equations. If the result of the coordinates substitution in the course plane equation becomes a positive value, then the aircraft is to the right of the reference trajectory. The negative value means that aircraft is to the left of the course plane. For the glide path plane, a positive value corresponds to an upward deflection, a negative value corresponds to a downward deflection. The quantitative measurement of the linear deviation can be performed using the equation (2):

$$d = \frac{|A \cdot x + B \cdot y + C \cdot z + D|}{\sqrt{A^2 + B^2 + C^2}} \qquad (2)$$

The angular deviation of the aircraft can be calculated using the equation:

$$\sin\alpha = \frac{|A \times l + B \times m + C \times n|}{\sqrt{A^2 + B^2 + C^2} \times \sqrt{l^2 + m^2 + n^2}} \qquad (3)$$

In the equation (3) A, B, C are the coefficients of the equation of the plane, l, m, n are the coefficients of the directing vector of the line which connects points M and P (the center of mass of the aircraft and the point at which the glide path is projected).

The next stage is ensuring required navigation performance. Navigating by satellite navigation systems requires continuous monitoring of the operational characteristics of the signal in space. Monitoring is subject to such parameters as:

- accuracy - the difference between calculated and true position of the aircraft;
- integrity - the probabilistic measure of trust in the correctness of information issued by the entire system. Integrity provides the ability of the system to alert the user that it should not be used for the intended flight operation. The integrity of GNSS is determined by on-board equipment through performing complex computing operations. The system has integrity if the error in the calculated location does not exceed the maximum allowed value for the operation being performed;
- continuity of service - the ability of the system to function without unplanned interruptions during the flight operation;
- availability of service - the period of time during which the system simultaneously provides required accuracy and integrity.

Table 1 shows some requirements for the accuracy, integrity, availability of service of the satellite radio navigation system for various landing categories in accordance with [12].

The integrity of satellite navigation systems is usually controlled by the GNSS control segment. However, it may take several minutes before the control segment detects a satellite's pseudorange measurement error and excludes the faulty satellite from the navigation solution. This time period which is uncritical for most GNSS users may be critical for

aircraft during the landing phase. Therefore GNSS navigation is not possible without integrity control performed directly in the on-board receiver (RAIM) or in the on-board computer using aid of other navigation devices (AAIM). For RAIM algorithms that are currently in use redundant measurements are required, i.e., at least 5 navigation satellites of one system should be visible to the on-board receiver if GNSS is used as a subsidiary navigation aid and at least 6 if GNSS is used in as the main navigation aid [13]. There are usually from 8 to 11 satellites in a well-viewed area. To determine the coordinates in 4D with one system, 4 satellites are sufficient. When small aircraft performs landing on an unequipped landing field, it is possible to reduce the number of visible navigation satellites to 4 due to terrain features or radio interference. The group of 4 satellites ensures location (according to [14], in 12% of cases dilution of precision (DOP) will have an acceptable value for landing), but standard RAIM algorithm will detect a non-alternative failure. Since landing is usually conducted in the local area, integrity can be controlled by the ground receiver. This will also make it possible to predict in advance which subcombinations of 4 satellites from the entire visible set of satellites will provide acceptable navigation accuracy. Information about all possible subcombinations and the geometric factor provided by each of them can be broadcasted using the radio data channel or pre-entered into the onboard computer.

Table 1

Requirements for the accuracy, integrity, availability of service of the satellite radio navigation system for various landing categories

Phase of flight	Accuracy (95% error)	Integrity		Alert Limit (H: horizontal, V: vertical	Continuity	Availability
		Time to Alert	Pr (HMI)			
LPV (APV 1.5)	H: 16 m V: 20 m	10 sec	$2*10^{-7}$/ approach	H: 40 m V: 50 m	$5,5*10^{-5}$/ approach	0.99 to 0.99999
APV-2	H: 16 m V: 7,6 m	6 sec	$2*10^{-7}$/ approach	H: 40 m V: 20 m	$5,5*10^{-5}$/ approach	0.99 to 0.99999
CAT I	H: 16 m V: 4 to 7,6 m	6 sec	$2*10^{-7}$/ approach	H: 40 m V: 10 to 12 m	$5,5*10^{-5}$/ approach	0.99 to 0.99999
CAT II	H: 6,9 m V: 2.0 m	2 sec	$2*10^{-9}$/ approach	H: 17,4 m V: 5,3 m	$4*10^{-6}$/ approach	0.99 to 0.99999
CAT III	H: 6.1 m V: 2.0 m	1 to 2 sec	$2*10^{-9}$/ approach	H: 15,5 m V: 5,3 m	H: $2*10^{-6}$/ 30 sec V: $2*10^{-6}$/ 15 sec	0.99 to 0.99999

The proposed integrity check algorithm, like the standard RAIM algorithms, consists of two stages. At the first stage the geometric factor of the visible satellites is determined. If the DOP value is unsatisfactory, computer doesn't perform further calculations and declares integrity failure. If DOP value is satisfactory, computer determines the test statistics.

In a second step computer calculates a pseudo-range discrepancy for each of the visible satellites, - the difference between the measured pseudo-range and the pseudo-range value which was predicted from the base receiver location data and ephemeris data.

According to [15], the connection between the discrepancies of pseudoranges to satellites and the error in users location determining is described by the equation:

$$\sigma_i = \sigma_0 \times DOP \qquad (4)$$

In the equation (4) σ_i is the standard error characterizing the accuracy of plan coordinates, height or time measuring, σ_0 is the standard unit weight error characterizing the accuracy of the pseudo-range (or phase) measurement.

If computer detects a satellite whose pseudo-range error exceeds the threshold calculated for a particular DOP value, it excludes such a satellite from the navigation decision. Since the elimination of the satellite entails a change in the geometric factor, computer calculates a new threshold for the new DOP value. The cycle is repeated until the value of the discrepancy (residual) for each of the satellites involved in solving the navigation task is less than the threshold, or until the number of satellites becomes less than 4 (in the latter case, a satellite navigation failure is declared). The scheme of the algorithm is shown in Fig. 3.

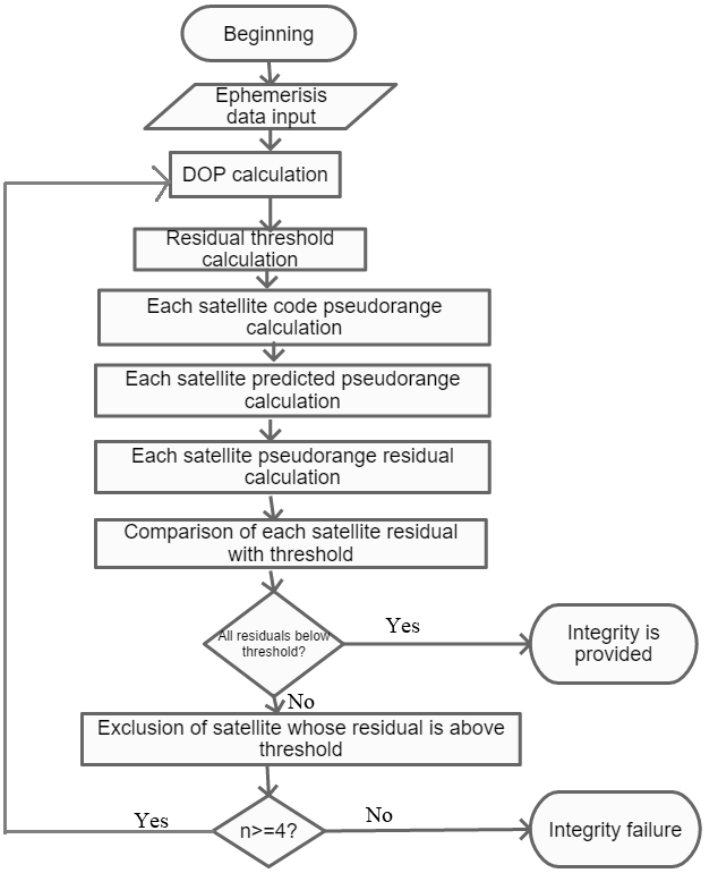
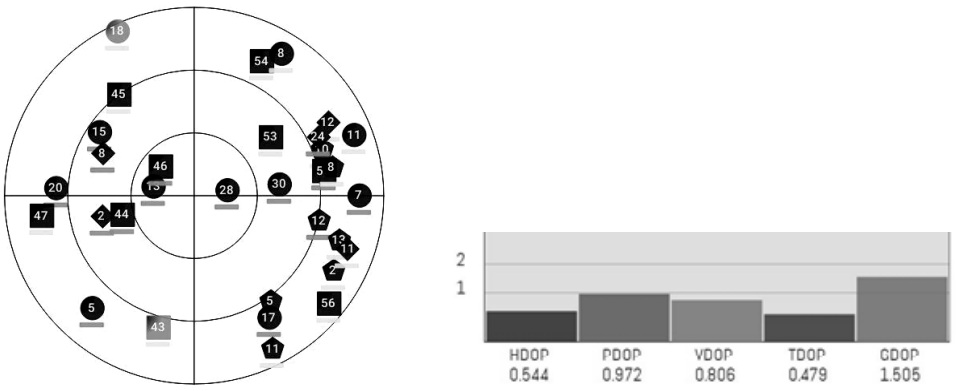


Fig. 3. The scheme of the integrity check algorithm

If flight management computer uses navigation equipment in which combined signals from GPS, GLONASS, GALILEO, COMPASS are processed, the task of integrity control can be solved according to the scheme described above, taking into account that the minimum number of satellites for coordinates measurement is:

$$Min = N + 3 \quad (5)$$

In the equation (5) N is the number of satellite systems being in use. Fig. 4 shows the instantaneous visibility of the satellites of the four systems.



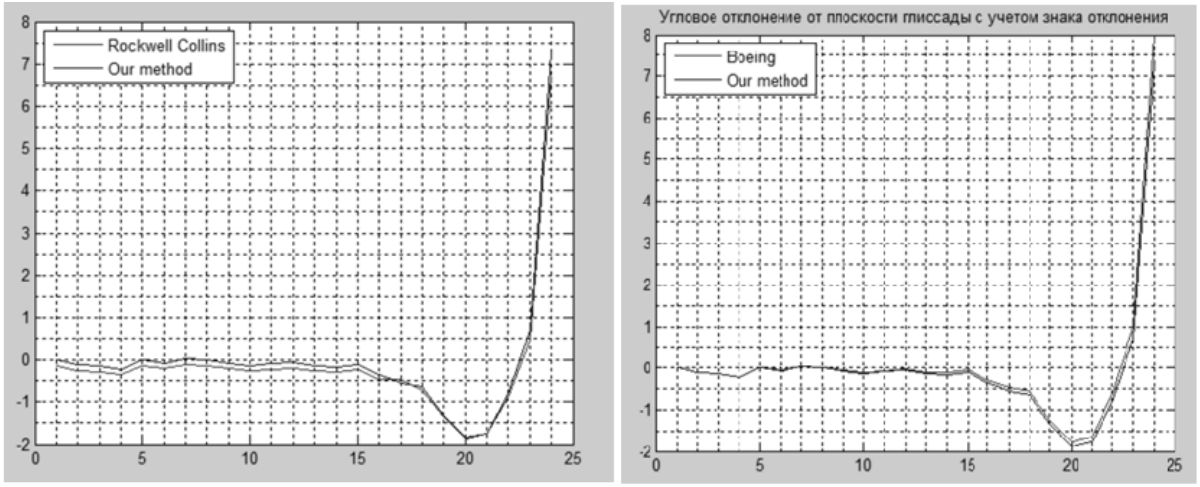
a *b*

Fig. 4. Visibility of the satellites: *a* – Instantaneous visibility of the satellites of the four systems; *b* – Geometric factors of visible satellites

In Fig. 4 there are 32 GPS, GLONASS, GALILEO and COMPASS satellites. Satellites 18 (GPS) and 43 (GLONASS) are not operable and they are excluded from the calculations. If we assume that during landing some of the satellites will be blocked, we can create a database of all combinations which contain 4 satellites out of visible 30, calculate geometric factors and select those combinations of satellites that provide the required accuracy and integrity (as a selection criteria we can take the value of DOP close to the values shown in Figure 4, b). Note also that the database can be expanded by using only two (three) systems. This approach to integrity control allows significant increasing the efficiency of evaluating the accuracy of determining the coordinates of integrity.

5. Results and discussion

An experimental study of the considered guidance algorithm showed insignificant discrepancies between the deviations obtained and the results of deviations calculating using the methods considered in [9-10] (Fig. 5).



a *b*

Fig. 5 The result of comparison of the obtained aircraft deviations from the reference surfaces with deviations obtained by: *a* - the Rockwell Collins method; *b* - the Boeing Company method

These results show principal possibility of considered technique implementation. But what is the impact of satellite landing system on the navigation efficiency?

The assessment of airline activities from an economic point of view is usually being performed according to the following criteria. One of the main indicators for firefighting, sanitation, ice reconnaissance, air defense and other industries, according to [16], is the total adjusted number of flying hours which is calculated by the equation:

$$W_{fh}^{adj} = \sum W_{fh}^{ij} \times K_{adj} \quad (6)$$

In the equation (6) K_{adj} is the modular ratio of various types of aircraft hour performance which is calculated by the following formula:

$$K_{adj} = \frac{A_{hour}^{i}}{A_{hour}^{AN-2}} \quad (7)$$

In the equation (7) A_{hour}^{i} is the hour performance of i-th type of aircraft, A_{hour}^{AN-2} is the hour performance of the An-2 aircraft taken as a comparison base. In addition, when performing aviation chemistry, the area of cultivated land is also taken into account. The criterion for passengers and cargo transportation is the volume of traffic. The main indicators that characterize the performance of the airport are the number of take-offs and landings served, as well as the number of shipments divided by type and destination. An essential role in the calculation of the profitability index is played by the utilization factor of aircraft in the flight hours. It can be calculated by the formula:

$$K_{W}^{i} = \frac{W_{jh}^{i}}{T_{calendar}} \quad (8)$$

In the equation (8) W_{fh}^{i} is the average annual flying hours per one aircraft of the i-th type, $T_{calendar}$ is the annual calendar fund of time in hours

(365 × 24 = 8760 hours). In turn, the utilization factor of aircraft is greatly influenced by the percentage of aircraft serviceability - the ratio of flying hours in good condition to the total number of aircraft hours. It should be borne in mind that even in good condition, aircraft can stand idle. Downtime in good condition includes, in addition to parking in intermediate and final airports and reserve, downtime due to meteorological conditions - periods of forced breaks in the functioning due to inconsistency between actual weather conditions and meteorological minima of the aircraft or aerodrome. The downtime due to meteorological conditions negatively affects the coefficient of aircraft usage per hour productivity, which is expressed by the formula:

$$K^{i}_{Ahour} = \frac{A^{i}_{hour}}{A^{i(\max)}_{hour}} \quad (9)$$

In the equation (9) A^{i}_{hour} and $A^{i(\max)}_{hour}$ are achieved and maximum possible hourly total productivity of the i-*th* type of aircraft respectively.

We will illustrate the effect of meteorological conditions on the small aircraft performance using example of the METAR weather report for the period from 1 to 30 November 2015. In Fig. 6 there is an analysis of statistical data about actual weather in the Kiev area (Borispol airport) for the specified period.

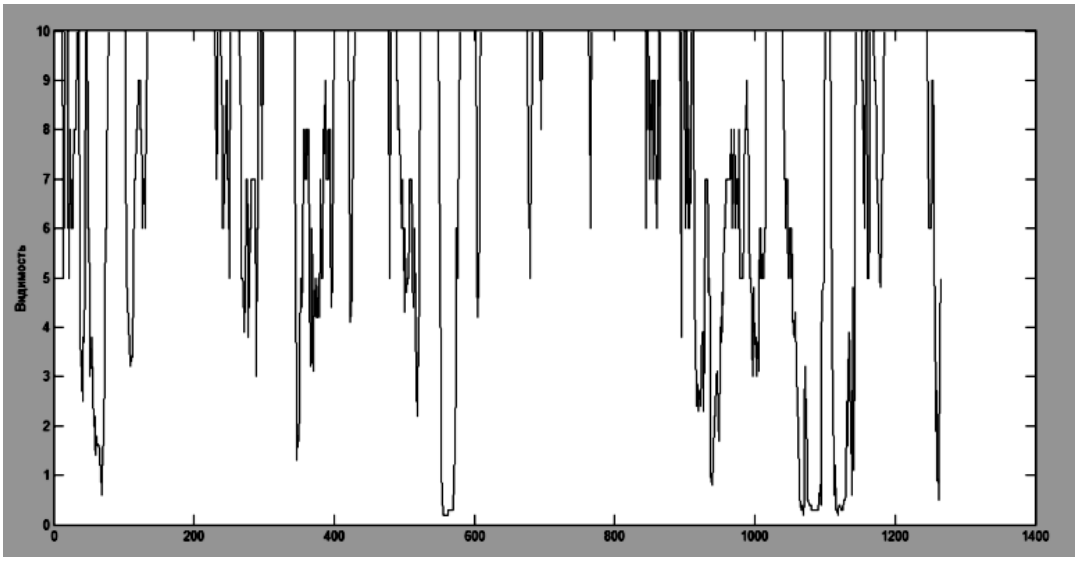


Fig. 6 Horizontal visibility in the Boryspil Airport area in the period from 1 to 30 November 2015

Such a parameter as horizontal visibility in kilometers was considered. It follows from Fig. 6, that 96 out of 1265 time periods (30 minutes each) were unsuitable for VFR flights in the take-off and landing zone in the conditions of flat and hilly terrain (horizontal visibility is less than 2000 meters) and 233 periods were unsuitable for VFR flights in mountainous terrain - (horizontal visibility is less than 5000 meters). Meanwhile, if the aircraft were equipped for IFR cat. I landing, there would be only 64 non-flying periods (horizontal visibility of less than 800 m). Cat. III landing would give us 0 non-flying periods. It can be concluded that the introduction of the presented method of horizontal and vertical aircraft guidance will reduce by 30% the number of non-flying meteorological periods with minimal financial and time costs.

6. Conclusions

The algorithm for the formation of virtual reference surfaces for calculating the horizontal and vertical aircraft deviations aircraft from the desired trajectory allows providing technical conditions for an instrument landing by GNSS signals at minimal costs. The ability to perform an instrumental landing allows crew to switch from VFR to IFR flights if needed, which reduces the number of non-flying meteorological periods by 30% and significantly improves performance.

The algorithm of autonomous integrity control, also considered in the article, allows monitoring integrity in the landing area using ground-based station with 4 visible navigation satellites of one system. It is shown that in 12% of cases 4 visible satellites provide sufficient accuracy for completing

the landing, while standard integrity control algorithms give a non-alternative failure under such conditions.

The potential use of a multisystem navigation receiver for improving navigation efficiency in conditions of limited satellites availability is illustrated.

Thus, the considered algorithm of integrity monitoring reduces the number of satellite navigation system failures and also contributes to increasing of flight performance and navigation efficiency.

References

[1] European GNSS Agency (2017), GNSS Market Report, Issue 5, available at https://www.gsa.europa.eu/system/files/reports/gnss_market_report_2017_-_surveying.pdf (Accessed 28 November 2017).

[2] Konin V.V., Zagoruyko V.V. (2000) Sputnikovye navigatsionnie sistemy [Satellite navigation systems]. *Money and technologies*, no. 4, pp.60–63. (In Russian).

[3] Konin V.V., Zagoruyko V.V. (2001) Obespechenie tochnyh zahodov na posadku metodami sputnikovoj navigacii vsisteme CNSATM Ukrainy [Precise landing using satellite navigation in CNSATM system of Ukraine]. *Space science and technology*, vol.7, no. 4, pp. 25–30. (In Russian).

[4] Konin V., Shyshkov F. (2015). Extending the Reach of SBAS Some Aspects of EGNOS Performance in Ukraine. *InsideGNSS*, Januaru–February 2015, pp.50–54.

[5] Konin V.V. (2016) Perspektivy razvitiya GNSS v Ukraine [GNSS development prospects in Ukraine]. *Proceedings of Engineering Academy of Ukraine,* no.2, pp.13-18. (In Russian)

[6] International Civil Aviation Organization (2017), Global Navigation Satellite System (GNSS) Manual Doc 9849, available at https://www.icao.int/Meetings/PBN-Symposium/Documents/9849_cons_en%5B1%5D.pdf (Accessed 28 November 2017).

[7] State Aviation Administration of Ukraine (2013), Implementation of Performance Based Navigation (PBN) Ukraine strategy and roadmap 2013–2025, available at https://www.icao.int/safety/pbn/PBNStatePlans/Ukraine%20PBN%20implementation%20plan.pdf (Accessed 29 November 2017).

[8] Olevinska T.I. (2017). Ispol'zovanie virtual'noj glissady dlya vychisleniya otklonenij letatel'nogo apparata na konechnom uchastke posadki [Application of virtual glide slope for aircraft deviation calculation during landing]. *Proceedings of Petersburg Transport University*, no. 2, pp. 381-391. (In Russian)

[9] Stratton D.A. Satellite landing system having instrument landing system look alike guidance. Patent US 6239745, available at https://www.google.com/patents/US6239745 (Accessed 29 November 2017).

[10] Fleiger-Holmes S.L, Murphy T.A., Crane J.M. (2012). Airplane position assurance monitor, Patent US 20120265376 A1. Available at http://www.google.it/patents/EP2511733A2?cl=en (Accessed 29 November 2017).

[11] Vygodskiy M.Y. (1977) *Spravochnik po vysshej matematike* [Reference book on higher mathematics]. Moscow, Science Publ., 852 p. (In Russian)

[12] International Civil Aviation Organization (2006), Aeronautical communication. Annex 10 to ICAO convention, issue 6, available at https://www.icao.int/Meetings/anconf12/Document%20Archive/AN10_V2_cons[1].pdf (Accessed 29 November 2017).

[13] Parkinson B.W., Spilker Jr J.J. (2013) Global Positioning System: Theory and Applications. Washington DC, American Institute of Aeronautics and Astronautics Publ., 793 p.

[14] Konin V.V., Olevinska T.I. (2016) [A method of autonomous integrity control of UAV]. *Tezisy nauchno-tekhnicheskoj konferencii "Problemy razvitiya global'noj sistemy svyazi, navigacii i nablyudeniya CNSATM*" [Collection of theses of the scientific and technical conference «Problems of the development of the global system of communication, navigation, surveillance and air traffic management CNSATM»]. (In Russian).

[15] Antonovich K.M. (2006) *Ispol'zovanie sputnikovyh radionavigacionnyh sistem v geodezii* [Satellite radio navigation systems in geodesy]. Moscow, Cartgeocentre Publ., 360 p. (In Russian).

[16] Stepanova N.I. (2014) *Ekonomika grazhdanskoj aviacii: uchebnoe posobie* [Civil aviation economics: students book]. Moscow. MGTU GA Publ., 130 p. (In Russian).

В.П. Харченко[1], В.В. Конін[2], Т.І. Олевінська[3]

Підвищення ефективності навігації літального апарату під час посадки за допомогою супутникової навігаційної системи

Національний авіаційний університет, просп.. Космонавта Комарова 1, Київ, Україна, 03680
E-mails: [1]kharch@nau.edu.ua, [2]konin2v@gmail.com, [3]olevinska-ans@yandex.ru

Мета: У цій статті представлено два алгоритми, що дозволяють підвищити ефективність навігації повітряного судна під час заходу на посадку за сигналами супутникової навігаційної системи. Перший алгоритм описує створення в просторі віртуальних опорних площин за координатами чотирьох точок на злітно-посадковій смузі та подальше обчислення горизонтального та вертикального кутового відхилення літального апарату від них. Другий алгоритм описує автономний контроль цілісності навігаційного поля в районі аеродрому за наявності в зоні видимості чотирьох супутників однієї системи. **Методи дослідження**: Використовувались методи планування експерименту, методи аналітичної геометрії та лінійної алгебри. **Результати:** Отримано нові експериментальні дані. **Обговорення:** Результати експериментального дослідження першого алгоритму показали принципову можливість обчислення відхилень літального апарату вказаним способом. Показано, що впровадження запропонованої технології дозволить підвищити ефективність навігації повітряних суден малої авіації під час посадки на аеродромах, які наразі не обладнані радіонавігаційними засобами для інструментальної посадки. Дослідження другого алгоритму показало, що зазначеним способом можливо зменшити кількість відмов супутникової навігаційної системи, що також позитивно впливає на ефективність навігації. Ці результати можуть бути використані у авіакосмічній галузі для зменшення кількості нельотних періодів повітряних суден малої авіації.

Ключові слова: глобальна навігаційна супутникова система; ефективність навігації; інструментальна посадка; посадка літального апарату; точна посадка.

В. П. Харченко[1], В.В. Конин[2], Т.И. Олевинская[3]

Повышение эффективности навигации воздушного судна во время посадки при помощи спутниковой навигационной системы

Национальный авиационный университет, просп. Космонавта Комарова 1, Киев, Украина, 03680
E-mails: [1]kharch@nau.edu.ua, [2]konin2v@gmail.com, [3]olevinska-ans@yandex.ru

Цель: В данной статье представлены два алгоритма, позволяющие повысить эффективность навигации воздушного судна при заходе на посадку по сигналам спутниковой навигационной системы. Первый алгоритм описывает создание в пространстве виртуальных опорных плоскостей по координатам четырех точек на взлетно-посадочной полосе и последующее вычисление горизонтального и вертикального отклонения летательного аппарата от них. Второй алгоритм описывает автономный контроль целостности навигационного поля в районе аэродрома при наличии четырех спутников в зоне видимости. **Методы исследования:** Применялись методы планирования эксперимента, аналитической геометрии и линейной алгебры. **Результаты:** Получены новые экспериментальные данные. Обсуждение: Результаты экспериментального исследования первого алгоритма показали принципиальную возможность вычисления отклонений летального аппарата указанным способом. Показано, что внедрение предложенной технологии позволит повысить эффективность навигации воздушных суден малой авиации во время посадки на аэродромы, которые в настоящее время не оборудованы радионавигационными средствами для инструментальной посадки. Исследование второго алгоритма показало, что предложенный способ позволяет уменьшить количество отказов спутниковой навигационной системы, что также положительно влияет на эффективность навигации. Эти результаты могут быть применены в авиакосмической отрасли для снижения количества нелетных периодов для воздушных суден малой авиации.

Ключевые слова: глобальная навигационная спутниковая система; инструментальная посадка; посадка летательного аппарата; точная посадка; эффективность навигации.

Kharchenko Volodymyr. Doctor of Engineering. Professor.
Vice-Rector on Scientific Work of the National Aviation University, Kyiv, Ukraine.
Editor-in-Chief of the scientific journal Proceedings of the National Aviation University.
Winner of the State Prize of Ukraine in Science and Technology, Honored Worker of Science and Technology of Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine.
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 520.
E-mail: knarch@nau.edu.ua

Konin Valeriy (1943). Doctor of Engineering. Professor of the National Aviation University, Kyiv, Ukraine.
Honored Mechanical Engineer of Ukraine.
Education: Rybinsk Aviation Technology Institute (1969).
Publications: 200.
E-mail: konin2v@gmail.com

Olevinska Tetiana (1988). Post-graduate student.
Education: National Aviation University, Kyiv, Ukraine (2011).
E-mail: olevinska-ans@yandex.ru
Publications: 6.

UDC 629.7.014.18.058.47:519.673 (045)
DOI: 10.18372/2306-1472.73.12166

Volodymyr Kharchenko[1]
Denys Matiychyk[2]

MATHEMATICAL MODEL OF UNMANNED AERIAL VEHICLE CONTROL IN SINGLE CONTROL CHANNEL

National Aviation University
1 Kosmonavta Komarova Avenue, 03680, Kyiv, Ukraine
E-mails: [1]kharch@nau.edu.ua; [2]belkaaden@gmail.com

Abstract

The main aim of this research is development of the mathematical model. Developed model will allow deeper, qualitative and faster selection of the proper values of coefficients that are necessary for optimal and effective interaction between the human and machine. ***Methods.*** *In order to develop a mathematical model of unmanned aerial vehicle control in a single control channel, the classical model of aircraft control was applied. Comparative analysis of turn execution in manual and semiautomatic control modes of unmanned aerial vehicle by remote pilot was applied.* ***Results.*** *The mathematical model "Remote pilot – Remote Control System – Unmanned Aerial Vehicle" under change of unmanned aerial vehicle heading on horizontal plane was proposed. The model takes into account the remote pilot's actions during airplane control, as well as of aircraft maneuverability when it is equipped with radio control and has a flight controller with several modes of operation.* ***Discussion.*** *The proposed model gives a possibility to analyze peculiarities of different control modes used for unmanned aerial vehicle operation. Select the proper values of coefficients that are necessary for optimal and effective interaction between the human and the machine.*

Keywords: automatic control system; control device; mathematical model; remote pilot; unmanned aerial vehicle.

1. Introduction

Today engineering systems can be made compatible with human characteristics and limitations only by means of quantitative analysis and experiment. The behavior of both man and machine can be described in comparable terms [1]. The use of Unmanned Aerial Vehicles (UAV) is urgent and has to be analyzed as interaction of the man and the machine.

During control of UAV on the distance in "semi-automatic" and "manual" control modes with the help of the video camera or Combined Flight Instrument (CFI) the problem of interaction of remote pilot and UAV arises. Its nature primarily lies in the difference of human (remote pilot) and machine properties. In our case, there is the difference of UAV and interface through which important data for the remote pilot passes. Modern flight controllers and means of receiving/transmitting commands allow fast adaptation of aircraft to automatics. But a problem of defining the proper coefficients arises when the coefficients must allow the remote pilot control the UAV effectively.

2. Analysis of the latest research and publications

Research on determination of conditions and type of control during maneuvering of aircraft is presented in work [2] which shows that when the aircraft is equipped with automatic control system it performs the tasks most effectively.

The most important task for a UAV is execution of the entire flight program in spite of all possible negative factors. Reference literature on the theory of automatic control was analyzed [3].

Tasks of UAV control are interconnected with the problem of interaction between the man and machine [4]. The latest literature about UAV application to various tasks under main flight control modes is analyzed [5].

3. Aim of research

The main aim of this research is development of the mathematical model that will allow deeper, qualitative and faster selection of the proper values

of coefficients that are necessary for optimal and effective interaction between the human and machine.

The UAV has to be directed at the necessary heading when the remote pilot observes on the screen the CFI and interacts with the UAV through the remote control system. The model shows the real heading of the UAV through CFI at the Route Turning Point (RTP). Selection of proper values of coefficients is necessary for optimal and effective interaction between the human and machine.

4. Research results

The mathematical model *"Remote pilot – Remote Control System – Unmanned Aerial Vehicle"* under change of the UAV heading in horizontal plane was proposed. The model takes into account the remote pilot's actions during airplane control, as well as aircraft maneuverability that is equipped by radio control and has a flight controller with several modes of operation. A statically stable aircraft was used in the model.

Law of coordinated rudder deflection for UAV is described by equation:

$$\delta_r = \frac{m_Y^{\beta}}{m_Y^{\delta_r}}\left[\tan^{-1}\left(\frac{B_{\max}e^{-kt}\left(-K\cos\omega t-\omega\sin\omega t\right)}{V_x}\right)+\tan^{-1}\left(\frac{B_{\max}e^{-kt}\left[\left(\omega^2-K^2\right)-K\right]}{V_x}\left(\cos\omega t-3\omega\sin\omega t\right)\right)\right], \quad (1)$$

where δ_r is the law of rudder deflection; $B_{\max}$ is the maximum possible UAV lateral divergence from flight direction, that is given at a given distance from the next RTP (D_{RTP}) still possible entering of UAV on routing line (RL) ($B_{\max}$ depends on overload, which have (Δn_z)); V is the UAV speed; K is the exponential coefficient, the value of which is advisable to change during flights in the range $0 \le K \le 0{,}1$ to provide appropriate control at different modes of flight: take-off/cruising flight/landing; ω is the angular frequency which is limited by lateral component (V_Z) of aircraft speed and angular velocity of control surface deflection ($\omega_{\text{defl.cs}}$); t is the current time of maneuver execution; $m_Y^{\beta}/m_Y^{\delta_r}$ are derivatives of rudder moment while slide and deflection of rudder.

Dynamic properties of the remote pilot are described by non-linear, discrete, nonsteady function with random variable coefficients. The remote pilot as a link of the automatic system *"Remote pilot – Remote Control System – UAV"* can be presented with a transfer function [6] as follows:

$$W_P(P) = \frac{K_0 K_N (T_1 P+1)}{(T_2 P+1)(T_N P+1)} e^{P\tau}, \quad (2)$$

where K_0 is the link amplifying coefficient; K_N is the amplifying coefficient that takes into account neuromuscular reaction of remote pilot; T_1 is the time constant of remote pilot adjustment, as forcing link of automatic system; T_2 is the time constant of remote pilot inertness; T_N is the time constant of neuromuscular reaction of remote pilot; τ is the time constant, that characterizes remote pilot reaction latency on external factors; P is the Laplace transform.

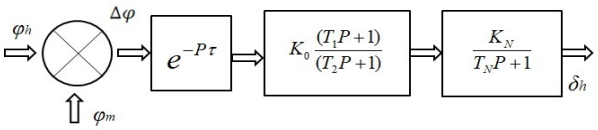


Fig. 1. Block diagram of transfer function implementation.

In Fig. 1, the first element with a transfer function describes the delay of the remote pilot's reaction on the difference of CFI readings which is in front of the eyes of the remote pilot on GCS display (variant: difference between the desirable and available heading which is defined visually when the UAV is controlled "from side") and the needed heading on the RTP which is described in the task.

The second element describes the remote pilot's inertance and his attempts to compensate for it with more energetic actions of UAV control device.

The third element, inertial link of the first order, describes the muscle influence of the remote pilot on the UAV control device.

The block diagram of UAV control contour in UAV targeting process on RTP on inclined surface is presented in Fig. 2.

Unmanned aerial vehicle movement in horizontal projection is regarded as the most complex. While targeting remote pilot has to control UAV in such a way for condition fulfilled:

$$\Delta\varphi_h = \varphi_h(t) - \varphi_{mh}(t) \quad (3)$$

where

$\varphi_h(t)$ – sight angle in horizontal plane;

$\varphi_{mh}(t)$ – heading angle of marker position;

$\Delta\varphi_h(t)$ – targeting error (control parameter).

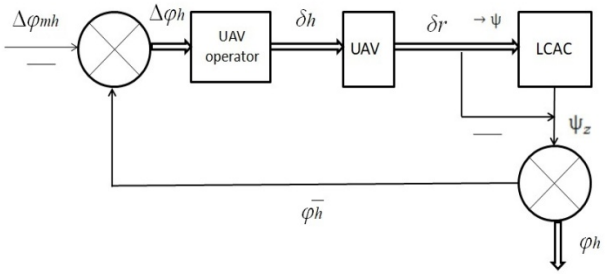


Fig. 2. Block diagram of UAV control contour

The element of the block diagram that deals with horizontal projection is described by equation (4), which links control δ_h (remote pilot's reaction on control parameter) with input signal $\Delta\varphi_h$:

$$\delta_r(P)=\left(K_{0h}\frac{T_{1h}P+1}{T_{2h}P+1}\times\frac{K_{Nh}}{T_{Nh}P+1}\times e^{-P\tau}\right)\Delta\varphi_h(P) \qquad (4)$$

Input and output signals of the links which characterize the remote pilot's reaction latency on the discrepancy parameter in general is linked by correlation:

$$Z(t)=KX(t-\tau), \qquad (5)$$

where,

$Z(t)$ – output signal of control device of directional axis;

$K = K_0K_N$ – remote pilot amplifying coefficient;

$K(t-\tau)=e^{-P\tau}$ – parameter that characterizes remote pilot inertness;

$X=\Delta\varphi$ – control parameter.

This correlation gives the possibility to consider the signal latency which comes to remote pilot's model input on time (τ). Then given signal without distortions comes to input of the next link.

Taking into account (5) we express (4) in the next form:

$$\ddot{\delta}(t)=a_1\Delta\dot{\varphi}_h(t-\tau)+a_2\Delta\varphi_h(t-\tau)-a_3\times \Delta\dot{\varphi}_h(t-\tau)-a_4\varphi_h(t) \qquad (6)$$

where,

$$a_1=\frac{K_hT_{1h}}{T_{2h}T_{Nh}};\ a_2=\frac{K_h}{T_{2h}T_{Nh}};\ a_3=\frac{T_{2h}+T_{Nh}}{T_{2h}T_{Nh}};$$

$$a_4=\frac{1}{T_{2h}T_{Nh}}; \qquad (7)$$

$$K_h=K_{0h}K_{Nh} \qquad (8)$$

$$\Delta\dot{\varphi}_h(t-\tau)=\dot{\varphi}_h(t-\tau)-\varphi_{mh}(t-\tau) \qquad (9)$$

For convenience of taking into account of the remote pilot's influence on law of control devices deflection (1) equation (6) takes the following form:

$$\Delta\delta(t)=\frac{a_1\Delta\dot{\varphi}_h(t-\tau)+a_2\Delta\varphi_h(t-\tau)-a_3\Delta\dot{\delta}_h(t)-\ddot{\delta}_h(t)}{a_4}\text{ or,} \qquad (10)$$

$$\Delta\delta(t)=K_hT_{1h}\Delta\dot{\varphi}(t-\tau)+K_h\Delta\varphi_h(t-\tau)-(T_{2h}+T_{Nh})\times\Delta\dot{\delta}_h(t)-\ddot{\delta}_h(t) \qquad (11)$$

where,

$\Delta\delta_h(t)$ – parameter of UAV control device position change during the influence of the remote pilot on UAV control in directional axis.

Conformity of UAV control device deflection $\Delta\delta_h(t)$ and rudder $\Delta\delta_r(t)$ established by selection of the amplifying coefficients values of control devices damper UAV (exponential curve, dual-rate and travel limit) in directional axis and has next form:

$$\Delta\delta_r(t)=\Delta\delta_h(t)K_{\dot{\psi}}^r \qquad (12)$$

Model conformity in real cycle is established by the selection of such values of the coefficients at which the average quadratic deviation of the total dissipation of optical vision center of the video camera on ground (total dissipation of aviation means) of targeting corresponds to the given value. Initial values of coefficients were taken according to the recommendations [6, 7] that are equal to the following values:

$$K_h=3;K_{\dot{\varphi}}^r=0,25;T_{1h}=1;T_{Nh}=1; \qquad (13)$$

The values of coefficients are taken from the radio transmitter Futaba used in the field experiment [8].

The coefficients were refined in the simulation process. Data analysis that carried out in work [4] indicates that the remote pilot's amplification coefficient K_h influences the established error. With increasing K_h we need to increase $K_{\dot{\varphi}}^r$ accordingly and vice versa.

The value of transfer process significantly is influenced by coefficient T_{1h} (time constant of remote pilot's preparation as the forming link of the automatic system). This is explained by the fact that under decreasing T_{1h} the remote pilot compensates his reaction latency faster on divergence of positions' alignment of CFI and the desired UAV heading.

The value of T_{2h} and T_{Nh} in the given mode $\Delta\varphi_h(t)$ transfers an insignificant influence.

For the lateral channel, there are the following coefficient values:

$$K_h\geq 3{,}5;\ 0{,}6\leq T_1\leq 1{,}5\text{ s};$$
$$T_2\leq 0{,}8\text{ s};\ T_N\leq 0{,}08\text{ s};\ \tau=0{,}3\text{ s}. \qquad (14)$$

These coefficients support the values of the remote pilot's model.

While targeting the UAV by ground markers in horizontal projection, equation (12) with equations that describe the UAV control model (1) form a closed system of differential equations: mathematical model *"Remote pilot – Remote Control System – UAV"*. Solving the given system of equations we can obtain the control devices deflection law considering the remote pilot's actions:

– for rudder:

$$\delta_r = \frac{m_Y^{\beta}}{m_Y^{\delta_r}}\left[\tan^{-1}\left(\frac{B_{\max}e^{-kt}\left(-K\cos\omega t-\omega\sin\omega t\right)}{V_x}\right)+\tan^{-1}\left(\frac{B_{\max}e^{-kt}\left[\left(\omega^2-K^2\right)-K\right]}{V_x}\left(\cos\omega t-3\omega\sin\omega t\right)\right)\right]+\Delta\delta_r(t) \quad (15)$$

or:

$$\delta_r = \frac{m_Y^{\beta}}{m_Y^{\delta_r}}\left[\tan^{-1}\left(\frac{B_{\max}e^{-kt}\left(-K\cos\omega t-\omega\sin\omega t\right)}{V_x}\right)+\tan^{-1}\left(\frac{B_{\max}e^{-kt}\left[\left(\omega^2-K^2\right)-K\right]}{V_x}\left(\cos\omega t-3\omega\sin\omega t\right)\right)\right]+\left[K_hT_{1h}K_{\dot\psi}^r(\dot\varphi_h(t-\tau)-\varphi_{mh}(t-\tau)\right]+\left[K_1K_{\dot\psi}^r(\dot\varphi_h(t-\tau)-\varphi_{mh}(t-\tau))\right]-\left[(T_{2h}+T_{Nh})K_{\dot\psi}^r\Delta\dot\delta_h(t)+K_{\dot\psi}^r\Delta\ddot\delta_h(t)\right] \quad (16)$$

In order to check the developed mathematical model test flights were conducted on the UAV airplane type equipped with RC equipment and flight controller [9]. UAV control modes used during flights include: *manual* control mode when the UAV executes commands directly through radio channel, flight controller stabilizers are not engaged.

The second control mode was *semiautomatic* control mode when all stabilizers were engaged (on three axes) [10].

The task of test flights was in UAV's heading change in horizontal plane from 0^0 to 24^0 (from RTP 1 to RTP 2) without the change of flight altitude.

Actually, the UAV reacts on stick deflection according to linear law. When the remote pilot switches to semiautomatic control mode, a turn is executed similarly to exponential law. This indicates that the stabilization units of the UAV counteract its turn, i.e. the stabilization units are trying to immediately return the aircraft to its initial position. The airplane reacts with inertance on control devices so the turn itself is delayed. Therefore, the UAV requires more distance and time to execute a turn.

As follows, to execute a more intensive turn the manual control mode is more beneficial. It is quite problematic to change control mode for the remote pilot (this may increase latency on time parameter for decision-making process of the UAV remote pilot). So we can recommend deactivation of the heading stabilizer while roll and pitch stabilizers are enabled for semiautomatic control mode in flight controller.

5. Conclusions

1. It was determined that the remote pilot should use of manual control mode in rudder channel for quick UAV setting on the desired heading. At the same moment, pitch and roll channels should be set on semi-automatic control mode.

2. Results of mathematical modeling and flight tests performance show that finding of coefficients that reflect the law of control surfaces deflection is an important factor in adjustment process of contour "*Remote pilot – Remote Control System – UAV*". Incorrect adjustment of channel transfer coefficient, in particular of the lateral channel, leads to excess/decrease of desired deflection values. This significantly complicates the hold of the UAV on heading and putting of the UAV on the necessary RTP.

3. To solve problem of modeling of the interaction of remote pilot and unmanned aerial vehicle a mathematical model was developed. The model considers the features of the human-remote pilot contour and features of machine contour, i.e. the UAV.

4. The UAV contour takes into account the main geometrical and dynamical characteristics of the aircraft: wing area, overload on channel, airspeed, angular velocity, time for maneuver execution, derivatives of rudder moment and air density.

5. Contour of the human-remote pilot describes latency of the remote pilot's reactions, remote pilot's inertance and his attempts to compensate for this by more energetic actions of the UAV control devices as well as inertial link of the first order, i.e. muscular influence of the remote pilot on the UAV control devices.

References:

[1] T.B. Sheridan, W.R. Ferrell. (1975) *Man-Machine Systems: Information, Control, and Decision Models of Human Performance*, The MIT Press, 468 p.

[2] *Sposob upravleniya letatel'nym apparatom* [Aircraft control method]. – M.: VVIA im. N.Ye. Zhukovskogo, avtor izobret. Yu.P. Belovodski i dr., zayavl. 7.03.85, № 3109220/40-23. (In Russian)

[3] T. Lombaerts, (2012) Automatic Flight Control Systems - Latest Developments, Publisher: InTech, Chapters published January 18, 214 p.

[4] Greg A. Jamieson, (2006) *Developing Human-Machine Interfaces to Support Monitoring of UAV Automation*, DRDC Toronto CR 2006-251, 45 p.

[5] Kenzo Nonami; Muljowidodo Kartidjo; Kwang-Joon Yoon; Agus Budiyono. (2013) *Autonomous Control Systems and Vehicles: Intelligent Unmanned Systems*. Springer, 250 p.

[6] Pashkovskiy I.M. (1975) *Ustoychivost' i upravlyayemost' samoleta*. [Aircraft Stability and Control] – M.: Mashinostroyeniye, – 328 p. (In Russian)

[7] Bodner V.A. (1978) *Aviatsionnyye trenazhery* [Aviation simulators]. – M.: Mashinostroyeniye, – 192 p. (In Russian)

[8] Futaba RC systems. Available at: http://www.futabarc.com/systems/futk9410-14sg/

[9] Pratt, R. W. (2000) *Flight Control Systems: Practical issues in design and implementation*. Edited by IEE Control Engineering Series 57, *IEEE Publ.*, Padstowe, Cornwall, 382 p.

[10] McLean, D. (1990) *Automatic Flight Control Systems*. Englewood: Prentice Hall Inc., 593 p.

В.П. Харченко[1], Д.М. Матійчик[2]

Математична модель керування безпілотним повітряним судном в одному каналі керування

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]kharch@nau.edu.ua; [2] belkaaden@gmail.com;

Мета: Головна мета дослідження – створення математичної моделі модель керування безпілотним повітряним судном в одному каналі керування. Створена модель дозволить більш глибоко, якісно і швидше підібрати потрібні величини коефіцієнтів, необхідних для оптимальної і ефективної взаємодії людини і машини. **Методи:** Для створення математичної моделі керування безпілотним повітряним судном в одному каналі керування було застосовано класичну модель керування повітряним судном. Було застосовано порівняльний аналіз виконання повороту оператором безпілотного повітряного судна в ручному та напівавтоматичному режимі керування. **Результати:** Запропонована математична модель «Оператор – система дистанційного керування – безпілотне повітряне судно» під час зміни напрямку по курсу в горизонтальній площині. Модель враховує дії оператора під час керування безпілотним повітряним судном, маневреність повітряного судна обладнаним системою дистанційного керування та польотним контролером із можливістю вибору декількох режимів керування. **Обговорення:** Запропонована модель дає можливість проаналізувати особливості різних режимів керування безпілотним повітряним судном, які застосовуються при функціонуванні безпілотного повітряного судна. Вибір відповідних коефіцієнтів на різних режимах керування безпілотним повітряним судном дозволяє оптимально та ефективно взаємодіяти людині з машиною.

Ключові слова: автоматична система керування; безпілотне повітряне судно; математична модель; оператор; орган керування.

В.П. Харченко[1], Д.М. Матийчик[2]

Математическая модель управления беспилотным воздушным судном в одном канале управления

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]kharch@nau.edu.ua; [2] belkaaden@gmail.com;

Цель: Главная цель исследования - создание математической модели модель управления беспилотным воздушным судном в одном канале управления. Созданная модель позволит более глубоко, качественно и быстрее подобрать нужные величины коэффициентов, необходимых для оптимальной и эффективной взаимодействия человека и машины. **Методы:** Для создания

математической модели управления беспилотным воздушным судном в одном канале управления было применено классическую модель управления воздушным судном. Был применен сравнительный анализ выполнения поворота оператором беспилотного воздушного судна в ручном и полуавтоматическом режиме управления. **Результаты:** Предложенная математическая модель «Оператор – система дистанционного управления – беспилотное воздушное судно» во время изменения направления по курсу в горизонтальной плоскости. Модель учитывает действия оператора при управлении беспилотным воздушным судном, маневренность воздушного судна оборудованным системой дистанционного управления и полетным контроллером с возможностью выбора нескольких режимов управления. **Обсуждение:** Предложенная модель позволяет проанализировать особенности различных режимов управления беспилотным воздушным судном, применяемых при функционировании беспилотного воздушного судна. Выбор соответствующих коэффициентов на различных режимах управления беспилотным воздушным судном позволяет оптимально и эффективно взаимодействовать человеку с машиной.

Ключевые слова: автоматическая система управления; беспилотное воздушное судно; математическая модель; оператор; орган управления.

Volodymyr Kharchenko. Doctor of Engineering. Professor.
Vice-Rector on Scientific Work of the National Aviation University, Kyiv, Ukraine.
Editor-in-Chief of the scientific journal Proceedings of the National Aviation University.
Winner of the State Prize of Ukraine in Science and Technology, Honored Worker of Science and Technology of Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine.
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 520.
E-mail: knarch@nau.edu.ua

Denys Matiychyk (1991). Postgraduate student.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2014).
Research area: Unmanned Aerial Systems.
Publications: 7.
E-mail: belkaaden@gmail.com

UDC 004.032.2:629.7.014 (045)
DOI: 10.18372/2306-1472.73.12167

Volodymyr Kharchenko[1]
Alexander Kukush[2]
Iurii Chyrka[3]

SIMPLE OBJECTS DETECTION AND RECOGNITION BY THE PROBABILISTIC APPROACH

[1,3]National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
[2]Taras Shevchenko National University of Kyiv
Volodymyrska st. 64, 01601, Kyiv, Ukraine
E-mails: [1]knarch@nau.edu.ua; [2]alexander_kukush@univ.kiev.ua; [3]yurasyk88@ukr.net

Abstract

Purpose: *The represented research results are aimed to better understanding of computer vision methods and their capabilities. The statistical approach of object detection and recognition allows processing of typical objects with simple descriptors.* ***Methods:*** *Considered approach is grounded at probabilistic methods, kernel density estimation and computer-based simulation as a verification tool.* ***Results:*** *Considered approach for object detection and recognition has shown several advantages in comparison with existing methods due to its simple realization and small time of data processing. Presented results of experimental verification prove that the considered method can be applied for detection and classification of objects with various shapes.* ***Discussion:*** *The approach can be implemented in a variety of computer vision systems that observe objects in difficult noisy conditions***.**

Keywords: Bayesian approach; object detection; probability density function; recognition.

1. Introduction

Pattern recognition is one of the biggest task fields of machine learning and computer vision. Its main purpose is detection and recognition of any specific objects or regular patterns in images or video data. Computer vision founds more and more applications in such areas as security systems, quality control in production, document processing, automatic vehicle navigation, image processing, medical decision support systems, remote sensing, etc. [1,2].

Pattern recognition is the technique that makes machine able to understand the environment and discriminate different patterns, and to make various types of decisions based on the environment observation [3]. There are two main divisions of classification according to the type of learning used to generate the output value: the supervised classification (discrimination) and the unsupervised classification (usually, called simply as classification or clustering). In the supervised classification, there are the training data samples with associated labels for corresponding class of pattern or object. In the unsupervised classification, the data are not labeled, and the classification algorithm has to find separate groups in the data and features that distinguish one group from another. Sometimes the mixed semi-supervised learning is utilized for better results. It uses a combination of labeled and unlabeled data for the classification [1].

2. Analysis of the research and publications

Due to the importance and variety of problems, which can be solved by pattern recognition, there have been discovered many methods. Based on [1], one can do the following classification of main pattern recognition methods:

– statistical pattern recognition,
– artificial neural networks,
– sparse kernel machines.

Statistical pattern recognition assumes the use of statistical techniques for analyzing measured data, information extraction, and decision making. Its task is to find, learn, and recognize patterns in complex data, for example in images, speech, biological pathways, and the Internet. Various models were proposed and used in recent publications, e.g., linear, logistic or basis function regression, Hidden Markov Model, etc. [2]

Statistical methods include estimation of the distributions of pattern feature vectors with and without objects of interest, and then apply a pattern classifier or an object detector to search over a range of other parameters that have influence on observed distributions. In this way the invariance to some unavoidable conditions is achieved. Specifically to statistical methods, the supervised classification assumes the knowledge of a probability density function (PDF) for each class of objects. Of course, in most real situations those PDFs are unknown and have to be estimated from a set of training samples with a correct label of each class.

3. Aim of the paper

The goal of the article is to analyze and verify the proposed earlier Bayesian approach for object detection and recognition on an example with graphics primitives.

4. Bayesian approach for object detection and recognition

We assume that N classes of objects are given. They correspond to prior probabilities $p_1,\ldots,p_N$, with

$$p_i>0,\ i=\overline{1,N},\ \sum_1^N p_i=1.$$

If there is a vector signal $\xi\in\Re^q$ from the object of ith class, it is described with a probability density function (pdf) $\rho_i(x;\theta)$, $x\in\Re^q$, $\theta\in\Theta\subset\Re^d$.

Here θ is a parameter that sets the observation conditions, such as certain angles associated with object; Θ is a parameter set for θ, i.e., a set where θ can vary. We suppose that the parameter θ is known exactly.

If none of the classes is observed, then the signal ξ has a pdf $\rho_0(x;\theta)$. It corresponds to the probability distribution of noise which contains a useful signal from neither object of neither class [5, 6].

We check the null hypothesis H_0: an object belonging to one of the abovementioned classes is observed, vs. an alternative hypothesis H_1: a pure noise is observed. Consider a test statistic

$$T_n=\prod_{k=1}^n\frac{\overline{\rho}(x_k;\theta_k)}{\rho_0(x_k;\theta_k)}.$$

Here

$$\overline{\rho}(x;\theta)=\sum_{i=1}^N p_i\rho_i(x;\theta)$$

denotes a weighted pdf of the signal. We suppose that α and β are given levels for a Type I error (the probability to reject H_0 under true H_0) and a Type II error (the probability to accept H_0 under true H_1).

We choose thresholds as

$$A=\frac{1-\beta}{\alpha},\ B=\frac{\beta}{1-\alpha}.$$

We continue observations until one of the inequalities holds true:

$$T_n\ge A\ \text{ or }\ T_n\le B.$$

In the first case, H_0 is accepted (an object is detected), and in the second case, H_0 is rejected (an object is not detected).

In practice, rarely there is any information about a probability distribution of required parameters. Therefore, some kind of estimates must be used in the equation for the test statistic instead of determined function values. We consider the kernel density estimates [7]. For this purpose we use the Epanechnikov kernel that is preferable over the Gaussian one due to absence of exponent and possible extremely large or small numbers.

The kernel density estimator is evaluated by observations as

$$\hat{f}_n(x)=\frac{1}{nh_1\ldots h_d}\sum_{i=1}^n\prod_{j=1}^d K\left(\frac{x_j-X_{ij}}{h_j}\right),$$

where $x=(x_1,\ldots,x_d)\in\Re^d$; h_j, $j=\overline{1,d}$, is a bandwidth for jth parameter. In order to choose h_j, $j=\overline{1,d}$, the cross-validation cost function is defined:

$$\hat{J}(h)=\int_{\Re^d}\hat{f}_n^2(x)dx-\frac{2}{n}\sum_{i=1}^n\hat{f}_{-i}(X_{-i}),$$

$$h=(h_1,\ldots,h_d)\in(0,+\infty)^d.$$

Here $\hat{f}_{-i}$ is the kernel density estimate constructed by the set of observations X_{-i} obtained from the total observation set after deleting the observations $X_{i,j}$, $j=\overline{1,d}$, which correspond to the time moment i. Then the asymptotically optimal estimate equals

$$\hat{h}:=\underset{h>0}{\arg\min}\,\hat{J}(h).$$

Suppose that an object has been detected. We continue the observations and receive new data

$$x_n,\ldots,x_m,\ \theta_n,\ldots,\theta_m,\ m\ge n.$$

Here we use the observation x_n which was received at the moment of recognition algorithm termination, and new observations as well.

Posterior probabilities can be evaluated as follows:

$$q_k^{(m)}=\frac{p_k\rho_k(x_n;\theta_n)\rho_k(x_{n+1};\theta_{n+1})\ldots\rho_k(x_m;\theta_m)}{\sum_1^N p_i\rho_i(x_n;\theta_n)\rho_i(x_{n+1};\theta_{n+1})\ldots\rho_i(x_m;\theta_m)},$$

with $k = 1,..., N$.

The observations can be terminated if the following condition holds true:

$$\max_{1 \le k \le N} q_k^{(m)} \ge P_C .$$

Here P_C is a probability of correct recognition. If in this inequality we have "strictly less" sign, then we continue observations until the termination condition is fulfilled. After the termination, the hypothesis H_j about belonging the object to jth class is accepted if

$$q_j^{(m)} = \max_{1 \le k \le N} q_k^{(m)} .$$

Since P_C>0.5, the accepted hypothesis is uniquely defined.

5. Discriminative features

Finding the correspondences between images with the same or similar objects, but taken from different sources or under different conditions is one of the most important tasks in image processing and computer vision. The idea of extracting a set of features of the desired object or pattern from the image, and describe each of them by the unique signature (descriptor), so that it can be automatically found again in other images by its signature, is the most popular approach for image recognition.

There are many requirements for a good feature descriptor. For example, it must be invariant to the complex changes of context and objects properties. It also has to be compact, fast to compute, and capable to encapsulate as much descriptive information as possible.

Among more complicated descriptors, there are 'classic' ones such as SIFT and SURF. They have been known as two of the most popular and successful feature descriptors which can be applied in many applications, from image registration to object recognition [8]. However, in many situations they are too excessive and can be replaced by a set of simple statistical parameters. In this paper, we consider such parameters as the eigenvalues of the covariance matrix and its first eigenvalue in particular, that describe the object's shape. Also such statistical values by each axis as a skewness and an excess kurtosis are defined. They describe shapes of brightness distribution.

6. Simulation results

The performance of the considered algorithm was tested on the basic set of filled objects represented by 5 graphics primitives that are shown in Fig. 1. For test purposes they were drawn separately and then imported in MATLAB where they were transformed accordingly to specified parameters and polluted by simulated noise. Hereafter they are processed as two-dimensional arrays.

All objects have the same extents, placed in the center of the observation window and have a fixed rotational angle.

Fig. 1. The set of simulated objects shapes

The simulations were carried out via Monte-Carlo method with the next general parameters and conditions: number of independent iterations 1,000; there were simulated grayscale images with size 64x64 pixels with the bit depth 8bit per pixel; five classes of filled objects (circle, square, parallelogram, isosceles (not right) triangles, and right triangles) with size 32x32 pixels have been randomly placed in the center of each image with equal probabilities, on three basic descriptors: first eigenvalue of the correlation matrix, skewness and the excess kurtosis by the x axis; signal-to-noise ratio SNR=0dB, training sample size for each class of objects N=100, maximal number of available observations for detection and recognition is limited by the training sample size, probabilities of false alarm and missing object are α, β =0.01; classification threshold $P_c = 0.99$; object brightness is set to 127 with the maximum brightness value 255, object to background brightness ratio is 1/4.

A few criterions of effectiveness have been considered: detection probability, correct classification probability, and number of observations when the object was detected and classified. Simulations have shown than in these conditions the method provided 100% detection probability in most cases except some situations with extremely strong noise. Classification probability is on the expected level as well. Therefore, plots for them are not shown here.

Fig. 2 shows plots of average number of observation at which detection and classification have been done for various signal to noise ratios.

It shows that the detector works well in a wide range of SNR, and even in severe noise conditions a single observation is enough. That can be explained by the fact that the distance between features classes with and without objects is big enough for brief detection of object presence. On the other hand, the

recognition procedure significantly drops at 5dB. Also there has been simulated the case for dependencies by the number of used criterions. Corresponding plots are shown in Fig. 3. It is well visible that sufficient performance is achieved when 4 features are used for the classification.

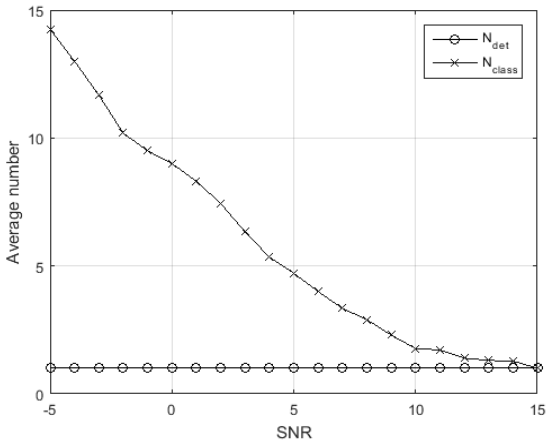


Fig. 2. Performance criterions plots at various SNR

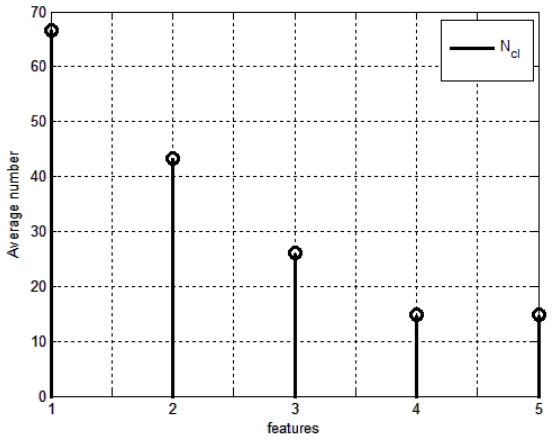


Fig. 3. Average number of observations at various features numbers

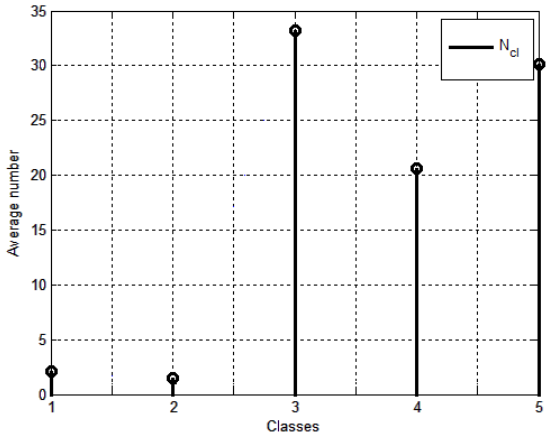


Fig. 4. Average number of observations required for classification of each class of objects

Additionally it has been estimated the complication of classification of each class. Fig. 4 represents average number of observations for recognition of each class of objects (1 – circle, 2 – square, 3 – isosceles triangle, 4 – parallelogram, 5 – right triangle)

It shows that such objects like a circle or a square are classified almost instantly, while triangular objects require much more observations.

8. Conclusions

The considered Bayesian approach to object detection and recognition for images processing has several advantages such as its simple realization, short time of processing and high level of object recognition. Presented simulation results prove that the considered method can be applied for detection and classification of objects with various shape.

References

[1] Bishop C.M. (2006) *Pattern Recognition and Machine Learning*. Singapore, Springer, 738 p.

[2] Ali Z., Shahzad S.K., and Shahzad W. (2017) Performance Analysis of Statistical Pattern Recognition Methods in KEEL. *Procedia Computer Science*, No. 112, pp. 2022-2030.

[3] Singh G., and Agrawal D.K. (2009) Pattern recognition: A review. In: *Information Technology*, Jain V.K., Ed. New Delhi, Excel Books Publ., pp. 399-405.

[4] Webb A.R. (2002) *Statistical Pattern Recognition*. Guildford, Surrey, GB, John Wiley & Sons, Ltd, 496 p.

[5] Kharchenko V.P., Kukush A.G., Kuzmenko N.S., and Ostroumov I.V. (2017) Probabilistic Approach to Object Detection and Recognition for Videostream Processing. *Proceedings of the NAU*, No. 2(71), pp. 8–14. doi: 10.18372/2306-1472.71.11741

[6] Kharchenko V.P., Ostroumov I.V., and Zaitsev Y.V. (2008) Multiparameter classification of spectrum of flight situations. *Proceedings of the NAU*, No. 4(36), pp. 4–9. (In Ukranian)

[7] Wasserman L. (2006). *All of Nonparametric Statistics*. Springer Texts in Statistics. New York, NY, Springer, 268 p.

[8] Pham C.H., Yaguchi Y., and Naruse, K. (2016) Feature Descriptors: a Review of Multiple Cues Approaches. Proc. 2016 IEEE Int. Conf. on Computer and Information Technology. Fiji, pp. 310-315. doi: 10.1109/CIT.2016.61

В.П. Харченко[1], О.Г. Кукуш[2], Ю.Д. Чирка[3]

Виявлення та розпізнавання простих об'єктів з використанням імовірнісного підходу

[1,3] Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
[2] Київський національний університет імені Тараса Шевченка, вул. Володимирська, 64, Київ, Україна, 01601
E-mails: [1]knarch@nau.edu.ua; [2]alexander_kukush@univ.kiev.ua; [3]yurasyk88@ukr.net

Мета: Представлені результати досліджень спрямовані на краще розуміння методів комп'ютерного зору та їхніх можливостей. Статистичний підхід до виявлення та розпізнавання об'єктів дозволяє обробляти типові об'єкти з простими дескрипторами. **Методи дослідження:** Розглянутий підхід базується на методах теорії ймовірності, ядерній оцінці щільності ймовірності та комп'ютерному моделюванні як засобі апробації. **Результати:** Розглянутий підхід до виявлення та розпізнавання об'єктів продемонстрував ряд переваг у порівнянні з існуючими методами завдяки простоті реалізації та швидкій обробці даних. Представлені результати експериментальної перевірки доводять, що розглянутий метод може використовуватись для виявлення та розпізнавання об'єктів різної форми. **Обговорення:** Підхід може бути реалізований у багатьох системах комп'ютерного зору, що оглядають об'єкти в складних шумових умовах.

Ключові слова: Байєсівський підхід; виявлення об'єкту; розпізнавання; щільність імовірності.

В.П. Харченко[1], А.Г. Кукуш[2], Ю.Д. Чирка[3]

Обнаружение и распознавание простых обьектов с помощью вероятностного подхода

[1,3] Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
[2] Киевский национальный университет имени Тараса Шевченка, ул. Владимирская, 64, Киев, Украина, 01601
E-mails: [1]knarch@nau.edu.ua; [2]alexander_kukush@univ.kiev.ua; [3]yurasyk88@ukr.net

Цель: Представленные результаты исследований направлены на лучшее понимание методов компьютерного зрения и их возможностей. Статистический подход к выявлению и распознаванию объектов позволяет обрабатывать типовые объекты с простыми дескрипторами. **Методы исследования:** Рассматриваемый подход базируется на методах теории вероятности, ядерном оценивании плотности вероятности и компьютерном моделировании как средстве апробации. **Результаты:** Рассматриваемый подход к обнаружению и распознаванию объектов продемонстрировал ряд преимуществ по сравнению с существующими методами благодаря простоте реализации и быстроте обработки данных. Представленные результаты экспериментальной проверки показывают, что данный метод может быть использован для обнаружения и распознавания объектов различной формы. **Обсуждение:** Подход может быть реализован во многих системах компьютерного зрения, которые осматривают объекты в сложных шумовых условиях.

Ключевые слова: Байесовский подход; обнаружение обьекта; плотность вероятности; распознавание.

Kharchenko Volodymyr (1943). Doctor of Engineering Sciences. Professor.
Vice-Rector on Scientific Work of the National Aviation University, Kyiv, Ukraine.
Editor-in-Chief of the scientific journal Proceedings of the National Aviation University.
Winner of the State Prize of Ukraine in Science and Technology, Honorable Worker of Science and Technology of Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine.
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 530.
E-mail: kharch@nau.edu.ua

Kukush Alexander (1957). Doctor of Physical and Mathematical Sciences. Professor.
Faculty of Mechanics and Mathematics, Taras Shevchenko National University of Kyiv. Education: Taras Shevchenko Kyiv State University, Kyiv, Ukraine (1979).
Research area: navigation and control of dynamical systems, mathematical and applied statistics, financial and actuarial mathematics.
Publications: 64.
E-mail: Alexander_Kukush@univ.kiev.ua

Chyrka Iurii (1988). Candidate of Engineering Sciences. Senior researcher.
National Aviation University.
Education: National Aviation University, Kyiv, Ukraine (2011).
Research area: control systems, radar signals processing, acoustic holography, and applied statistics.
Publications: 45.
E-mail: yurasyk88@ukr.net

UDC 629.7.05:656.7
DOI: 10.18372/2306-1472.73.12168

Volodymyr Kharchenko[1]
Valeriyan Shvets[2]

PULSE CHARACTERISTICS OF NETWORK SATELLITE SYSTEMS ADAPTIVE ANTENNA FOR ASSESSING CORRELATION INTERFERENCE MATRIX

National Aviation University
[1,2] Kosmonavta Komarova Avenu, 03680, Kyiv, Ukraine
E-mails: [1]kharch@nau.edu.ua; [2]hvan@nau.edu.ua

Abstract

Purpose: *On the basis of spatial filtering, we propose a method for direct calculation of the inverse correlation interference matrix with unknown parameters of the input action for controlling the pattern of the adaptive antenna array using the impulse response of the spatial filter.* ***Methods:*** *the approach is based on the theory of random processes and adaptive signal processing.* ***Results:*** *the proposed method of direct calculation of the inverse correlation matrix has shown the possibility of carrying out such calculations without a prior knowledge of the interference direction, the correlation function of the interference, and also the spectral characteristics of the interference. The method allows to reduce the calculation time of the inverse correlation matrix and eliminate the errors caused by constructive inaccuracies of the radio channels of the adaptive antenna array, which in turn reduces the error in measuring the direction of the interference source.* ***Discussion:*** *the method is suggested in order to ensure availability and consistency of network satellite systems' navigation data.*

Keywords: network satellite systems; correlation matrix; impulse characteristics; adaptive antenna array; beam pattern.

1. Introduction

Network satellite systems (NSS), which are based on the coordinated motion and radiation signals of the artificial Earth satellites network (AES), act as continuous global systems with almost instantaneous navigational definitions. Increased over time level of technical solutions allowed the NSS to significantly improve the accuracy of determining the coordinates and parameters of the consumer's traffic. Therefore, the NSS is a qualitatively new stage in the development of radio navigation technology.

Network satellite systems provide high-precision navigation on a global scale and are able to solve the problems of navigational support of any mobile objects. Such systems can be assigned tasks of determining the coordinates and speed components of the sea vessels, aircraft (AC), spacecraft (SC) and land vehicles. This feature can also facilitate vehicle steering, managing air traffic and navigation, maintaining flight safety, preventing collisions, approach and landing of aircraft at aerodromes, conducting rescue operations, etc.

One of the NSS segments are global navigation satellite systems (GNSS) GPS, GLONASS, GALILEO. These GNSSs provide coordinate-time support, which is the basis for the efficient operation of many economy branches and is an important part of modern transport systems, digital telecommunications systems, command and control systems and precision weapons.

After the euphoria of the first years of mastering satellite navigation and temporal technologies, the use of GNSS as the only source of coordinate-time information (CTI) is now more scrupulously analyzed, creating a more realistic approach to the prospects of using GNSS. First of all, this is due to the vulnerability of GNSS in case of unintentional and deliberate interference. The vulnerability of GNSS civilian receivers has been known for a long time [1-4], but it is rarely taken into account by the manufacturers of receivers and their users. Only when the US Department of Defense intensified its activities related to the use of GPS in military conditions (NAVWAR), it became apparent that deliberate interference with civilian receivers should

be considered as an important factor. The tests, which were conducted in the US in the New York area, [5] showed that a number of receivers installed on board of civil aircraft lost the ability to track GPS signals when approaching land at the international airport in Newark Liberty.

Several analyses of the transport systems vulnerability based on the use of GPS signals have been carried out [6-10]. One of the most important and timely reports on research in this area was the report of the Volpe Center [11] on GPS vulnerabilities, which concluded that the GPS system, like other radio navigation systems, is vulnerable to unintentional and deliberate interference, which is a threat to security and can have serious consequences for the economy and the environment. The report concludes that the growing use of GPS in civil infrastructure makes it an increasingly attractive target for the hostile actions of individuals and groups. At the same time, commercially available equipment for jamming has been identified [5].

Thus, the vulnerability of GNSS to the impact of unintentional and deliberate interference is now universally recognized. This vulnerability applies equally to GPS, GLONASS, GALILEO, since the principles of their construction and frequency bands are quite close.

2. Analysis of the research and publications

Since 2004 - 2007 scientists have been publishing in the open press works devoted to noise immunity improvement of GNSS consumer equipment (CE) based on [12-14], where it is proposed to use spatial filtering based on adaptive antenna arrays (AAA), in which the radiation pattern is defined as:

$$A(\theta,\varphi)=\sum_{i=1}^{N_x}\sum_{k=1}^{N_y} w_{i,k} e^{j(i-1)\psi_x} e^{j(k-1)\psi_y},$$

$$\psi_x = 2\pi\left(\frac{d_x}{\lambda}\right)\sin\theta\cos\varphi,$$

$$\psi_y = 2\pi\left(\frac{d_y}{\lambda}\right)\sin\theta\sin\varphi,$$

where d_x – the distance between AAA elements along x axis, $d_н$ – the distance between AAA elements along y axis, λ – the wavelength of the received electromagnetic wave, θ, φ – angles of arrival of the received electromagnetic fluctuation, $w_{i,k}$ – weight multipliers in elements (i, k) – AAA. Weight multipliers $w_{i,k}$ are defined with the help of the Wiener-Hopf equation.

$$\mathbf{w} = \mathbf{R}_{п}^{-1} \times \mathbf{s}, \quad (1)$$

where $\mathbf{w}$ – vector or weight multiplier, $\mathbf{R}_{п}^{-1}$ – inverse correlation matrix of interference, $\mathbf{s}$ – vector column characterizing the amplitude-phase distribution of the signal through the AAA reception channels.

However, papers [12-14] give recommendations concerning radiolocation, communication, and indicate difficulties in the direct calculation of the inverse correlation matrix of interference [14, 15].

According to the structure of signals and interference, GNSS differs from radar systems and radio communication systems. Therefore, when using adaptive methods for compensation of interference in GNSS channels, it is necessary to take into account a number of important features that often complicate the implementation of CE. So, unlike radar systems and radio communication systems, GNSS does not know the time-frequency structure of the useful signal in advance, thus excluding the possibility of using a number of widely used methods of adaptive interference compensation with the use of a reference signal. In [16], it was proposed to exclude the influence of the useful signal on the adaptation chains, but increasing the requirements for the accuracy of the coordinates determination requires new direct methods for determining the correlation interference matrices in AAA.

3. Research task

The task of the study is to propose on the basis of spatial filtration a direct calculation method of the inverse correlation matrix of interference with the unknown parameters of the input action for controlling the AAA pattern.

4. Results and Discussion

Let us suppose, that the source of the interference is a white noise of some power. Then the interference spectrum will form the following elements (Fig. 1), i.e. the filter F and the interference amplifier U, the propagation medium, A1, A2, A3, A4-antennas and the radio path of the adaptive antenna array. All

these elements will constitute a spatial filter with a certain impulse characteristics.

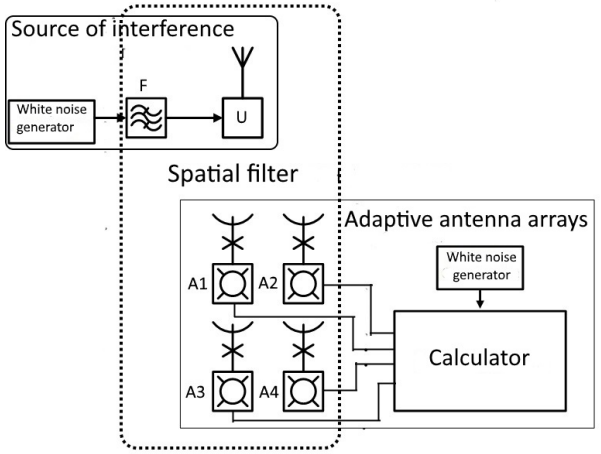


Fig. 1. Elements comprising a spatial filter

The spectral power of the interference density will be determined by expression:

$$G(\omega) = \int_{-\infty}^{\infty} R(\tau) e^{-j\omega\tau} d\tau , \qquad (2)$$

where $R(\tau)$ – correlating interference function.

Usually spectral density $G(\omega)$ decreases if ω is big enough, and becomes negligible starting with certain frequency ω_c. Then the interference $\xi(t)$ can be rather accurately replaced with the process $\xi_0(t)$ with energy spectrum

$$G_0(\omega) = \begin{cases} G(\omega) & |\omega| \le \omega_c , \\ 0, & |\omega| > \omega_c . \end{cases} \qquad (3)$$

We shall consider the random process $\xi_0(t)$ as a result of continuous white noise influence $x(t)$ with a limited by frequency ω_c spectrum on a continuous linear system which transfer function is determined by the relation

$$G_0 \left| K(j\omega) \right|^2 = G_0(\omega) , \qquad (4)$$

where G_0 is white noise spectral density (Fig. 2).

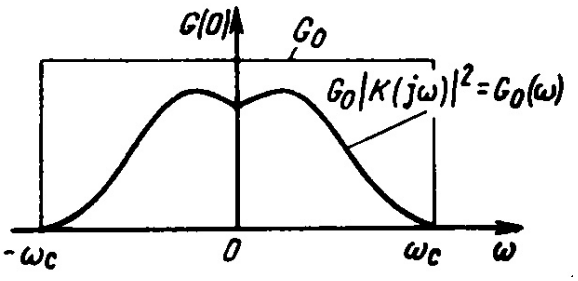


Fig. 2. Energy spectrum of white noise at the output of a linear system

Relation (4) expresses the fact known from the theory of random processes: the noise energy spectrum at the output of the linear system is equal to the product of the input noise power spectrum per square of the modulus of the system transfer function (complex frequency characteristics).

In order for the system transfer function to satisfy condition (4), it must look like

$$K_0(j\omega) = \left[\frac{1}{G_0} G_0(\omega) \right]^{\frac{1}{2}} . \qquad (5)$$

The impulse characteristics corresponding to the transfer function (5) is

$$h(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} K_0(j\omega) e^{j\omega t} d\omega = \frac{1}{\pi} \int_0^{\omega_c} \left[\frac{1}{G_0} G_0(\omega) \right]^{\frac{1}{2}} \cos \omega t d\omega . \qquad (6)$$

Let us substitute (2) in square brackets (6), then the impulse characteristics of the linear system (filter) can be expressed in terms of the interference correlation function

$$h(t) = \frac{1}{\pi} \int_0^{\omega_c} \left[\frac{1}{G_0} \int_0^{\tau} R(\tau) e^{-j\omega\tau} d\tau \right]^{\frac{1}{2}} e^{i\omega t} d\omega . \qquad (7)$$

Expression (7) can be written in the matrix form for discrete signals

$$\mathbf{h} = \mathbf{W}^* \left[\mathbf{W}\mathbf{r} \right]^{\frac{1}{2}} , \qquad (8)$$

where $\mathbf{W} = e^{-j\frac{2\pi kn}{N}}$ – matrix of turning factors of the discrete Fourier transform, $\mathbf{W}^*$ –complex conjugate matrix to $\mathbf{W}$, $\mathbf{r}$ – correlation function vector, $\mathbf{h}$ – impulse characteristics vector.

Proceeding from the fact that AAA is an element of a spatial filter, expression (8) can be written for a two-dimensional form of dimension $N \times N$

$$\mathbf{H} = \mathbf{W}^* \left[\mathbf{W}\mathbf{R} \right]^{\frac{1}{2}} , \qquad (9)$$

where $\mathbf{R}$ – interference correlation matrix.

Let us find the inverse correlation matrix from (9). After taking the squaring of (9), we obtain

$$\mathbf{H}^2 = \mathbf{W}^{*2} \mathbf{W}\mathbf{R} . \qquad (10)$$

Let us multiply both elements from the right side of (10) by $\mathbf{R}^{-1}$

$$\mathbf{H}^2 \mathbf{R}^{-1} = \mathbf{W}^{*2} \mathbf{W}\mathbf{R}\mathbf{R}^{-1} = \mathbf{W}^{*2} \mathbf{W}\mathbf{I} = \mathbf{W}^{*2} \mathbf{W} . \qquad (11)$$

Let us multiply both elements from the left side of (11) by $(\mathbf{H}^2)^{-1}$

$$\left(\mathbf{H}^2\right)^{-1}\mathbf{H}^2\mathbf{R}^{-1} = \left(\mathbf{H}^2\right)^{-1}\mathbf{W}^{*2}\mathbf{W},$$
$$\mathbf{I}\mathbf{R}^{-1} = \left(\mathbf{H}^2\right)^{-1}\mathbf{W}^{*2}\mathbf{W}, \quad (12)$$
$$\mathbf{R}^{-1} = \left(\mathbf{H}^2\right)^{-1}\mathbf{W}^{*2}\mathbf{W}.$$

where: $\mathbf{R}^{-1}$ — inverse correlation matrix of interference, **H** – impulse characteristics matrix of a spatial filter, **I** – unit matrix. Thus, (12) is an expression for determining the inverse correlation matrix of the interference.

In expression (12), the matrix **H**, like the matrix **R**, is unknown. In order to get the impulse characteristics of the filter we should use the *system identification* method. By the term *system identification* we mean the definition of the impulse response *h (n)* if it is not known.

The output of the system is connected with its input by the following relation (convolution)

$$y(n) = \sum_{m=0}^{n} h(m)x(n-m) = h(n) \otimes x(n), \quad (13)$$

where: $y(n)$ – output sequence (interference with correlation function ***r***), $x(n)$ – input sequence (normal white noise), $h(n)$ – the desired impulse characteristics of the shaping filter.

Thus, having a white noise generator from the input sequence (i.e. from the outputs of the intermediate frequency amplifiers) embedded in AAA, the system identification method determines the impulse characteristics of the spatial filter necessary to calculate the inverse correlation matrix of the interference (See Fig. 1).

Fig. 3 shows the impulse characteristics of the four AAA channels obtained by the system identification method, since the phase front of the interference depends on the direction of its arrival (angles θ and φ), so the impulse characteristics of the AAA channels will differ and carry the information about the correlation function of the interference (7)

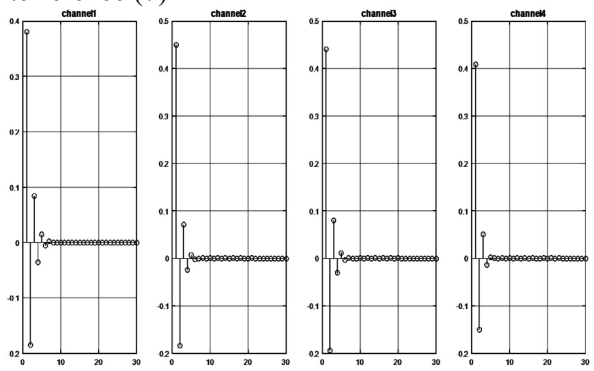


Fig. 3. AAA channel impulse characteristics view

Fig. 4 shows the AAA directivity pattern obtained while using expression (12).

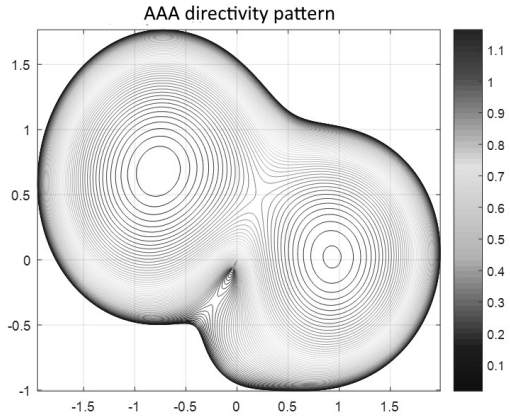


Fig. 4. AAA directivity pattern with generated "zero" gap to the source of interference

It can be seen from the figure above that in the directivity diagram a gap ("zero") is formed on the direction of the source of interference.

5. Conclusions

In order to increase the interference immunity of NSS while being a part of the GNSS equipment, it is possible to use AAAs, which allow to significantly reduce the signal reception coefficient from the direction where the source of interference is located.

To achieve the result it is proposed to use a qualitatively new method of direct calculation of the inverse correlation matrix based on the impulse response of the spatial filter (AAA). The proposed method makes it possible to reduce computational costs, due to the predetermined matrices of the turning multipliers of the Fourier transform. The matrix of the impulse characteristics is well-conditioned, so it is possible to calculate the inverse matrix of the impulse characteristics from it. Using the proposed method, it is possible to compensate for instrumental errors introduced by the design parameters of the AAA, which in turn reduces the error while measuring the direction of the source of interference.

References

[1]. R.S. Littlepage. (1998) The Impact of Interference on Civil GPS. Proceedings ION GPS-98. pp. 821-828.

[2]. Pinker, D. Walker, C.Smith. (1998) Jamming the GPS signal. Proceedings ION-98. pp. 829-837.

[3]. S. Gilmore. (1998) The Impact of Jamming on GPS. Symposium on GPS Interference and Mitigation Technique held ay the Volpe National Transportation System Center. pp. 467-478.

[4]. L. Bond. (1998) Overview of GPS Interference Issues. GPS Interference Symposium Volpe National Transportation System Center, Boston. pp. 341-352.

[5]. B. Forssel, T.B. Olsen. (2003) Jamming Susceptibility of Some Civil GPS Receivers. GPS World, no. 1, pp. 54-58.

[6]. Sushych O. P. (2012) Eksperymentalna otsinka vplyvu navmysnykh zavad na aparaturu spozhyvacha hlobalnoi navihatsiinoi suputnykovoi systemy [Experimental assessment of the effect of deliberate interference on the equipment of the consumer of the global navigation satellite system]. *Visnyk inzhenernoyi akademiyi Ukrayiny*, no. 3-4. pp. 32 – 35. (In Ukrainian).

[7]. Shvets V. A. (2012) Eksperymentalni doslidzhennya zavadostiykosti system GPS [Experimental studies of impedance of GPS systems]. *Visnyk inzhenernoyi akademiyi Ukrayiny*, no. 3-4. pp. 160 – 164. (In Ukrainian).

[8]. G. Colby, et al. (1997) Test Results of the Joint FAA/DoD Investigation of GPS Interference. Proceedings of the 10th International Technical Meeting of the Satellite Division of the Institute of Navigation, GPS-97, Kansas City. pp. 217-228.

[9]. Report of the Commission to Address United States National Security Space Management and Organizations, January 11, 2001. Available at: http://www.dtic.mil/get-tr-doc/pdf?AD=ADA404328 (accessed 13.11.2017)

[10]. John Hopkins University Applied Physics Laboratory // GPS Risk Assessment Study – Final Report, January 1999. Available at: http://www.rvs.uni-bielefeld.de/publications/Incidents/DOCS/Research/Other/Article/gps-risk-ass.pdf (accessed 13.11.2017)

[11]. Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System. A John Volpe National Transportation System Center Final Report, August 29, 2001. Available at: https://www.navcen.uscg.gov/pdf/vulnerability_assess_2001.pdf (accessed 13.11.2017)

[12]. R. A. Monzingo, T. W. Miller. (2004) Introduction to adaptive arrays. SciTech Publishing, Inc. 2004. 552 p.

[13]. Uidrou B., Strinz S. (1989) *Adaptivnaya obrabotka signalov* [Adaptive signal processing]. M: Radio i svyaz, 440 p. (In Russian).

[14]. Dzhigan V. I. (2013) *Adaptivnaja fil'tracija signalov : teorija i algoritmy* [Adaptive filtering of signals: theory and algorithms] Moscow "Tehnosfera" Publ., 528p. (In Russian).

[15]. Shvets V. A. (2013) Formuvannia vahovykh koefitsiientiv priamymy metodamy v antennykh reshitkakh system GPS [Formation of weight coefficients by direct methods in antenna arrays of GPS systems] *Visnyk inzhenernoi akademii Ukrainy*, no 1. pp. 92 – 94. (In Ukrainian).

[16]. Shvets V. A., Shvets O.V. (2013) Formuvannya vahovykh koefitsiyentiv bez opornoho syhnalu v adaptyvnykh antennykh reshitkakh system GPS, HALILEO, HLONASS [Formation of weight factors without reference signal in adaptive antenna arrays of GPS, GALILEO, GLONASS systems] *Visnyk inzhenernoyi akademiyi Ukrayiny*. No. 2, pp.147 - 149. (In Ukrainian).

В. П. Харченко[1], В. А. Швець[2], Імпульсна характеристика адаптивної антени мережевих супутникових систем для оцінки кореляційної матриці перешкоди

Національній авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]kharch@nau.edu.ua; [2]hvan@nau.edu.ua

Мета: На основі просторової фільтрації запропонувати метод прямого обчислення зворотної кореляційної матриці перешкоди при невідомих параметрах вхідного впливу для управління діаграмою спрямованості адаптивної антенної решітки, використовуючи імпульсну характеристику просторового фільтра. **Методи**: підхід базується на теорії випадкових процесів і адаптивної обробки сигналів.

Результати: запропонований метод прямого обчислення зворотної кореляційної матриці показав можливість проводити такі обчислення без апріорних знань про направлення приходу перешкоди, про кореляційної функції перешкоди, а також про спектральні характеристики перешкоди. Метод дозволяє зменшити час обчислення зворотної кореляційної матриці і виключити похибки, які викликаються конструктивними розбіжностями радіоканалів адаптивної антенної решітки, що в свою чергу знижує помилку вимірювання напрямку на джерело перешкод.

Обговорення: метод пропонується для забезпечення доступності та цілісності (підвищення завадостійкості) навігаційних даних мережевих супутникових систем.

Ключові слова: мережеві супутникові системи; кореляційна матриця; імпульсна характеристика; адаптивна антенна решітка; діаграма спрямованості.

В. П. Харченко[1], В. А. Швец[2],

Импульсная характеристика адаптивной антенны сетевых спутниковых систем для оценки корреляционной матрицы помехи

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]kharch@nau.edu.ua; [2]hvan@nau.edu.ua

Цель: На основе пространственной фильтрации предложить метод прямого вычисления обратной корреляционной матрицы помехи при неизвестных параметрах входного воздействия для управления диаграммой направленности адаптивной антенной решетки, используя импульсную характеристику пространственного фильтра. **Методы:** подход базируется на теории случайных процессов и адаптивной обработки сигналов. **Результати:** предложенный метод прямого вычисления обратной корреляционной матрицы показал возможность проводить такие вычисления без априорных знаний о направлении прихода помехи, о корреляционной функции помехи, а также о спектральных характеристиках помехи. Метод позволяет уменьшить время вычисления обратной корреляционной матрицы и исключить погрешности, которые вызываются конструктивными неточностями радиоканалов адаптивной антенной решетки, что в свою очередь снижает ошибку измерения направления на источник помех. **Обсуждение:** метод предлагается для обеспечения доступности и целостности (повышения помехоустойчивости) навигационных данных сетевых спутниковых систем.

Ключевые слова: сетевые спутниковые системы; корреляционная матрица; импульсная характеристика; адаптивная антенная решетка; диаграмма направленности.

Volodymyr Kharchenko. Doctor of Engineering. Professor.
Vice-Rector on Scientific Work of the National Aviation University, Kyiv, Ukraine.
Editor-in-Chief of the scientific journal Proceedings of the National Aviation University.
Winner of the State Prize of Ukraine in Science and Technology, Honored Worker of Science and Technology of Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine.
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 530.
E-mail: knarch@nau.edu.ua

Valerian Shvets. PhD. Associate Professor.
Department of Information Security, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Institute of Civil Aviation Engineers, Kyiv, Ukraine.
Research area: digital signal processing, adaptive information processing, information security, cybersecurity, biometrics, computer systems and programming.
Publications: 92.
E-mail: hvan@nau.edu.ua

UDC 629.7.077
DOI: 10.18372/2306-1472.73.12169

Svitlana Pavlova[1],
Dmytro Voloshenyuk[2]

METHOD OF AIRCRAFT LANDING BY CURVILINEAR GLIDE PATHS WITHIN THE BOUNDARY TRAJECTORIES

National Aviation University
Kosmonavta Komarova Avenue 1, 03680, Kyiv, Ukraine
E-mails: [1]psv@nau.edu.ua; [2]p-h-o-e-n-i-x@ukr.net

Abstract

Purpose: *The paper is dedicated to improving of civil aviation flight safety question by the way of new method of aircraft landing by curvilinear glide paths within the boundary trajectories. Proposed method ordered for improving of safety level, sustainability and cost effectiveness of the aircraft landing with own individual, optimal vertical descending profile from flight level to the runway threshold.* ***Methods:*** *Landing method, based on generation (calculation and construction) of virtual curvilinear glide paths of landing within the boundary trajectories with taking into account of "fully controllable state areas" of aircraft has been proposed.* ***Results:*** *New aircraft landing method that has large profit in the reducing of the level of noises, fuel consumption and harmful emissions.* ***Discussion:*** *The essence of the method consists in using of fully controllable state areas that are constructed taking into account on linearity in aircraft flight characteristics, probable changes into environmental state, criterion of landing implementation optimality, all functional and aerodynamic aircraft capabilities for virtual curvilinear glide path construction, meant by some aircraft traffic trajectory for time and distance reducing, that are necessary for stage from start of descending from flight level to runway threshold.*

Keyword: aircraft; air traffic; border trajectory; curvilinear glide path; landing method.

1. Introduction

Today civil aviation flight quantity is growing constantly, that leads to growing of aviation noises level, atmosphere pollution amount and flight control devices overweighting. Because of strict international legislation regulation of ecological safety rules, some limits of aircraft exploitation in airports have appeared correspondingly.

For these problems solving, the mission of aviation industry system creation correspondingly sets, that would allow:

– elevating of the ecological and economical level of flights quantitatively and qualitatively in aviation in general;

– essential elevation of safety flight level;

– unloading of holding area in the airport area;

– solving of the airport overloading problem, that is appearing afterwards rising of air traffic intensiveness;

– increase the efficiency of using aviation vehicles, etc.

Landing of the aircraft is the most responsible and difficult stage, that characterizes by the changing of flight mode, psycho physiological stresses and impermanence. Successive landing approach problem solving requires: clear crew definition of rules and landing approach accomplishment order; equipment of airfields, landing zones by special technical systems; development of methods, recommendations for the crew about usage of the landing systems and about operations during exceptional or dangerous situations. This is precisely why the new landing method development, which would at least partially solve the issue of air traffic conformity to modern aviation

requirements and that would allow to assure ensure the operation of air transport in the conditions of a sharp increase in air traffic - is the actual problem.

2. Analysis of recent research and highlighting the unresolved part of the problem

Modern status of research in the area of aircraft safe landing conditions definition characterizes by variety of approaches to improving air traffic control (ATC) procedures and aircraft control by automating the actions of air traffic control specialists and aircraft crews. Scientific problem solving of the development of methods, models and devices of informational decision making support for construction of optimal landing trajectory for further advancement of aviation safety level and improvement of ecological and economical aircraft usage rates is an important problem today.

After analyze of literature sources [1-8] further conclusions could be done - one of the efficiency improvement methods is an aircraft landing by border(free) trajectories. For example, such is the principle of the "flexible" trajectories [4]. Principle of the "flexible" trajectories implements a program strategy of control and it is in realization of "flexible", updating (frequently recalculating) with prescribed period, programmatic trajectory of aircraft movement, that provides accomplishing of the control during the "real conditions".

Principle resides in refusal of matching of controlled aircraft movement to preplanned (nominal) trajectory and formation (if necessary) of much more profitable traffic trajectories, correspondingly to current situation, on the assumption of factual conditions of the aircraft movement.

Basic difficulties of solving the problem of control for "flexible" trajectories are stipulated by its double point border character. Quite effective concept of its solving bases on usage of, so called, method of inverse dynamic problems. A characteristic feature of which lies in the fact that, at first, program aircraft movement is designated (that fulfills prescribed border conditions) and then control that realizes this movement is determined. However, such concept is unfit for general class of nonlinear control objects.

3. Statement of research problems

In basis of the work, creation problem of a new aircraft landing method has been set. This method would be directed to correspondence to current civil aviation requirements and enhancement of ecological level and flight economical efficiency.

The aim of the work is development of the generation method (calculation and construction) of virtual curvilinear glide paths of landing within the boundary trajectories with support of his own individual, optimal vertical descending profile from flight level to the runway threshold [9].

The aircraft landing by curvilinear glide paths is the procedure, during that an aircraft descends uninterruptedly from the horizontal flight to the landing with minimal thrust use [10-11].

An accomplishment of the assigned problem in the developed method provides that before the start of the aircraft landing maneuver, generation (calculation and construction) of the virtual curvilinear glide paths of landing within the boundary trajectories is carried out, for which in the method:

– data from ground-based dispatch center or from available onboard database about terminal aircraft landing point (her coordinates and characteristics of the runway, location, peculiarities of an airport), aircraft onboard system's data about current state of an aircraft, flight mode and characteristics and environment conditions, physical and aerodynamic parameters and characteristics of concrete aircraft type are using;

– construction of fully controllable state areas (in consideration of "margin of control"), including "zones of uncertainty" (ability of deviation during the calculation of exact aircraft coordinates, with periodical prediction of terminal state implementation) is providing;

– virtual curvilinear glide paths of landing within the boundary trajectories are being calculated and analyzed on the basis of total received data (trajectories that require the least resources and aircraft capacities, time and distance for the stage from the moment of the start of the flight level to the stop of the aircraft in the runway).

Besides, this method includes calculation algorithms of the landing trajectory performance optimality with maximal usage of the aerodynamic

components of the aircraft control system and minimal use of engines trust.

The analyzing and calculating process of virtual curvilinear glide path of landing is taking place in real time scale (with constant recalculation for every moment of time that takes as initial), with taking into account of all possible changes during the flight process [12].

4. Method of aircraft landing by curvilinear glide paths within the boundary trajectories

An aircraft landing by curvilinear glide paths is the method that could provide fluent aircraft descending from flight level with constant angle for landing on the runway. It intends for reducing expenditure of fuel and level of noises by the side of other traditional landing methods.

An aircraft landing by curvilinear glide paths within the boundary trajectories begins from the highest point of the descending start, in other words, on the cruise flight altitude and it allows aircraft to support own individual optimal vertical profile until the runway threshold.

The essence of method is in the accounting of fully controllable state areas of aircraft what are constructed with taking into account "uncertainty zones", nonlinearities in aircraft flight characteristics, possible changes into environmental state, optimality criteria for aircraft landing, all functional and aerodynamic aircraft abilities for virtual curvilinear glide path construction, which means a certain trajectory of the aircraft to reduce the time and distance necessary for the stage from the beginning of the descent from the flight level to the runway threshold. This will allow to assure guaranteed safety level of aircraft landing, to expand the condition field in which the method can function, to rise the aviation vehicle's use and crew's effectiveness, as well as to reduce harmful influence to the environment (as a result of emission and engine noises level reducing) and to assure fuel (material resources) economy.

This method is realized in the following way.

On a specific aircraft that is in flight at the level and approaches to the airport, from the moment of landing approach start in real time scale, exact aircraft situation coordinates are constantly determined (with discretization Δt) and considered possible deviations and uncertainties of its situation, that have been conditioned by current situation estimation errors, inadequateness of mathematical model, environmental influence, navigational deviations, etc. From the earth-based dispatch center an aircraft receives the exact information about the point of landing (information about territory, runway and environment), and from onboard systems it receives exact information about the status, characteristics and parameters of flight, weather conditions, physical and aerodynamic characteristics of concrete aircraft. Assessment and analysis of total received data are made and, correspondingly, fully controllable state areas of aircraft are calculated. These areas characterize an aircraft movement parameters changing capability during the one moment of time and allows characterizing nonlinearity of the aircraft's behavior and flight process in general. An example of calculated probable aircraft controllability area Q is shown in fig.1. Parameters of the aircraft's landing would be calculated thereafter, that are:

- coordinates of the initial point of descend;
- aircraft speed, angle of attack and flight-path angle from the initial point of descending to the terminal point with corresponding changes through the trajectory line of descend;
- coordinates of terminal point of the descend;
- necessary time for an aircraft descend;
- working parameters of the engines with taking into account maximal decreasing of its power;
- parameters of using of all aerodynamic components of the aircraft control system (elevator, ailerons, flaps, interceptors, etc).

Reducing of power of the engines allows decreasing of harmful influence on the environment (reducing of the emission, noises, vibrations and harmful atmospheric discharge near the airport), as well as to rise of the economical efficiency by the way of fuel economy and reducing of the engine wear. Using of all aerodynamic components of the aircraft control system will allow rising of the quality of control during the descend stage, regulating of the speed of the aircraft, to assuring of the worthy level of flight safety. Then, on the basis of the defined parameters, virtual curvilinear glide path of the aircraft landing generates (calculates and constructs).

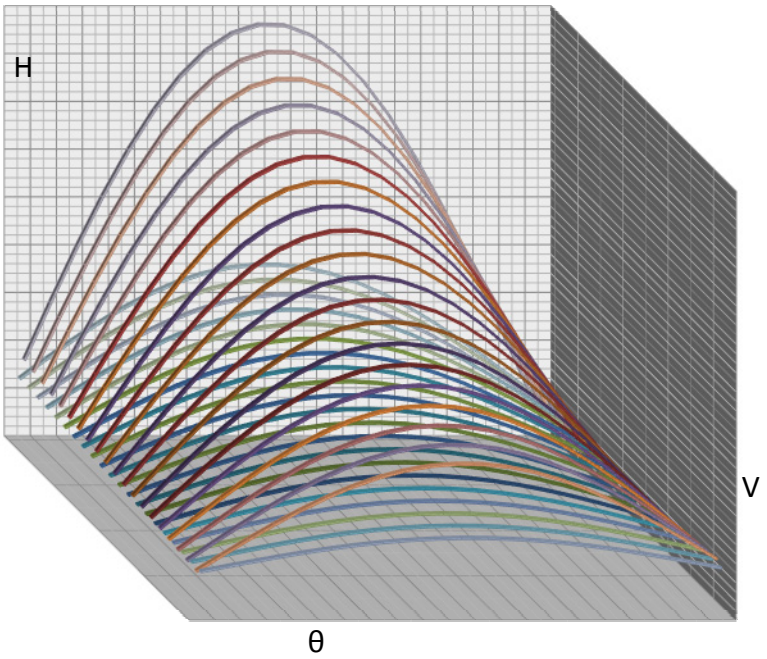


Fig. 1. The example of the projection of the fully controllable state area of aircraft $Q(H, V, L, \theta)$ on parameters (H, V, θ)

The aircraft virtual curvilinear glide path directs to reducing of time and distance, that are necessary for descending of an aircraft, assurance of maximal precision of the descending maneuver accomplishment by the way of virtual curvilinear glide path updating in each moment of time with prescribed discretization (generation of the glide path takes place in the real time scale), accomplishment of each plane individuality, flight conditions and other parameters. Generation of virtual landing curvilinear glide path takes place in following mathematical tool:

$$r_1 = \frac{V_1^2}{2 * g * (\cos(\theta_1) - n_{y1})} + \frac{V_2^2}{2 * g * (\cos(\theta_2) - n_{y1})},$$

$$r_2 = \frac{V_3^2}{2 * g * (n_{y2} - \cos(\theta_3))} + \frac{V_4^2}{2 * g * (n_{y2} - \cos(\theta_4))},$$

$$\Delta h_1 = -r_1 * (\cos(\theta_1) - \cos(\theta_2)),$$

$$\Delta h_2 = r_2 * (\cos(\theta_3) - \cos(\theta_4)),$$

$$\Delta H = -(\Delta h_1 + \Delta h_2),$$

where r_1 - radius of the first part of the landing curvilinear trajectory;

V_1 – aircraft speed at the beginning of the trail along the first part of trajectory;

V_2 – aircraft speed at the end of the trail along the first part of trajectory;

g – acceleration of gravity;

θ_1 – flight-path angle at the beginning of first part of trajectory;

θ_2 – flight-path angle at the end of first part of trajectory;

n_{y1} – overload along the whole trajectory;

Δh_1 – altitude drop during the descending maneuver at the first part of the trajectory;

θ_3 – flight-path angle at the beginning of the second part of trajectory;

θ_4 – flight-path angle at the end of the second part of trajectory;

r_2 – radius of the second part of the landing curvilinear trajectory;

V_3 – aircraft speed at the beginning of the trail along the second part of the trajectory;

V_4 – aircraft speed at the end of the trail along the second part of the trajectory;

Δh_2 – altitu dedrop during the descending maneuver at the second part of the trajectory;

L – distance;

ΔH – common altitude drop of the whole trajectory.

Assurance of the aircraft landing by virtual curvilinear glide path will allow additionally reducing the workload of pilots, air traffic control agencies, to discharge airports and approach of

aviation industry to transition from area navigation to free flights.

Moreover, during the generation of aircraft landing virtual curvilinear glide path mathematical probabilities and adaptive optimality criteria's are used. They are directed to assurance of landing border trajectory construction that is necessary for maximal reducing of time and distance essential for landing, assurance of minimal power of engines on the stage of landing. An illustration of construction of the landing virtual curvilinear glide path within the boundary trajectories is shown in fig.2.

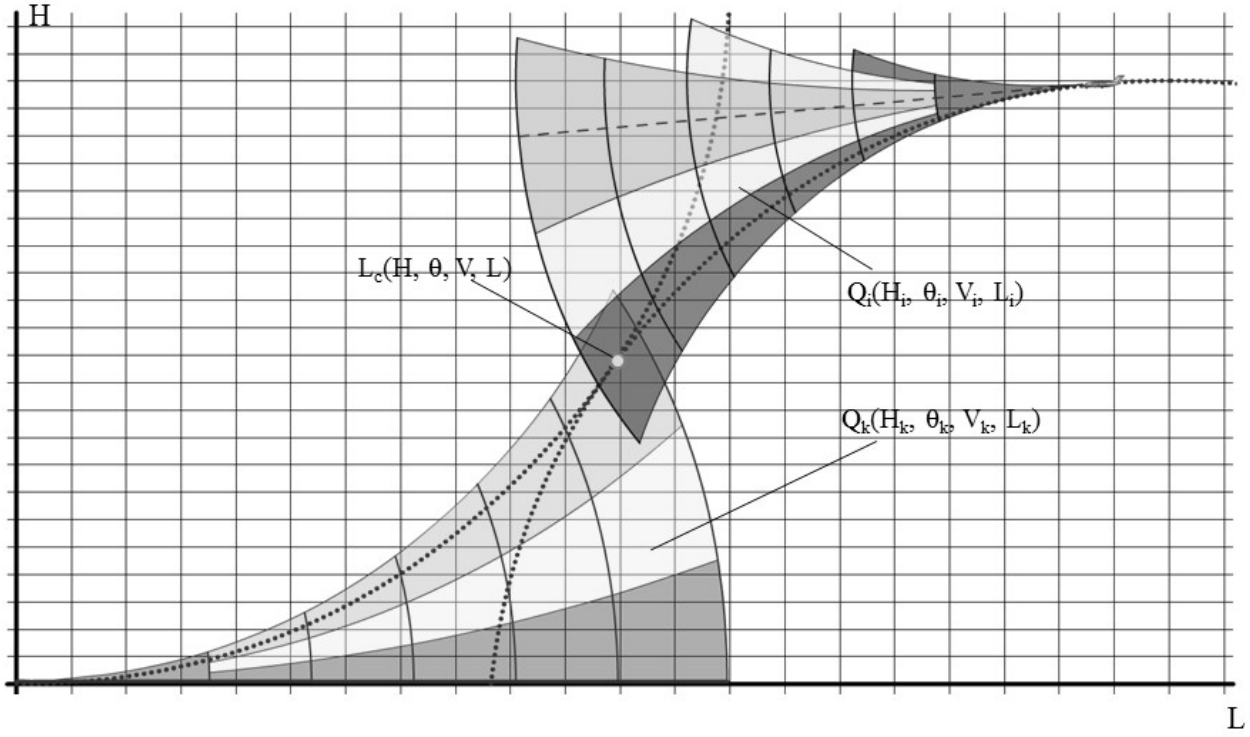


Fig. 2. The illustration of principle of construction of the landing virtual curvilinear glide path within the boundary trajectories (L_c – point of union of two trajectory parts; $Q_i(H_i, V_i, L_i, \theta_i)$ – area of possible aircraft movement trajectories at the first part of landing; $Q_k (H_k, V_k, L_k, \theta_k)$ – area of possible aircraft movement trajectories at the second part of landing)

During the method realization process after construction of landing glide path, test simulation of aircraft trajectory accomplishment takes place for assurance of appropriate safety level. An example of generated virtual landing glide path within the boundary trajectories of the concrete aircraft during the test simulation process is shown on fig.3.

According to the results of test simulation, formation of control commands to the aircraft systems and indication and signalization tools takes place. An example of indication of the probable aircraft movement on the stage of landing by the declared method is shown on fig.4. (square signs - modern standard of an aircraft landing approach by the glide path, round signs - an aircraft landing by curvilinear glide paths).

After the end of implementation of the method (after every landing of the aircraft) recording of all landing parameters and virtual curvilinear glide path to the storage database takes place for the simplification of method realization in case of repetition of flight conditions. Verification to the database takes place at the beginning of every realization of the method.

The method has a cyclic implementation, is performed on each aircraft during the landing procedure in real time.

The aircraft landing by curvilinear glide paths within the boundary trajectories proposes flexible uninterrupted descending flight trajectory during the landing approach, that assures basic ecological and economical profits, including reducing of fuel combustion, gaseous emissions and noise influence without any negative influence on the safety by virtue of:

1) minimal thrust of the engines, that has been set during the descending;

2) minimal atmospheric drag due to active using of aerodynamic components and capabilities of aircraft;

3) enhanced altitude of flight trajectory during the landing approach process.

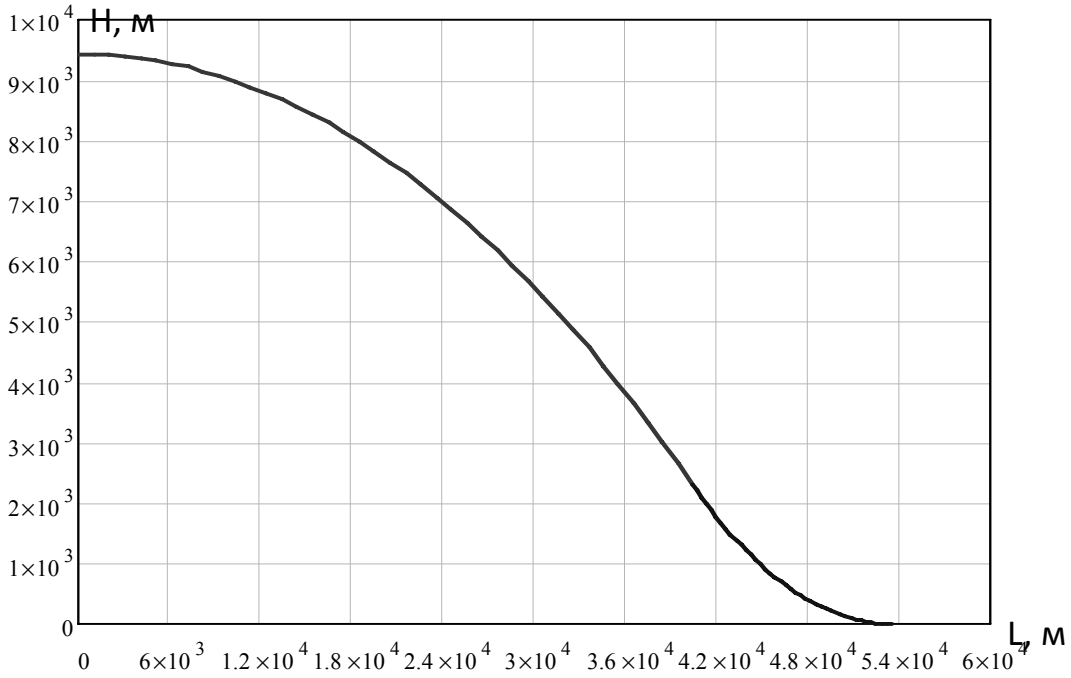


Fig. 3. Example of generated virtual landing glide path within the boundary trajectories of the concrete aircraft

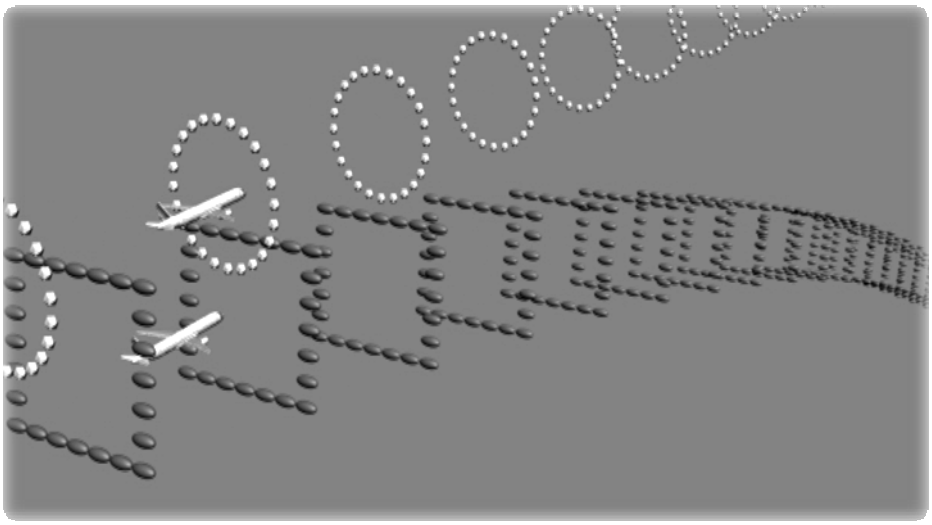


Fig. 4. Indication of probable aircraft movement on the stage of landing

5. Conclusions

The aircraft landing by curvilinear glide paths within the boundary trajectories could have essential profits in reducing of the level of noises, fuel consumption and harmful emissions.

The influence on the environment in current time is a serious problem for aviation in complex, so such factor should be considered during the designing of air space and procedures of instrument flights and, also, during the air traffic control.

Method, that has been proposed, is based on using of all aerodynamic and functional aircraft abilities for the control of lift force, speed and drag during the process of descending. Defined, that during the descending all the engines are kept in the

mode of "flight-idle". It tends to fuel economy, reducing the level of noises and harmful emissions at the atmosphere. Moreover, construction of the curvilinear glide paths allows reducing of total distance that is an indispensable condition for the aircraft landing from descending from the flight level to the runway threshold from 200 km to around 70 km that reduces time necessary for landing. It would essentially reduce the intensiveness of the air traffic in the airport zones.

It is predicted, that method of the aircraft landing by curvilinear glide paths would allow enhancing of the acceptance rate of the airports by 30-40%.

References

[1] Pavlov V.V., Skripets A.V. (2000), *Ergonomicheskie voprosy sozdaniya i ekspluatatsii aviatsionnyih elektrifitsirovannyih i pilotazhno-navigatsionnyih kompleksov vozdushnyih sudov* [Ergonomic questions of electrified aeronautic and flight control complex creation and exploitation]. Kyiv, "KMUGA" Publ., 460 p. (In Russian)

[2] Rogozhyin V.O., Sineglazov V.M., Filyaschkin M.K. (2005), *Pilotazhno-navigatsiyni kompleksy povitryanyh sudden: Pidruchnyik* [Flight control complexes of airborne vehicles: Handbook] – Kyiv: "NAU" Publ., – 502 p. (In Ukrainian)

[3] *The ICAO circulars on ergonomics and human factors* (№. 1-12) (2000), – "ICAO".

[4] Teryaev E.D., Petrin K.V. (2009), *Development of the concept of flexible trajectories in the backs of the terminal control moving objects*. Bulletin of the Institute of Mechanical Engineering RAS – Moscow. – pp. 18-23.

[5] Petrov B.N., Portnov-Sokolov Yu.P., Andrienko A.Ya., Ivanov V.P. (1983), *Onboard terminal management system: Principles and elements of the theory* – Moscow: "Mashinostroenie" Publ., – 542 p.

[6] Bek V.V., Vishnyakov Yu.S., Mahlin A.R. (1989) *Integrated systems of the terminal control* – Moscow: "Nauka" Publ., – 254 p.

[7] A.A. Zhevnin, K.S. Kolesnikov (1985), *Synthesis of terminal control algorithms based on the concept of inverse problems of dynamics.* Bulletin of the Academy of Sciences of the USSR. "Tehn. Cybernetics", issue no. 4, – pp. 180-188.

[8] Mhitaryan A.M., Laznyuk P.S., Maksimov V.S. and other (1978) *Aircraft Flight Dynamics*. – Moscow, "Mashinostroenie", 424 p.

[9] *Continuous descent approach*. Wikipedia the free encyclopedia – available at: https://en.wikipedia.org/wiki/ Continuous _descent_ approach.

[10] *International civil Aviation Vocabulary Doc 9713* (2007), - issue no. 3., Montreal, ICAO. – 816p.

[11] *Continuous Descent Operation (CDO) Doc ICAO 9331* – "Erwin Lassooij PBN program office, ICAO/International civil aviation organization" Publ., – available at: http://www.icao.int/icaonet/.

[12] Pavlova S., Volkov O. (2017), *System of guaranteed resolution of dynamic conflicts of aircrafts in real time.* Proceedings of the National Aviation University: Scientific journal: scientific article. Kyiv, N 1. pp. 29-35.

С.В. Павлова[1], Д.О. Волошенюк[2]

Метод посадки літаків за криволінійними глісадами в межах граничних траєкторій

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]psv@nau.edu.ua; [2]p-h-o-e-n-i-x@ukr.net

Мета:Робота присвячена питанню підвищення безпеки польотів у цивільній авіації шляхом створення і впровадження нової системи посадки літаків за криволінійними глісадами в межах граничних траєкторій. Запропоновано метод спрямований на підвищення безпеки, екологічності та економічності посадки літаків із підтримуванням свого індивідуального, оптимального, вертикального профілю зниження з ешелону польоту до початку злітно-посадкової смуги. **Методи дослідження:** Пропонується метод посадки, заснований на генерації (розрахунку і побудові) віртуальних криволінійних глісад посадкового зниження, в межах граничних траєкторій, з урахуванням «областей повністю керованого стану» літаків. **Результати:** Новий метод посадки літака, що має значні вигоди в зменшенні рівня шуму, витрат палива і шкідливих викидів. **Обговорення:** Суть методу полягає в розрахунку та використанні областей повністю керованого стану, що враховують нелінійності у характеристиках літака, можливі зміни у стані навколишнього середовища, критерії оптимальності виконання посадкового зниження літака, всі функціональні та

аеродинамічні можливості літака, для побудові віртуальної криволінійної глісади, під якою розуміється деяка траєкторія руху літака, що може бути суттєво викривлена на межі його можливостей, для зменшення часу і відстані необхідних для етапу від моменту початку зниження з ешелону польоту до початку злітно-посадкової смуги.

Ключові слова: гранична траєкторія; криволінійна глісада; літак; метод посадки; повітряний рух.

С.В. Павлова[1], Д.А. Волошенюк[2]

Метод посадки самолетов по криволинейным глиссадам в пределах граничных траекторий

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]psv@nau.edu.ua; [2]p-h-o-e-n-i-x@ukr.net

Цель: Работа посвящена вопросу повышения безопасности полетов в гражданской авиации путем создания и внедрения новой системы посадки самолетов по криволинейным глиссадам в пределах граничных траекторий. Предложен метод направленный на повышение безопасности, экологичности и экономичности посадки самолетов с поддержанием своего индивидуального, оптимального, вертикального профиля снижения с эшелона полета до начала взлетно-посадочной полосы. **Методы исследования:** Предлагается метод посадки, основанный на генерации (расчет и построение) виртуальных криволинейных глиссад посадочного снижения, в пределах граничных траекторий, с учетом «областей полностью управляемого состояния» самолетов. **Результаты:** Новый метод посадки самолета, который имеет значительные выгоды в уменьшении уровня шума, расхода топлива и вредных выбросов. **Обсуждение:** Суть метода заключается в расчете и использовании областей полностью управляемого состояния самолета, учитывающих нелинейности в характеристиках самолета, возможные изменения в состоянии окружающей среды, критерии оптимальности выполнения посадочного снижения самолета, все функциональные и аэродинамические возможности самолета, для построении виртуальной криволинейной глиссады, под которой понимается некоторая траектория движения самолета, которая может быть существенно искажена на грани его возможностей, для уменьшения времени и расстояния необходимых для этапа с момента начала снижения с эшелона полета до начала взлетно-посадочной полосы.

Ключевые слова: воздушное движение; криволинейная глиссада; метод посадки; предельная траектория; самолет.

Pavlova Svitlana (1966). Doctor of Engineering. Professor.
Head of the Department of Avionics, National Aviation University.
Education: Kyiv Civil Engineering Institute, Kyiv, Ukraine (1988).
Research area: analysis and synthesis of nonlinear ergatic systems, critical technology, nonlinear dynamics.
Publications: 200
E-mail: psv@nau.edu.ua

Dmytro Voloshenyuk (1990). Post-graduate Student.
Lead Engineer, Department of Avionics, National Aviation University.
Education: National Aviation University, Kyiv, Ukraine (2013).
Research area: flight dynamics, intelligent control of dynamic objects.
Publications: 75
E-mail: p-h-o-e-n-i-x@ukr.net

UDC 629.3.025.2(045)
DOI: 10.18372/2306-1472.73.12170

Olha Sushchenko

SIMULATION OF PRECISION ATTITUDE AND HEADING REFERENCE SYSTEM PERTURBED BY ENVIRONMENTAL DISTURBANCES

National Aviation University
Kosmonavta Komarova Avenue 1, 03680, Kyiv, Ukraine
E-mail: sushoa@ukr.net

Abstract

Purpose: *The paper focuses on problems of simulation of perturbed robust precision attitude and heading reference systems, which can be applied in navigation of marine vehicles. The main goal is to create the mathematical model adapted to simulation of the perturbed system and models of the environmental disturbances.* ***Methods:*** *To solve the given problem the methods of the robust control system theory, filtration theory and probability theory are used.* ***Results:*** *The model of the perturbed attitude and heading reference system created by means of Simulink is given. The expression for the disturbance moment is proposed. Analysis of possible environmental disturbances for a system of the considered type has been done. Models of environmental disturbances based on the filtration theory are obtained. Comparison of two approaches to development of models of environmental disturbances is carried out.* ***Conclusions:*** *The results of simulation of the precision attitude and heading reference system taking into consideration environmental disturbances are represented. Obtained results can be useful for design of precision navigation systems of the moving vehicles.*

Keywords*:* attitude and heading reference system; environmental disturbances; perturbed system; robust systems; simulation.

1. Introduction

Now processes attending operation of the vehicles are sufficiently complicated. To provide the high accuracy of navigation information measurements it is necessary to use the high precision attitude and heading reference systems. Synthesis of such systems is implemented in conditions of uncertainties caused by both inaccuracies of the mathematical description of the real system and influence of the internal and external disturbances. Mainly, the systems designed for operation at the marine vehicles are subjected to influence of the disturbances caused by the sea irregular waves. The modern approach to these systems design is creation of the robust systems able to operate in conditions of both the parametrical structured and the external coordinate disturbances. Simulation of the system perturbed by environmental disturbances is the important stage of the robust gimballed precision attitude and heading reference systems.

2. Analysis of the latest researches and publications

This paper completes the series of papers dealt with development of the precision attitude and heading reference systems [1-3]. The papers [1, 2] describe basic features of creation of the mathematical models of such systems. The mathematical descriptions of the high-precision attitude and heading reference systems with biaxial and triaxial platforms are given in these papers. Features of robust design of such systems are analyzed in the paper [3]. Both robust parametrical optimization and robust structural synthesis of the precision attitude and heading reference system are given in this paper. Features of stochastic precision attitude and heading reference system are given in the paper [4]. The general achievements of gimballed stabilization systems design and gimballed precision navigation systems are represented in papers [5, 6]. Features of simulation of robust systems by means of MatLab are described in the textbook [7].

3. Research tasks

The main goal of the research is to represent features of environmental disturbances typical for application of precision attitude and heading reference system, create mathematical models of these disturbances and carry out simulation of

attitude and heading reference system in complex conditions of real operation.

4. Mathematical model of stochastic precision attitude and heading reference system

The studied gimballed system for the marine vehicle navigation represents the indicated or indirect inertially stabilized platform by its principle of operation. In such systems the gyro devices do not implement direct stabilization of some object, for example, the platform but represent indicator units, which control by servo-drive providing an object's stabilization [8].

In such systems compensation of disturbances that act on the stabilized platform are implemented due to moments created the actuators mounted at the gimbals axes. Control by the stabilization contours is carried out by the gyro devices signals which are corrected by signals of accelerometers and additional devices using the complex control laws.

In the studied system the control loops can be divided into navigation and stabilization ones that allows to carry out their simulation independently [3]. In this case, division of control functions takes place: the stabilization engines provide agreement of the stabilization object position with the position of the gyro device and the torques sensors implement correction of the rotor motion by the computing device based on information of accelerometers and data about the Earth and object motion [8].

If consider influence of rolling and pitching small, it is possible to neglect by the mutual influence of the gimbals. In this case, stabilization of the navigation devices by one channel can be researched only. This simplifies essentially simulation of the system.

If the dynamically tuned gyro is used as the sensor of the system, it is necessary to take into consideration that it operates in the indicated mode. Such mode does not require the high stability of the transfer coefficient but its sensitivity is very important. It means that the large slope of the statistic characteristic curve is close to zero and the low threshold of sensitivity must be provided. These factors lead to small angles of the rotor turns and correspondingly to the small operation range [8]. Therefore to improve stabilization accuracy it is necessary to use units which sufficiently increase the stabilization contour gain. Moreover, taking into consideration the operation principle of the dynamically tuned gyro it is necessary to use the selective filter. The structural scheme of the selective filter is given in Fig. 1.

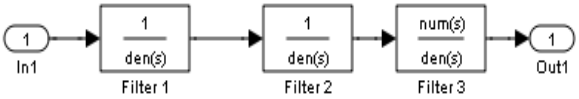


Fig. 1. Selective filter of the attitude and heading reference system (Simulink model)

For the studied system the basic disturbance moment acting at the input of the platform can be described by the expressions

$$M_{db1} = M_0 + M_{fr}\text{sign}(\sin \omega t) + M_s \sin \omega t \,, \quad (1)$$

$$M_{db2} = M_0 + M_{fr}\text{sign}(\sin \omega t) + M_{irr} \quad (2)$$

here M_0 is the constant disturbance moment caused by the construction defects; M_{fr} is the moment of dry friction; M_s is the amplitude of the moment due to sea regularities; ω is the frequency of the sea regularities; M_{irr} is the moment caused by the irregular sea.

Simulink model of disturbances (1), (2) are given in Fig. 2.

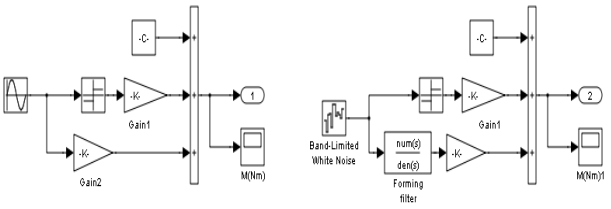


Fig. 2. Simulink model of determinate and random disturbance moments

Simulink model of perturbed precision attitude and heading reference system is shown in Fig. 3.

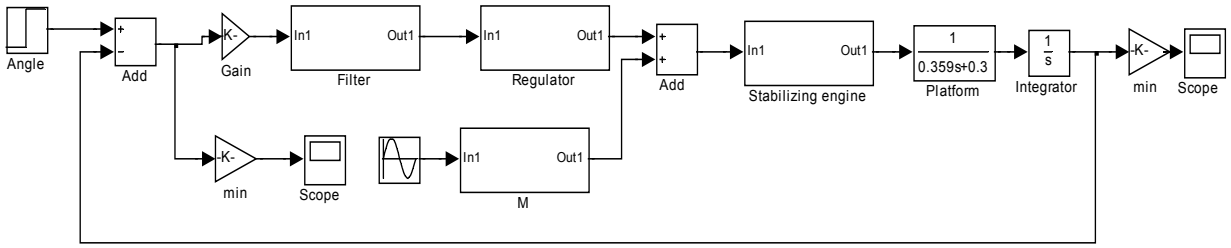


Fig. 3. Simulink model of the perturbed system

5. Characteristic of environmental disturbances

It should be noted that marine precision attitude and heading reference systems are subjected to influence of sea waves, wind and flows. The most important disturbances such as wind and sea waves are interconnected and correlated. Sea waves arise as result of the wind rippling by the speed and direction on the sea surface. The free waves, which are spread by inertia, are observed out zone of wind action or after its stopping.

Characteristics of both regular and irregular waves are given in [9]. Regular waves represent harmonic waves, which are spread on the sea surface. In the general case, the irregular sea is three-dimensional. The two-dimensional correlation function, which defines correlation between wave ordinates in different points of the sea at some time interval, can be accepted as the first approximation of the three-dimensional random process.

To solve some navigation problems of marine vehicles is possible using a simplified approach, for which the sea irregular waves are believed to be two-dimensional. The ordinate of the wave profile $\zeta(t)$ is considered to be a function of two variables such as the linear coordinate of the sea surface point and the time interval. The correlation function of wave profile ordinate at the given sea point $K_\zeta(t)$ or appropriate spectral density $S_\zeta(\omega)$ are characteristics of the function $\zeta(t)$ [10].

In accordance with theoretical and experimental researches represented in [11], irregularities of the sea surface can be considered as a time-invariant ergodic process with the zero mathematical expectation as the first approximation. This process is distributed in accordance with the normal distribution law. Waves are believed to spread in the same direction. It means that the spectral density depends on frequency only.

There are some known expressions of the spectral density, which can be used for mathematical description of irregular sea waves, for example, Neumann and Derbyshire filters. It should be noted that low frequencies are not taken into consideration in these filters. The bandwidth of the marine vehicles lies in the region of low frequencies at the same time.

Therefore it is convenient to use Rachmanin and Firsov filters [11]. In this case, the correlation function of wave ordinates can be represented by the formula

$$K(\tau) = D_r e^{-\mu t} \cos \lambda t , \qquad (3)$$

here D_r is the variance of wave ordinates; μ is coefficient of the correlation function, which characterizes a level of sea irregularity; λ is the resonance frequency of the irregular sea spectrum. This frequency for rolling and pitching is equal to frequencies of the object characteristic oscillations.

In accordance with (2) the spectral density can be determined in the following way [11]

$$S_r(\omega) = \frac{2D_r\mu}{\pi} \frac{\omega^2 + \mu^2 + \lambda^2}{(\mu^2 + \lambda^2 + \omega^2)^2 - 4\lambda^2\omega^2} . \qquad (3)$$

In some cases, it is convenient to represent the correlation function of the sea irregular waves in the following form [11]

$$K(\tau) = D_r e^{-\mu t}\left(\cos \lambda t + \frac{\mu}{\lambda} \sin \lambda \tau \right). \qquad (4)$$

Then the expression for spectral density determination becomes

$$S_r(\omega) = \frac{2D_r\mu}{\pi} \frac{\mu^2 + \lambda^2}{(\mu^2 + \lambda^2 + \omega^2)^2 - 4\lambda^2\omega^2} . \qquad (5)$$

This dependence corresponds to real irregular sea in the region of spectrum maximum amplitudes

on contrary to regions of the low and high frequencies. The correlation function (4) for $\mu \to 0$ becomes cosine function and the spectral density – δ-function at the frequency λ. It should be noted that λ characterizes frequency of the periodic process similar to the random process $\zeta(t)$. The parameter μ characterizes level of the function $\zeta(t)$ irregularities. Its kind depends on ratio between μ and λ. If the ratio μ/λ is small, the function $\zeta(t)$ is similar to the sine function with the slowly changed amplitudes and phase. If the ratio μ/λ increases, the periodicity decreases.

For the correlation function [11]

$$K(\tau) = D_r \sqrt{1+\left(\frac{\mu}{\lambda}\right)^2} e^{-\mu t}\left(\cos\lambda t + \frac{\mu}{\lambda}\operatorname{arctg}\frac{\mu}{\lambda}\right), \quad (6)$$

the expression for determination of the spectral density becomes

$$S_r(\omega) = \frac{2D_r\mu\omega^2}{\omega^4 + 2(\mu^2-\lambda^2)\omega^2 + (\mu^2+\lambda^2)^2}. \quad (7)$$

To determine the spectral density of the wave ordinates described by (6), (7), it is necessary to determine the variance and parameters μ and λ based on data about intensiveness of the irregular sea. Usually the wave ordinates are believed to be distributed by the normal law.

In this case, amplitude values will be distributed by the Rayleigh law. As maximum values are realizations of a random variable, the function of probability distribution $P_\zeta(\zeta)$ depends on width of the spectrum defined by the formula [9]

$$\Delta = \sqrt{1-\frac{T_g}{T_n}}, \quad (8)$$

here $T_n = 2\pi\sqrt{m_\zeta^0 / m_\zeta^2}$ is time of transition through zero; $T_g = 2\pi\sqrt{m_\zeta^2 / m_\zeta^4}$ is average period between wave crests; m_ζ^0, m_ζ^2, m_ζ^4 are statistical moments of orders 0, 2, 4. If $T_g << T_n$ and width of the spectrum (8) tends to one ($\Delta \to 1$), a realization of the random process is characterized by sufficient quantity of maximums and minimums.

In this case, the spectrum is believed to be broadband and the distribution law – normal. If $T_g \approx T_n$, then $\Delta \approx 0$. It means that the multiple maximums and minimums are absent in the realization. The spectrum is believed to be narrow-band. In this case, amplitude values of wave heights are ordered in accordance with the Rayleigh law, which depends on the parameter $B = \sqrt{m_\zeta^0}$. In these conditions the following expression takes place [9]

$$p_\zeta(\zeta) = (\zeta / m_\zeta^0)\exp(-\zeta^2 / 2m_\zeta^0). \quad (9)$$

The variance of values distributed by the Rayleigh law (9) is defined by the formula

$$D_r = \frac{4-\pi}{2}B^2.$$

If a vehicle moves with some speed, the observed frequencies differ from the same frequencies in the immovable reference frame. The spectrum of the wave, which is observed from the vehicle, is called the imaginary wave spectrum.

5. Simulation of environmental disturbances

Simulation of environmental disturbances is the important stage of the precision attitude and heading reference system simulation. For this it is necessary to give the white noise at the input of the forming filter. There are different approaches for filter implementation.

To obtain the transfer function of the forming filter using the first approach, the Wiener filtration theory is used. Factorization of the expression for irregular sea spectral density can be represented as product of stable and unstable multipliers

$$S_\zeta(\omega) = \left|W_f(j\omega)\right|^2 S_w(\omega),$$

here $S_w(\omega)$ is the white noise intensity.

To factorize the spectral density by the expression (3) it is convenient to represent it in the form

$$S_\zeta(\omega) = \frac{2D_r\mu}{\pi}\frac{\omega^2+\mu^2+\lambda^2}{\omega^4 + 2(\mu^2-\lambda^2)\omega^2 + (\mu^2+\lambda^2)^2}. \quad (10)$$

The factorization of the expression (10) can be carried out in the following way

$$S_\zeta(\omega)=\frac{2D_r\mu}{\pi}\frac{s^2+\mu^2+\lambda^2}{(j\omega)^4+2(\mu^2-\lambda^2)(j\omega)^2+(\mu^2+\lambda^2)^2}=$$
$$=\sqrt{\frac{2D_r\mu}{\pi}}\sqrt{\frac{2D_r\mu}{\pi}}\frac{(-j\omega+\sqrt{\mu^2+\lambda^2})(j\omega+\sqrt{\mu^2+\lambda^2})}{a_2^2(j\omega)^4+(2a_0a_2-a_1^2)(j\omega)^2+a_0^2}= \quad (11)$$
$$=\sqrt{\frac{2D_r\mu}{\pi}}\sqrt{\frac{2D_r\mu}{\pi}}\frac{(-j\omega+\sqrt{\mu^2+\lambda^2})(j\omega+\sqrt{\mu^2+\lambda^2})}{(a_2(j\omega)^2+a_1j\omega+a_0)(a_2(j\omega)^2-a_1j\omega+a_0)},$$

here

$a_2^2=1;\ 2a_0a_2-a_1^2=2(\mu^2-\lambda^2);\ a_0^2=(\mu^2+\lambda^2)^2,$

and $a_2=1;\ a_1=2\lambda;\ a_0=\mu^2+\lambda^2.$

Finally, expression for the forming filter transfer function, which can be obtained based on the relation (11) becomes

$$W_f(j\omega)=\sqrt{\frac{2D_r\mu}{\pi}}\frac{(j\omega+\sqrt{\mu^2+\lambda^2})}{(j\omega)^2+2\lambda j\omega+\mu^2+\lambda^2}. \quad (12)$$

It should be noted that for the studied system it is necessary to take into consideration disturbances by the angle slope. The spectral density of the angle slope α measured in direction of wave motion can be determined by the expression [11]

$$S_\alpha(\omega)=S'\zeta(\omega)=k^2S_\zeta(\omega)=\frac{\omega^2}{g^2}S_\zeta(\omega). \quad (13)$$

Using the expression (13), the forming filter transfer function (12) can be transformed to the form

$$W_f(j\omega)=\sqrt{\frac{2D_r\mu(\mu^2+\lambda^2)}{\pi}}\frac{j\omega}{g}\frac{(j\omega+\sqrt{\mu^2+\lambda^2})}{(j\omega)^2+2\lambda j\omega+\mu^2+\lambda^2}. \quad (14)$$

Carrying out the comparative analysis of expressions (3), (5) it is possible to write the transfer function of the forming filter based on the expression (5) in the following way

$$W_f(j\omega)=2\sqrt{\frac{D_r\mu(\mu^2+\lambda^2)}{\pi}}\frac{j\omega}{g}\frac{\sqrt{\mu^2+\lambda^2}}{(j\omega)^2+2\lambda j\omega+\mu^2+\lambda^2}. \quad (15)$$

The expressions (14), (15) take into consideration that variance of the angle slope is determined by the formula $D_\alpha=(\mu^2+\lambda^2)D_r$ [10].

The forming filter (15) in the state space can be represented in the following way

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}0 & 1\\ -\mu^2-\lambda^2 & -2\lambda\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}0\\ k\end{bmatrix}\omega;$$
$$y=\begin{bmatrix}0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}, \quad (16)$$

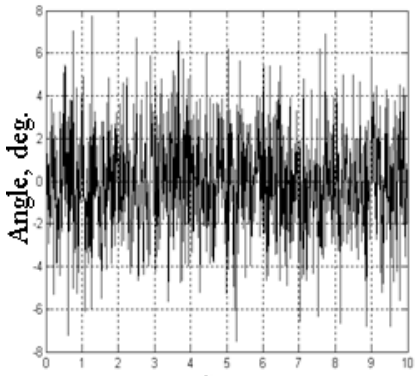
here $k=2\sqrt{\frac{D_r\mu}{\pi}}\frac{\mu^2+\lambda^2}{g}$.

Random processes with spectral densities (3), (5) can be simulated as result of passing random signal (the white noise) through forming filters (14), (15). Simulation results are given in Fig. 4.

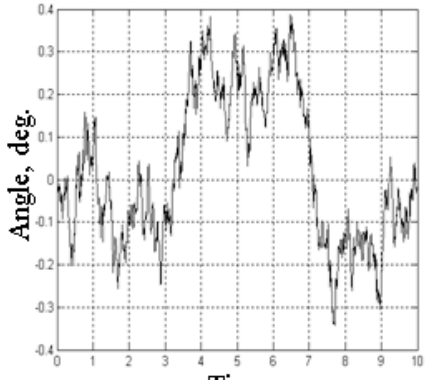
Simulation results show that random signal forming by means of the forming filter (14) allows to give the more rigid operations conditions.

It was obtained based on results of experimental researches that variance is related with the height of the wave of 3% provision by the relation [10]

$$D_r=D[\zeta(t)]=0{,}143(h_{3\%}/2)^2.$$



a



b

Fig. 4. Random signals: *a* – simulation based on the formula (14); *b* – simulation based on the formula (15)

The second approach foresees usage of the forming filter, which provides simulation of disturbances with the given spectral density as some approximation.

As in the previous case, the forming filter is determined using factorization. As a rule, the given structure is used. The most widespread structure is the filter of the second order [11]

$$W_f(j\omega) = \frac{2\xi\omega_n(j\omega)}{(j\omega)^2 + 2\xi\omega_n(j\omega) + \omega_n^2}. \quad (17)$$

For this filter

$$|W_f(j\omega)|^2 = \frac{4(\xi\omega_n\omega)^2}{(\omega_n^2 - \omega^2)^2 + 4(\xi\omega_n\omega)^2},$$

hence

$$\max_{\omega} S_\zeta = |W_f(j\omega)|^2 \, S_w.$$

Parameters of the filter can be chosen in the following way [11].

1. The intrinsic frequency of the filter is defined by the formula

$$\omega_n \approx \arg\max_{\omega} S_\zeta(\omega).$$

2. Damping coefficient $0 < \xi < 1$ is chosen to provide correspondence between variance of the filter output and variance of the given spectrum.

Similar to expression(16), the forming filter (17) in the state space can be represented in the form

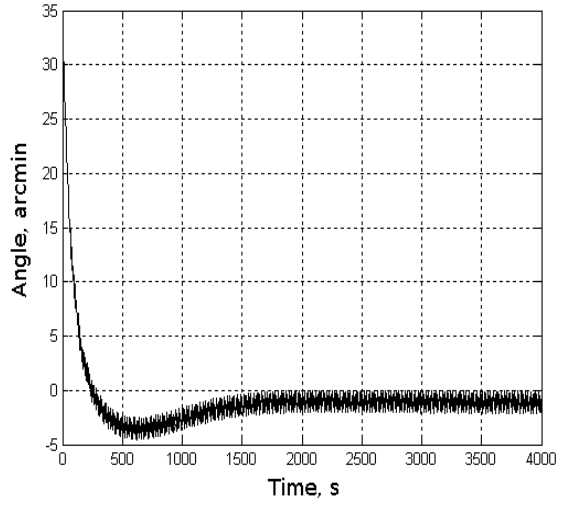
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\omega_n^2 & -2\xi\omega_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 2\xi\omega_n \end{bmatrix} \omega;$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}.$$

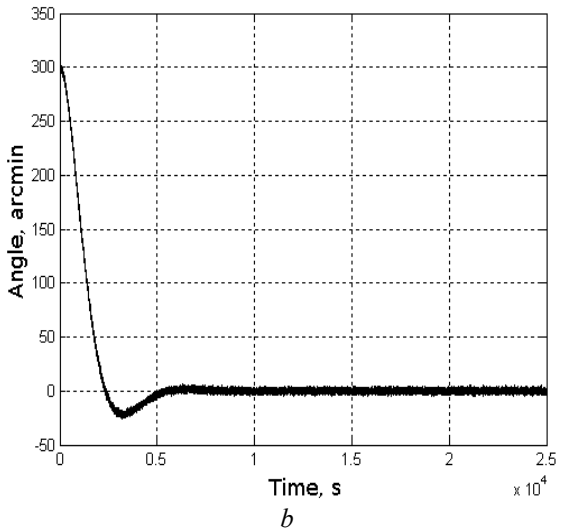
6. Simulation results

Expressions for determination of forming filters (3), (5) can be applied for forming disturbance moment (2).

Results of the perturbed system simulation are given in Fig. 5.



a



b

Fig. 5. Simulation of the perturbed system: transient processes by the pitch *(a)* and heading (*b*)

The represented results have been obtained for the case of the most complex operation conditions.

7. Conclusions

The mathematical model of the stabilizing system for the marine navigation complexes is created.

Characteristic of irregular sea waves is given. Analysis of mathematical descriptions of environmental disturbances is carried out. Expressions for determination of forming filters, which allow to simulate the perturbed motion of marine vehicles are obtained.

References

[1] Sushchenko O.A. (2017) Mathematical model of attitude and heading reference system with biaxial platform. *Proceedings of the National Aviation University*, no. 1, pp. 31–41. doi: 10.18372/2306-1472.71.11745.

[2] Sushchenko O.A. (2017) Mathematical model of triaxial multimode attitude and heading reference system. *Proceedings of the National Aviation University*, no. 2, pp. 31–41. doi: 10.18372/2306-1472.71.11745.

[3] Sushchenko O.A. (2017) Design of robust navigation laws and stabilization contours of precision attitude and heading reference system. *Proceedings of the National Aviation University*, no. 3, pp. 48–56. doi: 10.18372/2306-1472.72.11981.

[4] Tunik A.A., Sushchenko O. A. (2013) Usage of vector parametric optimization for robust stabilization of ground vehicles information-measuring devices. *Proceedings of the National Aviation University*, no. 4, pp. 23–32. doi:10.18372/2306-1472.57.5530.

[5] Hilkert J.M. (2008) Inertially stabilized platform technology. *IEEE Control Systems Magazine*, vol. 28, no. 1, pp. 26 – 46. doi:0.1109/MCS.2007.910256.

[6] Wang H.G., Williams T.G. (2008) Strategic inertial navigation systems. *IEEE Control Systems Magazine*, vol. 28, no. 1, pp. 65 – 85. doi: 10.1109/ MCS.2007.910206.

[7] Gu D.W, Petkov P., Konstantinov M. (2013) *Robust control design with MATLAB*. Berlin, Springer, 465 p.

[8] Aleksandrov A.D. (1979) *Yndykatornie hyroskopycheskye platformi* [Indicated gyroscopic platforms. Moscow, Nauka Publ., 239 p. (in Russian)

[9] Perez T. (2005) *Ship Motion Control*. London: Springer-Verlag, 300 p.

[10] Rivkin S.S. (1978) *Stabylyzatsyya yzmery-tel'nikh ustroystv na kachayushchemsya osnovanyy* [Stabilization of measuring devices on swinging base]. Moscow, Nauka, 239 p.

[11] Petrov Y.P. (1973) *Optymyzatsyya upravly-aemikh system, yspitivayushchykh vozdeystvye vetra morskoho volnenyya* [Optimization of controlled systems diturbed by the wind of sea irregular waves]. Saint-Petersburg, Sudostroenie, 214 p.

О.А. Сущенко

Моделювання високоточної системи визначення просторової орієнтації під дією збурень зовнішнього середовища

Національний авіаційний університет, пр. Космонавта Комарова, 1, Київ, Україна, 03680
E-mail: sushoa@ukr.net

Мета: У статті розглянуто проблеми моделювання робастних високоточних систем визначення просторової орієнтації, які можуть використовуватися у навігації морських рухомих об’єктів. Головною метою є створення математичної моделі, пристосованої для моделювання збуреної системи, та моделей збурень зовнішнього середовища. **Методи дослідження:** Для розв’язання даної проблеми було використано теорію робастних систем управління, теорію фільтрації та теорію ймовірностей. **Результати:** Представлено модель збуреної системи визначення просторової орієнтації, створеної за допомогою засобів Simulink. Запропоновано вираз для визначення моменту збурення. Виконано аналіз можливих збурень зовнішнього середовища для системи досліджуваного типу. Отримано моделі збурень зовнішнього середовища на основі теорії фільтрації. Виконано порівняння двох підходів до розробки моделей зовнішнього середовища. **Висновки:** Представлено результати моделювання високоточної системи визначення просторової орієнтації рухомих об’єктів з урахуванням збурень зовнішнього середовища. Отримані результати можуть бути корисними для проектування високоточних навігаційних систем рухомих об’єктів.

Ключові слова: збурена система; моделі збурень; моделювання; робастні системи; система визначення просторової орієнтації.

О.А. Сущенко

Моделирование высокоточной системы определения пространственной ориентации под действием возмущений внешней среды

Национальный авиационный университет, Космонавта Комарова, 1, Киев, Украина, 03680
E-mail: sushoa@ukr.net

Цель: В статье рассмотрены проблем моделирования робастных высокоточных систем определения пространственной ориентации, которые можно использовать в навигации морских подвижных объектов. Главной целью является создание математической модели, приспособленной к моделированию возмущенной системы. **Методы исследования:** Для решения данной проблемы были использованы теория робастных систем управления, теория фильтрации и теория вероятностей. **Результаты:** Представлена модель возмущенной системы определения пространственной ориентации, созданной при помощи средств Simulink. Предложено выражение для определения момента возмущения. Выполнен анализ возможных возмущений внешней среды для системы исследуемого типа. Получены модели возмущений внешней среды на основе теории фильтрации. Выполнено сравнение двух подходов к разработке моделей внешней среды. **Выводы:** Представлены результаты моделирования высокоточной системы определения пространственной ориентации подвижного объекта с учетом возмущений внешней среды. Полученные результаты могут быть полезными для проектирования высокоточных навигационных систем подвижных объектов.

Ключевые слова: возмущенная система; модели возмущений; моделирование; робастные системы; система определения пространственной ориентации.

Olha Sushchenko (1956). D. Sci., Associate Professor.
Aircraft Control Systems Department of the National Aviation University, Kyiv, Ukraine.
Education: Kyiv Polytechnic Institute, Kyiv, Ukraine (1980).
Research area: systems for stabilization of information and measuring devices.
Publications: 200.
E-mail: sushoa@ukr.net

DOI: 10.18372/2306-1472.73.12176

Mykhailo Matiychyk[1]
Natalya Suvorova[2]
Dmytro Tereshchenko[3]
Ievgen Plakhotniuk[4]
Kateryna Trachuk[5]

INFLUENCE OF ICING ON AIRCRAFT PERFORMANCE OF UNMANNED AERIAL VEHICLE M-10-2 "OKO"

National aviation university
Kosmonavta Komarova ave., 1, 03680, Kyiv, Ukraine
E-mails: [1]nvcba@nau.edu.ua; [2]suv_nat@bigmir.net; [3]tedmiv@gmail.com;
[4]iesp@i.ua; [5]kate.trachuk@ukr.net

Abstract

Purpose: *Carry out the analysis of lifting surface area of unmanned aerial aircraft. Icing appeared during test flights of unmanned aerial aircraft.* ***Methods:*** *Analysis of flight results in icing conditions using design flight characteristics of unmanned aerial vehicle and data from flight recorder was conducted. The largest ice formations observed on along whole length leading edge of the wing and whole length leading edge of winglets.* ***Results:*** *Under certain meteorological conditions ice deposits forms on parts of small unmanned aerial vehicle similar to how it is formed on a large-sized aircraft was found in practice. Ice formation distorted wing leading edge and front part and bottom and top wing curves. Analogically way tail unit was distorted by ice formations. In addition icing of front surface of telemetry and video antennas, and front part of airspeed sensor tube was found. Formation belongs to pike-shaped type was specified.* ***Discussion:*** *Icing of lifting surface area of aircraft during flight can cause undesirable consequences both in manned and unmanned aviation. Real test flights of unmanned aerial vehicles of SPCUA "Virazh" of National Aviation University in the winter period showed, that ignorance of icing problem could decrease flight safety level up to aviation accident. Fact of icing was discovered after unmanned aerial vehicle landing.*

Key words: aircraft performance; icing; lift surface; pitch; unmanned aerial vehicle; wing profile.

1. Introduction

It is known that icing of aircraft (AC) lift surfaces has a negative influence on aircraft performance and can lead to an aviation accident. Deposits of ice on the earth are well considered in the works [1, 2]. Ice deposition on surfaces is assisted by coincidence of meteorological and other factors, among which the most import are dimensions and drops concentration, AC speed of flight, and air temperature [3-5].

2. Problem statement

Primary source analysis shows that attention is usually given to "regular" AC of general aviation [6]. However, information about UAVs is almost absent and icing influence is not considered.

Practical test flights of UAVs in winter period executed by specialists of SPCUA "Virazh" of National Aviation University shown, that ignorance of problem consideration can decrease the flight safety level up to preconditions of aviation accident.

As example we will take day flights of UAV M-10-2 "Oko" under next meteorological conditions (MC): air temperature: from 0°C to -5°C; speed of surface wind – up to 4 m/s; wind speed at altitude: – up to 10 m/s; clouds bottom limit – 400 m [7].

Cruising speed of UAV on the route amounted 20 m/s; no precipitation. Before flight, during before flight tests there were no icing revealed. AC launch performed in automatic mode without shortcomings. Planned and achieved flight altitude – 600 m; maximum distance – around 15,5 km. All ground

and board systems operated in regular mode. The battery capacity installed in UAV was 16 Ah; its charge at the launch moment was 95 %.

3. Flight results

Above the mission area (15 km away from control station) UAV got into conditions, which led to icing. Ice formed at leading edge of wing and tail unit, frontal surfaces of video antennas and on pitot static tube (PST).

Icing fact was investigated after UAV landing. During flight recorded via telemetry, that at the altitude 600 m UAV stall started. Autopilot managed to level off UAV without operators assistance, however UAV lost altitude and descended at 400 m, but after leveling off returned to assigned altitude of flight and continued flight on planned route. After mission completed UAV returned to the launch position and performed parachute landing.

4. Solution

During study of consequences of UAV M-10-2 "Oko" icing scheme of ice deposits location on the surfaces was defined (Fig.1).

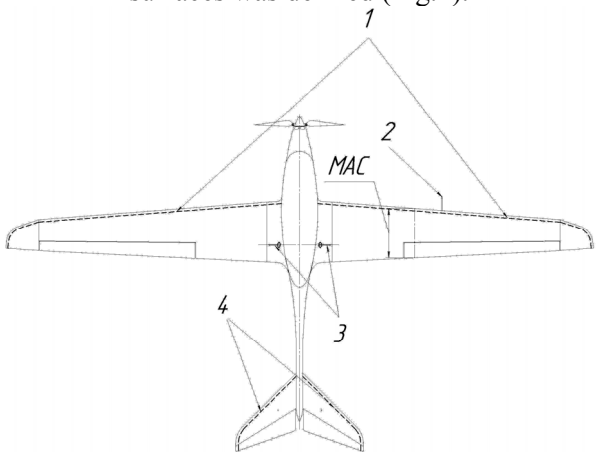


Fig. 1. Scheme of ice deposits location on the surfaces of unmanned aerial vehicle M-10-2 "Oko" (top view): *1*– on the wing leading edge; *2* – on the front part of the pitot static tube; *3*– on the front surfaces of the video antennas; *4*–on the leading edge of the tail unit; mean aerodynamic chord (MAC) – projections location of the MAC to the horizontal

The biggest ice formations observed on leading edge of the wing almost along all its length; ice formations also covered whole leading edge of winglets. Ice formations on wing were loose, without "gloss" signs. Formation binding is not strong, because during parachute landing part of them loosed of wing. Character and dimensions (mm) of wing leading edge icing are shown on Fig.2 (formations on top view) and on Fig.3 (formations on bottom view).

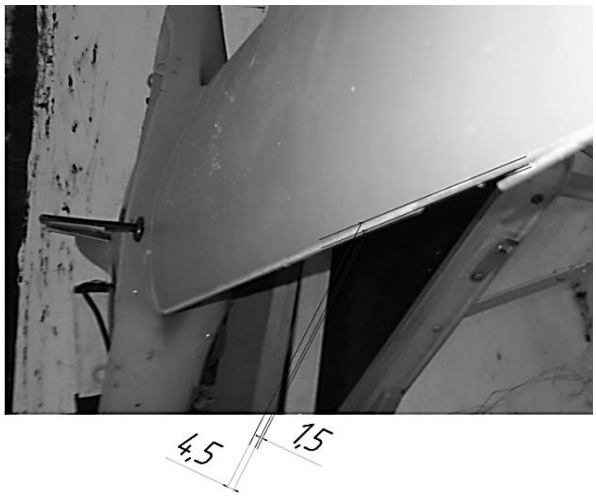


Fig. 2. Icing of the leading edge of the wing (top view)

Tail unit surfaces covered with ice had character similar to wing formation: formation width from top view – 2 mm, bottom view 3,5 mm.

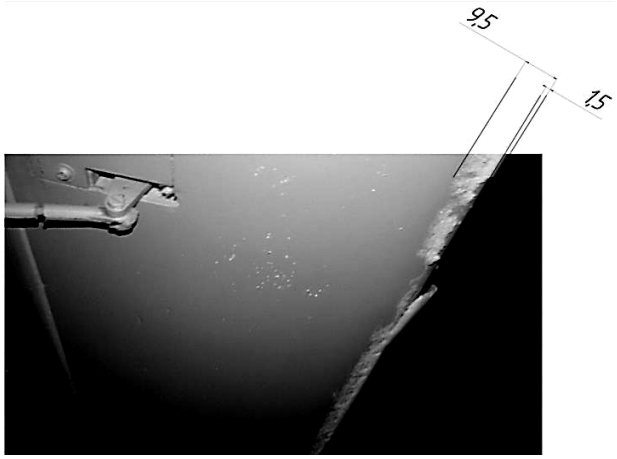


Fig. 3. Icing of wing leading edge (bottom view)

Scheme of distortion of original wing profile Wortmann FX61-184 was developed with ice deposits of specified dimensions (Fig.4 *a* and Fig.4 *b*).

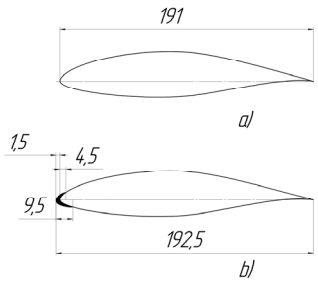


Fig. 4. Scheme of distortion and changes of geometrical dimensions of original wing profile Wortmann FX61-184: *a*) original profile contour along mean aerodynamic chord*; b*) distorted profile contour along mean aerodynamic chord

Specified that formation is related to icing type "pike-shape formation", which is characterized with opacity, dimness and looseness; ice contains a significant amount of small drops and ice crystals or their mix. Such type of ice is formed on relatively narrow section of profile [8, 9].

Icing of the PST inlet had gloss surface of grey color; formations closed measuring hole of dynamic pressure, and static pressure holes continued to be non-iced and passable. Formation binding with metal of PST is strong. Character and dimensions (mm) of PST icing is shown on Fig. 5.

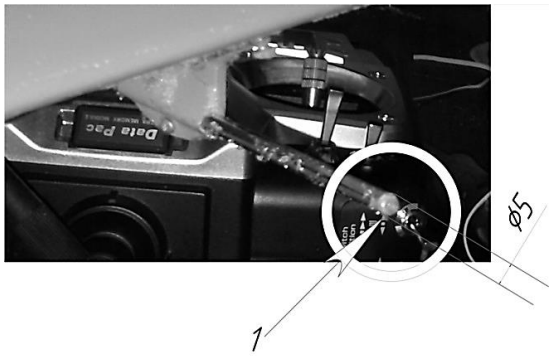


Fig. 5. Character and dimensions (mm) of PST icing:
1– icing of tube cap (inlet) of PST

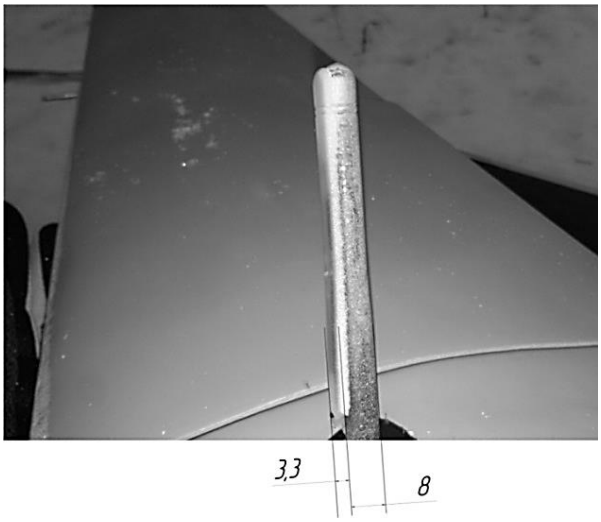


Fig. 6. Icing of the video channel antennas

Antennas have been iced from the front side; formation surface has been solid on the top and gloss, and under the solid top there was a loose layer. Character and dimensions (mm) of video channel antennas icing is shown on Fig. 6.

5. Results analysis

Analysis of flight results in conditions of icing conducted using the design aircraft performance of the UAV and data obtained from mode of flight recorder (MFR). The hypothesis was that UAV in icing conditions successfully performs flight mission, but that achieved by significant excess of its energy consumption.

Input data for calculation:

1. Autopilot controlled cruising speed of flight of UAV– 20 m/s;
2. Maximum take-off weight (MTOW) – 5 kg (50N);
3. Wing area of UAV, S_w – 0,38 m^2;
4. Air density (for ISA) – 1,225 kg/m^3;
5. $C_{y_{m.b.i}}$ – lift force coefficient for cruising mode before icing;
6. $C_{y_{m.a..i}}$ – lift force coefficient for cruising mode after icing;
7. Wing setting angle of UAV +0,5 degrees.

The basis of calculation was estimation of increment of drag force as the result of icing.

It is known, that at the cruising mode of operation next condition must be fulfilled:

$$MTOW = Y$$

During calculation known formulas were applied for lift and drag force estimation, also for lift force coefficient:

$$Y = \frac{\rho V^2}{2} C_y S_w,$$

$$X = \frac{\rho V^2}{2} C_x S_w$$

Drag force coefficient was determined from next relation:

$$C_y = \frac{Y}{\frac{\rho V^2}{2} S_w}$$

During results generation drag force before and after icing used a combined data array, taken from MFR and from UAV aerodynamic characteristics, obtained on design stage. Calculation algorithm was next.

Using data of MFR and input data: cruising speed, MTOW and air density defined in-flight value of $C_{y_{m.b.i}}$.

$$C_{y_{m.b.i.calc.}} = 50/(1,225 \cdot 324/2) \cdot 0,38 =$$
$$= 50/198,45 \cdot 0,38 = 50/75,4 = 0,66$$

From dependence $C_y f(\alpha)$ for UAV M-10-2 «Oko» (wing profile Wortmann FX61-184) was found respective values of angle of attack and drag force coefficient (Fig. 7).

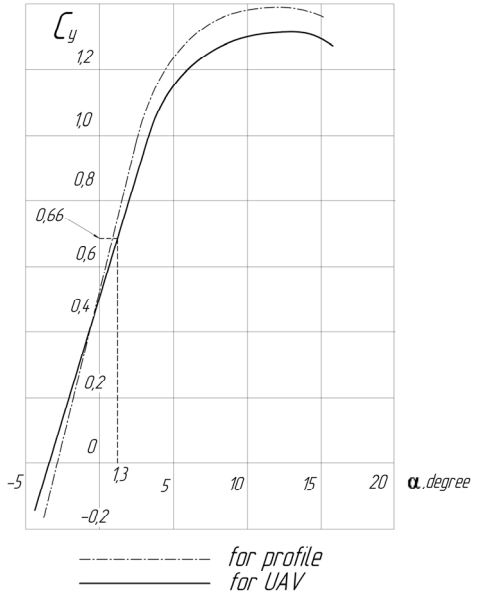


Fig. 7. Dependence of lift coefficient of UAV on an angle of attack

Upon respective value of angle of attack from polar curve defined coefficient $C_{x_{m.b.i.}}$ for UAV.

Respectively calculated value of drag force before icing was:

$$X_{b.i} = \frac{\rho V^2}{2} C_x S_w = \frac{1,225 \cdot 20^2}{2} \cdot 0,06 \cdot 0,38 = 5,58N$$

Calculation results are presented in Table 1.

Table 1

Calculation results of drag force on UAV icing

№	Parameter	Value
1	$C_{y_{m.b.i.calc.}}$	0,66
2	Angle of attack α, *degree*	$1,3^0$
3	$C_{Xpc.}$ *(from UAV polar curve)*	0,06
4	Drag force value $X_{b.i.}$	5,58*N*
5	Current aerodynamic quality, K	11 units

Similarly calculated drag force of UAV after icing. The difference was that current value of angle of attack at cruising mode we take from MFR through current value of pitch angle. Calculated value of drag force after icing equal:

$$X_{a.i} = \frac{\rho V^2}{2} C_x S_w = \frac{1,225 \cdot 20^2}{2} \cdot 0,095 \cdot 0,38 = 8,84N$$

Calculation results are presented in Table 2.

Table 2

Calculation results of drag force after UAV icing

№	Parameter	Value
1	$C_{y_{m.a.i.calc}}$	0,74
2	Angle of attack α, *degree*	$2,4^0$
3	C_{Xa} *(polar curve of UAV)*	0,095
4	Drag force value $X_{calc.}$	8,84*N*
5	Current aerodynamic quality, K	7,8 units

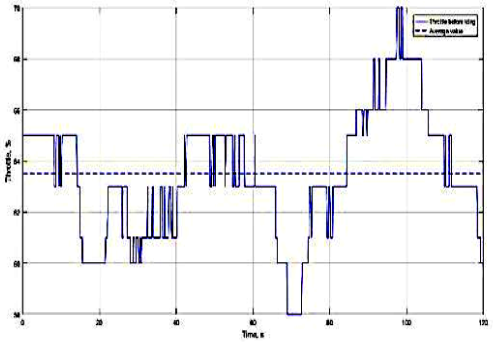
Upon the data from Table 1 and Table 2 it is apparent that before icing UAV had aerodynamic quality about 11 units. Wing surfaces, antennas etc. were not distorted by ice, so UAV performance was in design range. The aircraft was influenced by aerodynamic drag force 5,58*N* at flight speed 20 m/s.

After icing UAV automatics independently taken into account deterioration of its aerodynamics from icing, to maintain cruising speed at level 20 m/s, that lead to setting new angle of attack, current wing angle of attack $2,4^0$, so as consequence, to increase of coefficient of aerodynamic drag $C_{X_{a.}}$ to value 0,095. Respectively drag force increased to value 8,84*N*, that in comparison to drag force before icing is 40 % more. The result is correlated with the conclusions of the authors in the work [10].

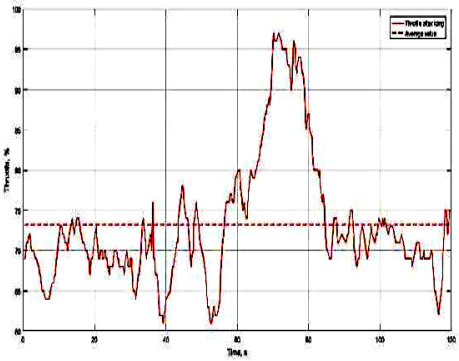
For the actual proof of danger presence from icing of air frame surface of UAV were analyzed flight data, obtained from MFR at two segments during flight. First segment was taken during steady horizontal flight till the icing moment, second segment after icing.

Data comparison shows, that for maintaining given flight parameters autopilot had to increase thrust level on an average 10 % (Fig. 8 a, 8 b).

Average value of current from battery increased respectively from 25,5A to 35A (Fig. 9 a, 9 b).

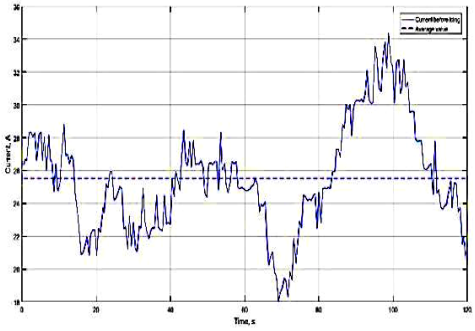


a

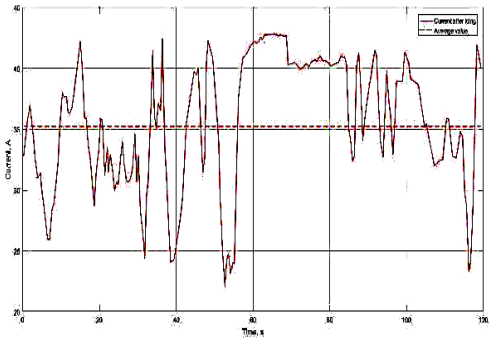


b

Fig.8. Dependence of engine throttle level on time; *a*– before icing; *b*– after icing



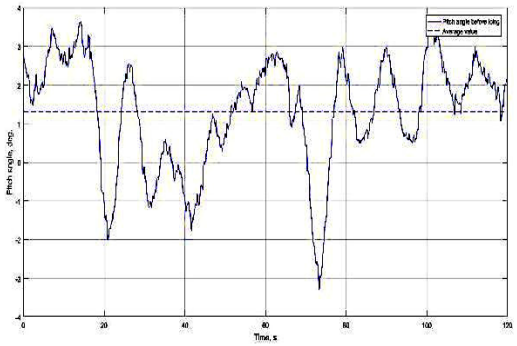
a



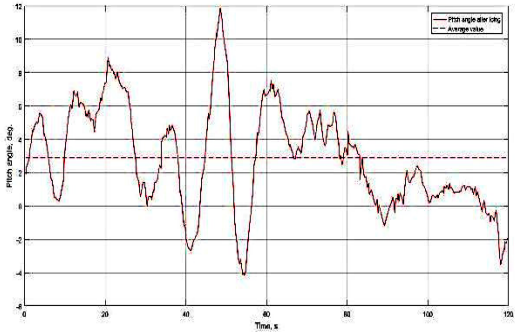
b)

Fig.9. Electrical energy consumption depending on time: a– before icing; b– after icing

The reason for these indices increase in general is increase of UAV control surface deflection to maintain given flight parameters. This can be clearly seen on Fig. 10 a and Fig. 10 b, apparent, that average angle of positive pitch increased from $1{,}3^0$ before icing to almost 3^0 after icing.



a)



b)

Fig. 10. Dependence of pitch level on time: a–before icing; б–after icing

Sharp increase of pitch has caused the wing to set a greater angle of attack, that has caused increase of C_x coefficient, aerodynamic quality of UAV has decreased, increased level of engine throttle and consequently greater electrical energy consumption.

6. Conclusions

1. In practice identified, that upon certain meteorological conditions ice formations are formed on parts of small UAVs, by the similar scheme, as they form on large AC.
2. Distortion from ice formation take place on the leading edge of the wing and front part of bottom and upper airfoil sections; similarly iced tail unit of the AC. In addition, icing formed at frontal surfaces of telemetry and video antennas, and inlet of PST.
3. Maximum linear dimensions of formations on the wing amounted up to 9,5 mm, their thickness reached 1,5 mm.

4. In wing section through MAC chord of distorted profile increased from 191 mm to 192,5 mm.
5. Force of aerodynamic drag before and after icing increased from 5,58*N* to 8,84*N*, increased by more than 40%.
6. UAV icing lead to significant decrease of UAV performance, namely: thrust level increased on an average 10 %; average index of battery current increased respectively from 25,5A to 35A; pitch angle on cruising mode increased from $1,3^0$ before icing to $2,8^0$ after icing.
7. Identified calculated angle of attack $2,4^0$ that differs from recorded by the MFR $2,8^0$ on $0,4^0$, that can be explained by errors in calculation and current value of angle of attack, measured by the MFR at given moment of time.

References

[1] Storozhuk M.V. (2015) *Ground icing, of aircraft: measures to prevent assidents.* Moscow, Scientific Bulletin MGTU GA, no. 219, pp. 93-98

[2] Simonenkova R.V., Vmnogradova L.M., and others (1982) *Protection of aircraft from ground icing* [The aviation industry], no. 8. Available at: http://www.viam.ru

[3] Mazin I.P. (1957) *Fizicheskiye osnovy obledeneniya samoletov,* Moscow

[4] Borovikov A.M. i dr. (1961) *Fizika oblakov*. Gidrometizd. L-d, 435 p.

[5] Astapenko P.D., Baranov A.M., Shvarev I.M. (1980) *Pogoda i polety samoletov i vertoletov.* Gidrometizd. L-d, 186 p.

[6] *Mobile unmanned complex M-10 "Oko 2"* (2017) NAU. Available at: http://uav.nau.edu.ua

[7] Klemenkov G.P., Prikhod'ko YU.M. i dr. (2008) [Modelirovaniye protsessov obledeneniya letatel'nykh apparatov v aeroklimaticheskikh trubakh]. *Trudy Instituta teoreticheskoy i prikladnoy mekhaniki im. S.A. Khristianovicha* [Teplofizika i aeromekhanika]. T.15, no. 4, pp. 563-572

[8] Thomas P. Ratvasky, Billy P. Barnhart Bihrle, Sam Lee (2008) *Current Methods for Modeling and Simulating Icing Effects on Aircraft Performance, Stability and Control*. National Aeronautics and Space Administration Glenn Research Center Cleveland, Ohio 44135, pp. 4-13

[9] Grzegorz Kowaleczko, Michał Wachłaczenko (2012) *Aircraft dynamics during dynamics flight in icing conditions.* Warsaw, Journal of Theoretical and Applied Mechanics, 50, 1, pp. 269-284

[10] Xuan Zhang, Jingchun Min, Xiaomin Wu (2016) *Model for aircraft icing with consideration of property-variable rime ice*. International Journal of Heat and Mass Transfer. Available at: http://www.elsevier.com/locate/ijhmt

М.П. Матійчик[1], Н.О. Суворова [2], Д.І. Терещенко[3], Є.С. Плахотнюк[4], К.В. Трачук[5]

Вплив зледеніння на льотно-технічні характеристики безпілотного повітряного судна М-10-2 «Око»

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]nvcba@nau.edu.ua; [2]suv_nat@bigmir.net; [3]tedmiv@gmail.com; [4]iesp@i.ua; [5]kate.trachuk@ukr.net

Мета: Проведення аналізу зледеніння несучих поверхонь безпілотного повітряного судна. Зледеніння відбулося при випробувальних польотах безпілотного повітряного судна. **Методи дослідження:** Аналіз результатів польоту в умовах зледеніння проводився із використанням проектних льотно-технічних характеристик безпілотного повітряного судна, а також даних, отриманих із бортового самописця. Найбільші льодові формування було зафіксовано на поверхні передньої кромки крила практично по всій її довжині; відкладення накрили також всю передню кромку вінглетів. **Результати:** Практично встановлено, що за відповідних метеоумов на частинах малорозмірних безпілотних повітряних суднах утворюються відкладення льоду, за схемою подібною, як вони утворюються на великорозмірних повітряний суднах. Спотворення від утвореного льоду відбулось по передній кромці крила та передній частині нижньої та верхньої дужок крила; аналогічним чином обмерзло хвостове оперення. Крім того обмерзанню піддались фронтальні поверхні телеметричної та відеоантен, а також передня частина трубки приймача повітряного тиску. **Обговорення:** Зледеніння

несучих поверхонь повітряного судна під час польоту може мати небажані наслідки як для великої авіації, так і для малих безпілотних повітряних суден. Практичні випробувальні польоти безпілотних повітряних суден НВЦБА "Віраж" Національного авіаційного університету в зимовий період показали, що ігнорування розгляду проблеми може знижувати рівень безпеки польотів аж до виникнення передумов до авіаційних подій. Факт зледеніння був виявлений після посадки безпілотного повітряного судна.

Ключові слова: безпілотне повітряне судно; зледеніння; льотно-технічні характеристики; несучі поверхні; профіль крила; тангаж.

М.П. Матийчик[1], Н.А. Суворова [2], Д.И. Терещенко[3], Е.С. Плахотнюк[4], Е.В. Трачук[5]

Влияние обледенения на летно-технические характеристики беспилотного воздушного судна М-10-2 «Око»

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]nvcba@nau.edu.ua; [2]suv_nat@bigmir.net; [3]tedmiv@gmail.com; [4]iesp@i.ua; [5]kate.trachuk@ukr.net

Цель: Проведение анализа обледенения несущих поверхностей беспилотного воздушного судна. Обледенение произошло во время испытательных полетов беспилотного воздушного судна. **Методы исследования:** Анализ результатов полета в условиях обледенения проводился с использованием проектных летно-технических характеристик беспилотного воздушного судна, а также данных, полученных с бортового самописца. Наибольшие ледовые формирования были зафиксированы на поверхности передней кромки крыла практически по всей ее длине; отложения накрыли также всю переднюю кромку винглетов. **Результаты**: Практически установлено, что при соответствующих метеоусловиях на частях малоразмерных беспилотных воздушных судов образуются отложения льда, по схеме подобной, как они образуются на крупноразмерных воздушных судах. Искажение от образованного льда произошло по передней кромке крыла и передней части нижнего и верхнего обвода крыла; аналогичным образом обледенело хвостовое оперение. Кроме того, обледенению подверглись передние поверхности телеметрической и видеоантен, а также передняя часть трубки приемника воздушного давления. **Обсуждение:** Обледенение несущих поверхностей воздушного судна во время полета может иметь нежелательные последствия, как для большой авиации, так и для малых беспилотных воздушных судов. Практические испытательные полеты беспилотных воздушных судов НПЦБА "Вираж" Национального авиационного университета в зимний период показали, что игнорирование рассмотрения проблемы может снижать уровень безопасности полетов включительно с предпосылками к авиационным происшествиям. Факт обледенения был обнаружен после посадки беспилотного воздушного судна.

Ключевые слова: беспилотное воздушное судно; летно-технические характеристики; несущие поверхности; обледенение; профиль крыла; тангаж.

Mykhailo Matiychyk (1960). Ph.D., Associate Professor, Docent.
Chief designer of Unmanned Aircraft Systems Scientific and Production Center of Unmanned Aviation “Virazh”, Kyiv, Ukraine.
Education: Ternopil National University, General Engineering and Technology Faculty, Ternopil, Ukraine (1985).
Research area: mechanics, aerodynamics and concepts of unmanned aircraft.
Publications: 82.
E-mail: a04misha8@meta.ua

Natalya Suvorova (1974). Lecturer.
Department of Aviation Operations and Services, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2002).
Research area: Unmanned Aerial Systems.
E-mail: suv_nat@bigmir.net

Dmytro Tereshchenko (1987).
Aviation engineer, LLC 'Ukrspecsystems', Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2011).
Research area: air navigation systems, communication systems, unmanned aerial systems.
Publications: 15.
E-mail: tedmiv@gmail.com

Ievgen Plakhotniuk (1988). Researcher.
Scientific and Research part of National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2010).
Research area: Unmanned Aerial Systems.
Publications: 6.
E-mail: iesp@i.ua

Kateryna Trachuk (1991). Junior researcher.
Scientific and Research part of National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2013).
Research area: Unmanned Aerial Systems.
E-mail: kate.trachuk@ukr.net

UDC 621.396.4
DOI: 10.18372/2306-1472.73.12177

Alexander Lysenko[1]
Olena Tachinina[2]

METHOD OF PATH CONSTRUCTING OF INFORMATION ROBOT ON THE BASIS OF UNMANNED AERIAL VEHICLE

[1] National Technical University of Ukraine «Igor Sikorsky KPI»
37, Peremohy ave., Kyiv, 03056, Ukraine
[2] National Aviation University
1, Kosmonavta Komarova ave., Kyiv, 03680, Ukraine
E-mails: [1]lysenko.a.i.1952@gmail.com; [2]tachinina@mail.ru

Abstract

Purpose: *The purpose of this article is to present a method for constructing the branching path of the information robot (IR) that is a compound dynamic system (CDS) allowing us to formulate, in terms of optimal control theory, conditions of CDS path modeling with an arbitrary branching scheme.* ***Methods:*** *The article describes a method of theory of discontinuous dynamical systems optimal control, which is used to prove the optimality conditions for phase coordinates in the points of structural transformations of the IR's branching path.* ***Results:*** *The necessary conditions for the optimality of the branching path along which the IR moves are defined. These conditions allow using standard subprograms to solve ordinary differential and algebraic equations and thereby to solve the task of modeling the optimal path of CDS with an arbitrary branching scheme.* ***Discussion:*** *The proposed method is the methodological basis for definition the computing algorithms allowing to simulate the optimal CDS paths. The proposed procedure of optimal branching paths simulating is part of the IR's computer-aided design software and can be used to define computing algorithms taking into account the peculiarity of information-telecommunication interaction of CDS's specific elements.*

Keywords: unmanned aerial vehicles; information robot; compound dynamic system; optimal control; branching path

1. Introduction

Currently, the successes achieved in the development of unmanned aerial vehicles (UAVs), both military and civilian, create technological conditions for expanding the areas of its application. One of the promising areas is creation of an information robot based on the UAV group for on-line collection and transmission the data about the state of operational landscape and environment in the protected areas of critical infrastructure facilities (nuclear power plants, oil and gas pipelines, military bases and warehouses, chemical industry enterprises, etc.), in the natural or anthropogenic disasters area.

Information robot (IR) is a compound dynamic system (CDS) [5], its elements are: a basic UAV (UAV-carrier); a group of various mobile UAVs (drones) equipped with multisensors and interconnected through a common information and telecommunications network.

The basic UAV is used as an airplane for drones delivery and primary deployment in studied (investigated) area; to collect, accumulate, preprocess on-line data received from the drones; and to retransmit real-time received data to a command control post. Depending on the tasks to be performed, various scenarios of drones mobility, deployment plan and its interaction with the basic UAV can be provided.

Depending on specified scenario, separate drones can operate as independent repeaters or data storage devices, as well as a network of interacting nodes, and can be used as a repeater for other drones.

2. Analysis of the research and publications

The efficiency of using the IR will depend on spatial coordinates and time instants when the structural transformations occur, as well controlling IR's components as they move along the path branches in time intervals between sequential structural transformations.

The paths of such CDS in the modern scientific literature have been called 'branching paths', knowing that they consist of sections of joint

movement of constituent parts and segments of its individual movement to the target along separate path branches.

The prototypes in theory of such systems are systems considered in the publications of Bryson E., Ho Y. [1], Aschepkov L. T. [2], Samoylenko A. M, Perestyuk N.A. [3], Lysenko A.I. [4] and others.

However, all these publications were of a theoretical nature and did not contain detailed study, which would provide to design a computer-aided technology of optimal branching path automated synthesis and optimal control of CDS for each specific case.

Therefore, the scientific problem, related to improvement and development of methods of designing branching paths that would allow to solve on a real time basis the tasks of CDS' definition optimal paths of this type, is actual.

3. Aim of the paper

The purpose of this article is to present a method for constructing the branching path of the IR that is a compound dynamic system allowing us to formulate, in terms of optimal control theory, conditions of CDS path modeling with an arbitrary branching scheme.

4. Problem statement

Consider, for example, the motion of a hypothetical IR, which includes a basic UAV and four drones, three of those are based on the UAV, and fourth one starts motion out of the UAV. During motion, the IR's elements can: be grouped together for data exchange; be separated for the purpose of individual performance of the task; to influence mutually on the motion dynamics of the IR's elements. The scheme of the motion of the IR's elements is shown in Fig. 1.

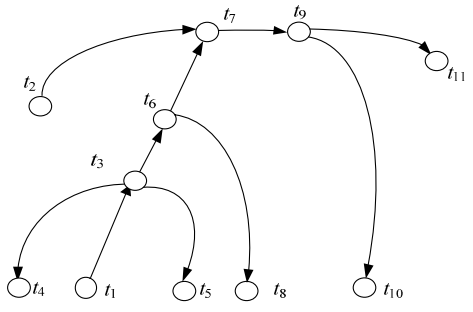


Fig.1. The example of an arbitrary branching scheme for the path of IR's elements

At the initial time t_1 – the basic UAV starts as a single unit containing three drones. During the motion at the time t_3 – the basic UAV drops two drones, completing its motion at time points t_4 and t_5. Next, at the time t_6 – there is a separation of the third drone completing the motion at the time t_8. At the time point t_7 – the base UAV and the fourth drone (started at the time t_2) are mated (mechanically or by compactly grouping, then the fourth drone follows the UAV as follower after leader). At the end of joint motion at the time t_9 – the basic UAV and the fourth drone are unmated and move individually up to time points t_{10} and t_{11}. The path of CDS motion shown in Fig. 1. is related to the class of branching paths [4].

The task will be to find the optimal control vector that minimizes energy consumption for control, providing the maximum coverage area of monitored territory and uninterrupted transmission of information about its state.

5. Method of path constructing of information robot

When solving the tasks of modeling the optimal CDS motion, it is necessary to consider branching paths of various complexity in comparison with the scheme given in the example. At present, optimality conditions are formulated for particular schemes of branching paths, it requires a complete solution of the task whenever the new branching path does not coincide with known particular cases [6, 7]. Before proceeding to generalized formulations, consider the examples of elementary branching paths (Fig. 2), which enable us to ground the required generalizations.

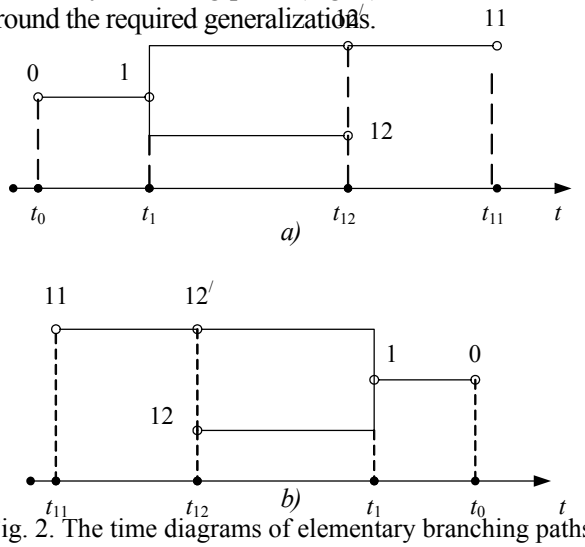


Fig. 2. The time diagrams of elementary branching paths: *a* – scheme with separation of subsystems; *b* – scheme with grouping of subsystems

The equations describing the CDS motion with separation (Fig. 2, *a*) are as follows:

$$\dot{x}_1 = f_1(x_1,u_1), t\in[t_0,t_1], \quad (1)$$

$$\dot{x}_{11} = \begin{cases} f_{11}^{12}(x_{11},u_{11};x_{12},u_{12}), t\in[t_1,t_{12}], \\ f_{11}(x_{11},u_{11}), t\in[t_{12},t_{11}], \end{cases} \quad (2)$$

$$\dot{x}_{12} = f_{12}^{11}(x_{12},u_{12};x_{11},u_{11}), t\in[t_1,t_{12}], \quad (3)$$

where $x_p(t)\in R^n$, $u_p(t)\in R^{m_p}$, $u_p\in\Omega_p$,

p–quantity of subsystems (1, 11, 12).

The vector criterion for the quality of CDS functioning can be written in the additive form

$$I = S(x_1t_0),t_0;x_1(t_1),t_1;x_{12}(t_{12}),t_{12};x_{11}(t_{11}),t_{11}) + \\ + I_1 + I_{11} + I_{12}, \quad (4)$$

where

$$I_{12} = \int_{t_1}^{t_{12}} \Phi_{12}(x_{12},u_{12};x_{11},u_{11})dt,$$

$$I_{11} = \int_{t_1}^{t_{12}} \Phi_{11}^{12}(x_{12},u_{12};x_{11},u_{11})dt + \int_{t_{12}}^{t_{11}} \Phi_{11}(x_{11},u_{11})dt.$$

The optimality criterion corresponds to Bolze's form, where the function $S(\cdot)$ physically reflects the requirements for the values of coordinates of the CDS elements motion at the moments of start and end, as well as for the values of time moments. The integral terms of criterion show the requirements for character of the motion of CDS elements along corresponding path branches. The mutual influence of elements within the time interval $[t_1,t_{12}]$ is described as in the equations of its motion (2), (3) as well in particular integral criteria I_{11} and I_{12}. The equations describing the motion of elements and the criterion in the scheme with grouping (Fig. 2, *b*) have the same form as ones for the scheme with separation, differing only in the sign of the time variation.

It is necessary to choose the controls $u_1(t)\, t\in[t_0,t_1]$, $u_{11}(t)\, t\in[t_1,t_{11}]$, $u_{12}(t) t\in[t_1,t_{12}]$, vectors of phase coordinates $(x_1(t_0),x_1(t_1),x_{11}(t_{12});x_{12}(t_{12}),x_{11}(t_{11})$ and time points t_0,t_1,t_{11},t_{12} for both branching schemes (Fig. 2, *a, b*), so that the functional I takes the smallest possible value. We formulate the necessary conditions for the optimality of branching path along which the CDS moves (Fig. 2, *a, b*) [5].

Let $x_1(t),u_1(t)\, t\in[t_0,t_1]$; $x_{11}(t),u_{11}(t),x_{12}(t)$, $u_{12}(t)\ \ t\in[t_1,t_{12}]$; $x_{11}(t),u_{11}(t)\ \ t\in[t_{12},t_{11}]$; – allowable processes. For the optimality of processes, solutions must exist $\lambda_1(t)\in[t_0,t_1]$; $\lambda_{11}^{12}(t)$, $\lambda_{12}(t)$, $t\in[t_1,t_{12}]$, $\lambda_{11}(t)t\in[t_{12},t_{11}]$ for the adjoint vector equations

$$\dot{\lambda}_1 + \frac{\partial H_1}{\partial x_1} = 0, \dot{\lambda}_{I_1}^{12} + \frac{\partial H_{11}^{12}}{\partial x_{11}} + \frac{\partial H_{12}}{\partial x_{11}} = 0, \quad (5)$$

$$\dot{\lambda}_{12} + \frac{\partial H_{11}^{12}}{\partial x_{12}} + \frac{\partial H_{12}}{\partial x_{12}} = 0, \dot{\lambda}_{11} + \frac{\partial H_{11}}{\partial x_{11}} = 0, \quad (6)$$

such that the conditions are valid:

1) transversality for complementary functions and Hamiltonians

$$\left.\frac{\partial S}{\partial x_1(t_0)}\right|_{\wedge} - (-1)^{\beta}\lambda_1(\hat{t_0}) = 0; \left.\frac{\partial S}{\partial t_0}\right|_{\wedge} + (-1)^{\beta}H_1\Big|_{\wedge} = 0, \quad (7)$$

$$\left.\frac{\partial S}{\partial x_{1i}(t_{1i})}\right|_{\wedge} + (-1)^{\beta}\lambda_{1i}(\hat{t_{1i}}) = 0; \left.\frac{\partial S}{\partial t_{11}}\right|_{\wedge} - (-1)^{\beta}H_{11}\Big|_{\wedge} = 0, \quad (8)$$

2) jump for complementary functions and Hamiltonians

$$\left.\frac{\partial S}{\partial x_1(t_1)}\right|_{\wedge} + (-1)^{\beta}\left[\lambda_1(\hat{t_1}) - \lambda_{11}^{12}(\hat{t_1}) - \lambda_{12}(\hat{t_1})\right] = 0, \quad (9)$$

$$\left.\frac{\partial S}{\partial t_1}\right|_{\wedge} - (-1)^{\beta}\left[H_1\Big|_{\wedge} - H_{11}^{12}\Big|_{\wedge} - H_{12}\Big|_{\wedge}\right] = 0, \quad (10)$$

$$\left.\frac{\partial S}{\partial x_{11}(t_{12})}\right|_{\wedge} + (-1)^{\beta}\left[\lambda_{11}^{12}(\hat{t})_{12} - \lambda_{11}(\hat{t})_{12}\right] = 0, \quad (11)$$

$$\left.\frac{\partial S}{\partial t_{12}}\right|_{\wedge} - (-1)^{\beta}\left[H_{11}^{12}\Big|_{\wedge} + H_{12}\Big|_{\wedge} - H_{11}\Big|_{\wedge}\right] = 0, \quad (12)$$

3) minimum of the Hamiltonians at the time $t\in[t_q,t_p]$ for control $u_p\in\Omega_p$

$$H_p\Big|_{\wedge} = \min H_p\Big|_{\wedge,u_p(t)}, \quad (13)$$

where p – quantity of subsystems, q – indices of sections of the branching path (p=1, q=0; p=11, q=12),

4) minimum of the linear combination of Hamiltonians at time instants $t\in[t_1,t_{12}]$ for control $u_p\in\Omega_p$ (p=11, q=12),

$$H_{11}^{12}\Big|_{\wedge} + H_{12}\Big|_{\wedge} = \min\begin{bmatrix} H_{11}^{12}\Big|_{\wedge,u_{11}(t),u_{12}(t)} + \\ + H_{12}\Big|_{\wedge,u_{12}(t)} \end{bmatrix}. \quad (14)$$

Herein icon «^» notes the optimal variables and parameters; symbol $|_{\wedge,\xi}$ means that the expression should be calculated for the optimal values of variables and parameters, except for ξ; parameter β takes the value = 1 or 2, for the related scheme with

separation or grouping; $H_p(\cdot)=\Phi_p(\cdot)+\dot{\lambda}_p^{\mathrm{T}} f_p(\cdot)$ (p=1, 11, 12), $H_{11}^{12}(\cdot)=\Phi_{11}^{12}(\cdot)+{}_{11}^{12}\lambda^{\mathrm{T}} f_{11}^{12}(\cdot)$.

On the basis of stated above conditions (5) – (14) and considering a complex branching path as a package of simple ones, we formulate the following method for modeling the optimal branching path of the CDS with an arbitrary branching scheme.

For the optimality of a branching path with an arbitrary branching scheme, existence of solutions of adjoint vector equations in the intervals of time between t_N-start of the motion, t_R-separation, t_G-groupings, t_K- end of motion of compound elements, is required.

$$\dot{\lambda}_L+\frac{\partial H_L}{\partial x_L}+\sum_q^M\frac{\partial H_q}{\partial x_L}=0 \qquad (15)$$

where L – index of section of the branching path; M– quantity, q– indices of sections of the branching path whose partial Hamiltonians depend on the phase coordinates of L-section so that the following conditions are valid:

1) transversality at time instants $\hat{t}_N=\hat{\tau}_1$ and $\hat{t}_k=\hat{\tau}_2$

$$\left.\frac{\partial S}{\partial x_{L(\tau_i)}}\right|_{\wedge}-(-1)^i\lambda(\hat{\tau}_i)=0,\ (i=1,2), \qquad (16)$$

$$\left.\frac{\partial S}{\partial \tau_i}\right|_{\wedge}+(-1)^i H_L\Big|_{\wedge}+\sum_{\nu}^{p}(H_\nu|_{\wedge,\hat{\tau}_i-0}-H_\nu|_{\wedge,\hat{\tau}_i+0})=0, \qquad (17)$$

where p - quantity of subsystems whose motion is affected by start or end of the motion of subsystem along the L-section; ν – indices of the sections of branching path along which these subsystems move;

2) jump at instants $\hat{t}_R=\hat{\tau}_1$ and $\hat{t}_G=\hat{\tau}_2$, related with division of the subsystem moving along the L–section, by r–subsystems or grouping r–subsystems into the subsystem moving along the L–section of the branching path

$$\left.\frac{\partial S}{\partial {}_j x_L(\tau_i)}\right|_{\wedge}+(-1)^i{}_j\lambda_L(\hat{\tau}_i)-(-1)^i\sum_{\nu}^{p}{}_j\lambda_q(\hat{\tau}_i)=0;$$

$$\left.\frac{\partial S}{\partial {}_n x_L(\tau_i)}\right|_{\wedge}+(-1)^i{}_n\lambda_L(\hat{\tau}_i)-(-1)^i\sum_{q}^{r}\xi_q{}_n\lambda_q(\hat{\tau}_i)=0;$$

$$(j=\overline{1,n-1};i=1,2),\xi_q\ge 0,\sum_q^r\xi_q=1, \qquad (18)$$

$$\left.\frac{\partial S}{\partial \tau_i}\right|_{\wedge}-(-1)^i H_L\Big|_{\wedge}+(-1)^i\sum_q^r H_q\Big|_{\wedge}+$$
$$+\sum_{\nu}^{p}(H_\nu|_{\wedge,\hat{\tau}_i-0}-H_\nu|_{\wedge,\hat{\tau}_i+0})=0; \qquad (19)$$

where q – indices of sections of the branching path along which the subsystems move after separation or before grouping; p – quantity of subsystems, ν – indices of sections of the branching path, along which these subsystems move, not participating in the points of time t_R and t_G in division or grouping, but the motion of which is affected by the separation or grouping of subsystems moving along sections with indices L and q; ${}_n x_L(t)$ – phase coordinate describing mass change; jump condition on the μ-section of branching path at time $\hat{t}_s$, coinciding with one of the instants associated with structural changes in the CDS caused by start or end of the motion, separation or grouping of subsystems not related to μ–section, but influencing it

$$\left.\frac{\partial S}{\partial x_\mu(\tau_s)}\right|_{\wedge}-\lambda_\mu(\hat{\tau}_s-0)+\lambda_\mu(\hat{\tau}_s+0)=0; \qquad (20)$$

3) minimum of the linear combination of Hamiltonians at the instants between the moments t_N, t_R, t_G, t_K

$$\sum_q^{\Lambda}H_q\Big|_{\wedge}=\min_{u_q\in\Omega_q}\sum_q^{\Lambda}H_q\Big|_{\wedge,u_q} \qquad (21)$$

where Λ – number of subsystems with interacting controls within specified time intervals; Q –indices of the sections of branching path along which these subsystems move.

The stated method is the methodological basis for constructing computing algorithms that allow modeling the optimal paths of the CDS motion. The method for modeling optimal branching paths is a part of the software of CDS computer-aided design system.

Consider an example illustrating use of the simulation method for the optimal branching path.

According to the specified scheme of branching path (Fig. 1), its time diagram is drawn up (Fig. 3), in which the time instants of structural transformations in the CDS motion pattern with indication its membership to the corresponding types of time moments are arranged chronologically: $\hat{t}_N$, $\hat{t}_R, \hat{t}_G, \hat{t}_K$.

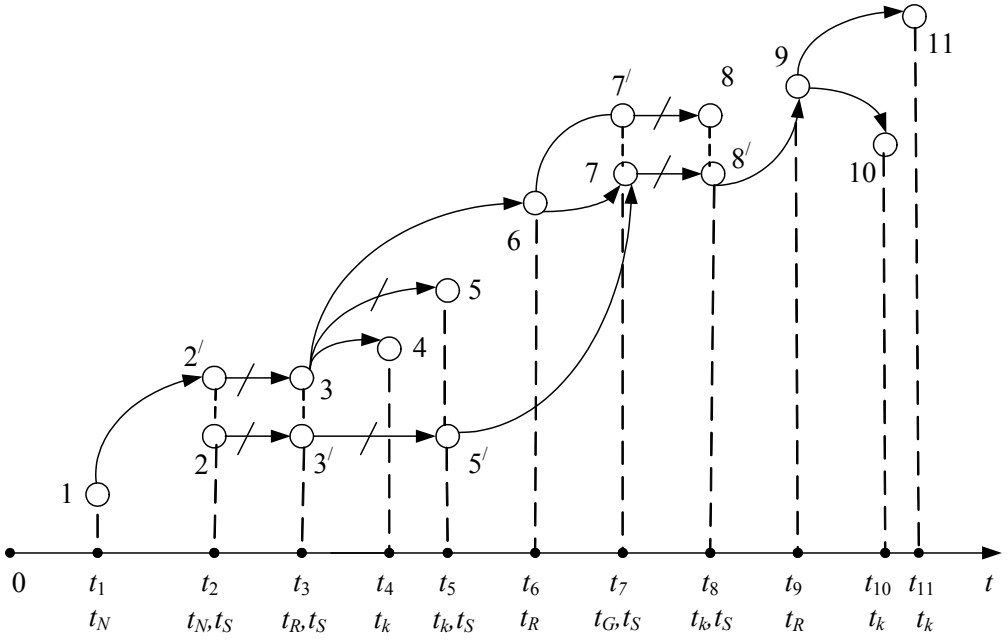


Fig. 3. Time diagram of the branching path

The path sections, moving along which the CDS elements interact each with other, are marked with a line.

The optimality criterion is written in the form consisting of the terminal part $S(\cdot)$, dependent on the coordinates of elements at time instants $t_i (i = \overline{1,11})$ and these moments of time, as well as the sum of particular integral criteria

$$I_i = \int_{t_a}^{t_b} \Phi_i(\cdot) dt \ (i = 1,11), (a \neq b), (a = \overline{1,11}), (b = \overline{1,11}),$$

recorded for the each section of branching path (Fig. 3), enclosed between neighboring points located on it.

The motion of elements along the path is defined by equations of $\dot{x} = f(\cdot)$ type, where $f(\cdot)$ – function that depends on the controls and coordinates of the subsystem, as well as on the controls and coordinates of the interacting subsystem, if the branch section is marked with a line. Applying the procedure formulated below, we obtain condition – for the optimality of path (Fig. 3) it is necessary to have solutions of adjoint vector equations of type (15) such there conditions of type (16-21) are valid.

To solve finally the task of modeling the optimal branching path, it is necessary to add the listed differential equations and algebraic conditions with the differential equations of motion of the subsystems along the path branches.

Note that the sequence of time instants $t_1 < t_2 < .... < t_{10} < t_{11}$ in the task with free time is given from physical considerations and is approximate. If it is disturbed, as a result of solution of the task, and the change in the sequence of branches of the path is permissible by the physical meaning of the task, then repeating all calculations for new refined sequence of time instants is required.

The information given in Tables 1 – 3 is initial data that allows using standard subprograms for solving ordinary differential and algebraic equations, and thereby complete practically solution the CDS optimal path modeling task.

Table 1

Conditions for formulation of equations for conjugate variables

Type of equation	Legend of branch, L							
	$1;2^/$	$2^/;3$	$2;3^/$	$3;4$	$3;6$	$3;5$	$3^/;5^/$	$5^/;7$
(15)	M=0 –	M=1 q=(2; 3/)	M=1 q=(2/; 3)	M=0 –	M=0 –	M=1 q=(2/; 5/)	M=1 q=(3; 5)	M=0 –

Table 1 cont'd

Type of equation	Legend of branch, L						
	6; 7	6; 7′	7′; 8	7; 8′	8′; 9	9;10	9; 11
(15)	M=0 –	M=0 –	M=1 q=(7; 8′)	M=1 q=(7′; 8)	M=0 –	M=0 –	M=0 –

Table 2

The solutions of differential equations for conjugate variables must meet the following conditions

Condition type	t_1	t_2	t_3	t_4	t_5	t_6
(16)	L=(1; 2′); i=1	L=(2; 3′); i=1	–	L=(3; 4); i=2	L=(3; 5); i=2	–
(17)	L=(1; 2′); i=1; p=0	L=(2; 3′); i=1; p=1; $н$=(1; 2′; 3)	–	L=(3; 4); i=2; p=0	L=(3; 5); i=2; p=1; $н$=(3′; 5′; 7)	–
(18)	–	–	L=(2′; 3); i=1; r=3; q=(3;1), (3;5), (3;4)	–	–	L=(3; 6); i=2; r=2; q=(6; 7′), (6; 7)
(19)	–	–	L=(2′; 3); i=1; r=3; p=1; q=(3;6), (3;5), (3;4); $н$=(2;3′;5′)	–	–	L=(3; 6); i=2; r=2; q=(6; 7′), (6; 7)
(20)	–	$м$=(1;2;3)	$м$=(2;3;5)	–	$м$=(3′; 5′; 7′)	–

Table 2 cont'd

Condition type	t_7	t_8	t_9	t_{10}	t_{11}
(16)	–	L=(7′; 8); i=2	–	L=(9; 10); i=2	L=(9; 11); i=2
(17)	–	L=(7′; 8); p=1; $н$=(7; 8′; 9)	–	L=(9; 10); i=2	L=(9; 11); i=2
(18)	L=(7; 8′); i=2; r=2; q=(6; 7), (5′; 7)	–	L=(8′; 9); i=2; r=2; q=(9; 10), (9; 11)	–	-
(19)	L=(7; 8′); i=2; r=2; p=1; q=(6; 7), (5′; 7); $н$=(6; 7′; 8)	–	L=(8′; 9); i=2; r=2; p=0; q=(9; 10), (9; 11)	–	-
(20)	$м$=(6; 7′; 8)	$м$=(7; 8′; 9)	–	–	-

Table 3

Conditions for Hamiltonian minimizing

Equation	Time space							
	t_1–t_2	t_2–t_3	t_3–t_4	t_3–t_5	t_3–t_6	t_5–t_7	t_6–t_7	t_6–t_7
(21)	Л=1 q=(1; 2′)	Л=1 q=(2′; 2), (2; 3′)	Л=1 q=(3; 4)	Л=2 q=(3; 5), (3′; 5′)	Л=1 q=(3; 6)	Л=1 q=(5′; 7)	Л=1 q=(6; 7)	Л=1 q=(6; 7′)

Table 3cont'd

Equation	Time space			
	t_7–t_8	t_8–t_9	t_9–t_{10}	t_9–t_{11}
(21)	Л=2 q=(7′; 8), (7; 8′)	Л=1 q=(8′; 9)	Л=1 q=(9; 10)	Л=1 q=(9; 11)

6. Conclusion

The article suggests the method for constructing a branching path of the information robot motion that is a compound dynamic system. The method allows to formulate the procedure for modeling the optimal branching path of the compound dynamic system with an arbitrary branching scheme in terms of the theory of optimal control.

The procedure is a part of the software of information robot computer-aided design system and

can be used to construct computing algorithms taking into account the specificity of information-telecommunication interaction of elements of specific compound dynamic systems.

References

[1]. Bryson E., Yu-Chi Ho. (1975) Applied Optimal Control. New York, USA, Revised edition, 482 p. (United States).

[2]. Ashchepkov L.T. (1987). Optimal'noye upravleniye razryvnymi sistemami [Optimal control of discontinuous systems]. Novosibirsk, Nauka Publ., 226 p. (in Russian).

[3]. Samoylenko A. M, Perestyuk N.A. (1987). Differentsial'nyye uravneniya s impul'snym vozdeystviyem [Differential equations with impulse action]. Kiev, Higher school, 228 p. (in Ukranian).

[4]. Lysenko A. I. (1988). Usloviye skachka v zadache optimal'nogo upravleniya ob"yektom [The jump condition in the problem of optimal control of a compound object]. Adaptive systems of automatic control, vol. 6, pp. 136-141. (in Ukranian).

[5]. Lysenko A. I., Tachinina O. M. (2014). Matematicheskaya postanovka zadachi optimizatsii dvizheniya gruppy letayushchikh robotov na baze bespilotnykh letatel'nykh apparatov [The mathematical formulation of the optimization problem of motion group flying robots based unmanned aerial vehicles]. Scientific Bulletin of the Academy of Municipal Management, vol. 1, no. 7, pp 83-100. (in Ukranian).

[6]. Lysenko A. I., Tachinina O. M. Alekseeva I.V, and Chumachenko S. M. (2015). The Scenario-Based Approach for Control of Multi-Object Dynamic System Motion. IEEE 3rd International Conference «Actual problems of unmanned aerial vehicles developments», October 13-15, pp. 305-308. (in Ukranian).

[7]. Lysenko A. I., Tachinina O. M. (2016). Optimal principle for dynamical system with alterative orbiting. Electronics and control systems, vol. 4, no. 50, pp. 108-113. (in Ukranian).

О.І. Лисенко[1], О.М. Тачиніна[2].

Метод конструювання траєкторії руху інформаційного робота на базі безпілотного літального апарата

[1] Національний Технічний Університет України «КПІ» ім. І. Сікорського, пр. Перемоги, 37, Київ, Україна, 03056

[2] Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680

E-mails: [1]lysenko.a.i.1952@gmail.com; [2]tachinina@rambler.ru

Мета: Метою даної статті є викладення методу конструювання розгалуженої траєкторії руху інформаційного робота, що являє собою складену динамічну систему, який дозволяє сформулювати в термінах теорії оптимального управління умови моделювання оптимальної розгалуженої траєкторії складеної динамічної системи з довільною схемою розгалуження. **Методи:** У статті розглянуто метод теорії оптимального управління розривними динамічними системами, який застосовувався для доказу умов оптимальності фазових координат, в точках структурних перетворень розгалуженої траєкторії руху інформаційного робота. **Результати:** Сформульовано необхідні умови оптимальності розгалуженої траєкторії, по якій переміщається інформаційний робот, які дозволяють перейти до застосування стандартних підпрограм рішення звичайних диференціальних рівнянь та алгебраїчних рівнянь і тим самим вирішити задачу моделювання оптимальної траєкторії складеної динамічної системи з довільною схемою розгалуження. **Обговорення**: Запропонований метод є методологічною основою для побудови обчислювальних алгоритмів, що дозволяють моделювати оптимальні траєкторії руху складених динамічних систем. Запропонована процедура моделювання оптимальних розгалужених траєкторій є частиною математичного забезпечення системи автоматизованого проектування інформаційного робота і може бути використана для побудови обчислювальних алгоритмів, які враховують специфіку інформаційно-телекомунікаційної взаємодії елементів конкретних типів складених динамічних систем.

Ключові слова: безпілотні літальні апарати; інформаційний робот; складена динамічна система; оптимальне управління; розгалужена траєкторія.

А.И. Лысенко[1], Е.Н. Тачинина[2].

Метод конструирования траектории движения информационного робота на базе беспилотного летательного аппарата

[1] Национальный Технический Университет Украины «КПИ» им. И. Сикорского, пр. Победы, 37, Киев, Украина, 03056
[2] Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mails: [1]lysenko.a.i.1952@gmail.com; [2]tachinina@rambler.ru.

Цель: Целью данной статьи является изложение метода конструирования ветвящейся траектории движения информационного робота, представляющего собой составную динамическую систему, позволяющего сформулировать в терминах теории оптимального управления условия моделирования оптимальной ветвящейся траектории составной динамической системы с произвольной схемой ветвления. **Методы:** В статье рассмотрен метод теории оптимального управления разрывными динамическими системами, который применялся для доказательства условий оптимальности фазовых координат, в точках структурных преобразований ветвящейся траектории движения информационного робота. **Результаты:** Сформулированы необходимые условия оптимальности ветвящейся траектории, по которой перемещается информационный робот, которые позволяют перейти к применению стандартных подпрограмм решения обыкновенных дифференциальных уравнений и алгебраических уравнений и тем самым решить задачу моделирования оптимальной траектории составной динамической системы с произвольной схемой ветвления. **Обсуждение:** Предложенный метод является методологической основой для построения вычислительных алгоритмов, позволяющих моделировать оптимальные траектории движения составных динамических систем. Предложенная процедура моделирования оптимальных ветвящихся траекторий является частью математического обеспечения системы автоматизированного проектирования информационного робота и может быть использована для построения вычислительных алгоритмов, учитывающих специфику информационно-телекомуникационного взаимодействия элементов конкретных типов составных динамических систем.

Ключевые слова: беспилотные летательные аппараты; информационный робот; составная динамическая система; оптимальное управление; ветвящаяся траектория.

Lysenko Alexander. Doctor of Engineering, Professor.
Department of Telecommunication, National Technical University of Ukraine «Igor Sikorsky KPI».
Education: Kiev Higher Military Aviation Engineering School, Ukraine (1974).
Research area: flight dynamics, automatization, optimal control.
Publications: 300.
E-mail: lysenko.a.i.1952@gmail.com.

Tachinina Helen. Candidate of Engineering, Associate Professor.
Department of Automation and Energy Management, National Aviation University
Education: National Aviation University, Kyiv, Ukraine (1999).
Research area: flight dynamics, automatization, optimal control.
Publications: 100.
E-mail: tachinina@rambler.ru

MODERN AVIATION AND SPACE TECHNOLOGIES

UDC 629.7.067:632.982.4(045)
DOI: 10.18372/2306-1472.73.12178

Tatiana Udartseva

RAISING LEVEL OF FLIGHT SAFETY DURING AGRICULTURAL-AIR WORKS

National Aviation University
1, Kosmonavta Komarova avenue, 03680 Kyiv, Ukraine
E-mail: ute1@meta.ua

Abstract

The article presents an analysis of the causes of a serious incident that occurred during the aircraft-chemical works on the An-2 plane. ***Objective:*** *The aim of this work is to investigate the causes of aircraft collisions with electric power lines during the agricultural-air works and to develop preventive measures.* ***Metods:*** *Using the SHEL model recommended by ICAO, the main and additional causes of the aircraft collision with the electric power line are established.* ***Results:*** *The article contains the results of an analysis of data from investigations of accidents and incidents involving civil aircraft that occurred in Ukraine in 2013 - 2016. During this period, there were five collisions of aircraft with electric power lines, two of them with a fatal outcome. Since such cases are of a non-individual nature, the authors have developed appropriate preventive measures.* ***Discussion***: *Aviation incident prevention during low-level flights consists of the implementation of the ICAO experience, namely flight crew training programs: cabin crew optimization (CRM) and flight training in conditions close to real (LOFT). The introduction of issues related to real aviation accidents and incidents, as well as the use of air stimulators for training pilots, are proposed in the training programs for small airline pilots. As a precautionary measure, it is proposed to mark the wires of electric power lines with plastic balls according to international practice. It is proposed in the cockpit of the An-2 airplane install the car restorer of the instrument panel to obtain objective information about the flight parameters and simultaneously to write the talks in the cockpit.*

Keywords: agricultural-air works; aviation incident; flight safety; training of pilots.

1. Introduction

Over the last 10 years a number of evidences were found to confirm that about 70% of aircraft accidents and incidents were caused (sometimes partially) by inability of crew to use available means optimally. Quite often the crew face the problems related to inability to make group decisions, lack of communication, inadequate management or poor work organisation [1, 2]. Typically aircraft accidents and incidents are the result of the combined effect of the organisational factors (i.e. working conditions are the cause of wrong actions of the crew resulting in disruption of the whole system) and hidden circumstance, which potentially can disrupt the work of existing systems that guarantee flight safety and affect on it [3-5].

2. Analysis of research and publications

Many traditional training programs are focused exclusively on the technical aspects of flight fulfilment, with virtually no attention to the different types of strategies and methods to optimize the operation of the crew, which is also necessary to ensure safety. These findings have led to the emergence of a consensus in industry and government agencies about the need to pay more attention to the factors that affect the coordination of the crew and optimize the use of crew funds available [6, 7].

One of the important components of safety is the provision of information to airmen about

special situations in flight, erroneous operation, incidents. The main observations in providing information to the airlines that illuminate the problematic issues of safety are as follows [8]:

1. The information published on the issues of safety in many cases reflects not the true reason of the event, but the facts stated in the acts of the investigation.

2. The timeliness of receipt of information about aviation events and incidents. Through the media the incident report are received earlier than through official sources.

3. The lack of a unified state system of providing airline information on flight safety and changes in the operational and guiding documents.

4. The lack of information about research and development in universities of civil aviation.

5. The materials safety issues are very rare.

6. Inadequate coverage of prevention measures, the compilation of operating experience. There is no clear reporting system about aviation events.

7. Newsletters in a few sentences state the facts about aviation events, incidents; there is no available analysis of what happened and detailed information delivery to crews.

8. Untimely receipt of information about accidents and incidents, as well as analysis of the causes of their appearance.

A top concern for airlines is information related to the reliability of aviation equipment, the peculiarities of the manifestation of the human factor, training of crews, organization and ensuring of flights on the ground.

Therefore, it is necessary to reorganize the programs of training of flight personnel and include in programs:

1. Information about the real accidents and incidents, their causes and consequences.

2. Consolidation of learning outcomes working off similar situations in the flight simulator.

3. Purpose of the work

The analysis of incidents during agricultural-air works in Ukraine demonstrates drawbacks in the organisation of pilot's flight preparation for specific flight conditions [9-12].

The aim of this work is to investigate the causes of aircraft collisions with electric power lines and to develop preventive measures.

4. Materials and methods of research

The materials of research are the reports of the National Bureau of investigation of aviation events and incidents with civil aircraft for 2013-2016p. [9-12]. The research method is the analysis of data using the SHEL model recommended by ICAO [7].

5. Analys of incident during agricultural-air works

Consider the incident, which happened on 2 September 2013 at 16:32, during agricultural-air works near village Oleksandrivka, Kryukiv district of Chernihiv region, with "Universal-Avia" An-2 UR-62681 aircraft.

The flight crew consisting of the head of flight service and the captain, while processing the edge of the field along the high-voltage electric line, magnetic heading MH = 75^0, before leaving the track, saw high voltage wires across the flight direction, which branched from the main line and were poorly visible across the background of afforestation (fig.1). Because of the short distance to the power line and that the altitude of the flight was less than the height of the power line, the captain made a decision to descent and fly under the power line in order to avoid collision. Flying under the power lines, the aircraft collided with two bottom wires and broke them, damaged the tip of the vertical stabiliser and broke drain system mast. As the result of collision the crew was not hurt. According to the committee conclusion, the cause of serious incident (collision with the power electric line) during agricultural-air works was insufficient preparation of the crew for the flight in terms of studying the ground obstacles located on the field. Factor: human factor (crew). More oven preparation for the observation flight with actual ground observation of the field of works was recommended for the aircraft operators [9].

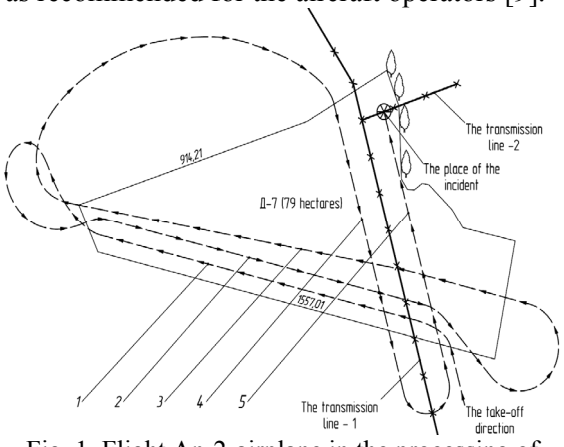


Fig. 1. Flight An-2-airplane in the processing of agricultural lands D-7 (79 hectares)
1 – The first long rut. *2* – The second long rut. *3* – The third long rut. *4* – The route along the transmission line. *5* – Route along the edge of the field

Detailed analysis of serious incident, we considered, shows that its main cause was the disruption of connection "subject-procedure". In particular, execution of the "Rules of the organisation and accomplishment of aviation works in agricultural and forest husbandry" approved by the Ministry of Transport and Communication, order №1179 from 22 December 2006 (The Rules) [13].

According to The Rules before take off for the execution of agricultural-air works the head of flight service must examine the area of works together with crew, paying attention to terrain taking into account local relief (p. 5.6.10); after arrival to the place of agricultural-air works the captain is obliged to instruct (with signatures) customer's staff concerning performance of their duties, safety rules for works near the aircraft, familiarise signalmen (with signatures) with the Instruction of signal organisation and interaction of aircraft crew with signalmen during the execution of agricultural-air works (p. 5.7.3 e), receive from the customer's representative the Task for agricultural-air works, land plans (p. 5.7.3 ж); according to customer's Task for agricultural-air works it is necessary to examine the area of flight (location, topography, agricultural areas configuration); identify presence and type of obstacles, put their location on land plans and on the basis of this circumstances determine the complexity of works over each area, outline the procedure for their cultivation and signalisation, perform necessary calculations for flight (p. 6.1.2).

The captain must investigate each area before cultivation of the field by performing personal detour or in special cases by observation flight on the aircraft; together with customer's representative, who determines areas, which will be banned for cultivation as such that do not provide flight safety; before cultivation the captain performs observation flight along the rectangular route on altitude not less than 50m in order to determine the location of signals, obstacles and specific references (p. 6.1.4).

The Rules provide that before the flights the distance calculations from the signal signs to the obstacles are carried out in order to determine the paths for climb and descent to enter and leave the track (p. 6.3.5). In addition, obstacles located in the area of works and on its surroundings, should be marked by warning signals, warning signs (red flags), which are installed near obstacles. Before the start of flight the captain together with the representative of the customer instructs (with signatures) all workers, including signalmen, regarding their duties (p. 7.3.1). In p.6.3.17 it is clearly stated that the captain is prohibited to flights and works over the areas without signals.

Interaction "subject-object". Evidentias base of the dynamics of overflight of the aircraft under the power line could be only information from the cockpit. The only information source of flight information on An-2 during agricultural-air works is barograph. Consequently, for the proper analysis of the causes of aviation incidents during agricultural-air works, video recorders should be installed on An-2 and other light aircrafts to capture dashboard and control column. For this purpose video recorder DOS LS400W or cheaper option ImCam 2701 (automobile video recorder) could be used.

Interaction "subject-environment". Physical wear of the aircraft and vertical wind gust could create a side effect, which led to serious incident. The Rules state that the captain must get the weather forecast before the start of the agricultural-air works (p. 5.12.4). One reason of the serious incident is that the place, which can be characterised as a "trap" was not marked. The solution of such problem could be marking of the power lines in the areas of the aircrafts operations, e.g. in the United Arab Emirates white plastic balls are placed on the power lines.

Interaction "subject-subject". The communication between the captain and co-pilot was disrupted because of sudden emergency situation and necessity to avoid collision with the power line wires. The interaction between the crew and signalman (the representator of the customer), which ensures the flight safety during the flights near obstacles was not provided during flight preparation phase.

Actions of the captain. According to the Rules procedure and conditions for carrying out agricultural-air works flights are determined by the instruction made by the captain. The flights near the power lines are allowed with the height not less than 10 m over the power lines when the wind speed is lower than 4 m/s and not less than 20 m when wind speed is over 4 m/s (p. 6.3.6). During the agricultural-air works the flights over the power lines (more than 1000 V) are allowed only with turned off agricultural equipment on the height not less than 50 m. During the flight along

the power lines with strain more than 750 kV and more the distance must be increased by 50 m.

Because the height of the flight was less than height of the power line, the captain decided to descent and fly under the wires in order to avoid collision. In the emergency situation, possibility of the collision with the power line the actions of the pilots were correct but the manoeuvre was started too late, which can be explained by poor visibility of the wires across the background of afforestation.

6. Results Discussion

In Ukraine during the period for 2013-2016, there were five collisions of aircraft with electric power lines, two of them with a fatal outcome. In addition to the above serious incident, the following events occurred [9-12]:

1. 17.07.2014 in the unauthorized performance of aviation-chemical works in the area of the np Bilashki, Talne region, Cherkasy region. On the plane AI-10, the plane collided with electric power lines, resulting in falling to the ground and burned. The pilot of the plane was killed.
2. 26.07.2014 in the village of Lisnevichi, Pustomytiv district, Lviv region. During an unauthorized flight on an unregistered X-32 Bekas plane, the plane collided with electric power lines and fell to the ground. As a result of the event, the pilot of the plane died.
3. 09.09.2014 while performing unauthorized agricultural-air works on the plane X-32 Bekas around village Repki, Chernihiv region. The aircraft collided with wires power lines, causing fell to the ground and explosion. The pilot of the plane died.
4. 7.06.2016 near Ivanovka, Novooshitsky area, Khmelnytskyi region, the Cheleng Aero helicopter Robinson-44 UR-LWW, performing a flight to demonstrate the work of agricultural equipment, collided with electric power lines and tore off their helicopter carrying roller shaft. As a result, the helicopter fell to the ground.

The fact that such cases are repeated indicates that there are systemic deficiencies in the preparation of pilots and organization of flights. Their warning in the future requires the development and implementation of preventive measures.

7. Conclusion

In order to prevent aviation incidents and accidents during the agricultural-air works the ICAO experience should be implemented. Namely, crew training programmes: crew resource management (CRM) and line oriented flight training (LOFT). These programmes should be complemented by the critical analysis of specific aviation accidents and incidents, which took place during agricultural-air works.

The full scale CRM training programme is the best decision for small airlines, but a number of problems arise. Among them high staff and instructors turnover, relatively low level of pilots and strict financial constrains.

There are a number of differences between small and large operators:

1. High number of short flight because of a number of areas with frequent take-offs and landings;
2. Minimal financial support of expenses on additional trainings;
3. Limited possibilities to attract crew members to CRM training;
4. Insufficient amount of training equipment available in some small operators [1].

Because of such drawbacks the creation of own programmes for some airlines could be quite difficult. We propose to develop a basic programme for small airlines, which are involved in agricultural-air works. The first stage of this programme is “study”, namely collection and update of the data and its verification. Second stage - “discussion” - presentation of thoughts and doubts and searching of ideas. Third - “decision making” - taking right decisions to ensure flight safety. Fourth – “critical analysis” – a review of plans and results, active feedback.

Financial problems can prevent implementation of the training programme. In this case flight simulators can become a solution. Flight simulators can help for training flights in fog, with strong cross wind and with various failures of equipment.

Among available flight simulators Microsoft Flight Simulator X (FSX), X-Plane, Prepar 3D can be used. The FSX has the following advantages: better visual effects, a number of addons, which have a lot of modern and old planes. X-Plane has better model of flight. Blade element theory used in X-Plane allows more realistic modelling of objects behaviour in flight. Therefore, X-Plane was certified by Federal Aviation Administration (FAA) for training flights. The main features of Prepar 3D are steady software operation and more realistic entourage [5].

The huge step in improving flight safety in future is creation of database with maps and flight steps for processing. This database should be available for airlines members.

For analysis of aviation accidents and incidents during agricultural-air works it is necessary to install video recording equipment in the cockpit, to capture instrument panel and record pilots communications.

The power electric lines should be marked with plastic balls in accordance with international practice as preventive measure.

It is proposed in the cockpit of the An-2 airplane install the car restorer of the instrument panel to obtain objective information about the flight parameters and simultaneously to write the talks in the cockpit.

References

[1] E. Salas, D. E. Maurino (2013) *Human factors in aviation* (2 nd ed.). Amsterdam, Academic Press/Elsevier. 711 p.

[2] Dennis A. Vincenzi, John A. Wise, Mustapha Mouloua, Peter A. Hancock (2008) *Human Factors in Simulation and Training*. WF Moroney, MG Lilienthal, CRC Press, 472 p.

[3] A. Shanmugam, T. Paul Robert, (2015) Human factors engineering in aircraft maintenance: a review. *Journal of Quality in Maintenance Engineering*, vol. 21, issue: 4, pp.478-505, doi: 10.1108/JQME-05-2013-0030

[3] Udartseva T. (2014) *Pratsezdatnist aviatsiynich spetsialistiv* [The Performance of aviation specialists]. Kiev; Slavutich-Delhpin, 108p.

[4] Udartseva T. (2008) Otsinuvannya stanu pratsezdatnosty aviatsiynich operatoriv [Evaluation of state capacity of aviation operators]. *Otkritie informatsionnie i komputernie integrirovanie technologii*, no.39, pp.92-95.

[5] Kozlov V. (1998) Medico-psychologicheskiy analis prichin aviatsionnich intsidentov [Medical psychological analysis of the causes of aviation incidents]. Vestnic MACCAK, no. 2, pp. 11-15.

[6] International Civil Aviation Organization (1993) Training of flight crew in the cockpit (CRM) and flight training in the conditions approached to real (LOFT) Human factor: proceedings of No. 2, ICAO circular 217 – AN / 132. Montreal, Canada, 72 p.

[7] International Civil Aviation Organization (1998) Human factors training manual Doc 9683 – AN/950 (first ed). Montreal, Canada, 302 p.

[8] Chuntul A., Kosolapov O., Dudin V., Nesvizh R., Pisarenko A. (1998) Rezultati markrtingovich issledovaniy potrebnostey aviakompaniy v informacionnom obmene po sluchayam slognich i opasnich situaciy v poletach [Marketing research results of aviation company necessities in information exchange about difficult and dangerous flight cases]. Vestnic MACCAK no. 2, 60 – 68 pp.

[9] National Bureau of investigation of aviation events and incidents with civil aircraft (2013) Analysis of data on the safety results of the investigation of accidents with civilian aircraft that occurred in 2013. Available at: http://nbaai.gov.ua/uploads/pdf/Analysis _2013_ 2.pdf

[10] National Bureau of investigation of aviation events and incidents with civil aircraft (2014) Analysis of data on the safety results of the investigation of accidents with civilian aircraft that occurred in 2014. Available at: http://nbaai.gov.ua/uploads/pdf/Analysis_2014.pdf

[11] National Bureau of investigation of aviation events and incidents with civil aircraft (2015) Analysis of data on the safety results of the investigation of accidents with civilian aircraft that occurred in 2015. Available at: http://nbaai.gov.ua/uploads/pdf/Analysis_2015pdf

[12] National Bureau of investigation of aviation events and incidents with civil aircraft (2016) Analysis of data on the safety results of the investigation of accidents with civilian aircraft that occurred in 2016. Available at: http://nbaai.gov.ua/uploads/pdf/Analysis_2016.pdf

[13] The Verkhovna Rada of Ukraine (2006) The rules of organization and performance of aviation works in agriculture and forestry, available at: http://zakon2.rada.gov.ua/laws/ show/z0286-07 (accessed 22 December 2006)

Т.Є. Ударцева

Підвищення безпеки польотів при проведенні авіаційно-хімічних робіт

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mail: ute1@meta.ua

У статті представлено аналіз причин серйозного інциденту, що стався при проведенні авіаційно-хімічних робіт на літаку АН-2. **Мета роботи**: дослідити причини зіткнення літаків з лініями

електропередач під час виконання авіаційно-хімічних робіт та розробити засоби профілактики. **Методи**: з використанням моделі SHEL, рекомендованої ІКАО, встановлено основну та додаткові причини зіткнення літака з лінією електропередач. **Результати:** стаття містить результати аналізу даних розслідувань авіаційних подій та інцидентів з цивільними повітряними суднами, що сталися в Україні на протязі 2013 – 2016 років. На протязі цього періоду сталися п'ять зіткнень літальних апаратів з лініями електропередач, два з них зі смертельними наслідками. Оскільки подібні випадки мають непоодинокий характер, авторами розроблено відповідні попереджувальні заходи. **Обговорення результатів**: профілактика авіаційних подій під час польотів на малих висотах полягає у впровадженні досвіду ІКАО, а саме програм підготовки льотного екіпажу: оптимізації роботи екіпажу в кабіні (CRM) та льотної підготовки в умовах, наближених до реальних (LOFT). Запропоновано внесення до програм підготовки пілотів малих авіакомпаній питань, що стосуються реальних авіаційних подій та інцидентів, а також використання авіасимуляторів для тренування пілотів. В якості запобіжного заходу пропонується маркування проводів ліній електропередач пластиковими кулями згідно з міжнародною практикою.

Ключові слова: авіаційно-хімічні роботи; авіаційний інцидент; безпека польотів; підготовка пілотів.

Т.Е. Ударцева

Повышение безопасности полетов при проведении авиационно-химических работ

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mail: ute1@meta.ua

В статье представлен анализ причин серьезного инцидента, произошедшего при проведении авиационно-химических работ на самолете Ан-2. **Цель работы**: исследовать причины столкновения самолетов с линиями электропередач во время проведения авиационно-химических работ и разработать меры профилактики. **Методы:** с использованием модели SHEL, рекомендованной ІКАО, установлены основная и дополнительные причины столкновения самолета с линией электропередач. **Результаты:** Статья содержит результаты анализа данных расследований авиационных происшествий и инцидентов с гражданскими воздушными суднами, произошедшими в Украине в 2013 – 2016 годах. На протяжении этого периода произошло пять столкновений летательных аппаратов с линиями электропередач, два из них со смертельным исходом. Поскольку подобные случаи имеют неодиночный характер, авторами разработаны соответствующие предупредительные мероприятия. **Обсуждение результатов:** Профилактика авиационных происшествий во время полетов на малых высотах состоит во внедрении опыта ИКАО, а именно программ подготовки летного экипажа: оптимизации работы экипажа в кабине (CRM) и летной подготовки в условиях, приближенных к реальным (LOFT). Предложены внесение в программы подготовки пилотов малых авиакомпаний вопросов, касающихся реальных авиационных происшествий и инцидентов, а также использование авиастимуляторов для тренировки пилотов. В качестве предупредительной меры предлагается маркировка проводов линий электропередач пластиковыми шарами согласно международной практике.

Ключевые слова: авиационно-химические работы; авиационный инцидент; безопасность полётов; подготовка пилотов.

Udartseva Taniana (1969). Doctor of philosophy, lecturer.
Department of Safety Human Activities, National Aviation University, Kiev, Ukraine.
Education: Ukrainian national medical university, Kiev, Ukraine (1994).
Research area: human factor in aviation, performance of aviation professionals, diagnostics of functional states.
Publications: 40
E-mail: ute1@meta.ua

BIOTECHNOLOGY

UDC 577.112 .856:616.379-008.64:57.084:635.615:581.192.2
DOI: 10.18372/2306-1472.73.12181

Oksana Kryvosheyeva[1],
Katerina Garkava[2],
Larysa Natrus[3]

INFLUENCE OF MICRODOSE OF FATTY ACIDS OF *CITRULLUS COLOCYNTHIS* EXTRACT ON LIPOPROTEIDS OF RAT BLOOD WITH DIABETES MELLITUS TYPE 1

[1,2]National Aviation University
Kosmonavta Komarova Avenue 1, 03680, Kyiv, Ukraine
[3] Bogomolets National Medical University
T. Shevchenka blvd. 13, 01601, Kyiv, Ukraine
E-mails: [1]oikeyu@ukr.net; [2]immunolog@ukr.net; [3]lnatrus777@gmail.com

Abstract

Purpose: *To investigate the effect of microdoses of fatty acids (FA) of partially defatted dry Citrullus colocynthis extract on the lipid metabolism of rats with type 1 diabetes mellitus (DM) has been studied.* ***Methods:*** *Raw materials were degreased by extraction in a Soxhlet apparatus under conditions of shortening the evaporation time. With the help of gas-liquid chromatographic research, trace concentrations of FA were revealed in the composition of the obtained dry extract of Citrullus colocynthis.* ***Results:*** *It was found that the introduction of the extract of the Citrullus colocynthis vegetal solution with a dose of 400 mg/kg to rats causes redistribution of the classes of lipoproteins to the values of the control group. The dose of 200 mg/kg – does not cause statistically significant changes in plasma lipoproteins.* ***Conclusions:*** *Finally the Citrullus colocynthis extract containing micro doses of FA in their uniform distribution has a positive effect on lipid metabolism, does not bring to an increase of level of the total cholesterol, does not cause an increase of body weight.*

Keywords: cholesterol; *Citrullus colocynthis*; diabetes mellitus; fatty acids; lipoproteins; triglycerides.

1. Introduction

An urgency of diabetic problems in recent years throughout the world is on the top of the scale of the global epidemic. It is known that today there are 382 million patients with diabetes in the world and according to conservative experts' forecasts in 2030 their number will be 592 million [1]. According to date of the Institute of Endocrinology and Metabolism of the National Academy of Medical Sciences of Ukraine for the ten years, the prevalence of diabetes in Ukraine has grown by one and a half times. The most dangerous consequences of the epidemic of diabetes are its systemic vascular complications, which are the main bring disability and mortality of patients with diabetes [2].

Despite the wide range of pharmacological antidiabetic drugs used for the treatment of diabetes and its complications, now more attention is paid on the using of phytotherapy, which is based on the using of plants as preventive and even therapeutic agents [3]. Plants as sources of phytopreparations have already found application in the therapy of a number of diseases, including diabetes. However, mechanisms which are in the base of their therapeutic effect, as well as the most active active ingredient included in their composition, are unknown [4]. Therefore, the search for new forms of herbal preparations, studies of their influence on the organs and systems of the organism, the particularities of the side effects of medicinal plants are important areas of modern biotechnology in pharmacology, and pharmacy.

2. Statement of problem and analysis of the last researches

Herbal preparations contain a number of active components. Harmonious combination and interaction of biologically active substances (BAS) causes high pharmacotherapeutic efficacy of herbal

preparations. The rich chemical composition allows to influence the various links of the pathological process, ensures the complex action, and helps to reduce the profile of side effects. Due to the receipt of the full complex of BAS in their natural ratio, the optimal choice for peripheral reception in the activity of the functional systems of the body is ensured. In a multicomponent drug, there is a mutual enhancement of the useful pharmacological properties of each ingredient, their compliance with the polyvalence of the pathogenesis of the disease, the effect on the patient's organism in general is corrective [2].

Citrullus colocynthis from the family of *Cucurbitaceae* is a perennial herb, common in African and Arab countries, India and the Mediterranean countries, adapted to the climate of Ukraine. Vegetable raw materials of the *Citrullus colocynthis* of different processing is ucesed as antidiabetic, laxative, insecticidal agent, as an antidote to snake poison, in the therapy of edema, bacterial infection, etc. [5]. Despite the existing data, the mechanisms which take part in the implementation of the action of biologically active constituents of *Citrullus colocynthis* fruits are completely unknown.

In the search of the most effective form of application of *Citrullus colocynthis*, authors propose to use different types of extracts [6]. But there is no consensus onabout which extract is the most effective and safe.

Researchers give very contradictory data about benefits of different types of extracts, their safety and effectiveness. So, *Marwat S.K.* a review of literature sources in which authors tell about the positive impact of various extracts of *Citrullus colocynthis* seeds (water extract, skim water extract, water-methanol extract, ethyl acetate and n-butanol extracts) on the next indicators: glucose tolerance, weight gain, pancreas, liver, kidney, testicles, epididymal fat (adipose testicular fat), diaphragm muscle tissue, serum cholesterol, triglycerides, urea, creatinine, transaminases and alkaline phosphatase in animals with the first type of diabetes - streptozotice-induced diabetes. Some authors conclude that the most pronounced effect in diabetic rats gave the normal aqueous and n-butanol extracts, the lowest is the defatted aqueous extract [6]. *Hii C.S.* has an opposite opinion, and believes that the most of extracts have a positive insulinotropic effect has, except for n-butanol [7].

So, the technology of obtaining of a medicinal product is equally important in the realization of the pharmacological result. Recently, more attention has been paid to the development of extraction forms from vegetable raw materials instead of decoctions and infusions, since it is known that the maximum yield of biologically active substances is provided in extraction preparations, the therapeutic effect due to the accuracy of dosing is increased, the rationality of their use, the prolongation of terms and optimization of conditions storage.

In the experiment, we used the dry fruit extract *Citrullus colocynthis (L.) Shrad.*, Which had been prepared in the laboratory of the Department of Pharmacognosy and Botany of the Bogomolets National Medical University.

The crushed parts of the fruit (shell, pulp, seeds) were mixed with each other for further extraction in the Soxhlet apparatus. Extraction of Soxhlet is recognized as the standard and reference method for achieving complete lipid extraction [8]. This method has many advantages, but its main drawback is a long extraction time – 16-24 hours. The procedure was modified to improve the efficiency and reduce the extraction time by 5-10 times by using a press and raising the temperature. But after aqueous extraction of vegetable raw materials in the obtained dry extract with gas-liquid chromatography, we found trace concentrations of fatty acids (FA). We believe that the reason for the presence in the raw material of a certain amount of lipids after extraction with chloroform in the Soxhlet apparatus may be incomplete solubility of polar lipids - phospho- and glycolipids in organic solvents, which unsaturated and saturated FAs are found in our extract. But there are trace microdoses of FA dry extract *Citrullus colocynthis* that can influence on the lipid metabolism. We found it relevant to investigate the effect of the obtained substance on the lipid metabolism of experimental rats and on the body weight.

3. Purpose of the study

The purpose of the work was to study the effect of microdoses of the FA of partially defatted dry extract of *Citrullus colocynthis* on the lipid metabolism of rats with diabetes.

4. Materials and Methods

The model of type 1 diabetes was reproduced by injecting of streptozotocin to rats intraperitoneally once at a dose of 50 mg/kg. Previously it was dissolved in 0,1

M citrate buffer (pH 4,5). The duration of the experiment is 1 month. Control of the development of hyperglycemia was the level of glucose in the blood – 24,24±0,79 mmol/l. In the control groupthe level of the glucose was 8,03±0,4 mmol/l.

Laboratory animals were in standard accommodations of the vivarium of the Bogomolets National Medical University. The maintenance, care for animals, marking and all manipulations were carried out according to the provisions of the "European Convention for the Protection of Vertebrates used for experimental and scientific purposes" [9]. Conformity of the conducted scientific research with ethical requirements is confirmed by the Commission on Bioethics of the Bogomolets National Medical University according to the order of the Ministry of Health of Ukraine №231 of 01.11.2000.

For the study, 24 white mongrel rats weighing 150-270 g were selected. The "Control" group – healthy rats (N=6) were kept in a vivarium under similar accommodations, as were rats for the experiment. Rats of the "Model" group – with SD have got per os for 14 days water for injections – placebo. Group 1 – rats with diabetes who have got a dry extract of *Citrullus colocynthis* with a dose of 200 mg/kg of mass, a group 2 – rats with diabetes who have got *Citrullus colocynthis* at a dose of 400 mg/kg of weight for 14 days.

The FA composition was studied by gas chromatography on a gas chromatograph "Tsvet-500" (Russia) in the laboratory of experimental research at the Research Institute of ECM of the Bogomolets NMU. The FA peaks were identified by comparison with the time of obtaining the standard FA peaks. Quantitative estimation of FA lipids was carried out by the method of normalizing the planes of the peaks of methyl derivatives of FA and determining their composition in percents.

The study of biochemical indices in rats was carried out in the clinical diagnostic laboratory of the Scientific Research Institute of Experimental and Clinical Medicine (SRI ECM) of the Bogomolets National Medical University according to standard unified methods. The lipid metabolism was studied by biochemical sets for the determination of: total cholesterol – *Cholesterol PAP*, triglycerides – *Triglycerides PAP*, cholesterol-lipoproteins high – *HDL Cholesterol*, and low density – *LDL Cholesterol*, manufactured by *Diagnosicum Zrt (Hungary)* [10].

The statistical processing of the received data samples was carried out with the program *Statistica for Windows, Release 6.0*. Samples were compared using Student's t-test.

5. Research results

In experimental animals were studied dynamics of changes in body weight (fig. 1), and the serum lipids content: total cholesterol (Hol), triglycerides (TrG) and classes of lipoproteids: high-density lipoproteins (HDLP), low (LDLP) and very low (VLDLP) density.

According to our data (fig 1), the modeling of diabetes by administering streptozotocin leads to a 15% decrease of the body weight of animals relative to Control on the 5th day of the experiment. In the Model group, which got a placebo, further significant weight loss wasn't observed. All differences in average weight in the Model and Control groups were within the statistical deviation. The introduction of the plant extract *Citrullus colocynthis* caused a significant ($p \leq 0.05$) decreasing of the body weight of all animals in 1.4 times in group 1 relative to the initial values and in 1.2 times in group 2. Thus, we found that the administration to animals with model of diabet of dry extract *Citrullus colocynthis* causes a significant weight loss of 1.2-1.4 times the initial values.

In the model of diabetes, the ratio of total cholesterol (Hol) and triglycerides (TrG) changed due to a decrease of level of the cholesterol in the Model group to 1,42±0,1 mmol/L from the control value of 1,66±0,12 mmol/L and an increase of level of triglycerides from 1,03±0,03 mmol/L in the Control group to 1,38±0,06 mmol/L in the Model group (fig. 2). Introduction to rats with a solution of *Citrullus colocynthis* with a dose of 200 mg/kg practically did not change this ratio of cholesterol and triglycerides and was in the group 1 Hol – 1,38±0,06 mmol/L and TrG – 1,25±0,11 mmol/L . Introduction of *Citrullus colocynthis* with a dose of 400 mg/kg caused an increase of cholesterol in group 2 to 1,56±0,08 mmol/l, which is not different from Control and a significants decrease of level of triglycerides to 0,77±0,06 mmol/L, even lower than Control.

The dynamics of VLDLP fluctuation was as follows: in the Model group, an increase to 0,64±0,03 mmol/L was observed, compared to the Control of 0,46±0,017 mmol/L - this was a significant difference. In group 1, VLDLP increased relative to the group with diabetes to 0,56±0,05 mmol/L, which did not differ significantly from Control, and in group 2 decreased to 0,35±0,03 mmol/L, which was statistically different from the

model and the Control group. LDLP in the observation dynamics revealed no statistically significant changes in the rats of the experimental groups. Observing the level of HDLP cholesterol showed that in rats with diabetes they decreased 2.3 times to 0,36±0,08 mmol/L in comparison with Control 0,84±0,1 mmol/L. The introduction of *Citrullus colocynthis* extract in a dose of 200 mg/kg practically did not change this ratio: in group 1 it was 0,42±0,3 mmol/L, and in group 2 the amount of HDLP was 0,86±0,8 mmol/L, then there was a rise to the level of Control.

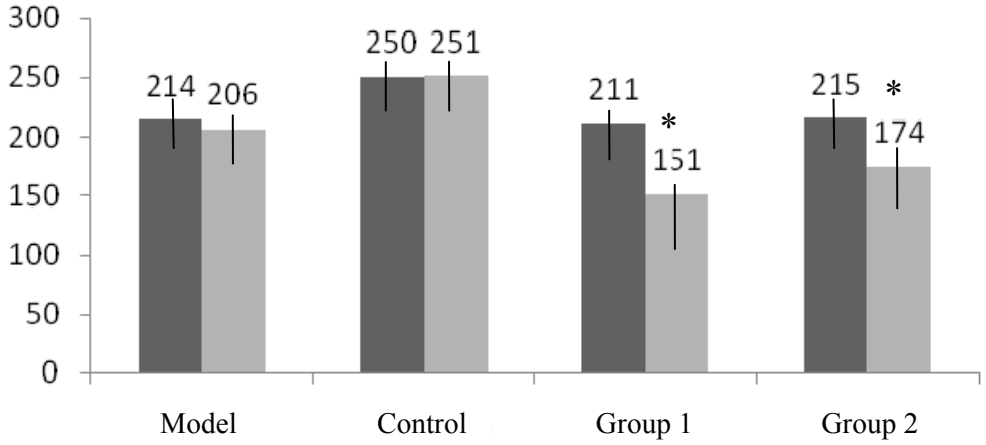


Fig. 1. Average body weight of animals (gr.) In groups of experimental rats on the 5th day of observation (dark bars) and on the 45th day of observation (light bars)
* - P≤0,05 statistically different from the baseline

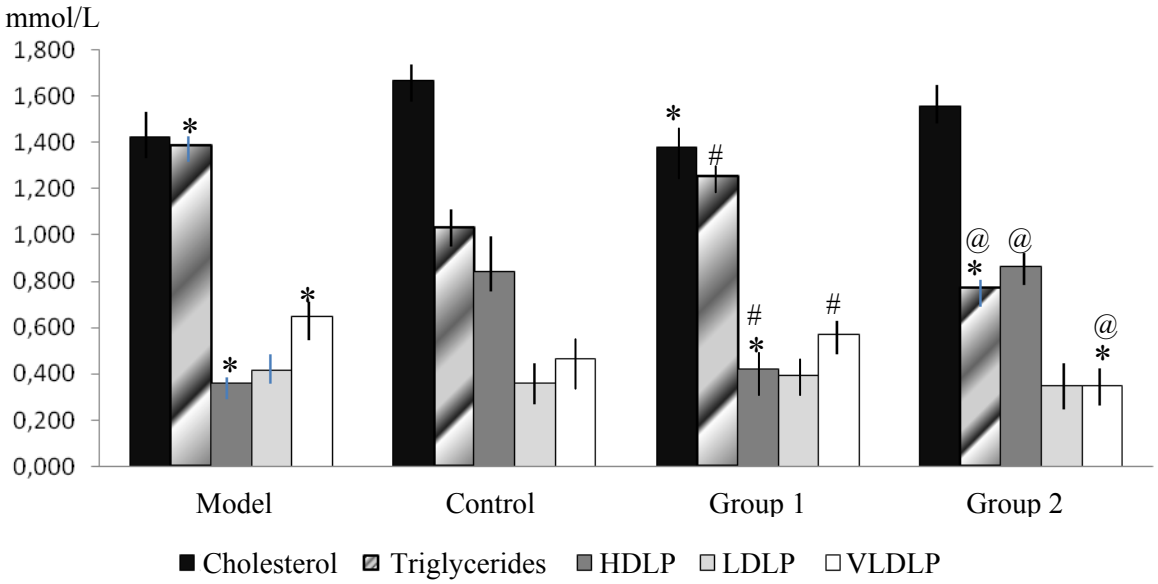


Fig. 2. Changes in lipids and classes of blood serum lipoproteins in rats of different experimental groups
* - Statistically significant difference compared to Control (p<0,05)
@ - Statistically significant difference in comparison with the diabet model (p<0,05)
# - Statistically significant difference between groups 1 and 2 (p<0,05)

Thus, we found that the introduction of dry extract *Citrullus colocynthis*, which is a source of FA, to the rats with the diabet model for 14 days, does not cause an increase in total plasma cholesterol. The effect of the *Citrullus colocynthis* plant solution 400 mg/kg caused a redistribution of the classes of

lipoproteins to the values of the control group. The dose of 200 mg/kg of the dry extract of *Citrullus colocynthis* does not cause statistically significant changes in plasma lipoproteins, but there is a positive tendency to establish a correlation of their classes.

Identification of changes in lipid metabolism under the influence of dry extract *Citrullus colocynthis* showed that the introduction of a small amount of FA into the body of an animal with type 1 diabetes can be effective and positively affect metabolic processes. Probably, not only the presence of saturated and unsaturated FA in partially defatted extract, but also their uniform distribution in raw materials, influenced the organism of experimental animals.

The study of the composition of the classes of lipoproteins was completely due to the fact that the FA is absorbed into the blood through the capillaries of the intestinal tract along with other nutrients. But the FA is too large to directly enter through small holes in the intestinal capillaries. Instead, they are absorbed by villi in the intestinal wall and synthesized into triglycerides. Triglycerides are coated with cholesterol and proteins to form chylomicron. In cells of peripheral organs and tissues, cholesterol exists mainly in the form of low density lipoproteins (LDLP) and in the form of phospholipids. Phospholipids are used by cells to build or renew their membranes. Cholesterol, which comes in the composition of LDLP, can also be used in cells to build membranes. Excess cholesterol in cell membranes disrupts their viscosity and the work of transmembrane transport systems.

High density lipoproteins (HDLPs) are particles that capture excess cholesterol from peripheral tissue cell membranes and transport it to either the liver or the intestines, that is, the functioning of HDLP cholesterol helps remove excess cholesterol from the body.

6. Conclusions

Introduction to rats with type 1 diabetes of the extract of a partially defatted *Citrullus colocynthis* extract with a dose of 400 mg/kg for 14 days causes a redistribution of classes of lipoproteins to the values of the control group. The dose of 200 mg/kg of the dry extract of *Citrullus colocynthis* does not cause statistically significant changes in plasma lipoproteins, but there is a positive tendency to establish a correlation of their classes.

Thus, *Citrullus colocynthis* extract, which contains micro doses of FA in their uniform distribution, has a positive effect on lipid metabolism, does not contribute to an increase in total cholesterol, does not cause an increase of the body weight.

References

[1] *Tron'ko N.D.*, Sokolova L.K., Vlasenko M.V., Kostyukevich A.A. (2015) Dostizhenie celej lecheniya pacientami s saxarny'm diabetom v Ukraine. Rezul'taty' Mezhdunarodnogo issledovaniya po izucheniyu praktiki vedeniya saxarnogo diabeta (IDMPS) [Achieving the goals of treatment for patients with diabetes in Ukraine. The results of the International Study on the Practice of Diabetes Mellitus (IDMPS)]. Endokry`nologiya, no. 4, pp. 658–668. (In Russian)

[2] *Chekina N.A.*, Chukaev S.A., Nikolaev S.M. (2010) Saxarny'j diabet: vozmozhnosti farmakoterapii s ispol'zovaniem sredstv rastitel'nogo proisxozhdeniya [Diabetes mellitus: the possibilities of pharmacotherapy with the use of herbal products] Vestnik Buryatskogo universiteta, no. 12, pp. 71–78. (In Russian)

[3] *Verma J.*, Rathore D.S., Agarwal S., Tripathi V. (2015) Effects of Citrullus colocynthis and Cucumis callosus extract on blood glucose levels in alloxan-induced diabetic rats. SGVU Int. J. Env. Sci. Technol, vol. 1, no. 1, pp. 50–56.

[4] *Hussain A.I.*, Rathore H.A., Sattar M.Z. [et al.] (2014) Citrullus colocynthis (L.) Schrad (bitter apple fruit): a review of its phytochemistry, pharmacology, traditional uses and nutritional potential. J. Ethnopharmacol, vol. 155, no. 1, pp. 54–66.

[5] *Shi C.*, Karim S., Wang C. [et al.] (2014) A review on antidiabetic activity of Citrullus colocynthis Schrad. Acta Pol. Pharm, vol. 71, no. 3, pp. 363–367.

[6] *Marwat S.K.*, Rehman F., Khan E.A. [et al.] (2014) Useful ethnophytomedicinal recipes of angiosperms used against diabetes in South East Asian Countries (India, Pakistan & Sri Lanka). Pak. J. Pharm. Sci, vol. 27, no. 5, pp. 1333–1358.

[7] *Hii C.S.*, Howell S.L. (1985) Effects of flavonoids on insulin secretion and 45Ca2+ handling in rat islets of Langerhans. J. Endocrinol, vol. 107, no. 1, pp. 1–8.

[8] *Virot M.*, Tomao V., Colnagui G. [et al.] (2007) New microwave-integrated Soxhlet extraction. An advantageous tool for the extraction

of lipids from food products. J. Chromatogr. A., vol. 1174, no. 1-2, pp. 138–144.

[9] *Lamazyan G.R.* (2015) Gipoglikemichna akty`vnist` suxogo ekstraktu plodiv Citrullus Colocynthis (L.) Shrad [Hypoglycemic activity of dry extract of fruits Citrullus Colocynthis (L.) Shrad]. Farmacevty`chny`j zhurnal, no. 5, pp. 90–94. (In Ukrainian)

[10] *Bazarnova M.A*., Gette Z.P. (1994) Klinichna laboratorna diagnosty`ka. Prakty`chni zanyattya z klinichnoyi bioximiyi [Clinical laboratory diagnostics. Practical classes in clinical biochemistry]. Ky`yiv, Vy`shha shkola Publ., 424 p. (In Ukrainian)

О.І. Кривошеєва[1], К.Г. Гаркава[2], Л.В. Натрус[3]

Вплив мікродоз жирних кислот екстракту *citrullus colocynthis* на ліпопротеїди крові щурів з цукровим діабетом 1 типу

[1,2]Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
[3]Національний медичний університет імені О.О. Богомольця, б-р Т. Шевченка, 13, Київ, Україна, 01601
E-mails: [1]oikeyu@ukr.net; [2]immunolog@ukr.net; [3]lnatrus777@gmail.com

Мета: Дослідити вплив мікродоз жирних кислот (ЖК) частково знежиреного сухого екстракту *Citrullus colocynthis* на ліпідний обмін щурів з цукровим діабетом (ЦД) 1 типу. **Методи дослідження:** Сировину знежирювали шляхом екстракції в апараті Сокслета за умов скорочення часу випарювання. За допомогою газорідинного хроматографічного дослідження виявлено у складі отриманого сухого екстракту *Citrullus colocynthis* слідові концентрації ЖК. **Результати:** Встановлено, що введення щурам екстракту рослинного розчину *Citrullus colocynthis* в дозі 400 мг/кг викликає перерозподіл класів ліпопротеїдів до значень контрольної групи. Доза 200 мг/кг – не викликає статистично достовірних змін ліпопротеїдів плазми крові. **Висновки:** Узагальнено, що екстракт *Citrullus colocynthis* який містить мікродози ЖК при їх рівномірному розподілу позитивно впливає на ліпідний обмін, не сприяє підвищенню загального холестерину, не викликає збільшення маси тіла.

Ключові слова: жирні кислоти; ліпопротеїди; тригліцериди; холестерин; цукровий діабет.

[1]О.И. Кривошеева, [2]Е.Г. Гаркава, [3]Л.В. Натрус

Влияние микродоз жирных кислот экстракта *citrullus colocynthis* на липопротеиды крови крыс с сахарным диабетом 1 типа

[1,2]Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
[3]Национальный медицинский университет имени А.А. Богомольца, б-р Т. Шевченко, 13, Киев, Украина, 01601
E-mails: [1]oikeyu@ukr.net; [2]immunolog@ukr.net; [3]lnatrus777@gmail.com

Цель: Исследовать влияние микродоз жирных кислот (ЖК) частично обезжиренного сухого экстракта *Citrullus colocynthis* на липидный обмен крыс с сахарным диабетом (СД) 1 типа. **Методы исследования:** Сырье обезжиривали путем экстракции в аппарате Сокслета в условиях сокращения времени выпаривания. С помощью газожидкостного хроматографического исследования выявлено в составе полученного сухого экстракта *Citrullus colocynthis* следовые концентрации ЖК. **Результаты:** Установлено, что введение крысам экстракта растительного раствора *Citrullus colocynthis* дозой 400 мг/кг вызывает перераспределение классов липопротеидов до значений контрольной группы. Доза 200 мг/кг – не вызывает статистически достоверных изменений липопротеидов плазмы крови. **Выводы:** Обобщено, что экстракт *Citrullus colocynthis* содержащий микродозы ЖК при их равномерном распределении положительно влияет на липидный обмен, не способствует повышению общего холестерина, не вызывает увеличения массы тела.

Ключевые слова: жирные кислоты; липопротеиды; сахарный диабет; триглицериды; холестерин.

Kryvosheyeva Oksana. Student.
Department of Biotechnology, National Aviation University.

Education: bachelor, National Aviation University, Kyiv, Ukraine (2016).
Research area: biotechnology, biology, theoretical medicine.
Publications: 16.
E-mail: oikeyu@ukr.net

Garkava Katerina. Doctor of Biology, Professor.
Head of the Department of Biotechnology, National Aviation University.
Education: Kyiv National Taras Shevchenko University, Kyiv, Ukraine (1974).
Research area: biotechnology, biology, ecobiotechnology, immunology.
Publications: 250.
E-mail: immunolog@ukr.net

Natrus Larysa. Doctor of Medicine, Professor.
Director of Scientific and Research Institute of Experimental and Clinical Medicine, Bogomolets National Medical University.
Education: Donetsk National Medical Gorky University, Donetsk, Ukraine (1994).
Research area: neurophysiology, clinical laboratory medicine, neurobiology, biology.
Publications: 300.
E-mail: lnatrus777@gmail.com

UDC 537.531:54-056:635.49 (045)
DOI: 10.18372/2306-1472.73.12187

Ludmila Kosogolova[1],
Bogdana Polishchuk[2],
Iryna Kryvutenko[3],
Kateryna Yablonska[4],
Zoriana Romanova[5],
Olena Hurska[6]

THE OPTIMIZING THE EXTRACTION PROCESS OF BIOLOGICALLY ACTIVE SUBSTANCES OBTAINED FROM DANDELION LEAVES (*TARAXACUM OFFICINALE* WIGG)

[1, 2, 3, 4,6]National Aviation University
Cosmonaut Komarov Avenue, 1, Kiev, Ukraine, 03680
[5]National University of food technologies
vul. Volodymyrska, 68, Kyiv, Ukraine, 01033
E-mails: [1,2,3]kbtnau@ukr.net ; [4]Katya_0126@bigmir.net ; [5]pani.zoriana@gmail.com ;
[6]helen.gurska@gmail.com

Abstract

Purpose: *to optimize the process of separation of biologically active substances from medicinal dandelion leaves.* ***Methods:*** *Different methods for the selection of biologically active substances from the medicinal dandelion (Taraxacum oficinale Wigg.), Including ultrasound treatment, were performed at 4, 5 and 6 W/m^2 at 5, 10, 15, 20, 25 minutes.* ***Results:*** *The aquatic extracts of dandelion officinalis (Taraxacum officinale Wigg) have been obtained for selecting biologically active substances, namely vitamin C. The optimal conditions for the extraction process are chosen: the ratio of raw material:extractant 1:20, extraction time - 30 minutes, temperature - 25 ° C . The extraction was performed with distilled water.* ***Discussion:*** *It was investigated that the extraction of medicinal plant material results in the diffusion of biologically active substances from the internal structures of the material particle. This process has its own peculiarities. First of all, the presence of porous septum, intercellular space and cellular movements reduces the diffusion rate. Secondly, in the porous partition, only those substances whose particles do not exceed pore sizes can penetrate. Also, the phenomenon of desorption observed in the cell after penetration of the extractant into it is characteristic. The optimal conditions for the extraction of biologically active substances from medicinal dandelion (Taraxacum officinale Wigg) were determined: - extractant water; - ratio of extractive raw material (1:20); - time of infusion 30 minutes; - temperature 25 °C. Ultrasonic fluctuations optimize the process of vitamin C extraction from dandelion leaf extracts and as a result, it has been found that the highest yield of ascorbic acid in extracts treatment by ultrasound for 25 minutes with a power of 6 W/m^2 and is 0.077 mg per 100 g of product.*

Keywords: dandelion officinalis (*Taraxacum officinale* Wigg); biologically active substance; ascorbic acid; extraction; ultrasound.

1. Introduction

Much attention has recently been paid to the extraction and study of biologically active substances (BAS) of wild plants, which are widely used in the food, perfumery, cosmetic and pharmaceutical industries. Natural regeneration and adaptability to the environment conditions make wildlife plants an inexhaustible raw material for BAS production [9].

The search and creation of new herbal medicinal products, the development of methods for controlling their quality with the use of modern methods of pharmaceutical analysis, as well as organizing their industrial production, is considered as an important task of biotechnology. The particular attention is paid to plants with centuries-old experience of using in folk medicine, including dandelion officinalis (Taraxacum oficinale Wigg).

Medicinal Dandelion is a perennial herb of Compositae family. It is spread everywhere and blossoms from spring to late fall. The plant has choleretic, antipyretic, expectorant, sedative, antispasmodic and mild hypnotic effects. Roots, leaves, grass, dandelion juice are all used for therapeutic purposes. The leaves of medicinal Dandelion, which contain hydroxycinnamic acids, flavonoids, amino acids, fatty acids, sugars, sterols, coumarins and vitamin C, are particularly rich in biologically active substances [12].

Multicomponent medical preparations, containing both a below-ground part (Hepatophyte, Detoxifit, Tonifit, Nephrophyte) and an above-ground part of medicinal Dandelion (Tonzilgon), are registered and widely used on the Ukrainian pharmaceutical market. The medications are used in case of acute and chronic respiratory disorders, diseases of the urinary tract, urinary-stone disease, as well as chronic cholecystitis, dyskinesia of the biliary tract, gall bladder, etc.

Among medical drugs of domestic production, there are currently no preparations made from the above-ground part of medicinal Dandelion, despite the wide spread of the plant throughout the area of Ukraine.

Methods of identifying and quantifying of biologically active substances (BAS) of medicinal Dandelion have not been elaborated sufficiently. Therefore, the development of BAT research methods and introduction of medicinal plant material into the biotechnological production are thought to be an actual direction of today's research [12].

Research methods and materials. The features of BAS extraction from materials with cellular structure are related to the fact that on the way to the substances contained in the cell, there is a cell wall, whose structure and physiological state may be different. Currently, the vast majority of extractive preparations are obtained from dried plant material, that is, dehydrated by natural or thermal drying. When dried, fresh plants lose water. The protoplasm shrinks and turns into a relatively small lump, the cellular juice passes into dry residue, and the cell's inner part is usually filled with air. Biologically active substances in dried raw materials are found in the form of dry conglomerates in the cell's cavity or adsorbed on cell's walls.

In many enterprises, the technology of long-term infusion of raw materials with an extractant (aqueous or hydroalcoholic solution with a 40-80% alcohol volume fraction) is widely used. The disadvantage of these processes is time duration, the need for a large number of solvents, which requires additional costs. Therefore, the scientists nowadays have developed a wide range of methods that contribute to intensifying the extraction process [5]. Among them, a great deal of attention is focused on the physical method, namely the use of ultrasound.

2. Materials and methods

Medicinal Dandelion raw material (leaves) was collected in the fall of 2016, when the leaves were fading. The raw plant material was dried to constant weight. The extraction of biologically active substances in the medicinal Dandelion raw material was carried out as follows: 2 g of crushed raw material (the degree of crushing is 2-3 mm) was placed into a conical flask of 100 ml capacity, then 40 ml of distilled water was added into it and the extracts were kept at room temperature for 30 minutes, and finally the extracts were processed by ultrasound.

3. Methods for determining vitamin C

There were placed from 1 to 10 cm3 of the test solution with the use of a pipette into a flask of 50 or 100 cm3 capacity, the volume was adjusted to 10 cm3 with the extractant and was titrated with a solution of 2.6-dichlorophenolindophenolate sodium, until a pale pink color appeared and did not disappear within 15-20 seconds.

At the same time, control studies on the content of reducing agents were performed. For doing this, the same amount of extract was placed to the flask, and as in the previous definition there were added the same amount of acetate buffer solution and 36-

40% solution of formaldehyde in the volume corresponding to the half volume of acetate buffer solution, then it was stirred and kept for 10 minutes, previously closing the flask with a plug. After that, the content was titrated with a solution of 2,6-dichlorophenolindophenolate sodium.

The calculation of ascorbic acid (X) output in mg per 100 g of the product is carried out by the formula:

$$X = \frac{(Y_1 - Y_2) \cdot T \cdot Y_3 \cdot 100}{Y_4 \cdot m}$$

4. Results and discussion

It is effective to apply ultrasonic vibrations in order to intensify the extraction process. At the same time, extraction is accelerated and the completeness of extraction of biologically active substances is achieved.

The greatest effect of ultrasound is detected when the cell of the extracted material is well saturated with an extracted ultrasound agent. Emerging ultrasound waves create cavitation. As a result, the impregnation of material and dissolution of cell's content are accelerated, the flow velocity of raw material particles increases, turbulent and vortex flows in the boundary diffusion layer of the extractant emerge. Molecular diffusion in the material cells and in the diffusion layer changes to convective one, which leads to the mass transfer intensification. The emergence of cavitation causes the destruction of cells. In this case, extraction is accelerated through the washing of extractive substances from destroyed cells. [2].

Ultrasonic extraction is one of the most common methods used in the process of obtaining biologically active substances from plant material. All extraction processes are limited by diffusion at the boundary of phase separation through a diffusion layer with a concentration gradient of extracting substance. The usage of ultrasound can significantly accelerate the extraction process, increase the output and reduce the cost of extracting substance, improve working conditions and increase its productivity.

When applying ultrasound, there is a sound-capillary effect. This leads to an increase in the depth and speed of liquid penetration in capillary channels under the action of ultrasound. In addition to accelerating the displacement of air bubbles, the ultrasound also creates conditions for their dissolution in liquid. It results in a sharp reduction of the extraction process [2].

The process of extraction from medicinal Dandelion leaves was performed under standard conditions, when the extracts were placed into flasks. Ultrasound processing was performed at 4, 5 and 6 W / m2 within 5, 10, 15, 20, 25 minutes. Control samples were exposed under the same conditions without irradiation, and the content of vitamin C was determined in all irradiated and control samples.

The content of ascorbic acid (X) in mg per 100 g of the product was determined by the formula:

$$X = \frac{(Y_1 - Y_2) \cdot T \cdot Y_3 \cdot 100}{Y_4 \cdot m},$$

Y1 is the volume of 2,6-dichlorophenolindophenolate sodium solution, which was spent on titrating the sample extract, cm3,

Y2 is the volume of 2,6-dichlorophenolindophenolate sodium solution, which was spent on the control test, cm3;

T is the titre of 2,6-dichlorophenolindophenolate sodium solution, mg / cm3;

Y3 is the extract volume obtained during extracting vitamin C from the product's weight, cm3;

Y4 is the extract volume used for titration, cm3;

M is the mass of product's weight, g

On the basis of obtained data, the diagrams of ultrasound influence on vitamin C extraction from medicinal Dandelion leaves were constructed.

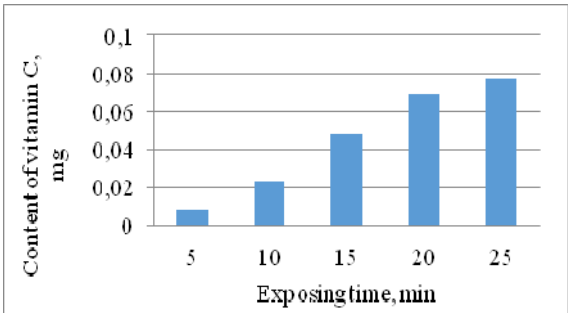


Fig.1 Exit of vitamin C at the power of ultrasonic oscillations 4 W/m^2

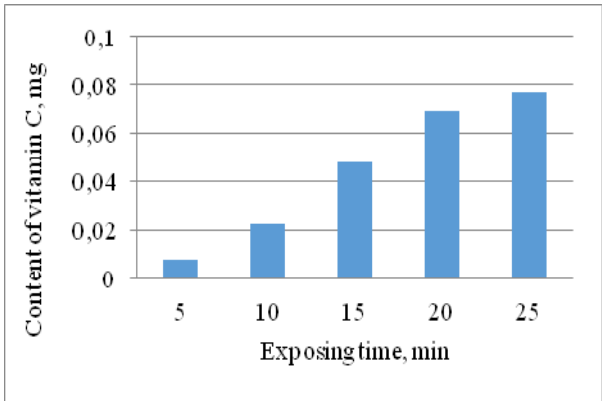


Fig. 2. Exit of vitamin C at the power of ultrasonic oscillations 5 W/m^2

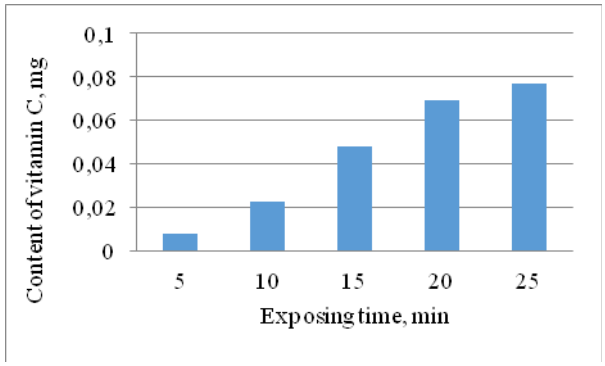


Fig. 3. Exit of vitamin C at the power of ultrasonic oscillations 6 W/m^2

Data in Fig. 1, Fig. 2 and Fig. 3 indicate that the highest content of vitamin C in extracts is observed under the influence of ultrasonic oscillations with a power of 6 W/m^2 for 25 minutes.

5. Conclusions

The optimal conditions for extracting biologically active substances from the leaves of Dandelion officinalis (*Taraxacum officinale* Wigg) were determined:

- extractant-water;
- ratio of raw material - extractant (1:20);
- infusion time - 30 minutes;
- temperature - 25 °C.

It was studied that the ultrasonic vibrations optimize the secretion process of vitamin C from Dandelion leaf extracts.

In addition, it was found that the highest yield of ascorbic acid occurs when processing extracts by ultrasound for 25 minutes with a power of 6 W/m^2 and corresponds to 0.076 mg per 100 g of product.

References

[1] Banyna I.P., Litvinenko M.M. (2003) *Pharmacological analysis of medicinal plant material: training manual.* Golden Pages, 86 p.

[2] Bezchasnyuk E.M., Dyachenko V.V., Kucher O. V. (2003) The process of extraction from medicinal plant material. *Farmakom*, no.1., pp. 54-56.

[3] Chopik V. I., Dudchenko L. G., Krasnov A.N. (1983) *Wildlife useful plants of Ukraine. Directory*. Kyiv, Scientific Opinion, 400 p.

[4] Gudzenko A.V. (2008) *The pharmacological study of the overhead part of the medicinal dandelion (Taraxacum officinale Wigg.) and the development of methods for the analysis of biologically active substances*. Diss. dokt. farm nauk [Pharmaceutical Chemistry and Pharmacognosy]. Kharkiv, 238 p.

[6] Yelin Yu. Ya., Zerova M. Ya., Luspa V. I., Shabarova S. I. (1979). *Gifts of forests*. Kyiv, Harvest, 440 p.

[7] Medicinal Dandelion (*Taraxacum officinale* Wigg.) [Ectopic Peppers]. Available at: http://hesychia.in.ua/taraxacum_officinale_uk.ht. (accessed 21.07.2014).

[8] Romanova Z.M., Kosogolova L.O. (2013) [Features of the technology of drinks from nontraditional raw materials]. *Problems of environmental biotechnology*, no.1. Available at: http://ecobio.nau.edu.ua/index.php/ecobiotech/article/view/4735/4849. (accessed 01.07.2013).

[9] Tsurkan O. O., Kovalchuk T. V., Gudzenko A.V. (2007). *The content of biologically active substances in the above-ground part of the medicinal dandelion depending on the vegetation phase.* Ternopil, Pharmaceutical Journal. no. 4., pp. 25.

[10] Zadorozhny A.M. (2000). *Herbs and health. Medicinal plants*. Moscow, Gamma Press, 512 p.

[11] Chopik V. I., Dudchenko L. G., Krasnov A.N. (1983). *Wildlife useful plants of Ukraine Directory*. Kyiv, Scientific Opinion, 400 p.

[12] Vitez L., Sluga H., Golc W.A., Mihelich E. (1986). *Contribution to the composition of dandelion*. Vol. 37, no. 5-6., pp. 193-197.

Л.О. Косоголова[1], Б.В. Поліщук[2], І.С. Кривутенко[3], К.М. Яблонська[4], З.М. Романова[5], О.О. Гурська[6]

Оптимізація процесу екстракції біологічно активних речовин, виділених з листя кульбаби лікарської (*Taraxacum officinale* Wigg).

[1, 2, 3, 4, 6] Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
[5]Національний університет харчових технологій, вулиця Володимирська, 68, м. Київ, Україна, 01033
E-mails: [1,2,3]kbtnau@ukr.net; [4]Katya_0126@bigmir.net; [5]pani.zoriana@gmail.com;
[6]helen.gurska@gmail.com.

Мета: оптимізувати процес виділення біологічно активних речовин з листя кульбаби лікарської. **Методи:** Розглянуто різні методи виділення біологічно активних речовин з кульбаби лікарської (*Taraxacum oficinale* Wigg.), в тому числі обробка ультразвуком, що проводили при потужностях 4, 5 та 6 Вт/м^2 протягом 5, 10, 15, 20, 25 хв. **Результати:** Отримано водні екстракти кульбаби лікарської (*Taraxacum oficinale* Wigg.) для виділення з них біологічно активних речовин, а саме вітаміну С. Підібрано оптимальні умови для процесу екстрагування: співвідношення сировина:екстрагент 1:20, час екстракції – 30 хв, температура – 25 °С. Екстракцію проводили дистильованою водою. **Обговорення:** Досліджено, що при екстрагуванні з лікарської рослинної сировини відбувається дифузія біологічно активних речовин із внутрішніх структур частинки матеріалу. Цей процес має свої особливості. Перш за все, наявність пористої перегородки, міжклітинного простору і клітинних ходів знижує швидкість дифузії. По-друге, у пори перегородки можуть проникати лише ті речовини, частинки яких не перевищують розмірів пор. А також характерним є явище десорбції, що спостерігається в клітині після проникнення в неї екстрагента. Визначено оптимальні умови екстрагування біологічно активних речовин з кульбаби лікарської (*Taraxacum officinale* Wigg): - екстрагент-вода; - співвідношення сировина-екстрагент (1:20); - час настоювання 30 хв; - температура 25 °С. Ультразвукові коливання оптимізують процес виділення вітаміну С з екстрактів листя кульбаби лікарської і в результаті цього встановлено, що найбільший вихід аскорбінової кислоти при обробленні екстрактів ультразвуком протягом 25 хв з потужністю 6 Вт/м^2 і становить 0,076 мг на 100г продукту.

Ключові слова: кульбаба лікарська (*Taraxacum officinale* Wigg), біологічно активна речовина, аскорбінова кислота, екстракція, ультразвук.

Л.О. Косоголова[1], Б.В. Полищук[2], И.С. Кривутенко[3], К.М. Яблонская[4], З.М. Романова[5], Е.О. Гурская[6]

Оптимизация процесса экстракции биологически активных веществ, выделенных из листьев одуванчика лекарственного (*Taraxacum officinale* Wigg).

[1, 2, 3, 4, 6] Национальный авиационный университет, ул. Космонавта Комарова, 1, Киев, Украина, 03680
[5]Национальний университет пищевых технологий, ул. Владимирская, 68, г. Киев, Украина, 01033
E-mails: [1,2,3]kbtnau@ukr.net; [4]Katya_0126@bigmir.net; [5]pani.zoriana@gmail.com;
[6]helen.gurska@gmail.com.

Цель: оптимизировать процесс выделения биологически активных веществ из листьев одуванчика лекарственного. **Методы**: Рассмотрены различные методы выделения биологически активных веществ из одуванчика лекарственного (*Taraxacum oficinale* Wigg.), в том числе обработка ультразвуком, проводившие при мощностях 4, 5 и 6 Вт / м^2 в течение 5, 10, 15, 20, 25 мин. **Результаты**: Получено водные экстракты одуванчика лекарственного (*Taraxacum oficinale* Wigg.) для выделения из них биологически активных веществ, а именно витамина С. Подобраны оптимальные условия для процесса экстрагирования: соотношение сырье:экстрагент 1:20, время экстракции - 30 мин, температура - 25 °С. Экстракцию проводили дистиллированной водой. **Обсуждение:** Доказано, что при экстрагировании из лекарственного растительного сырья происходит диффузия

биологически активных веществ из внутренних структур частицы материала. Этот процесс имеет свои особенности. Прежде всего, наличие пористой перегородки, межклеточного пространства и клеточных ходов снижает скорость диффузии. Во-вторых, в поры перегородки могут проникать только те вещества, частицы которых не превышают размеров пор. А также характерно явление десорбции, что наблюдается в клетке после проникновения в нее экстрагента. Определены оптимальные условия извлечения биологически активных веществ из одуванчика лекарственного (*Taraxacum officinale* Wigg): - экстрагент-вода; - соотношение сырье-экстрагент (1:20) - время настаивания 30 мин - температура 25 ° С. Ультразвуковые колебания оптимизируют процесс выделения витамина С из экстрактов листьев одуванчика лекарственного и в результате этого установлено, что наибольший выход аскорбиновой кислоты при обработке экстрактов ультразвуком в течение 25 мин с мощностью 6 Вт / м^2 и составляет 0,076 мг на 100г продукта.

Ключевые слова: одуванчик лекарственный (*Taraxacum officinale* Wigg); биологически активное вещество; аскорбиновая кислота; экстракция; ультразвук.

Ludmila Kosogolova (1958), Candidate of technical sciences, associate professor of Biotechnology Department, Educational and Scientific Institute of Ecological Safety, National Aviation University, Kyiv, Ukraine
Education: National University of food technologies, 1981
Research area: scientific researches are connected with the development of non-waste technologies of food products of prophylactic food from plant raw materials.
Publications: 105.
E-mail: kbtnau@ukr.net

Bogdana Polishchuk (1995), student of Biotechnology Department, Educational and Scientific Institute of Ecological Safety, National Aviation University, Kyiv, Ukraine
Education: National Aviation University, Kyiv, Ukraine
Research area: fermented beverages
Publications: 5.
E-mail: kbtnau@ukr.net

Iryna Kryvutenko (1995), student of Biotechnology Department, Educational and Scientific Institute of Ecological Safety, National Aviation University, Kyiv, Ukraine
Education: National Aviation University, Kyiv, Ukraine
Research area: fermented beverages
Publications: 4.
E-mail: kbtnau@ukr.net

Kateryna Yablonska (1989), assistant of Biotechnology Department, Educational and Scientific Institute of Ecological Safety, National Aviation University, Kyiv, Ukraine
Education: National Aviation University, 2012
Research area: fermented beverages
Publications: 20.
E-mail: Katya_0126@bigmir.net
Zoriana Romanova (1989), assistant of Biotechnology Department, Educational and Scientific Institute of Ecological Safety, National Aviation University, Kyiv, Ukraine
Education: National Aviation University, 2012
Research area: fermented beverages
Publications: 20.
E-mail: Katya_0126@bigmir.net

Olena Hurska (1975), Teacher of the Department of Foreign Languages in the specialty of the Educational and Scientific Humanitarian Institute, National Aviation University, Kyiv, Ukraine
Education: Kyiv State Linguistic University, 1999
Research area: Foreign Languages
Publications: 6.
E-mail: helen.gurska@gmail.com

DOI: 10.18372/2306-1472.73.12188

Taras Dvoretskij[1],
Vyacheslav Kukhtin[2]

THE TECHNOLOGY OF THE NEW INSTRUMENTAL ESTIMATION METHOD OF THE VEGETATION COVER MICROCLIMATIC CHARACTERISTICS

[1]Institute of Botany of the National Academy of Ukraine,
Department of Geobotanics and Ecology, 2, Tereshchenkivska st. 01601, Kyiv, Ukraine.
[2]Scientific and technical creative work Center for youth (Sphere),
Heroiv Stalinhradu Avenue, 18, 02000, Kyiv, Ukraine.
[1]E-mail: geobot@ukr.net; [2]E-mail: uanorb@ukr.net

Abstract

Purpose: *Development and approbation of the program-apparatus complex for the measurement of the basic microclimatic characteristics at the vegetation cover.* ***Methods:*** *The complex allows to measure simultaneously the air temperature and humidity, direct and indirect illumination into the sublayers and over the grass stand with the entry of the findings into the acting permanently storage device.* ***Results:*** *The device features control carried out on the experimental areas with the mire vegetation (Phragmito-Magno-Caricetea class association of the Klika in Klika and Novak 1941) demonstrated the compliance of the declared characteristics with the obtained results.* ***Discussion:*** *The question on the dependency form of the vegetation ecological role in the natural settings has not only practical importance, but vital theoretical significance, as the consequence transformation, in particular, the ecosystems, leads to the limit of their buffer possibilities and to the cessation of work on supporting of the existing soil and atmosphere balances. natural conditions, and under the anthropogenic impact, as well as the measures forming on the base of the obtained results, aimed to their conservation, recovery and inexhaustible use, is important and burning question. The systematic observation carrying out for the environment forming role change of the different ecosystem types under natural conditions, and under the anthropogenic impact, as well as the measures forming on the base of the obtained results, aimed to their conservation, recovery and inexhaustible use, is important and burning question.*

Keywords: automation; device; monitoring; microclimate; nature management.

1. Introduction

The estimation and monitoring of the vegetation cover microclimatic indexes are the practical tasks of big importance in view of the intensification of the anthropogenic impact and global climatic changes disturbing the balance of nature and the ecosystems stable functioning. The development and perfection of the vegetation cover microclimatic characteristics estimation direct methods is one of the key factors for the complex finding formation on the ecosystem current state. The development and upgrading of the direct methods of the vegetation cover microclimatic characteristics is one of the key factors in formation of the complex conclusion of the ecosystems current state. The development of the methods in this direction will provide the activity of immediacy and efficacy for the prevention of the nonreversible consequences and will allow to take measures on theirs localization, consequence ecosystem recovery and maintenance in virgin state. Not less important is the realization of the total ecological evaluation and monitoring of the vegetation environment forming role at the area of economic use.

2. Analysis of the latest research and publications

There exists the broad store of means and methods for ecological monitoring [1-8]. It was established that the formation and steady existing of the

vegetable associations is possible at the certain range of the microclimatic characteristics – the temperature and air humidity, direct and indirect illumination, albedo. Differing by considerable variability of values, depending of vertical and horizontal structures and vegetation state, the necessity arises in the synchronous measurement of characteristics enumerated above by all-height alignment of vegetation cover in the different points of experimental area, distributed on the considerable distance. The use of the conventional devices and technics imposes the limit on time for the experimenter movement from one point to another one, in preparation stage to the gauging, in convenience of measuring carrying out, and expectancy of the result wrongly recorded.

The creation of the efficacious control facilities operating with the minimum of hand man participation during the ecological investigation carrying out is very complicated problem, the decision of that is the object of interest through worldwide. The automatic posts for environment ecological monitoring has proved to be the most effective, have received the largest distribution [8] and the self-acting portable complex of meteorological stations too [9].

3. Research tasks

The similar posts created with some automation level are used in the USA (Chicago, Los-Angeles, and New-York) for example, in Japan, Gumma prefecture, Nagoya city, in Great Britain (the posts of Telstor firm), in Poland (Silesia mining industrial district) and others. The program-apparatus complex on such posts allows measuring of the temperature, the environment humidity, the wind direction, strength and velocity. Such posts are related to the posts of stationary type of automation posts for the environment ecological monitoring and are located into the specially equipped halls or into the heat-insulated containers. They are very complicated during the fabrication and operation and they do not allow deciding the problem of the microclimatic characteristic change in the specific vegetation associations. The second group, these are the separate devices that can carry out the necessary measurements as prepared for special tasks [11-12], and as well as industry output. The most close on the technical matter to the proposed method is the way of the multipoint temperature measurement necessary for the estimation of the environment forming vegetation role measurement, that are realized in the structures of A. Balakhtar [13] and I. Nechaev [14]. The versions of the multipoint measurement of the air relative humidity, direct and indirect illumination are absent.

4. Materials and methods of research

One of the modes for this problem deciding is the application of the technology on temperature, humidity and illumination sensors connection under the 1-Wire record with the obtained results fixation. As the temperature and humidity sensors, were selected the DHT22 chips of the Aosong Electronics Company [15]. In the range of -10°C up to +85°C, the producer warrants the absolute measurement error not less than ±0.5°C. For the illumination determination, is to be used MAX 44009, the Maxim producer [16], as the most perfect one. The optimal metrological characteristics, successful hardware-constructive decision, the possibility to joining up into the distributed network, makes attractive the digital sensors use at the microclimatic characteristics measurement under the field conditions. The chips transform the meaning of the temperature, humidity, and illumination into the digital code, that don't need the calibration and can be used in the temperature range of - 40 up to +85°C.

The task of the device created by the authors is the prompt measurement of the vegetation microclimatic characteristics (air temperature and humidity, as well as direct and inverse intensity of the solar radiation) in the different layers of the vegetation cover and of realizing it program-apparatus means, in that due to the introduction of the structure-time duplication, it provides the technical result obtaining, consisting of the linearity calibration parameters providing, increasing the sensibility, and practically, the exclusion of dependency from the instability of the semiconductor sensor individual parameters (Fig.1).

The given problem is to be decided by the unification of the air temperature, humidity and direct and inverse illumination sensors in the structural blocks of the information channel, that are connected with the electronic module for data processing and the investigation results storage (electronic memory).

The developed device involves the additional facilities: RTC (real time clock with the calendar) and the pressure sensor. All of them are connected in parallel with the electronic modules for data processing and the investigation results storage.

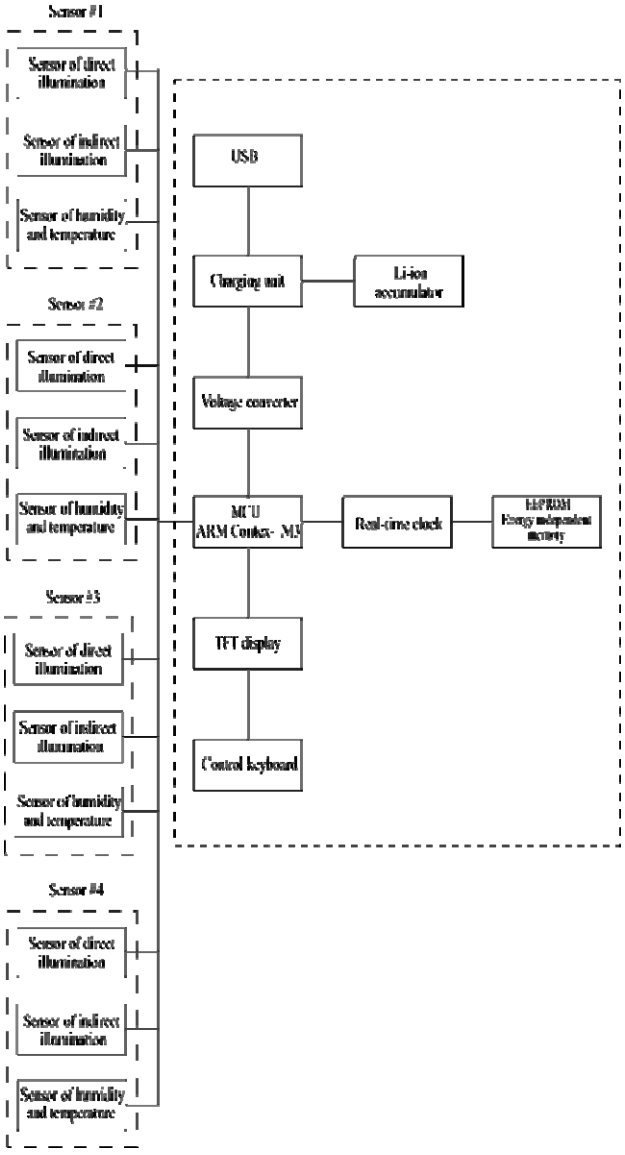


Fig. 1. Structural device chart for the microclimatic condition measurement

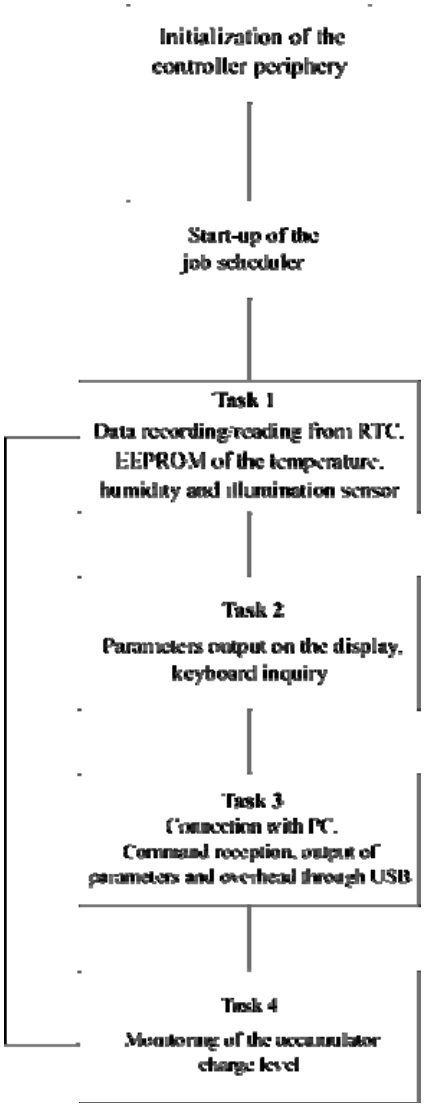


Fig. 2. Flow-chart of device operating

The device basic version allows connect four remote sensor blocks that can determine the air temperature in the range of -5° up to 100° C; the relative air humidity: of 10 up to 100%; the direct solar illumination of 1 to 999990 Lx; the backscattered solar radiation of 1 up to 99999 Lx.

The device operates as follows (Fig. 2):

1. At device switching, the microcontroller periphery initialization occurs: the readout from EEPROM (energy independent memory), task dispatcher starting. In case of malfunction detection (the data-transmitter unit didn't connect, or battery constant-voltage charge is insufficient), the text information is projected on display showing the malfunctions character and the recommendations on their elimination.

2. For user, on the display screen, the menu with the functions "Adjustment" and "Work" selections are proposed. The function "Adjustment" allows to a user with help of the key buttons "Up" and "Down", "Menu" and "Ok" to install the following parameters: the date (day, month, year), the time, manual or automatic mode for the characteristics measuring, the sensors sampling periodicity (in minutes), and the measuring result record in PSD (permanent storage device), as well as the work time beginning and end.

The function "Work" runs one of three modes selected by the user: "Manual", "Automatic", or "Data transfer to PC".

In any of listed modes, "Program control core" is monitoring the battery voltage measuring, is making the device keyboard sampling with the data reporting on display.

3. At "Manual" operation mode, the measuring is making on the "Ok" button press. It is reading the current time from the real time clock chip, reading of the air temperature and humidity values, the illumination level (direct and indirect), recording of the date, time, sensor indications into the energy independent memory with the data reporting on display.

4. At "Automatic" operation mode, the measuring is started to be conducted on the preset time achievement. Reading of the current time from the real time clock chip, reading of the air temperature and humidity values, the illumination level (direct and indirect), recording of the date, time, sensor indications into the energy independent memory are produced. At automatic mode operation, the display supply is switched off, and the output of the sensors stored data doesn't occur.

5. "Data transfer to PC" function is intended for the device porting through the USB port to the personal computer. The obtained measuring results represent the text file there the data are represented as follows:

- The date and the time of the gagging carrying out, the serial number of the gagging;
- The serial number of the data-transmitter units (upward) 0 – 3. Where 3, the data-transmitter units, shows the values of the abiotic parameters over the vegetation level. The data-transmitter units 0–2 show the values of the abiotic parameters at I-III vegetation sublayers;
- Sensor readout.

The transport of the obtained data to the Personal Computer should be carried out in the operating system Windows and Linux using the programs with access to the virtual serial port, for example, Cutecom.

The checkup of the functional possibilities put in the designed device was carried out at the areas occupied by the conventionally undisturbed mire vegetation located on the Trukhanov island, Kyiv city.

5. Results of the research

The determination of the mire vegetation microclimatic condition dynamics were carried out at the conventionally undisturbed *Phragmito-Magno-Caricetea*class associations of Klika in Klika et Novak 1941 represented by the *Carici acutae-Glycerietum maximae* associations Jilek et Valisek 1964, *Typhetum latifoliae* Lang 1973, *Eleocharitetum palustris* Ubrizsy 1948. The microclimatic characteristic changes of considered cenosis are connected with the species composition, its density, the phytomass, the grass stand layer age, as well as the growth place conditions. The variability of these factors changes considerably the character of the solar radiation distribution at the considered associations that in the end, produces the impact on their heat, water and energy balance.

As the initial base point, for the determination of the paludal ecosystem vegetation microclimatic characteristic variability, the riverside sandy strip bare, close to the experimental areas was selected. The measuring of the microclimatic characteristic values at the pulpit was made at the height compliant to the mire vegetation cover sublayers. Their average values are represented at the Table 1.

6. Discussion of the results

The *Carici acutae-Glycerietum maximae* vegetation association put together 13 – 15 species, the general projective cover (GPC) consisted of 100%, the phytomass varied of 644 up to 1048 g/m^2 , average – 926.4 g/m^2. The dynamics of the microclimatic conditions values has changed in the following limits: the air temperature over the grass stand, min - 35.5°C, max – 36.5°C, average – 35.9°C; the relative air humidity min – 37.4%, max – 45.7%, average – 41.4%; direct illumination min – 57507Lx, max – 78520Lx, average – 63590Lx; indirect illumination min – 3503Lx, max – 4262Lx, average – 3841Lx; albedo min - 5.4%, max – 6.5%, average – 6%; at the 3rd sublayer, the air temperature value changed of min – 37.8°C, up to 38.7°C, average – 38.3°C; relative humidity min – 31.7°C, max – 36.6%, average – 33.4%; direct illumination min – 56770Lx, max – 80732Lx, average – 67461Lx; indirect illumination min – 3087Lx, max – 3594Lx, average — 3427Lx; albedo min – 3.8%, max – 6.2%, average – 5.2%. The data for II and I sublayers are represented at the Table 1. At the *Typhetum latifoliae* vegetation association, it is represented 2 – 4 species, GPC – 100%, the phytomass varied of 1556 up to 6108g/m^2, average – 4255g/m^2. The data for II and I sublayers for the given association are represented at the Table 1.

The *Eleocharitetum palustris* vegetation association put together 9 – 11 species, GPC – 100%, the phytomass varied of 368 up to 1148 g/m^2, average – 610 g/m^2. The data for II and I sublayers are represented at the Table 1.

Table 1

Microclimatic characteristic value changes of *Phragmito-Magno-Caricetea* class association

Grass stand sublayer	Air temperature (C)			Relative air humidity (%)			Illumination (Lx)						Albedo (%)		
							direct			indirect					
	x	min	max	x	min	max	x	min	max	x	min	max	x	min	max
Carici acutae-Glycerietum maximae															
Over grass stand	35,9	35,5	36,5	41	37	46	63590	57508	78520	3842	3502	4262	6,1	5,4	6,6
III	38,3	37,8	38,7	33	32	37	67461	56771	80732	3427	3087	3594	5,2	3,8	6,2
II	37,4	36,1	38,8	40	39	42	23806	5368	62669	640	66	1284	6,4	0,2	18,1
I	34,3	33,1	36,9	48	44	53	11572	1290	37786	29,3	9	63	0,5	0,2	0,7
Typhetum latifoliae															
Over grass stand	28,9	28,6	29,6	57	49	61	65249	57508	79258	61546	53292	75525	5,8	3,9	7,3
III	28,7	27,3	30,2	53	47	60	26254	7004	77414	23786	5564	75007	20,5	3,1	29,9
II	30,0	29,1	30,6	53	49	54	54755	6682	77783	2935	1394	4585	8,9	3,9	20,9
I	30,3	28,3	32,5	56	52	60	2693	2177	3133	153	107	207	5,7	3,5	7,9
Eleocharitetum palustris															
Over grass stand	26,9	25,7	28	56	52	60	12481	1901	18248	1388	622	2004	14,4	7,3	32,7
III	26,4	24,6	27,3	54	49	62	7995	3364	16128	766	307	1319	10,0	6,7	12,3
II	30,1	24,0	27,9	52	48	69	7144	2592	16036	513	81	1267	5,8	2,3	10,2
I	27,8	24,1	31,6	53	43	67	3935	392	9861	113	2	269	2,3	0,5	4,4
Sandy beach															
Over grass stand	42,9	-	-	33	-	-	72662	-	-	18524	-	-	25,5	-	-
III	31,0	-	-	37	-	-	73359	-	-	15465	-	-	21,1	-	-
II	26,9	-	-	37	-	-	63775	-	-	17787	-	-	27,9	-	-
I	25,8	-	-	42	-	-	63775	-	-	10045	-	-	15,8	-	-

The obtained result analysis showed that all experimental areas of the mire vegetation are characterized by 1.2–1.5 multiple lesser value of the air temperature over the grass stand in comparison with controls ones. Vertical temperature gradient at the grass stand of all sublayers of the mire vegetation is bigger on 15–20% in comparison with control readings. The data of the relative air humidity over the grass stand at the experimental areas were higher on 30–45% than the control ones. The analysis of vertical gradient of the relative air humidity value showed that at III sublayer of considered cenosis, they were at 3–5% lesser than over the grass stand, whereas at II and I sublayers, the values of the air humidity increased a few (Table 1). Such distribution at the vertical cenosis structure of the relative air humidity values is explained by this that at III sublayer, two airflows intermixing occurs.

First, that is over the grass stand, and second one, that arises up from II and I sublayers. So, like this, the moisture transport process from the vegetation to the ground atmosphere occurs.

The temperature and the relative air humidity are one of the basic limiting factors for the vegetation existing. It was noted, that the environment factors of the considered cenosis form some specific areas defining the conditions of their habitat at the given territory (Fig. 3a).

The vertical change gradient of direct, indirect illuminations and albedo of paludal cenosis is characterized, practically, by linear dependence of the values dropping, depending of the vegetation sublayers state, and were at 1.5–2 times less than the control values (Table 1).

The direct and indirect grass stand illumination, also are the basic limiting factors for the vegetation development. It was identified, that the *Carici acutae-Glycerietum maximae* and *Typhetum latifoliae* cenosis, form two separated areas, that correspond to III and I grass stand sublayers (Fig. 3b). Such a distributionn is stipulated by the vertical cenosis structure with the species predominance at III and I sublayers. The *Eleocharitetum palustris* vegetation association is characterized by dense vertical species distribution that stipulates the compact area of the values distribution.

For the revelation of interdependency between the habitat formation role change and the type of cenosis organization, the comparative analysis of the microclimatic characteristic changes with the normalization of obtained results was carried out.

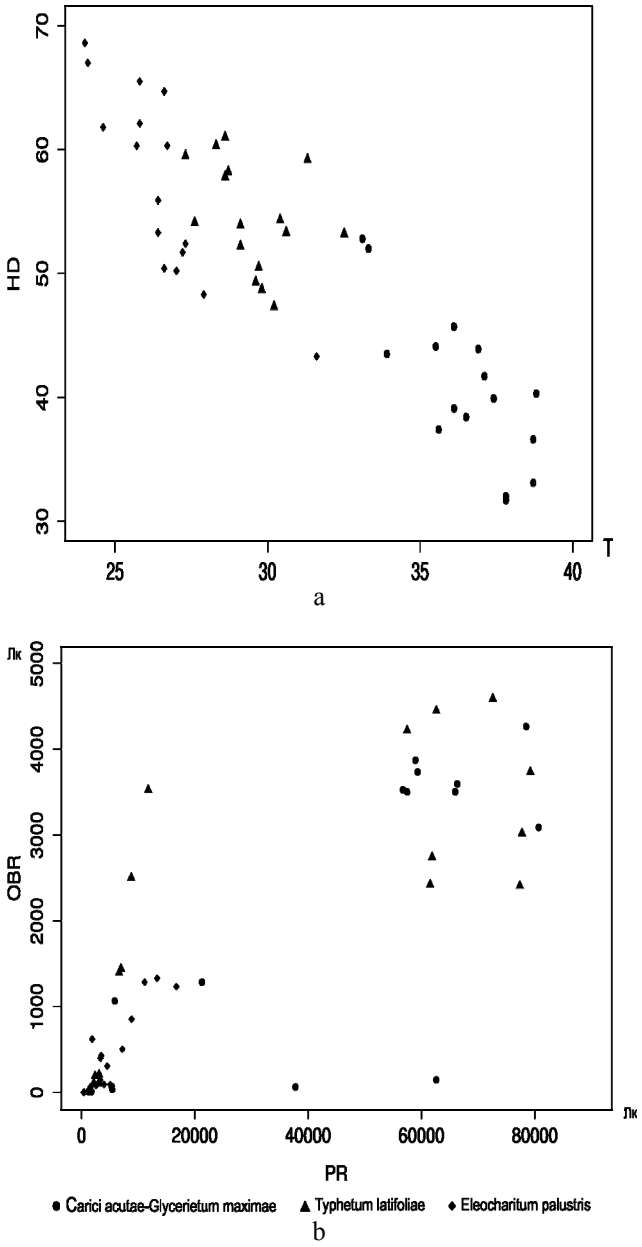


Fig. 3. Distribution of the basic microclimatic characteristics at the cenosis class Phragmito-Magno-Caricetea (Flood-lands of the Dnipro river, close to Kyiv city, Ukraine). Legend: T – air temperature in C, HD – relative air humidity in %, PR – direct solar radiation, OBR – indirect solar radiation.

In the capacity of 1, it was selected the values over the grass stand and was made the diagram of normalized value changes of the mire vegetation cenosis microclimatic characteristic (Fig. 4). The vertical gradient changes of the normalized temperature values and the relative air humidity for all considered cenosis are, practically, the same.

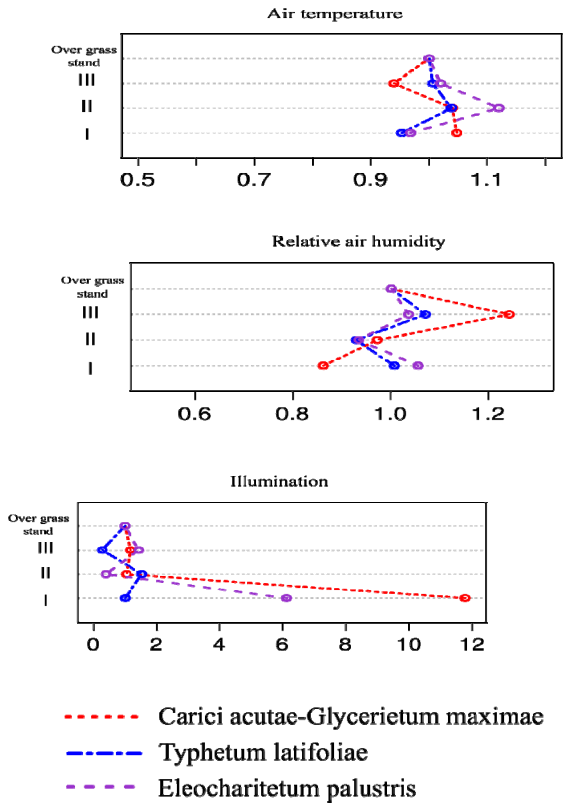


Fig. 4. Microclimatic characteristic value changes of the *Phragmito-Magno-Caricetea* class associations.

7. Conclusions

The question on the dependency form of the vegetation ecological role in the natural settings has not only practical importance, but vital theoretical significance, as the consequence transformation, in particular, the ecosystems, leads to the limit of their buffer possibilities and to the cessation of work on supporting of the existing soil and atmosphere balances. The systematic observation carrying out for the environment forming role change of the different ecosystem types under natural conditions, and under the anthropogenic impact, as well as the measures forming on the base of the obtained results, aimed to their conservation, recovery and inexhaustible use, is important and burning question. The analysis of the direct anthropogenic impact to the vegetation environment forming role, taking into account the nature changes, the most reasonably is to realize on the base of the complex approach – the consequence consideration of the basic factor impact to the ecosystem elements, the clarification of the relationships between them, the determination of the character and their interconnection direction. Evidently, to form the national policy on the anthropogenic impact consequence minimization, it

is necessary to carry out the permanent comprehensive tests aimed to the change determination of the vegetation microclimatic characteristics of the different ecosystem types.

References

[1] Bystritskaya T.L., Osychnyuk V.V. (1975) *Soils and initial biological efficiency of the steppes at the near-Azov area.* - Pub. House "Nauka", Moscow, 1975, p. 109. (in Russian).

[2] Koba V.P. (2004) [Dynamics of the temperature condition at the biocenosis Pinus pallasiana D. Don, damaged by fire] Scientific bulletin of UkrDLTU Conservation area matter at Galychyna, Podillya and Volyn. – Lviv: UkrDLTU. – 2004. Is. 14.8, pp. 434 – 438. (in Ukrainian).

[3] Smagin A.V., Sadovnikova N.B., Glagolev M.V., Kirichenko A.V. (2006) [New instrumental methods and portable electronic control devices for the ecological soil state and contiguous habitats] Ecological bulletin of the North Caucasus, 2006, v. 2, #1, pp. 5 – 16. (in Russian).

[4] Kalmykova A.L., Tereshin A.V. (2008) [The change of the microclimatic readings at the lianas use in Saratov city landscaping] Bulletin of the Saratov State Agrarian University after N.I. Vavilov, #3, 2008, pp. 20-23. (in Russian).

[5] Panfilovskaya K.A., Tikhodeyeva M.Yu. (2011) [Influence of the reserve condition to the dry meadow vegetation change at the birch overgrow] *Contemporary problems and prospects of the rational forest management under market conditions*. SPb: Pub. House SPbGLTU, 2011. pp. 104 – 108. (in Russian).

[6] Xiaoyu Liao, Zhaoli Liu, Yiyong Wang, Jiming Jin (2013) [Spatiotemporal variation in the microclimatic edge effect between wetland and farmland] Journal of geophysical research: atmospheres, 2013 vol. 118, P. 7640 – 76503. Available at: http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50573/pdf.

[7] Adam C. Watts, Leda N. Kobziar(2015) [Fire ecology hydrology and fire regulate edge influence on microclimate in wetland forest patches] Fire Ecology 2015. vol. 34(4), p.1383–1393. Available at: http://www.journals.uchicago.edu/doi/pdfplus/10.1086/683534.

[8] Bolotov A.G. (2012) [The measuring of the soil temperature using 1-Wire technology] Bulletin of the Altay State University #11(97), 2012, pp. 29-30. (in Russian).

[9] Pat. 2078357 RF, The station of the environment ecological monitoring / Gorelikov V.I., Banin V.N. # 2001120733/28; declared 24.07.2001, published 27.01.2003. (in Russian).

[10] Pat. 2199139 RF, The portal meteorological station. Gorelikov V.I., Tugaenko V.Yu. #2001123668/28; declared 28.08.2001; published 20.02.2003. (in Russian).

[11] Kurguzov A. (2004) Multipunctate thermometer. Available at: http://cxem.net/mc/mc8.php (in Russian).

[12] Girlin A. (2006)., The program-apparatus complex for multipoint monitoring of the temperature. Available at: http://www.schemz.narod.ru/TermN.htm (in Russian).

[13] Balakhtar A. (2005) Multipunctate thermometer Radio 2005, #4 – pp. 43-44 (in Russian).

[14] Nechaev I. (2003) Simple multipunctate thermometer Radio 2003, #7 – p. 35 (in Russian).

[15] Digital-output relative humidity and temperature sensor/module. Available at: https://www.sparkfun.com/datasheets/Sensors/Temperature/DHT22.pdf.

[16] Industry's Lowest-Power Ambient Light Sensor with ADC. Available at: https://datasheets.maximintegrated.com/en/ds/MAX44009.pdf.

Т.В. Дворецький[1], В.В. Кухтин[2]

Технологія нового інструментального методу оцінки мікрокліматичних умов рослинного покриву.

[1]Інститут ботаніки імені М.Г. Холодного НАН України м. Київ, вул. Терещенківська, 2 01601
[2]Центр науково-технічної творчості молоді «Сфера» м. Київ пр. героїв .Сталінграда, 18 02000
E-mails: [1]geobot@ukr.net; [2]uanorb@ukr.net

Мета: Розробка і апробація програмно-апаратного комплексу для вимірів основних мікрокліматичних характеристик в рослинному покриві. **Методи:** Комплекс дозволяє одночасно вимірювати температуру і вологість повітря, пряму і зворотну освітленість в під`ярусах і над

травостаном із занесенням отриманих даних в постійно запам'ятовуючий пристрій. **Результати:** Перевірка функціональних можливостей приладу, проведена на дослідних ділянках болотної рослинності (угруповання класу Phragmito - Magno - Caricetea Klika in Klika et Novák 1941) показала відповідність заявлених характеристик з отриманими результатами. **Обговорення:** Питання про форму залежності екологічної ролі рослинності в природних умовах має не лише практичне, але і дуже важливе теоретичне значення, оскільки подальша трансформація зокрема екосистем веде до межі їх буферних можливостей і припинення роботи по підтримці існуючих балансів ґрунту і атмосфери. Проведення систематичних спостережень за зміною средоутворючої ролі рослинності різних типів екосистем в природних умовах і під впливом антропогенних чинників, а також формування на основі отриманих результатів заходів спрямованих на їх збереження, відновлення і невичерпне використання є важливою і актуальною проблемою.

Ключові слова: автоматизація; прилад; моніторинг; мікроклімат; природокористування.

Т.В. Дворецкий[1], В.В. Кухтин[2]

Технология нового инструментального метода оценки микроклиматических характеристик растительного покрова.

[1]Институт ботаники имени Н.Г. Холодного НАН Украины г. Киев, ул. Терещенковская, 2
[2]Центр научно-технического творчества молодежи "Сфера", г. Киев.пр. Героев Сталинграда, 18 02000
E-mails: geobot@ukr.net; uanorb@ukr.net

Цель: Разработка и апробация программно-аппаратного комплекса для измерений основных микроклиматических характеристик в растительном покрове. **Методы:** Использование комплекса позволяет одновременно измерять температуру и влажность воздуха, прямую и обратную освещенность в подъярусах и над травостоем с занесением полученных данных в постоянно запоминающее устройство. **Результаты:** Проверка функциональных возможностей прибора, проведённая на опытных площадках болотной растительности (сообщества класса Phragmito-Magno-Caricetea Klika in Klika et Novák 1941) показала соответствие заявленных характеристик с полученными результатами. **Обсуждение:** Вопрос о форме зависимости экологической роли растительности в природных условиях имеет не только практическое, но и весьма важное теоретическое значение, поскольку дальнейшая трансформация в частности экосистем ведёт к пределу их буферных возможностей и прекращению работы по поддержанию существующих балансов почвы и атмосферы. Проведение систематических наблюдений за изменением средообразующей роли растительности различных типов экосистем в природных условиях и под воздействием антропогенных факторов, а также формирование на основе полученных результатов мероприятий направленных на их сохранение, восстановление и неистощимое использование является важной и актуальной проблемой.
Ключевые слова: автоматизация; прибор; мониторинг; микроклимат; природопользование.

Dvoretskij Taras (1971), PhD in Biology. Researcher of Department of geobotany department
Institute of Botany of the National Academy of Ukraine, Department of Geobotanics and Ecology. Kyiv, Ukraine
Education: National pedagogical Dragomanov university, 1998
Research area: ecology, biostatistics, wetlands' vegetation, research of botanical resources.
Publications: 35
E-mail: geobot_1@ukr.net

Kukhtin Vyacheslav (1979)
Scientific and technical creative work Center for youth (Sphere), Kyiv, Ukraine.
Education: NTUU "Igor Sikorsky Kyiv Politechnic Institute"
Research area: electronics, programming
Publications: 1
E-mail: uanorb@ukr.net

UDC 57.052(045)+57.088.5(045)
DOI: 10.18372/2306-1472.73.12189

Svitlana Gorobets[1]
Oksana Gorobets[2]
Oleksandr Medviediev[3]
Liubov Kuzminykh[4]

THE ROLE OF PATHOGENIC MICROORGANISMS IN THE ACCUMULATION OF BIOGENIC MAGNETIC NANOPARTICLES IN LUNG TISSUES

[1, 2, 3, 4]National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
37, Prospect Peremogy, Kiev, 03056, Ukraine
E-mails: [1]pitbm@ukr.net; [2]gorobets.oksana@gmail.com; [3]will.be.psychedelic@gmail.com;
[4]eugenekuz@gmail.com

Abstract

Purpose: *In this paper the role of pathogenic microorganisms in the accumulation of biogenic magnetic nanoparticles in lung tissues is examined. The main purpose of the present research is to prove that biogenic magnetic nanoparticles can be accumulated in lung tissues because of the pathogenic microorganisms during lung disease.* ***Methods:*** *Pairwise and multiple alignment of amino acid sequences, electron paramagnetic resonance.* ***Results:*** *The producers of biogenic magnetic nanoparticles were found among pathogenic microorganisms that cause lung disease. Biogenic magnetic nanoparticles can be accumulated in lung tissues because of these pathogenic microorganisms during relevant lung diseases. The presence of biogenic magnetic nanoparticles in lung tissues was proved using the electron paramagnetic resonance spectra analysis.* ***Discussion:*** *The results of the present research can be used to understand the possible reasons of toxic and allergic effects and even corking of vessels during uncontrolled accumulation of magnetic nanoparticles in different organs and tissues because of their magnetic dipole-dipole interaction with biogenic magnetic nanoparticles on cell membranes and to prevent it.*

Keywords: biogenic magnetic nanoparticles; biomineralization; electron paramagnetic resonance; lung tissues; pathogenic microorganisms.

1. Introduction

Biogenic magnetic nanoparticles (BMN) are the subject of intense research since 1975 when they were first found in magnetotactic bacteria (MTB) which show taxis in the direction of the geomagnetic field [1]. Since then, BMN were found in many other organisms that belong to all three domains: eukaryotes, prokaryotes and archaea.

In addition, the presence of the BMN were experimentally confirmed in such organisms as: protozoa and algae [2], worms [3], termites [4], snails [5], sea turtles [6], birds [7-9], ants and butterflies [10, 11], honey bees [12], lobsters [13], tritons [14], fish [15-17], dolphins and whales [18], bats [19] and human [20-22].

BMN were detected during experimental researches in several human tissues and organs: liver, heart, spleen [23], ethmoid bone [24], adrenal glands [25] and brain [21, 22]. BMN were also found in pathologically changed tissues after or during different neurodegenerative diseases [26], atherosclerosis [27], cancer [22, 28]. Moreover, BMN concentration is higher in the inflammation zone during cancer [22, 28] and neurodegenerative disease [29, 30] than in the same tissues in a normal state.

BMN are strong natural magnets and act as concentrators of various compounds and vesicles [31, 32]. BMN are located on cell membranes in several normal and abnormal human organs and tissues [21-26]. This may cause toxic and allergic effects and even corking of vessels during uncontrolled accumulation of magnetic nanoparticles in such organs and tissues [33] because of their magnetic dipole-dipole interaction with BMN on cell membranes [31, 32].

The problem of accumulation of magnetic nanoparticles in human organs, particular in lungs, is extremely relevant. Magnetic nanoparticles can reach organs and tissues in different ways. For example, accumulating during bacterial diseases

with pathogens in which BMN are present, during treatments with magnetic targeting drug delivery, produced as a result of biomineralization in the lung tissues or even get inside the human organism with contaminated air.

In view of the above, potential BMN producers research among different lung pathogens is important because of the possibility to prevent and cure possible corking of vessels, toxic and allergic effects during uncontrolled accumulation of magnetic nanoparticles

The main objective of this work is the detection of lung pathogens characterized by BMN biomineralization process and experimental confirmation of BMN presence in lung tissues.

2. Experimental part

To predict the pathogens that are potential producers of BMN, proteins homologues to the proteins of magnetotactic bacteria magnetosome island Magnetospirillum gryphiswaldense MSR-1 were found using the database and blast resource of the National center for biotechnology information.

A comparison of the amino acid sequences of the Mam group proteins, without which the BMN biomineralization in *Magnetospirillum gryphiswaldense* MSR-1 is impossible, was conducted using pairwise and multiple alignment of amino acid sequences methods with the proteins of the following bacteria *Streptococcus pneumoniae*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Mycobacterium tuberculosis*, *Mycobacterium bovis* and some other microorganisms of the following families: *Enterobacteriaceae* and *Peptostreptococcus spp*. as a pathogens with the inflammation zone and disease localization in the lung tissues.

In the present research the samples of *Sus domestica* lung, liver and heart tissues were used as a model, which is genetically close to the human organism and the mechanism of BMN biomineralization is the same for all the organisms of archaea, prokaryotes and eukaryotes domains. It is based on a set of homologous proteins to MTB proteins, without which the biomineralization of magnetic nanoparticles is impossible

Electron paramagnetic resonance (EPR) was used as a method for the presence of magnetic nanoparticles detecting in lung tissues as more suitable for biological samples analysis. Electron paramagnetic resonance is a method for studying materials with unpaired electrons. The basic concepts of EPR are analogous to those of nuclear magnetic resonance, but it is electron spins that are excited instead of the spins of atomic nuclei. EPR spectroscopy is particularly useful for studying metal complexes or organic radicals. BMN was experimentally found in the human heart and liver [23]. So, the samples of *Sus domestica* liver and heart were used for comparison of the EPR signal values (as the control samples).

Tissue samples were prepared at the Laboratory of magnetic nanotechnologies in biology and medicine of the chair of bioinformatics National Technical University of Ukraine “Igor Sykorsky Polytechnic Institute”. 5 *Sus domestica* lung tissue samples were taken for the research. 4 *Sus domestica* liver tissue samples and 4 *Sus domestica* heart tissue samples were taken as a control. All the samples were chiseled with a ceramic knife to prevent the ingestion of external iron particles. All the samples were dried to a constant mass in the drying cabinet at 105° C. 0,01 g of the dried substance of every sample was taken to determine the EPR spectrum.

The presence, quantity and character of magnetic nanoparticles in the investigated tissues were determined using the EPR spectroscopy method with dried samples. The samples were reused to determine the magnetic response after thermal treatment at 250° C.

The results obtained using EPR are usually presented through the first derivative of the absorption spectrum. Possible errors were taken into account in the calculations. Results were interpreted as for 1 g of raw tissues. Also, the average content of magnetite in each investigated tissue per 1 g of raw substance was determined. The diagrams of the dependence of the first derivative energy of adsorption of electromagnetic radiation from the magnetic field induction of dried and thermally treated samples of *Sus domestica* lung, heart and liver tissues are presented at the figures 1, 2 [34].

3. Results and discussion

As a result of the conducted bioinformatical analysis the following microorganisms were determined as synthesizers of crystalline biogenic magnetic nanoparticles: *Streptococcus pneumoniae*, *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Legionella pneumophila*, *Salmonella enterica*, *Yersinia pestis*, *Yersinia enterocolitica*. This is evidenced by the value of statistical numbers that showed the homology and common functions between the proteins of the investigated microorganisms and the proteins of MTB magnetosome island (MI), without which the biomineralization of magnetic nanoparticles is impossible.

The conducted bioinformatical analysis of the homology between MI MTB proteins and the proteins of pathogenic human microorganisms has shown that such microorganisms (pathogens of lung diseases) as *Staphylococcus aureus*, *Staphylococcus aureus* RF122, *Staphylococcus aureus subsp. aureus* ST228, *Klebsiella pneumoniae* RYC492, *Klebsiella pneumoniae* 342, *Legionella pneumophila*, *Pseudomonas aeruginosa*, *Pseudomonas aeruginosa* M18, *Enterobacteriaceaes*, *Salmonella enterica*, *Yersinia pestis*, *Yersinia enterocolitica*, *Yersinia enterocolitica* LC20, *Peptostreptococcus sp.* MV1, *Peptostreptococcus anaerobius*, *Peptostreptococcus anaerobius* VPI 4330, *Peptostreptococcus stomatis*, may be potential producers of amorphous BMN because mamA protein functions in this microorganism are different from the functions of the same MTB protein. In this case MamA can take part in the forming of BMN crystalline structure. For the intracellular crystalline BMN, that are localized in a cell as a chain, biomineralization, it is necessary to have all the homologues of the MI MTB proteins and the homologues of the mamK protein, that are responsible for the formation of BMN chains.

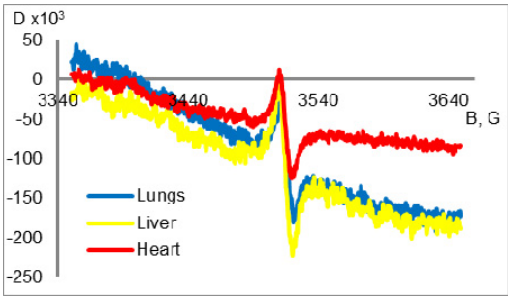


Fig. 1. EPR spectra: dependence of the first derivative of the electromagnetic microwave radiation absorption energy D on magnetic field flux density B for dried samples of Sus domestica lung, heart and liver tissues.

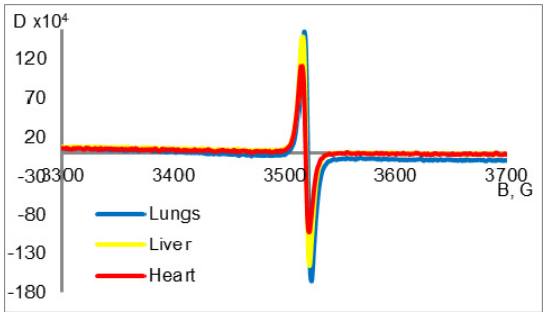


Fig. 2. EPR spectra: dependence of the first derivative of the electromagnetic microwave radiation absorption energy D on magnetic field flux density B for thermally treated samples of Sus domestica lung, heart and liver tissues.

At the same time, the functions of the MamK protein homologies in such organisms as *S. aureus*, *S. aureus subsp. aureus* ST228, *S. suis* BM407, *Enterobacter aerogenes* KCTC 2190, *Klebsiella pneumoniae* 342, Legionella pneumophila, P. aeruginosa, *S. enterica*, *Y. enterocolitica*, *Y. enterocolitica* LC20, *E. coli*, *M. tuberculosis complex*, *M. tuberculosis avium* are different from the functions of the same protein in MTB, which suggests a possible lack of BMN chain formation in these microorganisms and the localization of BMN in the cytoplasm (not on the membrane) due to the magneto-dipole interaction force.

56% of all analyzed microorganisms may be potential producers of BMN and 44% have no ability to magnetotaxis because of the MI MTB proteins lack.

Fig. 1, 2 shows dependences of the first derivative of adsorption energy of electromagnetic radiation (D) on the induction of a magnetic field (B, G) for dried and thermally treated samples. Figure 1 shows a diagram for all dried tissue samples: lungs, liver and heart. Figure 2 shows a diagram for all thermally treated tissue samples: lungs, liver and heart. As a result, the thermally treated samples show greater magnetic response than the dried samples.

In the present research the presence of the BMN in *Sus domestica* lung tissue was experimentally confirmed using analysis of EPR spectra of thermally treated and dried lungs, liver and heart samples. Moreover, BMN can be accumulated in lung tissues because of the above mentioned pathogenic microorganisms during relevant lung diseases. The BMN biomineralization process is the same for eukaryotes, prokaryotes and archaea. *Sus domestica* is a genetically close to human model organism, so we can assume, that the results of the present research are fair for the human lung tissues.

The results of the present research can be used to understand the possible reasons of toxic and allergic effects and even corking of vessels during uncontrolled accumulation of magnetic nanoparticles in different organs and tissues because of their magnetic dipole-dipole interaction with BMN on cell membranes and to prevent it.

References

[1] Blakemore R.P. (1975) Magnetotactic bacteria. Science, vol. 190, no. 4212 pp. 377-379. doi: 10.1126/science.170679

[2] Torres de Araujo F.F., Pires M.A., Frankel R.B., Bicudo C.E.M. (1986) Magnetite and

magnetotaxis in algae. Biophysical Journal, vol. 50, pp. 375-378.

[3] Cranfield C.G., Dawe A., Karloukovski V., Dunin-Borkowski R.E., de Pomerai D., Dobson J. (2004) Biogenic magnetite in the nematode Caenorhabditis elegans. Proceedings of the Royal Society, vol. 271, pp. 436-439. doi: 10.1098/rsbl.2004.0209

[4] Maher B.A. (1998) Magnetite biomineralization in termites. Proceedings of the Royal Society, vol. 265, pp. 733-737. doi: 10.1098/rspb.1998.0354

[5] Suzuki Y., Kopp R.E., Kogure T., Suga A., Takai K., Tsuchida S., Ozaki N., Endo K., Hashimoto J., Kato Y., Mizota C., Hirata T., Chiba H., Nealson K.H., Horikoshi K., Kirschvink J.L. (2006) Sclerite formation in the hydrothermal-vent "scaly-foot" gastropod—possible control of iron sulfide biomineralization by the animal. Earth and Planetary Science Letters, vol. 242, no. 1-2, pp. 39-50. doi: 10.1016/j.epsl.2005.11.029

[6] Irwin W.P., Lohmann K.J. (2005) Disruption of magnetic orientation in hatchling loggerhead sea turtles by pulsed magnetic fields. Journal of Comparative Physiology A, vol. 191, pp. 475-480. doi: 10.1007/s00359-005-0609-9

[7] Falkenberg G., Fleissner G., Schuchardt K., Kuehbacher M., Thalau P., Mouritsen H., Heyers D., Wellenreuther G., Fleissner G. (2010) Avian Magnetoreception: Elaborate Iron Mineral Containing Dendrites in the Upper Beak Seem to Be a Common Feature of Birds. PLoS One, vol. 5, no. 2. doi: 10.1371/journal.pone.0009231

[8] Cadiou H, McNaughton P.A. (2010) Avian magnetite-based magnetoreception: a physiologist's perspective. Journal of The Royal Society Interface, vol. 7, pp. 193-205. doi: 10.1098/rsif.2009.0423.focus

[9] Edelman N.B., Fritz T., Nimpf S., Pichler P., Lauwers M., Hickman R.W., Papadaki-Anastasopoulou A., Ushakova L., Heuser T., Resch G.P., Saunders M., Shaw J.A., Keays D.A. (2015) No evidence for intracellular magnetite in putative vertebrate magnetoreceptors identified by magnetic screening. PNAS, vol. 112, no. 1, pp. 262-267. doi: 10.1073/pnas.1407915112

[10] Ferreira de Oliveira J., Wajnberg E., Esquivel D. M., Weinkauf S., Winklhofer M., Hanzlik M. (2010) Ant antennae: are they sites for magnetoreception? Journal of The Royal Society Interface, vol. 7, pp. 143-152. doi: 10.1098/rsif.2009.0102

[11] Wajnberg E., Acosta-Avalos D., Alves O.C., Ferreira de Oliveira J., Srygley R.B., Esquivel D.M. (2010) Magnetoreception in eusocial insects: an update. Journal of The Royal Society Interface, vol. 7, pp. 207-225. doi: 10.1098/rsif.2009.0526.focus

[12] Hsu C.Y., Ko F.Y., Li C.W., Fann K., Lue J.T. (2007) Magnetoreception System in Honeybees (Apis mellifera). PLoS One, vol. 2, no. 4. doi: 10.1371/journal.pone.0000395

[13] Lohmann K.J., Lohmann C.M., Endres C.S. (2008) The sensory ecology of ocean navigation. Journal of Experimental Biology, vol. 211, pp. 1719-1728. doi: 10.1242/jeb.015792

[14] Brassart J., Kirschvink J.L., Phillips J.B., Borland S.C. (1999) Ferromagnetic material in the eastern red-spotted newt notophthalmus viridescens. Journal of Experimental Biology, vol. 202, pp. 3155-3160.

[15] Kirschvink J.L. (1989) Magnetite biomineralization and geomagnetic sensitivity in higher animals: an update and recommendations for future study. Bioelectromagnetics, vol. 10, no. 3, pp. 239-259.

[16] Diebel C.E., Proksch R., Green C.R., Neilson P., Walker M.M. (2000) Magnetite defines a vertebrate magnetoreceptor. Nature, vol. 406, pp. 299-302. doi: 10.1038/35018561

[17] Eder S.H.K., Cadiou H., Muhamad A., McNaughton P.A., Kirschvink J.L., Winklhofera M. (2012) Magnetic characterization of isolated candidate vertebrate magnetoreceptor cells. PNAS, vol. 109, pp. 12022-12027. doi: 10.1073/pnas.1205653109

[18] Zoeger J., Dunn J.R., Fuller M. (1981) Magnetic material in the head of the common Pacific dolphin. Science, vol. 213, pp. 892-894. doi: 10.1126/science.7256282

[19] Holland R.A., Kirschvink J.L., Doak T.G., Wikelski M. (2008) Bats Use Magnetite to Detect the Earth's Magnetic Field. PLoS One, vol. 3. doi: 10.1371/journal.pone.0001676

[20] Quintana C., Cowley J.M., Marhic C. (2004) Electron nanodiffraction and high-resolution electron microscopy studies of the structure and composition of physiological and pathological ferritin. Journal of Structural Biology, vol. 147, no. 2, pp. 166-178. doi: 10.1016/j.jsb.2004.03.001

[21] Collingwood J.F., Chong R.K., Kasama T., Cervera-Gontard L., Dunin-Borkowski R.E., Perry G., Pósfai M., Siedlak S.L., Simpson E.T., Smith M.A., Dobson J. (2008) Three-dimensional tomographic imaging and characterization of iron compounds within Alzheimer's plaque core material. Journal of Alzheimer's Disease, vol. 14, no. 2, pp. 235-245.

[22] Brem F., Hirt A.M., Winklhofer M., Frei K., Yonekawa Y., Wieser H.G., Dobson J. (2006) Magnetic iron compounds in the human brain: a

comparison of tumour and hippocampal tissue. Journal of The Royal Society Interface, vol. 3, pp. 833-841. doi: 10.1098/rsif.2006.0133

[23] Grassi-Schultheiss P.P., Heller F., Dobson J. (1997) Analysis of magnetic material in the human heart, spleen and liver. BioMetals, vol. 10, no. 4, pp. 351-355. doi: 10.1023/A:1018340920329

[24] Baker R.R., Mather J.G., Kennaugh J.H. (1983) Magnetic bones in human sinuses. Nature, vol. 301, pp. 78-80. doi:10.1038/301078a0

[25] Kirschvink J.L. (1981) Ferromagnetic crystals (magnetite?) in human tissue. Journal of Experimental Biology, vol. 92, no. 1, pp. 333-335.

[26] Hautot D., Pankhurst Q.A., Morris C.M., Curtis A., Burn J., Dobson J. (2007) Preliminary observation of elevated levels of nanocrystalline iron oxide in the basal ganglia of neuroferritinopathy patients. Biochimica et Biophysica Acta, vol. 1772, pp. 21-25. doi: 10.1016/j.bbadis.2006.09.011

[27] Alexeeva T.A., Gorobets S.V., Gorobets O.Yu., Demianenko I.V., Lazarenko O.M. (2014) Magnetic force microscopy of atherosclerotic plaque. Medical perspectives, vol. 19, no. 1, pp. 4-10.

[28] Kobayashi A., Yamamoto N., Kirschvink J.L. (1997) Studies of Inorganic Crystals in Biological Tissue: Magnetite in Human Tumor. Journal of the Japan Society of Powder and Powder Metallurgy, vol. 44, pp. 294-300.

[29] Moos T., Morgan E.H. (2004) The metabolism of neuronal iron and its pathogenic role in neurological disease: review. Annals of the New York Academy of Sciences, vol. 1012, pp. 14-26.

[30] Bartzokis G., Tishler T.A. (2000) MRI evaluation of basal ganglia ferritin iron and neurotoxicity in Alzheimer's and Huntingon's disease. Cellular and Molecular Biology, vol. 46, no. 4, pp. 821-833.

[31] Gorobets S.V., Gorobets O.Yu., Chyzh Yu.M., Sivenok D.V. (2013) Magnetic dipole interaction of endogenous magnetic nanoparticles with magnetoliposomes for targeted drug delivery. Biophysics, vol. 58, no. 3, pp. 379-384. doi: 10.1134/S000635091303007X

[32] Gorobets O.Yu., Gorobets S.V., Gorobets Yu.I. (2014) Biogenic Magnetic Nanoparticles: Biomineralization in Prokaryotes and Eukaryotes. In Dekker Encyclopedia of Nanoscience and Nanotechnology, Third Edition. CRC Press: New York, pp. 300 – 308.

[33] Kim D.H., Rozhkova E.A., Ulasov I.V., Bader S.D., Rajh T., Lesniak M.S., Novosad V. (2010) Biofunctionalized magnetic-vortex microdiscs for targeted cancer-cell destruction. Nature Materials, vol. 9, pp. 165-171. doi:10.1038/nmat2591

[34] Gorobets S.V., Gorobets O.Yu., Medviediev O., Golub V.O., Kuzminykh L.V. (2017) Biogenic magnetic nanoparticles in lung, heart and liver. Functional Materials, vol. 24, no. 3, pp. 405-408. doi:10.15407/fm24.03.405

С.В. Горобець[1], О.Ю. Горобець[2], О.В. Медвєдєв[3], Л.В. Кузьміних[4]

Роль патогенних мікроорганізмів у накопиченні біогенних магнітних наночастинок у тканинах легень

[1, 2, 3, 4]Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського", проспект Перемоги, 37, Київ, Україна, 03056
E-mails: [1]pitbm@ukr.net; [2]gorobets.oksana@gmail.com; [3]will.be.psychedelic@gmail.com; [4]eugenekuz@gmail.com

Мета: У цій роботі досліджується роль патогенних мікроорганізмів у накопиченні біогенних магнітних наночастинок у тканинах легень. Основна мета даного дослідження – довести, що біогенні магнітні наночастинки можуть потрапляти у тканини легень разом з патогенними мікроорганізмами та накопичуватись там при відповідних захворюваннях. **Методи дослідження:** Попарне та множинне вирівнювання амінокислотних послідовностей, електронний парамагнітний резонанс. **Результати:** Продуценти біогенних магнітних наночастинок були знайдені серед патогенних мікроорганізмів, що є збудниками захворювань легень. Біогенні магнітні наночастинки можуть потрапляти у тканини легень разом з патогенними мікроорганізмами та накопичуватись там при відповідних захворюваннях. Наявність біогенних магнітних наночастинок у тканинах легень була експериментально доведена в ході аналізу спектра електронного парамагнітного резонансу. **Обговорення:** Результати даного дослідження можуть бути використані для запобігання та розуміння можливих причин токсичного, алергічного впливу і закупорки судин під час неконтрольованого накопичення магнітних наночастинок в різних органах та тканинах через їх магнітні диполь-дипольні взаємодії з біогенними магнітними наночастинками на клітинних мембранах.

Ключові слова: біогенні магнітні наночастинки; біомінералізація; електронний парамагнітний резонанс; патогенні мікроорганізми; тканини легень.

С.В. Горобец[1], О.Ю. Горобец[2], А.В. Медведев[3], Л.В. Кузьминых[4]

Роль патогенных микроорганизмов в накоплении биогенных магнитных наночастичек в тканях легких

[1, 2, 3, 4] Национальный технический университет Украины "Киевский политехнический институт имени Игоря Сикорского", проспект Победы, 37, Киев, Украина, 03056

E-mails: [1]pitbm@ukr.net; [2]gorobets.oksana@gmail.com; [3]will.be.psychedelic@gmail.com; [4]eugenekuz@gmail.com

Цель: В данной работе исследуется роль патогенных микроорганизмов в накоплении биогенных магнитных наночастиц в тканях легких. Основная цель исследования – доказать, что биогенные магнитные наночастицы могут попадать в ткани легких вместе с патогенными микроорганизмами и накапливаться там при соответственных заболеваниях. **Методы исследования:** Попарное и множественное выравнивание аминокислотных последовательностей, электронный парамагнитный резонанс. **Результаты:** Продуценты биогенных магнитных наночастиц были обнаружены среди патогенных микроорганизмов, которые являются возбудителями заболеваний легких. Биогенные магнитные наночастицы могут попадать в ткани легких вместе с патогенными микроорганизмами и накапливаться там при соответственных заболеваниях. Наличие биогенных магнитных наночастиц в тканях легких была экспериментально подтверждена в ходе анализа спектра электронного парамагнитного резонанса. **Обсуждение:** Результаты данного исследования могут быть использованы для предотвращения и понимания возможных причин токсического, аллергического эффектов и закупорки сосудов во время неконтролируемого накопления магнитных наночастиц в различных органах и тканях вследствие их магнитных диполь-дипольных взаимодействий с биогенными магнитными наночастицами на клеточных мембранах.

Ключевые слова: биогенные магнитные наночастицы; биоминерализация; патогенные микроорганизмы; ткани легких; электронный парамагнитный резонанс.

Gorobets Svitlana. Doctor of Technical Sciences. Professor.
Chief of chair of Bioinformatics, Faculty of Biotechnology and Biotechnics, National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine.
Research area: bioinformatics, nanostructured materials, magnetic nanoparticles
Publications: 278
E-mail: pitbm@ukr.net

Gorobets Oksana. Doctor of Physical and Mathematical Sciences. Professor.
Chair of Bioinformatics, Faculty of Biotechnology and Biotechnics, National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine.
Research area: bioinformatics, nanostructured materials, nanomagnetic materials.
Publications: 184
E-mail: gorobets.oksana@gmail.com

Medviediev Oleksandr. Graduate student.
Chair of Bioinformatics, Faculty of Biotechnology and Biotechnics, National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine.
Research area: bioinformatics, magnetic nanoparticles.
Publications: 4
E-mail: will.be.psychedelic@gmail.com

Kuzminykh Liubov. Student.
Chair of Bioinformatics, Faculty of Biotechnology and Biotechnics, National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine.
Publications: 1
E-mail: 8eugenekuz@gmail.com

PROFESSIONAL EDUCATION

UDC 629.73-057.21:331.546(410)(045)
DOI: 10.18372/2306-1472.73.12190

Liliya Korol

PECULIARITIES OF CLASSIFYING AVIATION ENGINEERS ACCORDING TO THEIR SPECIALITIES IN GREAT BRITAIN

National aviation university, Aviation
1, Komarova avenue, Kyiv, 03680, Ukraine
E-mail: matroskina88@gmail.com

Abstract

Introduction*: The article deals with the issue of classifying aviation engineers in the system of higher education in Great Britain.* **Different ways of classification:** *There were considered both national classification and information sources available for future students.* **Types of aviation engineers:** *Joint Academic Coding System as well as jobs list available at Universities and Colleges Admissions Service were analyzed and three major groups of aviation engineers specializations were derived.* ***Conclusions****: We suggest that the results of the investigation should be used in further research of institutions that provide higher education for aviation engineers.*

Keywords: aviation engineer; classification; Great Britain; higher education; specializationб subject; training course.

1. Introduction

Aviation engineering is a vast field of study, which comprises numerous, sometimes intertwining, subjects. In order to advance in comparative analysis of aviation engineers' professional training in the United Kingdom and Ukraine, we need to define what aviation engineer is and what the main peculiarities of aviation engineer's classifications are there in the system of higher education of Great Britain. In order to do that it is necessary to consider different information sources, namely official list of professions, verified by the government, and information discourse available to future students, who are in the process of choosing a training course at a university.

2. Different ways of classification

Basically training courses in universities of Great Britain are classified according to the key subjects they are based on with the help of Joint Academic Coding System, which was developed by Higher Education Statistics Agency (HESA) and Universities and Colleges Admissions Service (UCAS) in 1999. There are 19 subject areas with numerous principal subjects associated with them. As aviation engineers can specialize on different aspects of aviation, they can choose the following principal subjects in the area H Engineering:

- General engineering
- Integrated engineering
- Safety engineering
- Computer-aided engineering
- Mechanics
- Fluid mechanics
- Solid mechanics
- Structural mechanics
- Energy resources
- Electromechanical engineering
- Aerospace engineering
- Aeronautical engineering
- Air passenger transport engineering
- Air freight transport engineering
- Air combat engineering
- Astronautical engineering
- Avionics
- Aerodynamics
- Flight mechanics
- Propulsion systems
- Aviation studies
- Aerospace engineering not elsewhere classified [1]

However, currently JACS does not fully meet the demands of comprehensive classification of profession in the contest of higher education. Although it was edited several times (in 200/2003, 2007/2008 and 2012/2013 academic years) [2] its hierarchical system is too rigid, thus not letting new specialties take their rightful place in the classification. That is why it is planned to develop and introduce a new Higher Education Classification of Subjects (HECoS) [3] in 2018/2019 academic year. This classification will not have strict structure, being just a list of subjects with corresponding codes, which will make it easier to integrate new subjects in the system of higher education of Great Britain. Moreover, it can be used to assist future students to choose training courses more efficiently.

Another way of classifying professions is introduced by special organizations and services, which provide information considering how to become a professional in a specific field to the public and can assist in choosing an appropriate course at the university. They can also inform you about national and international professional requirements, average salary and career prospects, and even offer psychological tests for a predisposition to a particular profession [4].

Some of these services target foreign students and were even created abroad, such as Study in UK (SI-UK) created in Japan in April 2003 [5], or StudyPortals, which has data on Bachelor and Master degrees in universities of various countries, Great Britain included. Other services, however, are national, thus providing information relevant for natives, and can even be restricted to specific territory (England, Scotland, Wales or Northern Ireland) [6] or are considered a charity organization [7].

Meanwhile, we consider The Royal Aeronautical Society (RAeS) and its online information resources of highest importance to our research, as it is dedicated to career perspectives specifically in aviation industry, aviation engineers included [8].

3. Types of aviation engineers

Having analyzed all the previously mentioned sources we can define that an aviation engineer is a person who is capable to create and develop new aviation and related to it technologies using his/her knowledge of mathematics, physics, and aerodynamics in order to design new aircraft as well as to improve already existing models and their maintenance. That is why the scope of activities of such a professional is huge and can be related with numerous aviation aspects from civil airport layout to high-tech military equipment. However one can distinguish three main subgroups of aviation engineers:

- air navigation engineers;
- space engineers;
- engineers with specializations related to aviation.

Air navigation engineers deal with creating and improving aircraft that can fly within the atmosphere of Earth. Therefore the most important field of study for them is mechanics, especially the aspects considering conventional flight and modernization of aircraft like an airplane.

Space engineers work in aeronautics, designing various spacecraft such as satellites as well as auxiliary technologies that could facilitate this process.

It is worth mentioning that nowadays these two types of aviation engineer often work in collaboration and their responsibilities sometimes can overlap. However we are still able to differentiate between the main fields of study for aviation engineers, namely aerodynamics, textures and materials, aircraft power plant, avionics, astronautics etc. [9]

Apart from air navigation and aeronautics there are other fields of science that in some way have an impact on the development of aviation industry. We consider among these such subjects as mechanics, electronics, system engineering and even astrophysics etc. [10]

Such variety of specializations for aviation engineers exists due to the fact that in order to function properly and effectively, aviation companies are in need of qualified engineering personnel that can work as a team and solve a problem of any difficulty. Each member of the team should be proficient in mathematics, physics, hydraulics and have auxiliary technical and management skills. Due to that universities try to provide a wide range of subjects for students to choose from without adhering exclusively to aviation topics [11].

Higher education institutions of Great Britain offer a great scope of subjects for aviation engineers with Bachelors and Masters Degrees, adapting to ever-changing demand of labour market of aviation industry. It is worth mentioning that training duration for a Bachelor Degree is three years with an additional year for on job training. Meanwhile

Masters need to study for another year [10]. This means that after 3-5 years of studying in a higher educational institution a person can get an aviation engineer diploma and start his/her career in aviation or proceed to postgraduate studies.

Nowadays according to UCAS statistics 48 higher educational institutions provide professional training for aviation engineers in Great Britain offering different training courses, including 8 courses for foreign students, 2 courses with the option to obtain a national certificate, 44 courses based on training programs [12].

The majority of these universities offer several training courses. However, having analyzed all propositions, we can distinguish among them 4 main categories:

- general subjects courses;
- courses with narrow field of study;
- major subject with additional non-engineering subject courses;
- combined subject courses.

General subjects refer to those subjects that embrace a wide scope of topics, such as aeronautics, airspace engineering, air transport, astrophysics etc. Those who finish general subject courses have extensive encyclopedia knowledge and can change specializations within the field easily due to that fact.

Courses with narrow field of study, on the other hand, are focused on one specific aspect of aviation engineering, investigating it in great detail. One can associate it with such subjects as air mechanics, spacecraft design, space system engineering. spacecraft materials, air transport management and logistics, airport and airlines management, avionics systems, space robotics etc.

Major subject with additional non-engineering subject courses are rather widespread in universities of Great Britain. Usually additional subjects are not connected with aviation, having a somehow practical nature. Thus, an aviation engineer with Bachelor or Master Degree will also be a certified pilot or a manager, have finished self-training or self-development courses or even have experienced intensive on job training for a whole year. We suggest that this additional feature gives specialists more opportunities and increases their chances to find a better well-paid position. Moreover, these specialists have better odds to get a promotion, as they have knowledge and skills which can be helpful on the workplace despite the fact that they are not strictly required.

Courses with combined subjects are distinguished by the fact that they combine two (sometimes several) major subjects which refer to one field of study. In the majority of cases general and narrow-focused subjects are combined, i.e. electronics and space systems technologies, aeronautics combined with aerodynamics, modern materials, aircraft system design, astronautics and calculated design, physics and satellite technologies or nuclear astrophysics etc. These training courses are available mainly for Masters Degrees, as they require from a student fundamental theoretical knowledge, which can be obtained during Bachelors training.

We can conclude that combined subject courses are the most beneficial kind of education and give the greatest opportunities on the global labour market, as they ensure professional and career development and provide basis for re-qualification if the need arises. This fact is considered a great advantage, taking into account the fact that aviation industry is developing rapidly as the new technologies appear, therefore causing extinction of some jobs like air navigator or onboard engineer, who are being replaced by modern equipment in the cockpit.

4. Conclusions

All things considered we can make a conclusion, that despite different ways to classify aviation engineers according to official JACS or other classification systems designed by various education information organizations, it is possible to group all aviation engineers' specializations according to the field of study and the way the courses are structured. After that it is possible to define the most advantageous and beneficial training courses, which will provide better chances to find a job and get a promotion. We have concluded that combined subject courses, which are mostly available as a Master's Degree course, are the most relevant nowadays, because they make a person holding this degree more competitive and better suited for sudden changes and new tendencies of the profession.

The classification of aviation engineers in the system of higher education of Great Britain is highly relevant in our further investigation and comparative analysis of the main distinctive features of aviation

engineers' professional training in Great Britain and Ukraine. We suggest to use the obtained data while conducting further research of the higher education providers for aviation engineers.

References

[1] Higher Education Statistics Agency (2012), JACS 3.0: Detailed (four digit) subject codes available at: https://www.hesa.ac.uk/support/documentation/jacs/jacs3-detailed (Accessed 31 October 2017).

[2] Hayward G., Hoelscher M., (2011) The Use of Large-Scale Administrative Data Sets to Monitor Progression from Vocational Education and Training into Higher Education in the UK: Possibilities and Methodological Challenges. Research in Comparative and International Education, vol. 6, no. 3, pp. 316-329.

[3] Youell A. (2017) Farewell to JACS, and Hello to HECoS. *Wonkhe.* Available at: http://wonkhe.com/blogs/data-farewell-jacs-hello-hecos/ (accessed 30.10.2017)

[4] Alpay E. (2013) Student Attraction to Engineering through Flexibility and Breadth in the Curriculum. European Journal of Engineering Education, vol. 38, no. 1, pp. 58-69

[5] Cox A., Taha N. (2016) International Students' Networks: A Case Study in a UK University. Studies in Higher Education, vol. 41, no. 1, pp. 182-198.

[6] Sedgmore L. (2012) Learners Need Face-to-Face Advice. Adults Learning, vol. 23, no 3, pp. 46-47.

[7] Hughes D. (2013) The Changing UK Careers Landscape: Tidal Waves, Turbulence and Transformation. British Journal of Guidance & Counselling, vol. 41, no. 3, pp. 226-239.

[8] *Careers In Aerospace* [Royal Aeronautical Society]. Available at: https://www.aerosociety.com/careers-education/resources/careers-information/careers-in-aerospace-website-and-social-media/ (accessed 16.10.2017)

[9] Davies P., Hughes A., Mangan J., Slack k. (2013) Labour Market Motivation and Undergraduates' Choice of Degree Subject. British Educational Research Journal. vol. 39, no. 2, pp. 361-382.

[10] Haas J., Ourtau M. (2009) Vocational Training and European Standardisation of Qualifications: The Case of Aircraft Maintenance. European Journal of Vocational Training, vol. 47, no. 2, pp. 180-200.

[11] Crawford I., Wang Z. (2016) The Impact of Placements on the Academic Performance of UK and International Students in Higher Education. Studies in Higher Education, vol. 41, no. 4, pp. 712-733.

[12] Aamodt P.O., Frolich N., Waagene E. (2011) Old Players--New Rules: Higher Education Institutions' Response to Educational Demand. Tertiary Education and Management, vol. 17, no. 2, pp. 163-179.

Л.П. Король

Особливості класифікації авіаційних інженерів відповідно до їх спеціальностей у Великій Британії

Кафедра авіаційної англійської мови,
Навчально-науковий інститут аеронавігації (Національний авіаційний університет, Україна, м. Київ. Пр. Комарова 1, e-mail: aamm@nau.edu.ua).
E-mail: matroskina88@gmail.com

Вступ: Стаття присвячена проблематиці класифікації авіаційних інженерів в системі вищої освіти Великої Британії. Ця тема є важливим аспектом компаративного педагогічного дослідження фахової підготовки авіаційних інженерів у вищих навчальних закладах Великої Британії. **Різновиди класифікації:** Автором було проаналізовано декілька класифікацій авіаційних інженерів відповідно до Загального класифікатору академічних спеціальностей та Служби прийому до університетів та коледжів. **Класифікація авіаційних інженерів:** В статті було виявлено типи авіаційних інженерів за їхніми спеціальностями, головними дисциплінами та типами навчальних курсів. Було визначено які типи навчальних курсів є найбільш ефективними та роблять дипломованих спеціалістів найбільш конкурентоспроможними на світовому ринку праці. **Висновки:** Результати дослідження рекомендовано використовувати для подальшого аналізу вищих навчальних закладів, що пропонують фахову підготовку для авіаційних інженерів.

Ключові слова: авіаційний інженер; Велика Британія; вища освіта; класифікація; спеціальність.

Л. П. Король

Особенности классификации авиационных инженеров по их специальностям в Великой Британии

Кафедра авиационного английского языка,
Учебно-научный институт аэронавигации (Национальный авиационный университет, Украина, г. Киев, пр. Комарова 1, e-mail: aamm@nau.edu.ua).
E-mail: matroskina88@gmail.com

Вступление: Статья посвящена проблеме классификации авиационных инженеров в системе высшего образования Великой Британии. Эта тема есть важным аспектом компаративного педагогического исследования профессиональной подготовки авиационных инженеров в высших учебных заведениях Великой Британии. **Виды классификации:** Автором было проанализировано несколько классификаций авиационных инженеров в соответствии с Всеобщим классификатором академических специальностей и Службы приёма в университеты и колледжи. **Классификация авиационных инженеров:** В статье было выявлено типы авиационных инженеров по их специальностям, главным предметам и типам учебных курсов. Было выделено какие именно типы учебных курсов являются наиболее эффективными и делают дипломированных специалистов наиболее конкурентоспособными на мировом рынке труда. **Выводы:** Результаты исследования рекомендовано использовать в дальнейших исследованиях провайдеров профессиональной подготовки авиационных инженеров.

Ключевые слова: авиационный инженер; Великая Британия; высшее образование; классификация; специальность.

Korol Liliya. (1988). Postgraduate student. Senior lecturer.
Aviation English department, National aviation university, Kyiv, Ukraine.
Education: Master's degree in Philology, Faculty of English language, Kyiv national linguistic university, Kyiv (2009).
Research area: comparative pedagogics, professional training, aviation engineers, higher education in Great Britain.
Publications: 17.
E-mail: matroskina88@gmail.com.

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Editor *Vira Kandynska*
Computer make-up *Nataliya Ahromenko*

Signed for printing 30.01.2018. Paper size 60x84/8. Published sheets 12,55. Quires 13,5. Print run 100 copies. Order N 10-1. Publisher and manufacturer National Aviation University, Kosmonavta Komarova avenue 1, 03680, Kyiv-58, Ukraine.
Certificate of Entry into the Public Register DK 977 of 5 July 2002.

Підп. до друку 30.01.2018. Формат 60x84/8. Ум. друк. арк. 12,55. Обл.-вид. арк. 13,5. Тираж 100 пр. Замовлення № 10-1.
Видавець і виготівник Національний авіаційний університет, проспект Космонавта Комарова, 1, Київ-58, Україна, 03680.
Свідоцтво про внесення до Державного реєстру ДК № 977 від 05.07. 2002.