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INFORMATION TECHNOLOGIES FOR MANAGING AVIATION SYSTEMS

Introduction

One of the promising categories of information technologies is the methods of processing and application of statistical and mathematical methods for decision-making. The use of information technologies in decision-making methods is of particular importance in areas for which the preservation of life is critically important. One of these industries is aviation. Its feature is rapid development and constant expansion, which requires an effective security system. Ensuring the safety of the aviation industry is a priority task for Ukraine.

The implementation of effective aviation safety control systems, the development of improved safety control systems including preventive risk management, is the basis of the global plan to ensure the safety of civil aviation.

ICAO Annex 19 contributes to the establishment of a uniform approach to flight safety management and flight safety oversight in all areas of the aviation industry. A general approach to evaluating the effectiveness of flight safety management systems requires approaches to determining the methods and means when an be used to make decisions related to aviation activities [1].

Problem statement

The implementation of a proactive approach to the aviation safety management system requires a systematic approach using modern information technologies to measure key parameters for the ability to make adequate decisions [2].

In accordance with a proactive approach to aviation safety management, it is necessary to use information technologies to assess the parameters of triggers (causes that can lead to the occurrence of a dangerous event) to make a decision about their condition. In the work, the human factor is considered as a trigger, in particular, the stability of the functional state of the operator, which is analyzed by known methods [2]. It is proposed to increase the reliability of the assessment of the functional state of the operator using existing information parameters based on the processing of secondary information to reduce uncertainty.

Therefore, the relevance of the work is aimed at analyzing the problem of assessing the impact of the human factor as one of the risk factors determined by the flight safety management methodology and determining its place in the flight safety management system.

Analysis of the latest research and publication

Today, more and more attention is paid to the implementation of the safety culture and the human factor in the flight safety management system [3]. In 2019, EASA (European Union Aviation Safety Agency) started implementing a new strategy to promote aviation safety for the period 2020–2024. The basis of this strategy is the use of a proactive approach in the field of aviation security. The EASA Safety Promotion program is a leader in safety promotion in Europe and around the world [4]. Particular attention is paid to issues of a proactive approach in the Manual of Air Safety (MAS) regulatory documents of the Air Safety Management of Military Aviation, where it is noted that air safety management is a key issue that contributes to ensuring a safe and effective operational capability and is necessary to ensure a comprehensive, systematic and proactive approach to air transport safety [5]. Ukrainian scientists have always paid attention to issues of aviation safety, but the strategy for ensuring it was reactive in nature, i.e. identifying dangerous factors (risks for flight safety), analyzing them and taking the necessary measures already after the occurrence of a dangerous event (refusals or violations that led to an aviation event, a serious incident) [6]. The latest requirements of the ICAO require the implementation of a proactive approach, which will allow predicting the occurrence of a dangerous event, and the development of approaches to identify, assess and predict risks that lead to aviation events [7].

The purpose of the article

The paper proposes the use of nonlinear dynamics methods to increase the reliability of decision-making based on secondary measurement information for predicting the occurrence of a dangerous factor, a malfunction of the operator's cardiovascular system, as one of the component risks of the influence of the human factor in the general system of risks for flight safety, which can lead to an aviation event. Thus, the purpose of this publication is to use information technologies to implement ways of using a proactive approach to flight safety systems.

Presentation of the main research material

When implementing a proactive safety management system, special attention is paid to the identification and elimination of triggers (causes of hazards and dangerous factors) in all aviation components involved in the work.

A proactive approach involves the creation of a safety management system in an airline that detects actual and potential hazards and their factors, guarantees the use of corrective measures necessary to reduce operational risks and provides continuous monitoring and regular assessment of the achieved safety level [2].

Therefore, the flight safety management system in the ideology of a proactive approach requires a set of measures carried out by the aviation system to detect and identify actual and potential dangers and their factors for its activity, assess the risk of their manifestation, develop and use corrective measures necessary to maintain an acceptable level of safety [8]. It is within the framework of this approach that the methodology for evaluating the flight safety management system was developed [8].

The authors in [2] proposed the use of functional modeling to determine the location of risk factors, particularly human risk factors. But as can be seen from Fig. 1, the decision-making process regarding the identification of hazards related to human and organizational factors remains an urgent task.

In turn, the phased implementation of the following processes: management of safety policy and objectives, management of flight safety risks, ensuring flight safety and promotion of flight safety issues, commitment to continuous improvement, ensuring compliance with all applicable legal requirements and standards, takes into account best practices. Therefore, making a decision about the danger of a dangerous event based on the human factor is closely related to the task of reducing uncertainty in obtaining primary information about changes in the properties of the diagnostic object.

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Since within the framework of a proactive approach there is a need to reduce to a minimum aviation accident due to human fault related to aviation.

Therefore, finding ways to identify hazards (triggers) related to the human factor in advance is an important task of the ideology of risk management. Assessing the risks associated with the human factor has the difficulty of promptly identifying the hazard.

Therefore, the evaluation of the current functional state of the operator will make it possible to reduce the development of a negative event involving a person with a predicted probability.

Therefore, making a decision about the danger of a dangerous event based on the human factor is closely related to the task of reducing uncertainty in obtaining primary information about changes in the properties of the diagnostic object.

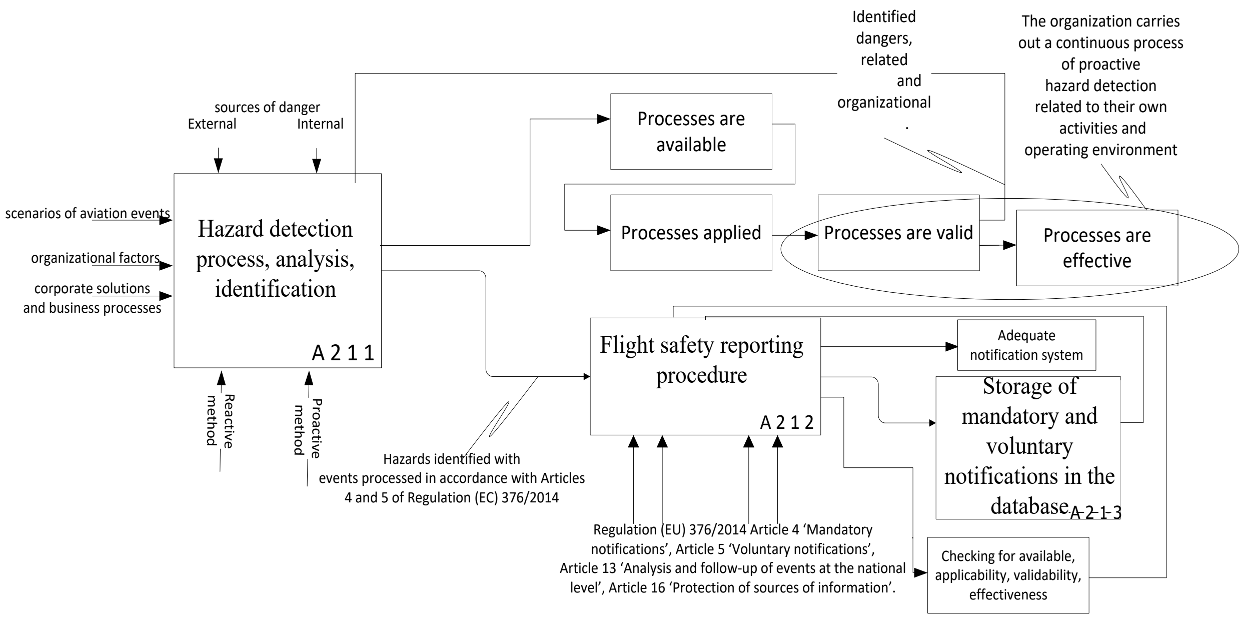

Fig. 1. Functional model to determine the location of risk factors

A peculiarity of decision-making based on information parameters by which the functional state of the operator can be assessed is the need to take into account the stochastic influence of random processes with different types of non-stationarity, which does not allow to assess qualitative changes in the state of a biological object with a given reliability.

If we consider a complex biological object, which is characterized by a number of parameters Y, then $X_1,\ldots, X_k$. These parameters are measurable physical quantities that reflect the properties of a physical object. Traditionally, to assess the state of a biological object, the parameters of the cardiovascular system are used as the most informative in terms of response to the action of destabilizing factors. In turn, Y (the functional state of the operator as a biological object) has to be considered as, in a certain sense, a random variable, which is due to the lack of the possibility of an accurate, metrologically justified reproduction of its given value in the range Ay of all its possible changes. However, the variance of the Y value is a constant value σ^2_y = const.

At the functional level, there is an a priori unknown relationship between the mean Y and $\{X_i\}$:

$$M[Y] = F(M[X_1], \ldots, M[X_k]).$$

For each parameter of the cardiovascular system, there is a conditional density $f\,(X_i \left| Y_j, X_{l\,1}^{\;k}, l \neq i\right.)$, which reflects the stochastic relationship between the value of X_i and the rest of the controlled values, provided that ($Y = Y_j$ =const, j = 1, 2…). The generalized decision-making structure based on the transformation of the measurement information about the Y value based on the measurement of the values of controlled quantities can be represented as follows. To make a decision about the state of a complex object, it is necessary at the first stage to obtain the value $X_1^*,\ldots, X_k^*$ by primary converters, which at the second stage are converted into an estimate Y^* of the value of the parameter Y. When making a decision, one $y_j\{a_l, b_c\}_1^m$ from the set $\{y_j\}_1^m$ of decisions about the value of Y according to the decision selection rule

$$\forall Y^*[Y^* \in (\alpha_j, b_j) \to Y^* \in Y_j].$$

Estimation of the amount of information about the Y parameter (assuming that the width Δ of the tolerance intervals a_j, b_j, j = (1, k) is the same, and their total number is equal to k) is determined by the expression the difference between the initial $H(Y)$ and the conditional entropy $H\,(Y|\,Y_j)$ [9]:

$$I = H\,Y - H\,Y|\,Y_j,$$

where $H\,Y = -\sum_{j=1}^{k}\left[\int_{a_j}^{b_j} f\;ydy]\ln\int_{a_j}^{b_j} f\;ydy\right].$

And $f\;y$ — the distribution density $f(y)$ of the Y value in the range Ay.

In turn, the conditional entropy can be defined in terms of the conditional probability $PY|\,Y_j$: of the value $M\;Y=Y_j$ if the solution γ_j gives the value $Y=Y_j$:

$$H\;Y = -\sum_{j=1}^{k} PY_i \left|Y_j\right. \ln PY_i \left|Y_j\right. .$$

If the variance σ^2_y of the deviation of Y^* from the value $M[Y]$ = const is, then:

$$H\,Y = \ln\frac{Ay}{\Delta};\ HY\Big|Y_j = \ln\frac{\sigma_y\sqrt{2\pi e}}{\Delta}.$$

In turn, the amount of information is written in the form:

$$I = \ln\frac{A_y}{\sigma_y\sqrt{2\pi e}}.$$

If the variance is presented in the form:

$$\sigma_y^2 = \Delta_\psi^2\left(1+\frac{k}{N}\sigma_x^2\right)n^{-1},$$

where σ_x^2 — variance of controlled information parameters $X_1^*,\ldots, X_k^*$; N — number of measurement; ψ — factors influencing the correct choice of the transformation model [10].

So:

$$I = \ln\frac{A_y}{\Delta_\psi\sqrt{2\pi e\left(\frac{1}{k}+\frac{\sigma_X^2}{N}\right)}}\sqrt{\frac{n}{k}}. \quad (1)$$

Equation (1) can be considered as the amount of expected information about the controlled information parameter with an unremovable dispersion $\sigma^2{}_X$ of the input measured parameters $X_1, \ldots, X_k$. of the cardiovascular system. The existence of this dispersion does not prevent us from increasing the amount of measured information by increasing k of these parameters. However, in this case, the ratio of the learning nipple n to the number k of the input information must remain constant or also increase [11]. It is possible to increase the reliability of decision-making by increasing the amount of information only by increasing the size of the training sample n. Increasing only the number N of multiple measurements does not eliminate the negative effects of ψ factors. Therefore, finding approaches that allow increasing the amount of information based on existing measurement results significantly increase the reliability of decision making [12]. As such an approach, non-linear dynamics methods are proposed, which make it possible to assess the non-stationarity of the measured biological signals [13].

The use of nonlinear dynamics methods to the already measured parameters of the cardiovascular system can provide an increase in the amount of information about the state of the operator and provide a new understanding of changes in the parameters of the cardiovascular system in hidden physiological states, providing additional prognostic information and complementing the traditional analysis in the time and frequency domains [14]. The methods of nonlinear dynamics provide additional and independent information about the physiological, as well as about the hidden physiological response to the destabilizing factors [15].

In the paper, as an example for processing already existing informational parameters of RR intervals of the electrocardiogram (ECG), their projection in phase space was carried out using Poincre maps to increase the informativeness of heart rate variability (HRV). RR intervals are presented as a time series, and a Poincaré map (Pplot), also known as a return or delay map, allows the estimation of heartbeat dynamics based on a simplified phase space embedding. Pplot is a two-dimensional scatterplot in which each RR interval, RR(i), is plotted as a function of the previous interval RR (i − 1). Pplot analysis is a new quantitative visual technique that uses a map shape to provide summary information about the heart's behavior. For a healthy heart, the cloud of points represents the shape of a comet oriented along the line of identity; the dynamics of heart failure is characterized by a stretched elliptical cloud of points also along the line of identity. In the case of atrial fibrillation (AF), the point cloud has a more circular shape, similar to what happens with a white noise time series [16].

The use of Poincaré maps is one of the simplest forms of presenting the phase space of a system, but they can provide important information about the dynamics, this method can be applied to any time series of sufficient length. A Poincaré map is also called a Lorentz plot, a delay map, or a return map [17].

Compared to a histogram, Poincaré maps provide additional information about the variability of a time series because it displays the correlation between successive readings of the data. However, standard ("black and white") Poincaré maps have a significant limitation: they do not provide information about the density of data points. The paper proposes to overcome this limitation by modifying the standard Poincaré map, which displays the relative frequency of pairs of consecutive data points, by constructing a 3D histogram RR(n), RR (n + 1) [18]. Examples of 3D Poincaré maps are given in the below.

However, such 3D Poincaré maps for the entire time series do not contain information about the evolution of the system's dynamics over time, and do not record the time sequence of state changes. This limitation becomes especially significant when studying the dynamics of physiological systems, which are usually non-stationary [16].

The signal files of the operator database are used in the work. The output heart rate variability is in binary files. The data files reflect the duration of the current RR interval (in ms) of the ECG signal.

This database includes RR interval files for 54 long-term ECG recordings of subjects with normal sinus rhythm. The original ECG recordings were obtained with a sampling frequency of 128 Hz, RR intervals were obtained using automatic analysis with manual verification and correction.

A standard Poincaré map overcomes one of the limitations of histograms, namely that a histogram does not represent correlations between data points.

When constructing a Poincaré map (scatterogram), a collection of points (cloud of points or Poincaré spots) appears, the center of which is located on the bisector. Usually, the Poincaré map for RR intervals has the shape of an ellipse. The distance from the center to the origin of the coordinate axes corresponds to the most expected duration of the cardiac cycle (mode M0). The deviation of the point from the bisector shows how much the nth RR interval is shorter or longer than the (n + 1)th RR interval [17].

To construct a standard Poincaré map, the following code (Listing 1) was developed in the MATLAB software environment

Listing 1. Code for constructing a Poincaré map

```
x1 = RR(1:end-1);
x2 = RR(2:end);
scatter(x1,x2,10,'filled'), grid on
xlabel('RR(n)'),
ylabel('RR(n-1)')
title(['Signal ' name])
```

Examples of the Poincaré map for HRV signals are shown in Fig. 2.

As can be seen from the images, standard Poincaré maps (one color, “black and white”) have a significant limitation: they do not store information about the density of data points. With a large number of data points (up to 10.000 or more), parts of the image may become completely black and it will be difficult to get an idea of the density of the distribution of points.

To overcome this limitation, it is advisable to include the relative frequency of pairs of consecutive data points in the standard Poincaré map, that is, to move from the construction of individual points to the presentation of their empirical distribution in the form of a three-dimensional histogram.

To construct 3D Poincaré maps, a modified version of the dscatter2 function [18] was used, which returns smoothed data (scatter diagram) for Poincaré map construction. The input parameters of the function dscatter2_1 are given by the vectors X and Y (they must be of the same size). The output parameters of the function are the midpoints of the data grouping intervals (ctrs1, ctrs2) and the matrix of the number of data counts (F) in the grouping intervals. Program code of the function (*Listing 2*).

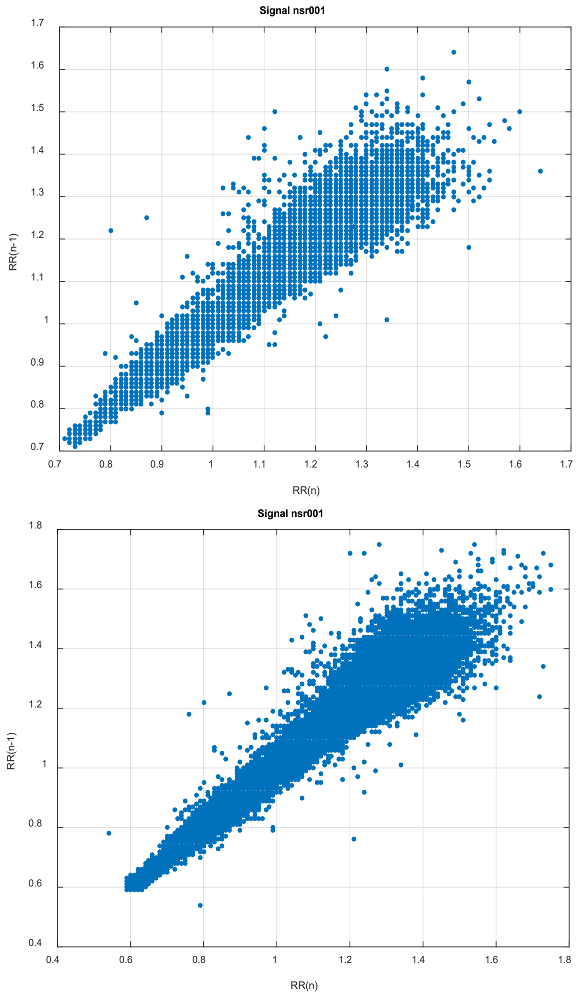

Fig. 2. Examples of Poincaré maps:
on the left n = 10000, on the right n = 60000

Listing 2. Code for constructing a 3D Poincaré maps

```
function [ctrs1, ctrs2, F] = dscatter2_1(X, Y)
nbins = [40 40];
minx = RRmin; maxx = RRmax;
miny = RRmin; maxy = RRmax;
edges1 = linspace(minx, maxx, nbins(1)+1);
ctrs1  = edges1(1:end-1) + 0.5*diff(edges1);
edges1 = [-Inf edges1(2:end-1) Inf];
edges2 = linspace(miny, maxy, nbins(2)+1);
ctrs2  = edges2(1:end-1) + 0.5*diff(edges2);
edges2 = [-Inf edges2(2:end-1) Inf];
[n, ~] = size(X); bin = zeros(n,2);
[~,~, bin(:,2)] = histcounts(X, edges1);
[~,~, bin(:,1)] = histcounts(Y, edges2);
H = accumarray(bin, 1, nbins([2 1])) ./ n;
G = expsm (H, nbins(2)/lambda);
F = expsm (G', nbins(1)/lambda)';
```

The last three lines of the dscatter2_1 function smooth the histogram using the method and code of the smoothing function. The color of the Poincaré map depends on the density of points in the scatter diagram. Basic calculations and visualization of heart rate variability dynamics are performed by the Poincare3D_2Dmap() function. The function receives a signal consisting of two columns of data: a vector of time counts, a vector of RR interval counts.

The subplot command, which creates two separate windows, is used for graphical output of the created figure. The first window with a three-dimensional coordinate system is intended for displaying the image of a single frame of the Poincaré map. The second window is designed to display a fragment of the RR interval signal corresponding to the specified frame (Listing 3).

Listing 3. The code of the main cycle is the formation of video frames

```
        k1 = 1; k2 = find(t >= T,1);
        while t(k2)<=t(end)
            t1 = t(k1); t2 = t(k2);
            t_disp = t(k1:k2); rr_disp = rr(k1:k2);
            y1 = rr_disp(1:end-1);  y2 = rr_disp(2:end);
            [ctrs1, ctrs2,F] = dscatter2_1(y1,y2,nbins);

surf(ctrs1,ctrs2,F,'FaceColor','interp','EdgeColor','none');
            plot(t_disp, rr_disp, 'r' ,'LineWidth', 1)
            Fr1 = getframe(fig);
            writeVideo(vidObj, Fr1);
            k1 = find(t >= t1 + Tshift,1);  k2 = find(t >= t2 + Tshift,1);
        end
        close(vidObj);
```

The main cycle — the formation of video frames is carried out as follows: the first lines of the main cycle calculate the coordinates of the beginning k1 and end k2 counts of the selected data segment. Vectors y1 and y2 form the data for calculating the scattergram.

The Poincaré map is calculated by the function dscatter2_1( ).

The output parameters of this function (vectors ctrs1, ctrs2 and matrix F) are used to construct a three-dimensional surface by the surf function. The function getframe getframe (Fig. 3) captures the internal part of the graphic figure with the identifier fig, together with the title of the axes, labels and divisions.

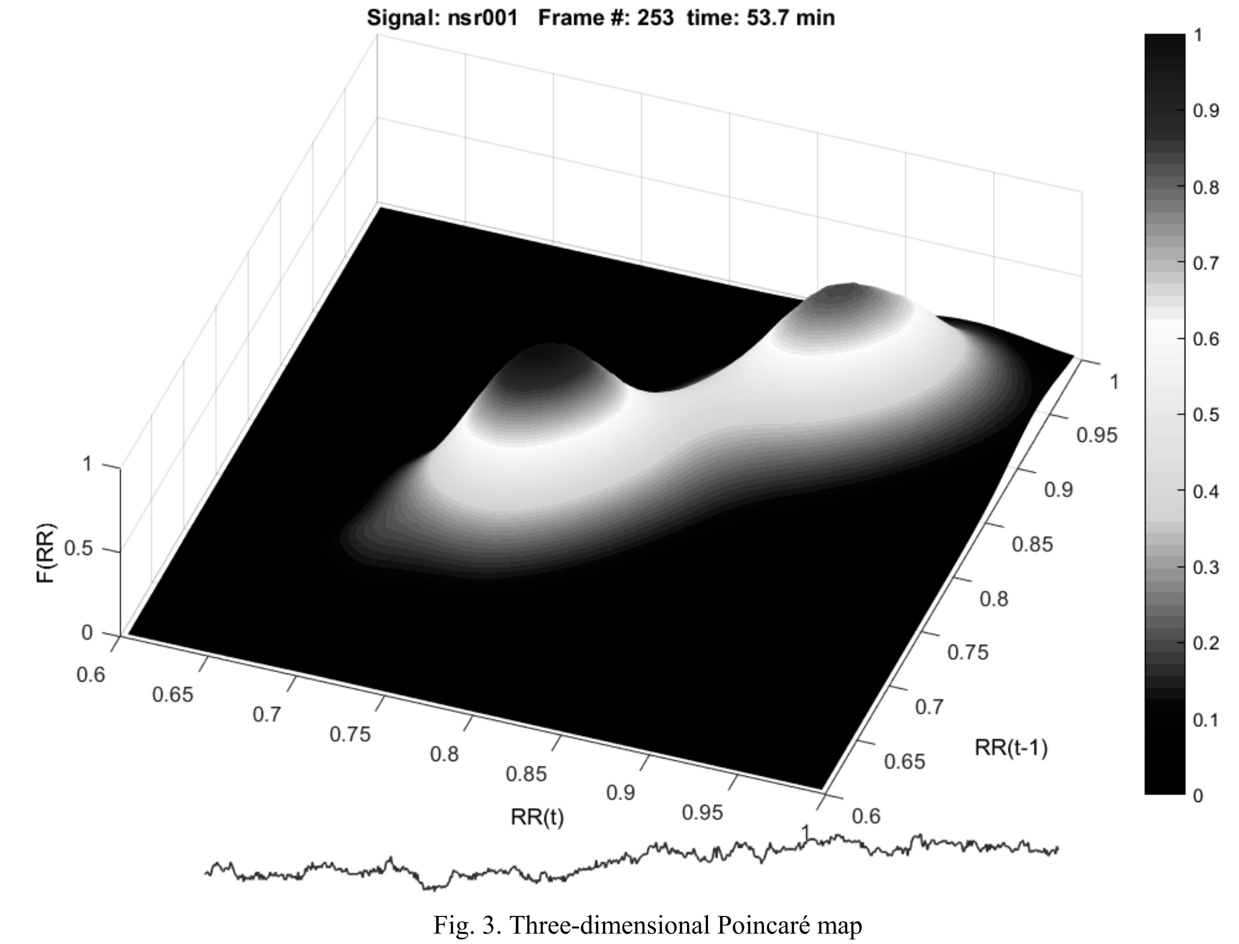

Fig. 3. Three-dimensional Poincaré map

The function write Video(vidObj, Fr1) writes data from the array Fr1 to the file associated with vidObj.

At the end of the cycle, the line calculates the coordinates of the beginning k1 and the end k2 of the new allocated data segment [18].

The results of the program with one of the signals are shown below.

In Fig. 3 the last frame of the video file showing the 3D Poincaré map is presented.

The dynamical images presented here demonstrate the type of nonstationarity characterized by relatively sharp state transitions typically observed in the output of “free” physiological signals [19].

Dynamic visualization of heart rate variability allows you to observe changes in this parameter over time. The perception of visualization results depends on several values: the number of histogram digits when constructing a Poincaré map, the angle of visualization of the Poincaré map, the duration of the data segment and the degree of their overlap, the choice of color map.

Conclusion

According to the proactive approach of the new concept of safety management, an analysis of the features of the components of the risk management methodology in the aviation industry was carried out to identify the human factor component. The human factor is identified as a source of danger that has a stochastic component. To increase the reliability of decision-making regarding the functional state of the operator as one of the triggers for the occurrence of a dangerous event in aviation, it is necessary to develop methods that, based on the existing measured information parameters, will allow to increase their informativeness without resorting to increasing the number of measurements. As such methods, the use of nonlinear dynamics methods is proposed, which allow to increase the informativeness of the existing cardio signals due to their processing. Visualization of the evolution in time of the signals of a complex dynamic system was developed in the work. Animations based on density delay maps provide visualization of dynamic properties of complex systems not visible in time series plots or standard Poincaré maps.

The use of Poincaré maps, as one of the methods of nonlinear dynamics, allows qualitative and quantitative analysis of cardiac signals, which reflects data variability. For the quantitative study of the data, it is necessary to match the ellipse to the shape of the graph by defining the SD1, SD2 descriptors and the SD1/SD2 ratio. Too low or too high values of the SD1/SD2 ratio for a biomedical signal have been suggested to be associated with disease, but this requires further study.

With the help of Poincaré maps, you can study not only R-R intervals, but also other signals; thanks to such studies of biomedical signals, a new interpretation of this method may appear.

Such easy-to-build graphs ("3D –maps") obtained in the work have an advantage in the implementation of their construction and can be used to illustrate such properties as non-stationarity and multistability, which are important for understanding the dynamics of physiological control systems in the presence of destabilizing factors. In addition, animation can reveal unexpected patterns in the data structure, which makes this technique useful for exploratory research, simplifying hypothesis formation, developing and testing mathematical/physiological models.

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ВИКОРИСТАННЯ ІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ В СИСТЕМАХ УПРАВЛІННЯ В АВІАЦІЇ

У запропонованій роботі аналізуються особливості впровадження проактивного підходу в авіації. У рамках цього підходу людський фактор розглядається як причина виникнення небезпечної події. Проведено аналіз особливостей прийняття рішень з метою визначення можливостей підвищення надійності прийняття рішень в авіації. Імовірність виникнення небезпечної події, тригером якої є людський фактор, запропоновано визначати на основі оцінки функціонального стану оператора за інформаційними параметрами серцево-судинної системи. У роботі запропоновано підхід до визначення інформативності параметрів, який безпосередньо залежить від кількості вимірювань цих параметрів. Підвищити достовірність прийняття рішень щодо стану об'єкта пропонується не шляхом збільшення кількості вимірювань, а шляхом додаткової обробки вже виміряних інформаційних параметрів, тобто отримання вторинної інформації. Як приклад оброблено результати вимірювань RR-інтервалів електрокардіограми методами нелінійної динаміки, а саме картами Пуанкаре.

Застосування методів нелінійної динаміки до вже виміряних параметрів серцево-судинної системи може забезпечити збільшення обсягу інформації про стан оператора та дати нове розуміння змін параметрів серцево-судинної системи при прихованих фізіологічних станах, забезпечуючи додаткова прогностична інформація та доповнення до традиційного аналізу в часовій та частотній областях. Методи нелінійної динаміки дають додаткову і незалежну інформацію про фізіологічну, а також про приховану фізіологічну відповідь на дестабілізуючі фактори. У роботі на прикладі обробки вже існуючих інформаційних параметрів RR-інтервалів електрокардіограми здійснено їх проекцію у фазовому просторі за допомогою карт Пуанкре для підвищення інформативності варіабельності серцевого ритму. Інтервали RR представлені у вигляді часових рядів, а карта Пуанкаре дозволяє оцінити динаміку серцевих скорочень на основі спрощеного вбудовування фазового простору.

Використання карт Пуанкаре, як одного з методів нелінійної динаміки, дозволяє проводити якісний і кількісний аналіз серцевих сигналів, що відображає мінливість даних. Отримані в роботі «3D карти Пуанкаре» мають перевагу в реалізації їх побудови і можуть бути використані для ілюстрації таких властивостей, як нестаціонарність і мультистабільність, важливих для розуміння динаміки системи фізіологічної регуляції за наявності дестабілізуючі фактори. Крім того, можна виявити несподівані закономірності в структурі даних, що робить цей метод корисним для дослідницьких досліджень, спрощуючи формування гіпотез, розробку та перевірку математичних/фізіологічних моделей

Ключові слова: безпека польотів, ризики, людській фактор, біомедичні показники, процес вимірювання, кількісне оцінювання.

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INFORMATION TECHNOLOGIES FOR MANAGING AVIATION SYSTEMS

The proposed work analyzes the peculiarities of implementing a proactive approach in aviation. Within the framework of this approach, the human factor is considered as the cause of the occurrence of a dangerous event. An analysis of decision-making features was carried out to determine the possibilities of increasing the reliability of decision-making in aviation. The probability of occurrence of a dangerous event, the trigger of which is the human factor, is proposed to be determined based on the assessment of the functional state of the operator based on the information parameters of the cardiovascular system. The paper proposes an approach to determining the informativeness of parameters that directly depend on the number of measurements of these parameters. It is proposed to increase the reliability of decision-making regarding the state of the object not by increasing the number of measurements, but by additional processing of already measured information parameters, i.e. obtaining secondary information. As an example, the results of measurements of the RR intervals of the electrocardiogram by methods of nonlinear dynamics, namely Poincaré maps, were processed. The use of nonlinear dynamics methods to the already measured parameters of the cardiovascular system can provide an increase in the amount of information about the state of the operator and provide a new understanding of changes in the parameters of the cardiovascular system in hidden physiological states, providing additional prognostic information and complementing the traditional analysis in the time and frequency domains. The methods of nonlinear dynamics provide additional and independent information about the physiological, as well as about the hidden physiological response to the destabilizing factors. In the paper, as an example for processing already existing informational parameters of RR intervals of the electrocardiogram, their projection in phase space was carried out using Poincre maps to increase the informativeness of heart rate variability \. RR intervals are presented as a time series, and a Poincaré map allows the estimation of heartbeat dynamics based on a simplified phase space embedding. The use of Poincaré maps, as one of the methods of nonlinear dynamics, allows qualitative and quantitative analysis of cardiac signals, which reflects data variability. The "3D Poincaré map" obtained in the work have an advantage in the implementation of their construction and can be used to illustrate such properties as non-stationarity and multistability, which are important for understanding the dynamics of the physiological regulation system in the presence of destabilizing factors. In addition, it is possible to reveal unexpected regularities in the structure of the data, which makes this method useful for research studies, simplifying the formation of hypotheses, the development and verification of mathematical/physiological models.

Keywords: flight safety, risks, human factor, biomedical indicators, measurement process, quantitative assessment.

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