Запропоновано методи верифікації та ідентифікації оператора за особливостями формування біометричних ознак мовленнєвого сигналу у системах управління безпілотними авіаційними комплексами.

Розроблено метод ефективної ширини спектру мовленнєвого сигналу, який дозволяє здійснювати ідентифікацію та верифікацію оператора безпілотного літального апарата на основі аналізу інформативних складових відбитків голосу в умовах високого рівня завад різного походження.

Розроблено метод найбільшої інформаційної ваги основного тону, в основі якого лежить використання найбільш інформативних складових спектрального представлення відбитків мовленнєвого сигналу.

Перший метод дозволяє ідентифікувати оператора безпілотного літального апарату по інформативним складовим спектрального уявлення відбитка мовного сигналу в умовах високого рівня перешкод. Високі показники, які досягаються шляхом використання даного методу, отримані за рахунок унікальності обраного простору ознак, які зберігають свої характеристики навіть при досить високому рівні перешкод.

Другий метод забезпечує ідентифікацію диктора безпілотного літального апарату по певного простору унікальних ознак голосу. В якості базових ознак обрано частоти основного тону і обертонів. Такий підхід до вирішення завдання ідентифікації забезпечує високу ймовірність визначення оператора при існуючому досить високому рівні перешкод і дозволяє скоротити час обробки інформації в порівнянні з методом ефективної ширини спектра.

Створення методів та моделей ідентифікації аудіосигналів у системах управління безпілотними авіаційними комплексами забезпечує підвищення рівня завадостійкості та захисту системи керування до втручань не санкціонованим операторм. Їх використання дозволяє створити систему розмежування доступу до процесу управління літальним апаратом і тим самим забезпечити безперервність функціонування інформаційної системи управління безпілотними авіаційними комплексами

Ключові слова: ідентифікація особи, частота основного тону, параметри мовленнєвого сигналу, безпілотний літальний апарат, сигнали телеметрії, санкціонований оператор

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DEVELOPMENT OF METHODS FOR IDENTIFICATION OF INFORMATION-CONTROLLING SIGNALS OF UNMANNED AIRCRAFT COMPLEX OPERATOR

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1. Introduction

The rapid development of public relations and their basic component – information and communication systems requires the creation of new technologies for processing, storage, transmission and display of information.

It is impossible to imagine a modern society without providing various classes of high-quality IT services in general and special purpose information systems (IS). This becomes a strategically important issue in the face of external aggression by other states in the processes of ensuring and efficient functioning of all parts of the public sector and the individual itself [1, 2].

A sharp increase in the number of users and software and hardware of IS, an increase in the requirements for the quality of processing processes and data coverage made it necessary to introduce information technology (IT) in the authentication and identification of critical information.

The use of biometric characteristics of users of information resources and systems gave a further impetus to scientific research in order to create new technologies based on a unique feature space.

The efficiency of processing and coverage of critical information in difficult emergency situations, as well as work on the prevention and detection of threats of various types in real time, have brought information technology to use unmanned aerial vehicles to a new level. The use of small unmanned aircraft has gone beyond military use only and has become widespread in various areas of society, such as energy, archeology, environmental protection, emergency work, and others. It is the efficiency of the use of unmanned aerial vehicles (UAVs) that becomes the basis for the development and improvement of information technology for the management of aviation unmanned systems in complex radio conditions.

So, the development of modern IT, management methods and models of unmanned aerial systems based on the use of unique biometric characteristics of voiced operator signals to identify critical information in access control processes is an urgent scientific and practical task.

2. Literature review and problem statement

Technical characteristics of the equipment, equipment and aerodynamic parameters of unmanned systems, determine one of the main directions of modern research and development of UAVs. In [3, 4], an analysis was made of the technical characteristics of aviation systems from the point of view of using automated systems and an ergonomic design. Obviously, the quality of the research data for each area of UAV use depends on the basic technical equipment of the unmanned system. But, due to the variety of UAV classifications, it is not quite complete and concerns narrow segmented UAV classes.

Based on the data presented in many works, it can be stated that the variety of models and methods of landing aircraft systems is also quite narrow. The range of practical methods can be reduced to such procedures as manual control of the device, commands for using the parachute type of landing. The most common solutions are semi-automatic control methods [5, 6]. However, all these methods have a number of disadvantages and can be implemented only in almost ideal operating conditions. These methods will cause emergency use and operation of unmanned systems under imperfect conditions. The reason for this is the lack of a system of authorized and protected operator commands to perform basic UAV procedures in conditions of an increased level of interference and in other critical modes.

Thus, one of the progressive directions of research should be the improvement and development of new methods for automatic or semi-automatic control of aviation unmanned systems in non-standard conditions. In [7–9], research is presented on the control of unmanned systems by laser pointing at a complex to determine the landing path and providing a clear glide path for UAVs; methods for transmitting critical information (audio, video) with guaranteed quality are presented. In these works, fundamental shortcomings of the proposed methods are given (insecurity of control signals when changing climatic conditions of operation, as well as during artificial interference in control systems by unauthorized operators), but directions for solving these limitations and eliminating shortcomings are not indicated.

In [11, 12], studies are presented on the development of remote sensing systems for the earth's surface based on UAVs. This area provides ample opportunities for obtaining large volumes of data and management decisions in crisis situations. The main feature of the methods used for this is the processing speed, the quality of the received video data and the processing efficiency of critical information to perform specified functions in a certain range of routes. But in these works there are no studies on control systems based on methods to counteract a high level of interference (artificial or natural origin), the issue of operator identification is not considered in the authorized management of aviation systems.

The studies presented in [13, 14] show that the basis for obtaining and processing critical information for control systems is to determine the most high-performance technologies, methods and practices for shooting video data for UAV systems. Cases of receiving video data without loss or with controlled loss of information under artificial intervention by unauthorized methods have not been fully investigated.

The safety of UAV flights in crisis situations and critical technical conditions is studied in [14, 15]. In particular, teams of authors offer automated systems for high-speed recalculation and selection of safe trajectories for performing UAV operational tasks in ambiguity and collision warning modes. But the safe operation of airborne systems in partially indefinite, unstructured environments against the background of a high level of interference of various types in these works is not exhaustively presented and not investigated. The studies performed in these studies of the recalculation of the trajectories of the routes and collision avoidance can be used in ideal technical conditions, the signal-to-noise ratio. But the issue of artificial intervention by unauthorized operators in the system of automatic recalculation of the unmanned complex trajectories is not considered.

Currently, the use of unmanned aircraft in agriculture has gained widespread use and scientific and applied development. The authors of [16, 17] substantiated and demonstrated the possibility of using UAVs in the agricultural sector using complex technical decision-making systems based on multi-informative data. However, the proposed methods and models for the use of UAVs are considered only for ideal technical conditions for fulfilling the assigned tasks. These studies are devoted to the quality of video processing in difficult collision avoidance conditions, but are not studied in conjunction with UAV control issues in critical conditions of a different interference class. A complete analysis of such methods and technologies is not given.

In [18, 19], the introduction of additional audio control functions for UAV trajectories was investigated; UAV identification by audio signals of power equipment; methods of identification of aircraft systems in emergency zones, but no research is presented on identification of the operator itself; methods of identification of information-control signals of the speaker against the background of a high level of interference have not been thoroughly studied. The issue of introducing UAV control commands based on audio signals (voiced) is not considered at all.

Recent studies of hardware and software systems using UAVs for military purposes are presented in [20–22]. But attention is concentrated only on the most common methods of processing and applying digital UAV images for ACS.

A wide range of risks associated with the potential for unauthorized actions in the framework of UAV tasks were investigated in [23, 24]. The authors proposed methods to counter the implementation of threats in case of unauthorized interference with control signals based on cryptographic methods, coding, or based on changes in the control frequency range. In [24, 25], the necessity of protecting information data streams based on modern methods of cryptography, coding, UAV identification by different classes of parameters, and protection of critical data by steganography methods is substantiated. UAV control at the command level using audio signals from an authorized operator, as well as the development of critical data protection procedures for control systems using encryption methods, encoding information flows or steganography methods, are also considered in the authors' works [26, 27]. However, the authors note that with the constant use of standardized protection algorithms in UAV automatic control systems, they lose stability and do not have fast dynamics in tactical conditions during the artificial intervention of an unauthorized intruder.

The authors of the studies [27, 28] propose a system for identifying the frequency range of operation of power plants of onboard equipment. But there are many unresolved issues in identifying and tracking the motion paths of unmanned vehicles using modern acoustic cameras. There is no study of the role of the UAV operator in decision making in critical situations of complex control.

Based on the analysis of scientific sources, it can be stated that the issue of controlling unmanned aerial systems in conditions of artificial unauthorized interference (not from authorized operators) in UAV control systems has not yet been resolved. Technical limitations for solving this problem should be the conditions for controlling the system against the background of an increased level of interference at low singing signal-to-noise ratios. This problem should also be solved in the conditions of tactical control of UAVs in a limited time frame.

Thus, the urgent task of further scientific research is the creation of new methods for identifying audio signals in UAV control systems based on the biometric characteristics of the voiced signal of an authorized operator.

3. The aim and objectives of the study

The aim of the study is to develop methods for identifying information-control signals of the operator of an unmanned aerial complex. A distinctive feature of the developed methods should be the use of biometric characteristics and the most informative components of the spectrum of the vocalized signal of an authorized (authorized) operator against a background of a high level of interference based on statistical methods for taking the target, which will make it possible to increase the noise immunity and protect the UAV control system from unauthorized interference.

Achieving this aim involves solving the following objectives:

– to develop a method for the effective width of the spectrum of a speech signal in order to identify and verify the operator of an unmanned aerial vehicle;

– to develop a method of the largest information weight of the fundamental tone, which is based on the use of the most informative components of the spectral representation of the fingerprints of the speech signal of an authorized operator.

4. Description of the basis for creating methods for text-based and text-independent identification of the UAV operator

One of the priority tasks of pattern recognition is the task of describing a dictionary of features and classes and finding their boundaries. The analysis of methods for processing audio signals in the problems of identifying images, classifying objects using decisive functions made it possible to create the theoretical basis for describing a dictionary of features of objects of various classes [15, 17].

Let there be an ordered set of object parameters in the dictionary – $x_1,...,x_N$, each of the objects in the N-dimensional attribute space can be represented as a vector $x=\{x_1,..., x_N\}$. To classify objects, it is necessary to construct the limit functions $F_i(x_1,..., x_N)$, $i=1,..., m$, which has the following properties: if the object is characterized by signs $x_1^0,\ldots,x_N^0$ of the class Ω_i, then the quantity $F_i\left(x_1^0,\ldots,x_N^0\right)$ should be the largest. It should be the largest for other values of features of objects of this class. If the feature vector of the object belongs to the class Ω_q defined as x_q, then the inequality F $F_q(x_q)>F_p(x_p)$, q, $p=1,..., m$, $q\neq p$ must hold. Let's denote F_q as the limiting function of the parameters of the attributes of space obtained experimentally, and F_p – the limiting function of the reference model of signs.

Thus, in the attribute space of the recognition system, the partition limit is expressed by the equation

$$F_q(x)-F_p(x)=0. \quad (1)$$

In the information technology for the management of unmanned aerial systems, the identification of the operator's face can be considered in terms of text identification. In this case, the system uses a fixed set of portraits of teams and certain characteristics of the voice. A more difficult task is to consider text-independent identification when voice characteristics are analyzed regardless of the semantic load of the commands.

In the identification process, let's determine the degree of proximity or similarity of objects in the N-dimensional vector space of features, for which let's introduce the Euclidean metric:

$$d^2\left(\varpi_{pk},\varpi_{ql}\right)=\sum_{i=1}^{N}\left(x_{pk}^{(i)}-x_{ql}^{(i)}\right)^2, \quad (2)$$

where

p, $q=1, 2,..., m$; $k=1, 2,..., k_p$; $l=1, 2,..., k_q$;

$x_{pk}^{(i)}$ – the value of the i-th feature of the k-th object of the p-th class, that is, the ϖ_{pk} object; $x_{ql}^{(i)}$ – the value of the i-th attribute of the l-th object of the q-th class, that is, the ϖ_{ql} object.

Next, it will be necessary to consider the degree of proximity of all objects of a given class and the degree of proximity of all objects of a given pair of classes. As a measure of the proximity of objects of this class W_p, $p=1, 2,..., m$, let's use the quantity

$$S\left(W_p\right)=\sqrt{\frac{2}{k_p}\frac{1}{k_q-1}\sum_{k=1}^{k_p}\sum_{l=1}^{k_q}d^2\left(\varpi_{pk},\varpi_{pl}\right)}, \quad (3)$$

which will be the RMS spread of the class or the RMS spread of objects inside the class W_p, as the degree of proximity of objects of a given pair of classes W_p and W_q, p, $q=1, 2,..., m$ – the value

$$R\left(W_p,W_q\right)=\sqrt{\frac{1}{k_pk_q}\sum_{k=1}^{k_p}\sum_{l=1}^{k_q}d^2\left(w_{pk},w_{ql}\right)},\qquad(4)$$

which is the RMS spread of objects of classes W_p and W_q.

The set of features of objects using in the working dictionary can be described by an N-dimensional vector $\lambda=(\lambda_1, \lambda_2,..., \lambda_N)$, the components of which take values 1 or 0 depending on the existing or absent ability to determine the corresponding feature of the object, i. e. $\lambda_i=\begin{cases}1\\0\end{cases}$.

Given λ, the distance between two objects w_{pk} and w_{ql}

$$d^2\left(w_{pk},w_{ql}\right)=\sum_{i=1}^{N}\lambda_i\left(x_{pk}^{(i)}-x_{ql}^{(i)}\right)^2.\qquad(5)$$

The RMS spread of the class and class objects can be written accordingly:

$$S\left(W_p\right)=\sqrt{\frac{2}{k_p}\frac{1}{k_q-1}\sum_{k=1}^{k_p}\sum_{l=1}^{k_q}\sum_{i=1}^{N}\lambda_i\left(x_{pk}^{(i)}-x_{pl}^{(i)}\right)^2},\qquad(6)$$

$$R\left(W_p,W_q\right)=\sqrt{\frac{1}{k_pk_q}\sum_{k=1}^{k_p}\sum_{l=1}^{k_q}\sum_{i=1}^{N}\lambda_i\left(x_{pk}^{(i)}-x_{ql}^{(i)}\right)^2}.\qquad(7)$$

Thus, the creation of methods for textual and textual identification of the UAV operator sets the task of creating a dictionary of portraits of the basic commands of UAV control objects.

5. Development of a method of effective spectrum width of voiced operator signal

An effective spectrum width method has been developed on the basis of multi-alternative decision-making rules by processing the input signal spectrum $Ssp_{l,i}$ of a fixed range and all reference spectral $Ssp_{k,i}$ models from an existing database of objects of various classes according to a specific attribute space. This method is designed to identify a voiced command set of the operator of an unmanned aerial vehicle with biometric characteristics under conditions of a high level of interference [6, 8, 13].

The main theoretical basis for the process of processing and making decisions on the identification of an information object should be the transition from the temporal plane to the spectral, as the most informative in terms of quantity and variety of analysis tool for the input signal sequence. This approach allows to increase the quantitative indicators of the quality of identification by the reduced volume of the sample space of class attributes in comparison with other methods.

Thus, a database of spectral portraits of speech signals of various operators and a specific dictionary of signs and classes of information objects with the aim of further identification have been formed. The solution to the problem of approximation and discontinuity errors in the Fourier analysis process is to use the Hamming window function, which in turn allows one to reduce the noise component.

Depending on the ratio of the amplitudes of the frequency components of the spectrum, the sound has different reproductions and is perceived by the identification system as tone or noise. The spectral representation of the signal was considered, and the dependences were established in the form of distinct peaks of amplitudes of the harmonic components of the spectrum and are systematically repeated with a certain frequency interval. It is proved that each such component reproduces one tone of the signal and should be perceived as an individual information characteristic of the message.

For a random value, the spectral representation of the operator's voice sample was taken in the form of a frequency portrait

$$Ssp_{l,i}=\sum_{i=0}^{N-1}x_{l,i}e^{\frac{-j2\pi i\omega}{N}}$$

with a Gaussian distribution, where $x_{l,i}$ – the value of the i-th sign of the l-th object that came to the input of the system for identification. The next step was a probabilistic-statistical analysis of the spectral portrait of the input and reference signals

$$Ssp_{k,i}=\sum_{i=0}^{N-1}x_{k,i}e^{\frac{-j2\pi i\omega}{N}},$$

where $x_{k,i}$ – the value of the i-th signs of the k-th object.

To make a decision in a multi-alternative situation, the Bayesian mathematical apparatus was used. This approach allows to make decisions based on the minimum sufficient amount of information on a specific decision threshold V_{opt}.

In the developed method of effective spectral width, the signal characterizes N features that may belong to the k-th database object, therefore, the probability that the event $Ssp_{k,i}=(x_1, x_2, ..., x_N)$ will occur is

$$P\left(\frac{Ssp_{k,i}}{Ssp_{l,i}}\right)=\frac{P\left(Ssp_{k,i}\right)f_{k,i}\left(Ssp_{l,i}\right)}{\sum_{i=1}^{K}P\left(Ssp_{k,i}\right)f_{k,i}\left(Ssp_{l,i}\right)},\ \text{at}\ V_{opt}\le P\left(\frac{Ssp_{k,i}}{Ssp_{l,i}}\right),\qquad(8)$$

where

$$f\left(Ssp_{k,i}\right)=\frac{1}{\sigma_k\sqrt{2\pi}}\prod_{i=0}^{N}e^{\frac{-\left(Ssp_{l,i}-Ssp_{k,i}\right)^2}{2\sigma_k^2}}$$

is the distribution density of the spectral representation of the input signal; $Ssp_{l,i}$ – the spectrum of the signal received at the input of the system; $Ssp_{k,i}$ – the spectrum of the signal from the database.

The posterior probability of classifying an object with a given class is defined as:

$$P\left(\frac{Ssp_{k,i}}{Ssp_{l,i}}\right)=\frac{\frac{1}{\sigma_k\sqrt{2\pi}}\prod_{i=0}^{N}e^{\frac{-\left(Ssp_{l,i}-Ssp_{k,i}\right)^2}{2\sigma_k^2}}}{\sum_{=1}^{K}\left(\frac{1}{\sigma_k\sqrt{2\pi}}\prod_{i=0}^{N}e^{\frac{-\left(Ssp_{l,i}-Ssp_{k,i}\right)^2}{2\sigma_k^2}}\right)}.\qquad(9)$$

The results of voice identification of the operator of an unmanned aerial vehicle are evaluated in accordance with the values of classical decision thresholds calculated for a certain number of hypotheses [9, 10].

Using the Bayesian mathematical apparatus, the value of the distribution density for all elements of the database and the posterior probabilities of the input signal $Ssp_{l,i}$ belonging to the class of database objects are calculated (Fig. 1).

The sequence of procedures for implementing the effective spectrum width method is presented by its structural-analytical model in Fig. 1.

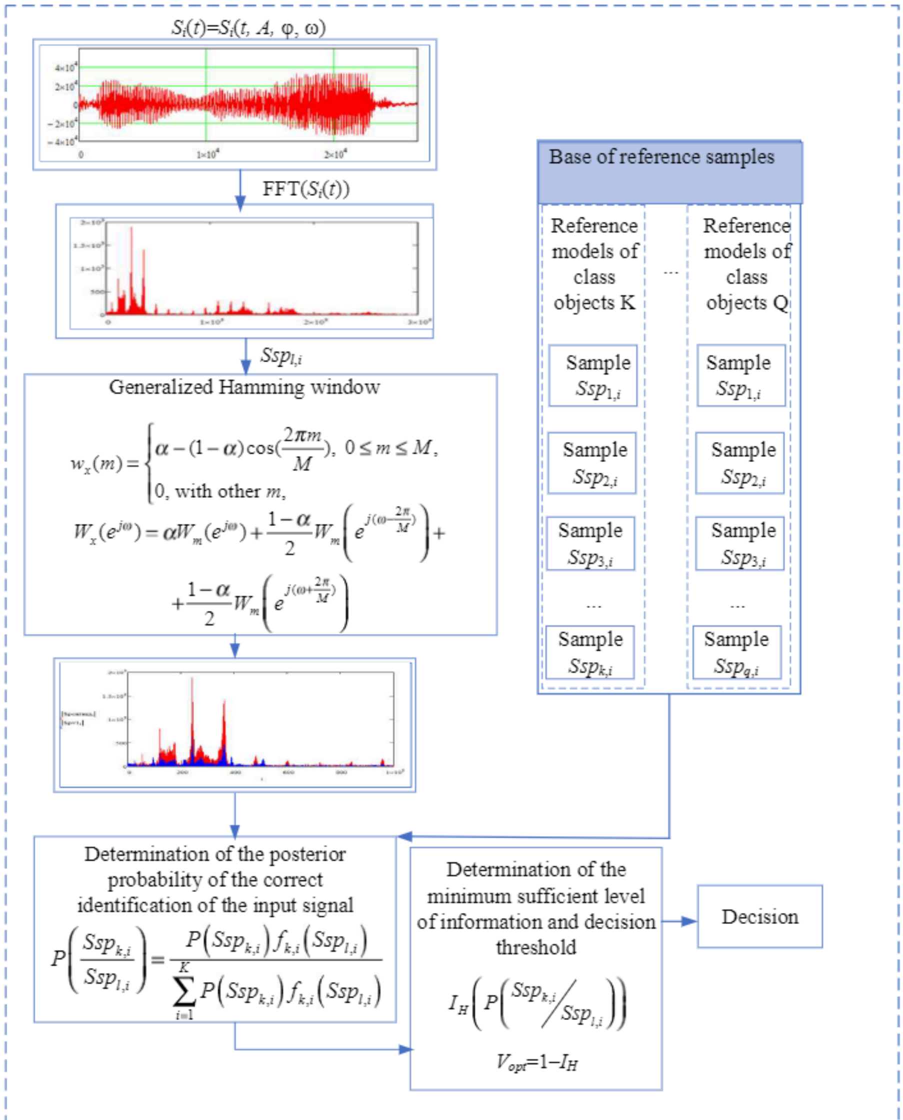


Fig. 1. Structural and analytical model for the implementation of the effective spectrum width method

Thus, the developed method makes it possible to identify the operator of an unmanned aerial vehicle by voice in conditions when the signal-to-noise ratio SNR (SNR/Signal-to-noise ratio)=–5.22 dB.

6. Development of the method of the largest informational weight of the fundamental tone

The method of the largest informational weight of the fundamental tone based on the multi-alternative decision-making rules for certain, the most informative biometric features. This allows identification of the operator of an unmanned aerial vehicle at lower time costs, compared with the effective spectrum width method.

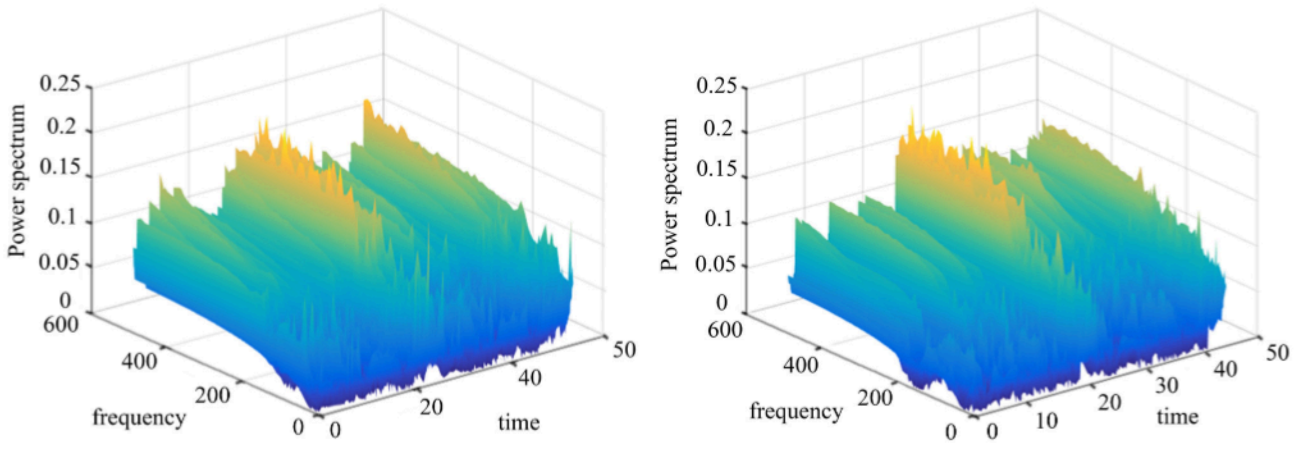
In the process of solving the problems of operator identification, the question of using the biometric characteristics of the vocal tract as signs of identification of the ditcor was resolved.

It has been established that the physical meaning of voice formation is such that, with increasing time, the amplitude of excitation and the duration of each subsequent period of the fundamental tone nT_0 change. The deviation in the change in the period of the fundamental tone in healthy people is in the range of 0.1–1 %. In people with certain diseases of the larynx, this range can vary significantly [29].

The developed method is based on a spectral analysis of signals (Fig. 2) and determination of the frequency of the fundamental tone as individual signs of voice identification. To do this, let's carry out the formation of a dictionary of portraits of basic UAV control teams. For example: "Takeoff", "Landing", "Autopilot", "Route one", "Route two". The place of the base of sample standards is shown in Fig. 3, which reflects the essence of the implementation of the method of the largest informational weight of the fundamental frequency (FF).

In the stationary section of the voiced low-noise signal, the form of the speech wave is almost exactly repeated at each successive period of the fundamental tone. The distance between the global maxima of the speech signal can be approximately considered equal to the period of the fundamental tone.

Thus, to determine the frequency of the fundamental tone, let's find the maximum value of the amplitude of the input filtered signal A_{max} and the points corresponding to the local minimum value a_1, and their module values differ from A_{max} by less than 10 dB.



a *b*

Fig. 2. Spectral representation: *a* – input; *b* – reference signals

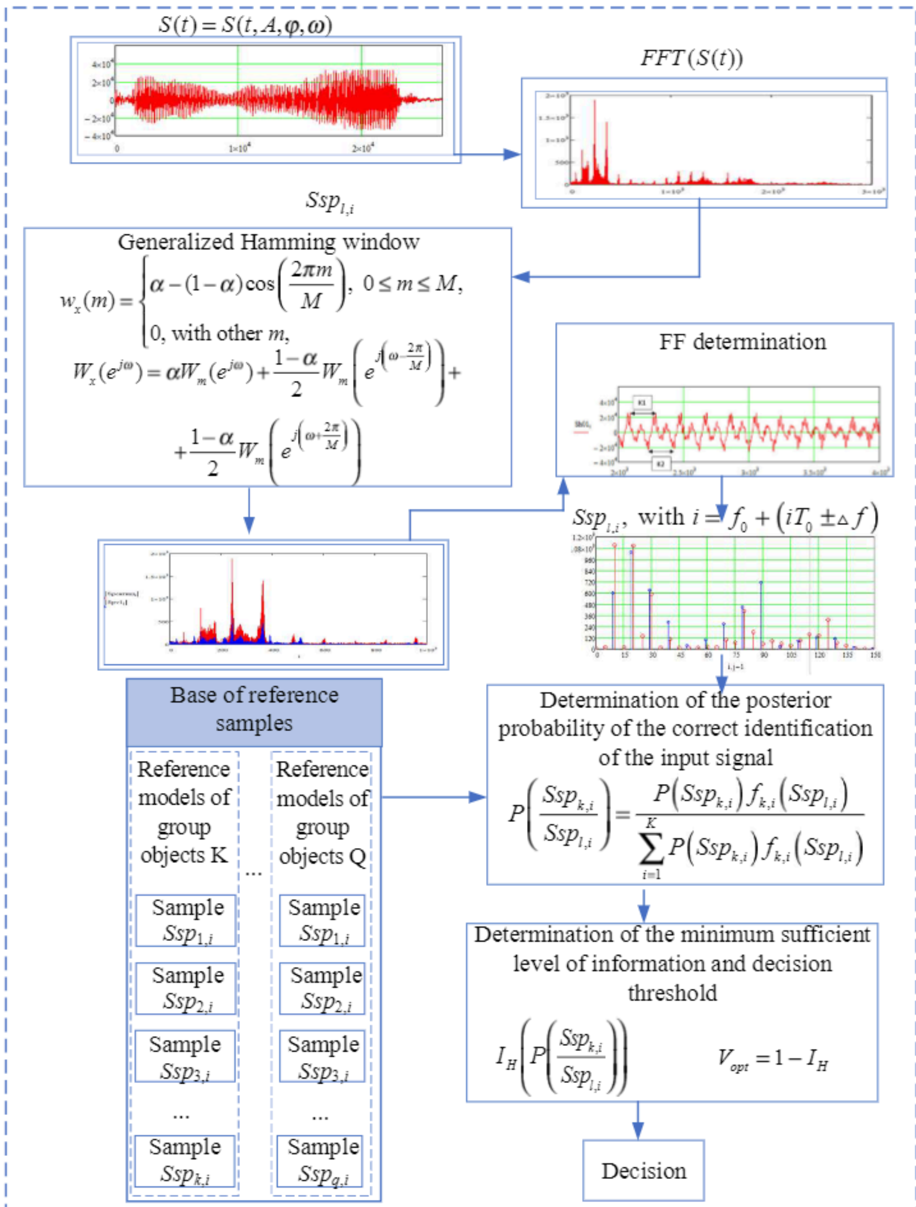


Fig. 3. Structural and analytical model for implementing the method of the largest informational weight of the fundamental frequency (FF)

Having received the sequence $a_1, a_2, ..., a_n \geq 5$, and two adjacent distances in this sequence differ by less than 15 % (periodicity condition), are determined

$$\bar{a} = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{1}{n}(x_1 + \cdots + x_n), \text{ for } n \geq 5. \quad (10)$$

The calculation in different parts of the speech signal may differ, therefore, the minimum $\overline{a_{\min}}$ is selected, for the maximum frequency of the fundamental tone – F_h. Thus, let's find all local minima with negative amplitude values in the chosen limits.

After performing calculations of the frequency of the fundamental tone and its period, it will filter out the spectrum of the presented signal, highlighting the main components and calculate the posterior probabilities of the input signal belonging to a certain class of objects.

Given that the feature space is the individual components of the spectral representation of the speech signal ($f_0+(nT_0\pm\Delta f)$, the amplitude-frequency characteristics of the input

$$Ssp_{l,i} = \sum_{i=0}^{N-1} x_{l,i} e^{\frac{-j2\pi i(f_0+(nT_0\pm\Delta f))}{N}}$$

and reference

$$Ssp_{k,i} = \sum_{i=0}^{N-1} x_{k,i} e^{\frac{-j2\pi i(f_0+(nT_0\pm\Delta f))}{N}}$$

signals are obtained for calculating the posterior probabilities of classifying objects using the method of the highest information weight of the fundamental tone (Fig. 3).

7. Discussion of the results of the introduction of methods for identifying the audio characteristics of the voiced UAV operator signal

As an experiment, to evaluate the effectiveness of the developed methods, a sample of the female voice of the operator was selected, which is subject to identification and authentication. The input signals received by the system are denoted by $S_{in1}(t)$ and $S_{in2}(t)$ depending on the following well-known parameters t, A, φ, ω. Samples of voice standards of the authorized operator affect $S_{in1}(t)=S_{ref}(t)$, and $S_{in2}(t)\neq S_{ref}(t)$ and are stored ideally in the signal base, which makes it possible to carry out identification and authentication for the effective spectral width method and the maximum information weight method main tone.

Regardless of the method used, let the signals $S_{in1}(t)$ and $S_{in2}(t)$ alternately arrive at the system input, which are subject to analysis and determination of their belonging to the set of values $DB=\{A, B\}$, where $A=\{Sm(t)_1, Sm(t)_2, Sm(t)_3, ..., Sm(t)_n\}$ – the set of samples of male voices, and $B=\{Sw(t)_1, Sw(t)_2, Sw(t)_3, ..., Sw(t)_n\}$ – the set of samples of female voices, respectively. The experiment used twelve audio recordings, among which eight were female and four were male. That is, 12 alternative hypotheses H1–12 were used in multi-alternative statistical rules.

The specific structure of all audio recording systems implies the presence of interference created by the system itself and environmental sounds during recording. In this case, it is possible to evaluate the system performance using the signal-to-noise ratio (SNR) [13, 14, 25].

Let there be a record in the database made by the voice of the same person $S_{ref}(t)$, then let's consider it as a reference. Thus, let's have set of female voices

$$B=\{S_{ref}(t), Sw(t)_1, Sw(t)_2, ..., Sw(t)_m\}.$$

Indicators of speaker identification using developed methods using 20 key textual and non-textual commands are presented in Table 1. Let's consider text-dependent teams to be such voiced signals that correspond to a specific list of standardized UAV control commands. According to the team's non-textual address, commands are received against the background of the operator's free speech in a certain period of time (T=3–10 sec.)

Table 1

Speaker identification indicators using developed methods

No.	SNR, dB	Effective spectrum width method		The method of the greatest informational weight of the fundamental tone	
		Text identification	Textless identification	Text identification	Textless identification
1	–2.88	1	1	1	0.99
2	–5.22	1	0.97	1	0.95
3	–6.59	0.99	0.91	0.99	0.91
4	–7.93	0.99	0.82	0.98	0.65
5	–8.9	0.98	0.69	0.97	0.64
6	–10.18	0.95	0.55	0.96	0.52
7	–11.46	0.85	0.46	0.9	0.5
8	–12.65	0.85	0.39	0.87	0.32
9	–14.63	0.65	0.25	0.67	0.23
10	–16.27	0.52	0.14	0.6	0.22
11	–17.53	0.45	0.16	0.4	0.16

Based on the developed software and hardware complex for mathematical modeling of processes (specialized software, C++ programming languages, PTC Mathcad | Mathcad) based on the implementation of the developed identification methods, the following results were obtained:

1) The probability of the correct identification of the female voice $S_{in1}(t)$ and $S_{in2}(t)$ in the plural DB is 100 % in the case when SNR=–5.22 dB for the effective spectral width method and SNR=–5.26 for the largest information weight method fundamental tone, and only after that begins to decline.

2) The frequency of the fundamental tone and overtone are used as the main informative components in the process of identifying a person by voice, which makes it possible to neglect another part of the spectrum. Using the method of the largest informational weight of the fundamental tone makes it possible to identify the voice for the signal-to-noise ratio of –5.21 dB, which reduces the effectiveness of text-independent identification by only 2.1 % and does not affect the likelihood of text-based identification.

3) Samples of male and female voices are in different frequency ranges, so it was advisable to divide them into two subsets A and B. The result of the experiment showed that accurate voice identification is possible when the SNR is –5.29 dB for the text case and –2.95 dB for text-free for

the effective spectral width method. A certain dynamics is also observed for the method of the largest information weight of the fundamental tone, respectively, the SNRs are 5.7 dB and 5.24 dB. So, based on the foregoing, it is possible to conclude that dividing the database into two sets with different groups of samples will increase the efficiency of the system by 16 % for text-independent identification and 2.4 % for text-based identification.

It is determined that there are currently no methods for organizing a UAV control system based on the operator's audio commands. A feature and a distinctive analytical feature of the developed methods and models is that the solution of the tasks set was based on consistent statistical rules for decision making using the most informative components of the spectrum. Unlike existing methods, the basic platform was the creation of a dictionary of attributes in the spectral plane of control messages of the authorized UAV operator, as well as the formation of threshold values taking into account multi-alternative rules.

The results are a consequence of the development of new methods and means of protecting critical information and UAV control signals, which is transmitted from the airborne segment to the ground (video, audio, other types of data) complex in real time.

The disadvantage of the developed models may be the generation of an unauthorized operator of different classes and the origin of artificial interference. An example of such techniques is chaotic impulse noise, as well as intentional artificial speech generation of a signal from an authorized UAV speaker in order to intercept control signals.

Thus, the direction of further research is being formed, namely, increasing the stability of the developed methods and models to various classes of artificial interference, taking into account the tactical time of UAV use in critical route areas.

8. Conclusions

1. A method has been developed for the effective width of the spectrum of a speech signal, which allows identification and verification of the operator of an unmanned aerial vehicle based on an analysis of the informative components of voice prints under conditions of a high level of interference of various origins.

2. A method has been developed for the largest informational weight of the fundamental tone, which is based on the use of the most informative components of the spectral representation of speech fingerprints.

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