Principles of constructing support systems for operational decision-making in the air traffic control tower

V. Mihaylenko*, V. Temnikov, A. Temnikov****

*Kyiv National University of Construction and Architecture, Kyiv, Ukraine
**National Aviation University, Kyiv, Ukraine
Corresponding author. E-mail: temnikov_v@ukr.net

Paper received 25.08.17; Accepted for publication 02.09.17.

Abstract. The main principles of constructing a voice system for information support of decision making by administrators of airport traffic control services in the process of exercising control over the actions of air traffic controllers during the performance of their functional duties are given. The developed information system is intended for permanent authentication of air traffic controllers and monitoring of their psychophysiological state. The system operates in real time.

Keywords: *decision support system, command and control tower, air traffic controller, psychophysiological state of a person, voice.*

Introduction. One of the main causes of accidents and emergencies in aviation is the human factor. Thus, published statistics in the literature indicate that, for example, up to 80% of all accidents and violations of the technological regime in aviation occur through the fault of the dispatching staff. Errors in his work are largely due to the presence of air traffic controllers in a state of permanent tension, associated with the responsibility for people's lives and possible significant material losses.

At present, there is clearly insufficient attention to the development of automatic systems for monitoring the actions of air traffic controllers. In particular, for air traffic controllers in the process of their work, only the visual control by the senior air traffic controller is carried out.

To reduce the impact of the human factor on flight safety, a system of information support for operational decisions (SISOD) has been developed by persons monitoring the actions of air traffic controllers (administrators, senior air traffic controllers).

The developed information system is intended for permanent authentication of air traffic controllers and monitoring of their psychophysiological state (PPS). SISOD, functioning in real time, will promptly signal violations in the work of air traffic controllers, which will allow more effective and earlier stages to prevent violations in the work of controllers, including removing from work of persons in an inappropriate emotional state, fatigue, Drowsiness, anxiety.

Using voice as an analyzed image makes it possible to control air traffic controllers contactlessly, remotely, without distracting them from work.

An important requirement for SISOD is the need to monitor the continuous continuous voice of the air traffic controller in real time. It should be noted that the provision of this requirement is facilitated by such specific requirements for air traffic controllers as the need to use a special normatively established phraseology, to ensure the dimensionality of speech and the invariance of the distance between the sound source and the microphone.

The article presents the principles of construction and methods for modeling the main subsystems of SISOD, which include authentication subsystems (for preventing access to information resources of unauthorized persons), identification (in case of failure to authenticate), monitoring (monitoring) of PPS (to prevent access of persons in an inadequate PPS) of air traffic controllers, as well as the subsystem of preliminary processing (sound-cleaning) of the speech signal.

Principles of construction and methods for modeling the subsystems for authentication, identification and monitoring of the PPS **of air traffic controllers.** Authentication and monitoring of PPS for continuous speech are reduced to the authentication and monitoring of PPS by keywords extracted from the continuous confluent speech of the air traffic controller. As keywords, words often used by air traffic controllers in the course of work or taken from professional phraseology established by regulatory documents can be chosen.

Subsystem for air traffic controllers authentication. The voice subsystem of authentication is proposed to build on the basis of the theory of pattern recognition [1].

Parametrization of the speech signal is proposed to be carried out using the method of short-term analysis [2]. In the process of developing SISOD, a joint development of the parametrization and classification modules was carried out. The parameterization module is recommended to be constructed in such a way as to ensure the efficient operation of the classification module. At the same time, the classification of air traffic controllers is proposed to be implemented on the basis of artificial neural networks (ANN) [3]. Their application together with other methods of computing intelligence allows you to take into account the incompleteness of the initial information.

To meet the requirements for speech parameters from the ANN side, a system of informative parameters was developed, based on the frame-wise computed cepstral coefficients of linear prediction.

Calculation of the cepstral coefficients can be performed using various methods, in particular, based on the preliminary determination of the chalk-cepstral coefficients, linear prediction coefficients (LPC), perceptual linear prediction coefficients, etc.

To calculate the cepstral coefficients, it is proposed to use a method based on the preliminary computation of the LPC.

The LPCs are calculated in such a way that the error in the sense of least squares is minimal for a predetermined prediction order p. In this case, the order of linear prediction, as a rule, is taken in the range from 8 to 20 depending on the purposes and methods of implementation.

The determination of the cepstral coefficients for the LPC should be carried out according to the formula:

$$c(n)=\begin{cases}0, n<0\\ \log_{\varepsilon}(A), n=0\\ a_n+\sum_{k=1}^{n-1}\left(\frac{k}{n}\right)c(k)a_{n-k}, 0<n<p\\ \sum_{k=n-p}^{n-1}\left(\frac{k}{n}\right)c(k)a_{n-k}, n>p\end{cases} \quad (1)$$

Where ai are the coefficients of linear prediction, c(i) are the cepstral coefficients, p is the order of linear prediction, n is the number of the cepstral coefficient, and A is the linear prediction error.

The above formula is recursive, which makes it possible to generate the desired number of coefficients for the parameterization. Their quality directly depends on the number of LPCs.

Experiments, during which several speakers repeatedly pronounced various phrases, showed a good repeatability of the values of cepstral coefficients. As a result, it was revealed that the first 12-20 cepstral coefficients are informative for authentication.

The specific form of the ANN and the values of the parameters of the parameterization and classification modules for voice signals are determined during the joint testing of these modules by the criterion of the maximum percentage of correct authentication. As a result of testing, the percentage of correct authentication was higher than 98%.

Subsystem control of the PPS **air traffic controller.** It is suggested to control the PPS of air traffic controllers on the basis of a comparative analysis of control and reference information parameters that characterize individual (primarily vowel) phonemes.

In the course of the research, theoretical and experimental studies were carried out, the purpose of which was to analyze the parameters characterizing speech fragments from the point of view of their effectiveness for determining PPS. Studies have shown that it is advisable to use the fundamental frequencies, the parameters calculated on their basis (in particular, the ruggedness), the formant frequencies of the vowel phonemes, as well as the length of the speech by the air traffic controller of speech fragments as informative parameters. Segmentation on phonemes is proposed, like noise suppression, to be carried out using wavelets.

Important in determining the PPS air traffic controllers is the lack of the need to recognize all the phonemes of the password speech fragment – to determine the PPS air traffic controller it is enough to recognize only a few first vowel phonemes.

Subsystem for the identification of air traffic controllers. The task of identification is significantly more complicated with a large number of supervised individuals and associated with it a large number of standards in databases (DB). Increasing the speed of identification (with a small increase in the percentage of misidentification) can be achieved by eliminating the areas of "silence" in the speech stream, as well as the development of new algorithms for fast searching in metric spaces.

An identification procedure based on cluster analysis methods has been developed [4]. The idea of the procedure is to cluster controllers' models in the database and to permanently reduce the number of air traffic controllers (clusters) to be compared from the database by comparing the models (clusters) to which the identified sample (voice or image) is least likely to be reduced.

In the case of a small number of monitored persons, in order to speed up the search for the violator of the access mode (if it is detected during the authentication process), in the developed SIPPOR instead of sequential authentication and identification it is proposed to immediately identify the air traffic controllers. For this, the identification subsystem is proposed to be built on the basis of ANN with several outputs.

The method of modeling the subsystem of preliminary processing (noise reduction) of a speech signal

A technique was developed to provide an enhanced level of purification of the speech signal from noise and interference, using wavelet data transformation technologies [5, 6].

Any signal under investigation contains not only useful information S(t), but also traces of some extraneous influences N(t) – noise or noise. The model of such a signal can be written as follows:

$$F(t)=S(t)+k\,N(t), \quad (2)$$

Where k is the coefficient specifying the level of noise or interference.

The noise component is Gaussian white noise, therefore, the useful signal S(t) will be concentrated in the low-frequency region of the spectrum of the signal F(t) under investigation.

The noise component was obtained by modeling the white noise in the MatLab packet with the number of samples equal to the number of samples of the useful signal.

The investigated noisy signal was formed by the following transformations:

$$F(t)= S(t)+0,7*N(t). \quad (3)$$

With a wavelet transform, the signal is decomposed into approximating coefficients, which are a smoothed signal, and the detailing coefficients describing the oscillations. In connection with the fact that the noise component is more reflected in the detailing coefficients, when removing noise, they are processed.

In accordance with the developed technique, the process of noise removal from the speech signal is proposed to be performed in the MatLab environment in the following sequence:

1. Decomposition. The wavelet and the decomposition level N are chosen. The wavelet decomposition of the original signal to level N is made. The choice of the wavelet used and the depth of decomposition, in general, depends on the properties of the particular signal. Smoother wavelets provide a smoother approximation of the signal and vice versa – "short" wavelets better track

the peaks of the approximated function. Depth of decomposition affects the amount of filtered parts.

In the experiment, the Haar wavelets, the discrete approximations of Meyer wavelets, the Daubechies wavelets, the simlets and coifs at the decomposition levels N=1÷8 were used to decompose the signal F(t).

2. Threshold processing of detailed wavelet coefficients. For each level from 1 to N, a threshold is selected and soft threshold processing of the detailing factors is carried out.

From the selection of the noise threshold (noise variance), the noise quality of the signal, estimated as a signal-to-noise ratio, depends. Setting small threshold values preserves the information about the noise component in the detail coefficients and therefore only leads to a slight increase in the signal-to-noise ratio. For large threshold values, it is possible to lose coefficients that carry essential information. Finding the optimal value means finding a threshold that, with the smallest offset of the reconstructed signal, provides the highest value of the signal-to-noise ratio.

To select the optimal threshold value in the experiment, Stein used the adaptive and heuristic criteria of unbiased risk assessment, the universal and minimax criteria [6].

Since the quality of the noise cancellation of the signal also depends on the way the thresholding is applied, for all the above criteria, multilevel processing using a threshold whose values vary from level to level was used and local processing involving the use of a threshold variable not only in terms of decomposition but Also depending on the position of the coefficients of detail at a given level.

3. Reconstruction. A wavelet reconstruction is performed based on the original approximating coefficients of the N level and the modified detailing coefficients from 1 to N.

4. Comparison of the purified signal S*(t) with the original signal S(t) by calculating the correlation coefficients R (S(t), S*(t)). Calculations were made for all eight levels of decomposition with the same characteristics of noise reduction.

5. The choice of optimal characteristics of noise reduction based on the analysis of the calculated correlation coefficients R (S(t), S*(t)). Namely: the wavelet type, the level of its decomposition, the criterion for calculating the threshold level and the processing method.

The signal obtained as a result of noise purification with the use of wavelet transform is suitable for further analysis, since the extraction of the noise component was carried out as correctly as possible without loss of information content of the original signal.

When using a wavelet transform to clear a speech signal from noise and interference, it is important to first estimate the spectral composition of the noise component, since this greatly influences the choice of the criterion for calculating the threshold level and the noise-processing method.

Conclusion. The combination of various methods of constructing SISOD subsystems (methods of cepstral analysis, wavelet transformations, clustering, etc.), application of ANN and algorithms based on metrics, allows creating high-quality SISOD in airport control services.

ЛИТЕРАТУРА

1. Амишвили Г.С. Автоматическое опознавание говорящего по голосу // М.: Радио и связь, 1981. – 224 с.
2. Абинер Л., Гоулд Б. Теория и применение цифровой обработки сигналов // М: Мир, 1978. – 848с.
3. Хайкин С. Нейронные сети // 2-е изд. Пер. с англ. – М.: Издательский дом "Вильямс", 2006. – 1104 с.
4. Мандель И.Д. Кластерный анализ. – М.: Финансы и статистика, 1988. – 176 с.
5. Donoho, D.L. De-Noising by soft-thresholding // IEEE Trans. on Inform. Theory. – Vol.41. – №3. – 1995. – P.613-627.
6. Смоленцев Н.К. Основы теории вейвлетов. – М.: ДМК, 2005. − 303 с.

REFERENCES

1. Ramiashvili G.S. Automatic speaker recognition by voice // M.: Radio and Communications, 1981. – 224p.
2. Rabiner L., Gould B. Theory and application of digital signal processing // M: Mir, 1978. – 848 p.
3. Khaikin S. Neural networks // 2-e ed. Trans. with the English. – M .: Williams Publishing House, 2006. – 1104 p.
4. Mandel I.D. Cluster analysis. - Moscow: Finance and Statistics, 1988. – 176 p.
5. Donoho, D.L. De-Noising by soft-thresholding // IEEE Trans. on Inform. Theory. – Vol.41. – №3. – 1995. – P.613-627.
6. Smolentsev N.K. Foundations of the theory of wavelets. – M.: DMK, 2005. − 303 p.

Принципы построения систем поддержки принятия оперативных решений на командно-диспетчерских пунктах аэропортов

В. М. Михайленко, В. А. Темников, А. В. Темников

Аннотация. Приведены основные принципы построения систем информационной поддержки принятия оперативных решений администраторами командно-диспетчерских пунктов аэропортов в процессе осуществления контроля за действиями диспетчеров управления воздушным движением (авиадиспетчеров) во время выполнения ими функциональных обязанностей. Разработанная информационная система предназначена для перманентной аутентификации авиадиспетчеров и мониторинга их психофизиологического состояния. Система функционирует в режиме реального времени.

Ключевые слова: *система поддержки принятия решений, командно-диспетчерский пункт, авиадиспетчер, психофизиологическое состояние человека, голос.*