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Development of Network Training Complexes Using Fuzzy Models and Noise-Resistant Coding

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***Abstract* — In this paper, an analysis of world experience was conducted and it was concluded that one of the ways to improve the efficiency of aviation security in the Russian Federation is to use modern network training complexes. A new approach to assessing the competence of aviation security screeners was proposed and tested, allowing taking into account the parameters of oculomotor activity and heart rate variability of test aviation security screeners, and differing from the existing approaches by using fuzzy classification models. According to the results of an experimental study, three different models were synthesized. The results of the comparison showed that the Sugeno model, trained using the ANFIS-algorithm, is more accurate than the Mamdani model and the linear regression model depends on the competence assessment of aviation security screeners. It described ways of addressing the important task of obtaining more precise relevant digital data in network training complexes using noise-resistant coding tools. It presented a model of a permutation decoder of a non-binary redundant code based on a lexicographic cognitive map. This model of a redundant code decoder uses cognitive data processing methods for completing permutation decoding procedures in order to protect remote control commands from the influence of destructive factors on the control process.**

Keywords — aviation security; aviation security screener; training machine; fuzzy model; eye-trackung techology; network technologies; error correcting coding; cognitive data processing.

I. Introduction

The increasing volume of baggage and cargo transported by air, and at the same time the level of potential threats, require using innovative technologies in aviation security. One of the main measures to ensure aviation security is the process of screening passengers, checked and unchecked baggage. The inspection is carried out by aviation security screeners with the use of X-ray television introscopes. The main problems that contribute to the negative manifestation of the human factor in the inspection procedure are: insufficient preparation and objectivity in the quality control of aviation security screeners. To solve these problems, it is necessary to increase the level of intellectualization of decision-making processes for assessing the competence of aviation security screeners and implement the integration of training systems into a single information space. This will allow developing and implementing the efficient network training simulators for air transport.

The initial training of aviation security screeners is implemented using specialized computer simulators, and the current on-the-job training is implemented using the threat image projection (TIP) technology. TIP technology is «a technology that allows you to project fictitious objects prohibited for transportation on the x-ray image of the passenger's real baggage after scanning them on the inspection equipment» [1]. According to the recommendations of the International Civil Aviation Organization (ICAO), the training of aviation personnel should be based on the Evidence Based Training (EBT). The high-quality training of aviation personnel in the framework of EBT is primarily achieved through the introduction of psychophysiological monitoring equipment. The use of biofeedback provides objective and comprehensive information about the simulator training of aviation security screeners. In this paper, it is proposed to use the Eye tracking technology and the method of variation cardiointervalometry (VCM) in order for a wide range of diagnostic tasks in the training of aviation security screeners with biological feedback to be solved. The use of Eye tracking technology makes it possible to assess the strategy of visual search for prohibited items by aviation security screeners. The use of VCM method in turn makes it possible to assess the degree of psycho-physiological tension (PPT) (psychophysiological «prices» of the task) of the aviation security screeners during the simulator training. Research on eye movements in solving professional problems during training is progressing greatly in medicine [2,3], sports [4,5] and aviation [6,7]. The existing models [8], used to assess the competence of aviation security screeners apply only final results of their activities, without taking into account the parameters of the oculomotor activity and their PPT. Moreover, a large information array is generated during one EBT training session, which is why it is necessary to apply data mining technologies. In this regard, the current task is to develop a new approach to support decision making on assessing the competence of aviation security screeners. This approach is to apply instrumental methods for diagnosing the psychophysiological state of students with subsequent automatic design of fuzzy models from experimental data. Due to the fact that decision making in aviation security often occurs under uncertainty and incompleteness of basic reference data, the use of fuzzy models is justified.

In Europe the initial step of using the network technologies in aviation security was the establishment of a unified control center for the training of aviation security screeners at the end of 2005. For this purpose, the special computer simulator «X-Ray Tutor» was designed. The presented network system includes a situational center with the central server «XRT Server Tools» and a database united by a single network with several dozen airports, in which the «X-Ray Tutor» simulators are installed [9]. The last generation of TIP technology has also been implemented using network technologies. A typical configuration of the TIP network system consists of inspection equipment, a switch, a central server and an automated workstation with special software installed [10]. The next step in the development of network technologies in Europe was the research project «Automatic Comparison of X-ray Images for cargo scanning» (ACXIS) implemented by the European Union in 2012 [11, 12]. The main goal of this project is to increase the efficiency of cargo inspection procedures at customs and border points [6]. Network technologies for the information exchange between customs and border control points allow: firstly, to increase the competence of aviation security screeners in detecting illegal goods; secondly, develop algorithms for the automatic recognition of dangerous and illegal goods based on machine learning methods. Therefore, an important task of the «ACXIS» project – is «the development of special systems for automatic image recognition to facilitate and improve the detection of both legal and illegal cargo in containers and trucks» [13]. The introduction of network technologies in aviation security screeners training process places high demands on communication channels. For such real-time systems, it is absolutely necessary to ensure the quality of visual data, the timeliness and reliability of the received and processed digital information. In this case, even using the highly reliable optical communication systems, there is an urgent need to use means and methods of noise-resistant coding to protect data from errors. In this regard, the justification and choice of an effective concept of noise-resistant coding in the telecommunications component of the training complex is certainly an urgent task.

II. Fuzzy Models Assessing the Competence of Aviation Security Screeners

A. *Automated Fuzzy Modeling Design by Clustering Results*

In practice, two main types of fuzzy models are most often used: the Mamdani model and the Sugeno model. Mamdani’s fuzzy inference assumes that all values of the input and output variables are given by fuzzy sets. Sugeno’s fuzzy inference suggests that the conclusions of the rules are linear functions of the inputs. The technique of automatic design of fuzzy models from experimental data suggests that there is a dependency $y = f(X)$, which can be described by a fuzzy knowledge base. At the same time, there is a training sample of *M* data pairs, which connects the input data (*x*) with the output (*y*) of the studied dependence [14]:

$$(X_r, y_r),\ r = \overline{1, M}, \tag{1}$$

where X_r – the value of the input in the *r*-th row of the sample and y_r – corresponding output.

The procedure for generating a model of Sugeno from experimental data consists of two stages. At the first stage, subtractive clustering is used to synthesize the basic structure of a fuzzy model. At the second stage, the obtained basic model is trained using the ANFIS-algorithm. The Sugeno model is trained by the criterion of the root-mean-square error ($RMSE_s$):

$$RMSE_s = \sqrt{\frac{1}{M}\sum_{\underline{r=1.M}}(y_r - F(P,B,X_r))^2}, \tag{2}$$

where *P* – vector of membership functions (MF) for terms of variables (*x*); *B* – coefficient vector in the conclusions of the Sugeno knowledge base rules; $F(P,W,X_r)$ – the result of Sugeno’s fuzzy inference.

The generation of experimental data from fuzzy Mamdani model is implemented using clustering based on a fuzzy *c*-means algorithm. The Mamdani model is trained by the criterion of the root-mean-square error ($RMSE_m$):

$$RMSE_m = \sqrt{\frac{1}{M} \sum_{r=1,M} (y_r - F(P,W,X_r))^2}, \qquad (3)$$

where P – vector of MF for terms of variables (x) and (y); W – knowledge base rules coefficient weight vector; $F(P,W,X_r)$ – the result of Mamdani's fuzzy inference.

Terms of variables are represented by fuzzy sets with Gaussian MF. To assess the quality of splitting the source data into fuzzy clusters, it is used the Xei-Beni index (*IXB*) [15]:

$$IXB = \frac{\sum_{i=1,c} \sum_{k=1,M} (\mu_{ki})^m \left\| X_k - V_i \right\|^2}{M \min_{i \neq j} (\left\| X_k - V_i \right\|^2)}, \qquad (4)$$

where μ_{ki} – fuzzy matrix element, at that $\mu_{ki} \in [0,1]$, $k = \overline{1, M}$, $i = \overline{1, c}$; X_k – k-th element of common set X; V_i – centers of fuzzy clusters; m – exponential weight, $m \in (1, \infty)$.

Partitioning into compact and separable clusters meets criterion *IXB* < 1. As input variables (x) of the models, 4 indicators are used, which are presented in the authors' work [14]. Three indicators describe strategies of aviation security screeners visual search (DT, SE и ET), and the fourth *HR* is psycho-physiological stress, which is based on an analysis of heart rate. The output of the model (y) is the frequency of detection of prohibited items. Thus, the task is to identify the non-linear relationship between the indicators of the oculomotor activity of the operators by its PPT and the frequency of detection of prohibited items.

B. *Generating Fuzzy Models Assessing the Competence of Aviation Security Screeners*

To develop a fuzzy model, experimental studies were conducted in Ulyanovsk Civil Aviation Institute. As a means of picking up indicators of aviation security screeners activities there were used the mobile eye-tracker Eye Tracking Glasses 2.0 and a device of psychophysiological testing devices UPFT-1/30 «Psychophysiologist». 35 cadets took part in testing, 30 of them were included in the training sample and 5 – in the testing sample.

In order to assess the quality of the initial data, a robust assessment was performed, which is presented in Table 1.

TABLE I. STATISTICAL ANALYSIS

	Trimmed mean, 5,000 %	Winsorized mean, 5,000 %	Grubbs Test Statistic	p-value	Std. Dev.
DT	2.989	2.985	2.208	0.795	0.445
SE	0.100	0.106	2.072	1.000	0.094
ET	2.258	2.294	2.603	0.219	0.695
HR	0.958	0.955	3.037	0.038	0.049

Grubbs criteria for the maximum values of the indicators *DT*, *SE*, *ET* and *HR* have a significance level of 0.7952; 1; 0.2199; 0.03858 respectively, which is greater than the selected level of significance α = 0.01. The calculated Grubbs criteria do not exceed a critical value of 3.33 with α = 0.01. Thus, the maximum values are not emissions. The values of the accuracy of sample characteristics are equal: $Ar_{DT} = 2.5234$ %, $Ar_{SE} = 14.9901$ %, $Ar_{ET} = 5.1421$ %, $Ar_{HR} = 0.8634$ %. The *Ar* value for *DT* and *HR* is below the specified criteria, which indicates sufficient accuracy of these characteristics. For the remaining integral indices, the value of *Ar* slightly exceeds 5 %. The analysis showed the suitability of the obtained statistical data for teaching a fuzzy model.

Fuzzy Logic Toolbox from Matlab was used to generate fuzzy models. Using the genfis2 function, a Sugeno model is generated using subtractive clustering. The radius of the clusters is 0.7. As a result, it is synthesized a fuzzy Sugeno model with three rules:

IF *DT*=in1cluster1 AND *SE*=in2cluster1 AND *ET*=in3cluster1 AND *HR*=in4cluster1, THEN *DP*=out1cluster1;
IF *DT*=in1cluster2 AND *SE*=in2cluster2 AND *ET*=in3cluster2 AND *HR*=in4cluster2, THEN *DP*=out1cluster2;
IF *DT*=in1cluster3 AND *SE*=in2cluster3 AND *ET*=in3cluster3 AND *HR*=in4cluster3, THEN *DP*=out1cluster3.

The simulation error on the training sample according to (2) is equal to $trnRMSE_1^1 = 0.0105$, and on the testing sample – $chkRMSE_1^1 = 0.8313$. The results of testing the model on the training sample after subtractive clustering are presented in Fig. 1.

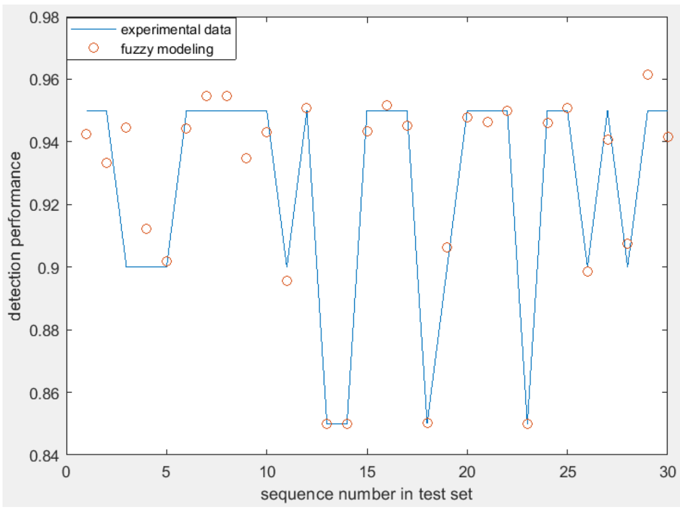

Fig. 1. Surgeno model testing

After learning the model over 200 iterations using the ANFIS-algorithm, the error value decreased to $trnRMSE_2^1 = 0.0025$ and $chkRMSE_2^1 = 0.0329$. A comparison of experimental data with the results of fuzzy modeling after ANFIS-training is presented in Fig. 2.

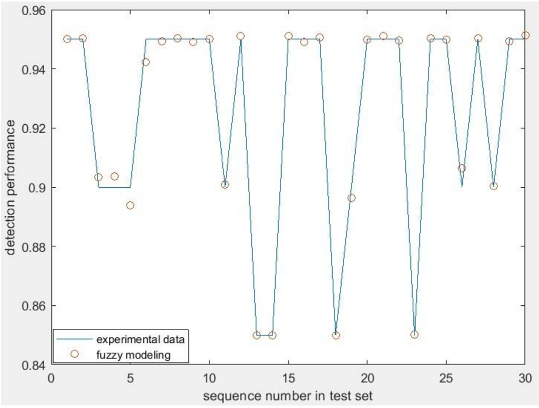

Fig. 2. Sugeno model testing after ANFIS-training

Fig. 3 shows the model learning curves using the ANFIS-algorithm.

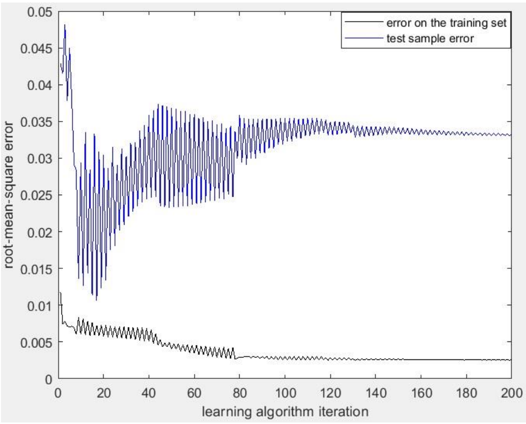

Fig. 3. Dynamics of Surgeno model learning

Analysis of the learning dynamics (Fig. 3) allows us to conclude that the error on the test sample reaches its lowest value at the 20th iteration ($chkRMSE_{test}^{1} = 0.0106$).At the same time, the error on the training sample decreases for all 200 iterations. Fig. 4 and 5 show the MF to fuzzy clusters for the HR variable before and after learning by the ANFIS-algorithm are presented.

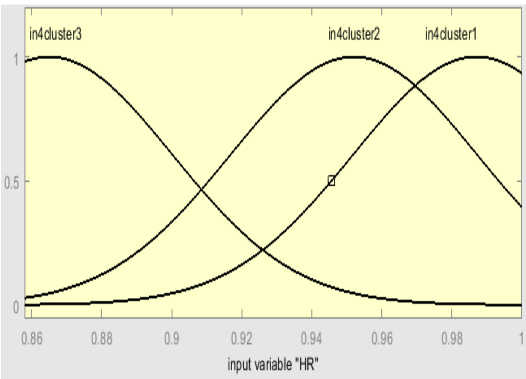

Fig. 4. Membership functions to fuzzy clusters of HR variable before learning

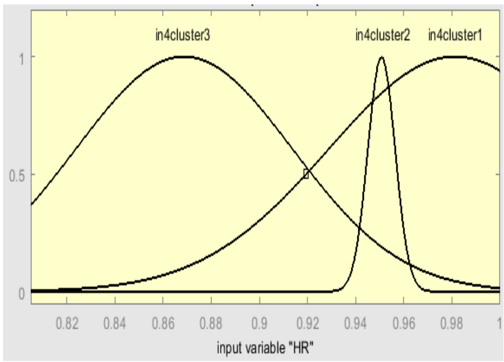

Fig. 5. Membership functions to fuzzy clusters of HR variable after ANFIS learning

Similarly, after applying the ANFIS-algorithm we refined parameters of the MF of the input variables and parameters in the conclusions of the Sugeno model rules.

Using the genfis3 function, a fuzzy Mamdani model was generated. The parameters of the fuzzy *c*-means algorithm were chosen as follows: the number of clusters is 3; the exponential weight is 2; the value of the improvement of the objective function for one iteration is 0.00001; the number of iterations is 100. As a result of fuzzy clustering, the Mamdani model was generated, which also contains a knowledge base of 3 rules. The simulation error on the training sample according to (3) is equal to $trnRMSE_3^1 = 0.0323$, and on the testing sample – $chkRMSE_3^1 = 0.0360$. The results of testing the model on the training set are presented in Fig. 6.

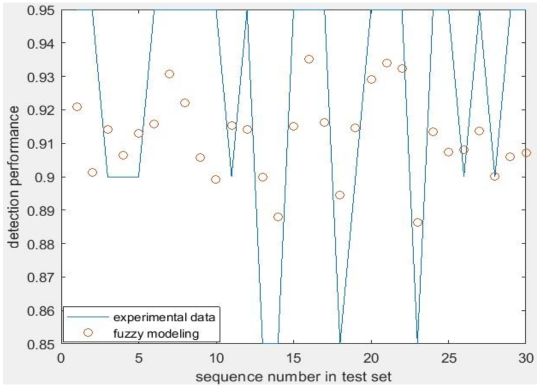

Fig. 6. Mamdani model testing

The next stage of the study was the regression analysis. The parameters of the regression model for the studying dependence are presented in Table 2.

TABLE II. PARAMETERS OF THE REGRESSION MODEL

Variable	Coefficient	Standard error	Value of Student t-criterion	Test significance (p-value)
Constant	0.554	0.103	5.332	9.102E-06
DT	-0.025	0.007	-2.874	0.007
SE	0.095	0.034	2.873	0.008
ET	-0.005	0.005	-0.920	0.364
HR	0.467	0.084	5.595	4.339E-06
R^2	0.83			

Model error on the training set is equal to $trnRMSE_4^1 = 0.0368$, and on the testing sample – $chkRMSE_4^1 = 0.0393$. The assessment of the accuracy of the chosen cluster number was carried out by criterion *IXB* and according to (4) was 0.6892. Thus, it was concluded that compact and separable fuzzy clusters were obtained. At the last stage, the results of fuzzy identification were compared with a linear regression model (Table 3).

TABLE III. COMPARISON OF MODELS ESTIMATION OF COMPETENCE OF AVIATION SECURITY SCREENERS

Fuzzy model	*RMSE* on training sample	*RMSE* on test sample
Sugeno (without the ANFIS-training)	0.0105	0.8313
Sugeno (with the ANFIS-training)	0.0025	0.0329
Mamdani	0.0323	0.0360
Linear regression model	0.0368	0.0393

According to Table 3, it can be seen that the Sugeno model that was trained using the ANFIS-algorithm more accurately than other models identifies the dependence under investigation according to the competence of inspectors.

III. APPLICATION OF NOISE-RESISTANT CODING IN NETWORK TRAINING COMPLEXES

A. *The Concept of Cognitive Metaphor in Permutation Decoding*

The objective basis for the intellectualization of many promising information and technological processes is the improvement of the management procedure during their implementation in real time. The latter requires finding ways to shorten the cycle of obtaining the desired image, introducing the principles of cognitive adaptation and artificial intelligence. Obviously, the use of non-binary codes is indisputable. Then it becomes obvious that the strict requirements for the duration of the training video presentation cycle do not allow to use the noise-tolerant coding theory properly in order to reach this goal, for example, in the form of turbo coding systems with a number-intensive procedure for iterative data conversion or a system based on polar codes. These designs are not sufficiently adapted to process non-binary signals. Against this background, there is a problem of effective using of short non-binary error-correcting codes to protect vector images with maximum use of the redundancy introduced into such codes and the rapid identification of digital data. A method is proposed in which the time-consuming procedure for solving a system of linear equations is replaced by a template stored in the decoder's memory. The method is based on the possibility of creating a set of equivalent codes in the system of permutation of code vector symbols [20, 21]. The advantage of permutation decoding (PD) over other methods in the context of cognitive data processing is the presence of a deterministic component that a decoder can calculate in the process of work and store in a cognitive map. This approach dramatically reduces the complexity of the implementation of the decoding procedure on programmable logic integrated circuits (PLIC).

B. *Results of Noise-Resistant Coding on the Cognitive Metaphor Base*

The analysis shows that the target function of the PD algorithm contains several stochastic parameters and a single deterministic component. The image of the objective function can be represented as:

$$F\{\bullet\} = \begin{cases} \{V_k\} \oplus e(h); \\ \{P_{n.}\}, \end{cases} \tag{5}$$

where $\{V_k\}$ – many random vectors that make up the core of the management team, and $e(h)$ – probability of occurrence of interference vectors of length n as a function of the signal-to-noise ratio at $h = E_b/N_0$, acting on the elements of the set $\{V_k\}$.It is advisable to include many permutations $\{P_n\}$, forming in the second stage of the implementation of PD, to deterministic component.

In principle, such permutations can be calculated in advance (during the learning process of the decoder) and the results of the matrix calculations can be recorded in the memory of the decoder, essentially in its cognitive map. In this case, the second stage of the PD algorithm, which is difficult to implement, unambiguously loses its negative value in the implementation of the PD procedure..

Let the non-binary Reed-Solomon (RS) code with parameters be used in the data exchange system (7,3,5). The generator matrix $\mathbf{G}$ of this code in a systematic form has the form:

$$\mathbf{G} = \begin{Vmatrix} \alpha^0 & 0 & 0 & \alpha^4 & \alpha^0 & \alpha^4 & \alpha^5 \\ 0 & \alpha^0 & 0 & \alpha^2 & \alpha^0 & \alpha^6 & \alpha^6 \\ 0 & 0 & \alpha^0 & \alpha^3 & \alpha^0 & \alpha^1 & \alpha^3 \end{Vmatrix}, \tag{6}$$

and the matrix columns are numbered normally from left to right. Hereinafter α – is a primitive element of the field $GF(2^3)$. Suppose that the reliable symbols in some adopted code vector of the RS code are the characters with the numbers (2 4 5), and less reliable characters in descending order of values are arranged in the sequence of the form (6 7 1 3). Then (7) follows from (6):

$$G' = \begin{Vmatrix} 0 & \alpha^4 & \alpha^0 & \alpha^4 & \alpha^5 & \alpha^0 & 0 \\ \alpha^0 & \alpha^2 & \alpha^0 & \alpha^6 & \alpha^6 & 0 & 0 \\ 0 & \alpha^3 & \alpha^0 & \alpha^1 & \alpha^3 & 0 & \alpha^0 \end{Vmatrix}. \tag{7}$$

In systematic form, the matrix (7) takes the form:

$$\mathbf{G}'_{\mathbf{sis}} = \begin{Vmatrix} \alpha^0 & 0 & 0 & \alpha^6 & \alpha^2 & \alpha^6 & \alpha^2 \\ 0 & \alpha^0 & 0 & \alpha^3 & \alpha^3 & \alpha^1 & \alpha^1 \\ 0 & 0 & \alpha^0 & \alpha^5 & \alpha^4 & \alpha^4 & \alpha^5 \end{Vmatrix}. \qquad (8)$$

Note that in order to calculate the matrix (8), when implementing the known PD algorithm, we had to perform 336 arithmetic operations in the field $GF(2^3)$.

During online data processing, the combination of reliable code combination symbols in the form (2 4 5) even in one communication session can be repeated with high probability. Therefore, in order to save the decoder's computational resource, it is advisable to save this result in the processor's memory and use this data with possible permutation repetitions with numbers (2 4 5). The test part of the matrix, obtained from expression (8) and presented in Fig. 7, with a strictly increasing sequence of line numbers is called canonical, and the matrix itself is a reference:

$$\begin{array}{ccccc} \alpha^6 & \alpha^2 & \alpha^6 & \alpha^2 & 2 \\ \alpha^3 & \alpha^3 & \alpha^1 & \alpha^1 & 4 \\ \alpha^5 & \alpha^4 & \alpha^4 & \alpha^5 & 5 \\ 6 & 7 & 1 & 3 & \end{array}$$

Fig. 7. The structure of the reference matrix in canonical form with reliable symbols

During the research it was found that firstly you should rearrange the rows of the reference matrix, and secondly - the columns of this new matrix when storing the position numbers in permutations of k reliable and $(n-k)$ unreliable characters. Following the principles of cognitive data processing, the decoder, receiving, for example, a tuple of values of reliable symbols in the form (5 2 4) for the first k reliable combination symbols and the remaining $(n-k)$ less reliable symbols in the form (3 7 1 6), forms a matrix $\mathbf{G}'$, based on the structure of the reference matrix (9), as shown below

$$\mathbf{G}'_{\mathbf{sis}} = \begin{Vmatrix} \alpha^0 & 0 & 0 & \alpha^5 & \alpha^4 & \alpha^4 & \alpha^5 \\ 0 & \alpha^0 & 0 & \alpha^2 & \alpha^2 & \alpha^6 & \alpha^6 \\ 0 & 0 & \alpha^0 & \alpha^1 & \alpha^3 & \alpha^1 & \alpha^3 \end{Vmatrix}. \qquad (9)$$

For this, three actions are performed with permutation of rows, for example, the second row from the reference matrix from the first position is set to the second position in accordance with the permutation (5 2 4), etc. And then four column permutations of the newly formed matrix are performed with the corresponding configuration of unreliable characters (3 7 1 6). Only 7 actions to copy and transfer data instead of 336 arithmetic operations. Verification of the result obtained (and many others) using the classical method showed the validity of the proposed PD model.

$$\begin{array}{ccccc} \alpha^6 & \alpha^2 & \alpha^6 & \alpha^2 & 2 \\ \alpha^3 & \alpha^3 & \alpha^1 & \alpha^1 & 4 \\ \alpha^5 & \alpha^4 & \alpha^4 & \alpha^5 & 5 \\ 6 & 7 & 1 & 3 & \end{array} \Rightarrow \begin{array}{ccccc} \alpha^5 & \alpha^4 & \alpha^4 & \alpha^5 & 5 \\ \alpha^6 & \alpha^2 & \alpha^6 & \alpha^2 & 2 \\ \alpha^3 & \alpha^3 & \alpha^1 & \alpha^1 & 4 \\ 6 & 7 & 1 & 3 & \end{array} \Rightarrow$$

$$\begin{array}{ccccc} \alpha^5 & \alpha^4 & \alpha^4 & \alpha^5 & 5 \\ \alpha^2 & \alpha^2 & \alpha^6 & \alpha^6 & 2 \\ \alpha^1 & \alpha^3 & \alpha^1 & \alpha^3 & 4 \\ 3 & 7 & 1 & 6 & \end{array}$$

It becomes obvious that the decoder does not perform arithmetic operations in the Galois fields to search for the reference matrix, but implements the trivial procedure of copying and address data transfer. In the latter case, the number of such operations will always be equal to the length of the code vector n.

TABLE IV. EVALUATION OF A WINNING BY NUMBER OF OPERATIONS

Reed-Solomon Code	Classic method	Proposed method
Code $RS(7,3,5)$	336	7
Code $RS(15,5,11)$	$2.4\ 10^{3}$	15
Code $RS(15,9,7)$	$2.9\ 10^{6}$	15
Code $RS(15,13,3)$	$6.8\ 10^{10}$	15

The advantages of the proposed method are obvious, especially for codes with different correction powers and a fixed length of the code vector.

For the first time, a model of a redundant code decoder was developed using cognitive data processing methods when implementing a permutation decoding procedure to protect remote control commands from the destructive factors.

The apparatus of fast matrix transformations of reference matrices is mathematically invalid and the cyclic properties of such matrices are proved. Despite a certain increase in the computational load on the decoder's processor it reduces the volume of its cognitive map to acceptable sizes. Modern element base allows implementing PD algorithms.

Increasing the speed of obtaining the final result allows us to talk about the feasibility of using PD algorithms for real-time systems, in particular, when building network training complexes for aviation security personnel.

IV. CONCLUSIONS

Thus, at present, in the practice of aviation security in the Russian Federation, there is no possibility of using modern network technologies, which makes it difficult to implement mechanisms for timely response to new threats, the organization of centralized management and coordination of inspection systems at various airports. Based on the analysis of foreign experience, we can conclude that one of the ways to improve the effectiveness of aviation security in the Russian Federation is to use modern network training complexes. This will allow implementing mechanisms for timely response to new threats, as well as improving the preparation and objectivity of quality control of aviation security screeners at transport infrastructure facilities. A new approach has been developed to support decision-making in assessing the competence of aviation security screeners, which consists in using instrumental methods for diagnosing the psycho-physiological state of students, followed by automatic design of fuzzy models from experimental data. The paper describes ways to solve an important task of increasing the reliability of data transmission in network training complexes based on the application of noise-resistant coding. The paper presents the results of modeling a permutation decoder of a non-binary redundant code based on a cognitive map.

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