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COMPARATIVE ANALYSIS OF DIFFERENT METHODS APPLIED FOR AZERBAIJANI HAND-PRINTED CHARACTERS RECOGNITION

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Applicant: **Elviz Ismayilov**

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Scientific supervisor	Riyaziyyat elmləri doktoru, prof. **Araz R. Aliev**
Official opponents	1. Doctor of technical sciences, prof. **Latafat A. Gardashova** 2. Doctor of technical sciences, prof. **Mahammad N. Nuriev** 3. Philosophy doctor on engineering, **Uzeir G. Gurbanli**

Dissertation council ED 2.02 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at Azerbaijan State Oil and Industry University.

Chairman of the Dissertation Council:	Doctor of technical sciences, prof. **Mustafa B. Babanli**
Scientific secretariat of the Dissertation Council:	Doctor of philosophy on technical sciences, assoc. prof. **Tahir G. Jabbarov**
Chairman of the Scientific Seminar:	Doctor of technical sciences, prof. **Tarlan S. Abdullayev**

GENERAL DESCRIPTION OF THE DISSERTATION

The actuality of the topic. Visual interpretation of the environment is one of the tasks we perform subconsciously. For example, when a person sees an object, he does not examine it before determining whether it is a machine, a tree, or another person. However, for a computer, recognizing a person (distinguishing him from any animal, chair, or other human being) is quite a complex issue. When the human eye looks at an object, it searches for information about its size, structure, and color. First, the analysis of the image is performed superficially, then the characteristic details are studied.

- Similar steps are performed in the proposed algorithms for image recognition:
- Defining contours;
- Focus on sections with more and less information content;
- Detailed image analysis;
- Detection of special shapes, colors, given characteristics;

One of the most memorable events of the 1950s was the revolutionary change in document circulation[1]. Optical character recognition or OCR, allows scanned documents to be stored not only as image files, but also as recognizable text files, and to be searchable within those documents. OCR extracts relevant information from images and automates this process instead of entering them into the system manually..

OCR generally deals with the recognition of account checks in a number of areas, including the legal field, banking, health care [2] and more. OCR also serves to automate people's work in other areas, such as screen reading - Captcha, digitization of libraries, optical

[1] Bachuwar K., Singh A., Bansa G., Tiwari S., "An Experimental Evaluation of Preprocessing Parameters for GA Based OCR Segmentation" // 3rd International Conference on Computational Intelligence and Industrial Applications (PACIIA 2010), 2010, proceedings, Vol. 2, p. 417-420.

[2] M.D. Ganis, C.L. Wilson, J.L. Blue, Neural network-based systems for handprint OCR applications // IEEE Transactions on Image Processing, 1998, Vol: 7, Issue: 8, p. 1097 – 1112.

recognition of music, recognition of machine numbers[3] or printed manuscripts.

One of the main problems in OCR is the primary image processing (noise removal, segmentation, screening, etc.) operations. Numerous algorithms have been proposed for this purpose in the literature[4,5]. In the dissertation, these algorithms were studied and applied to the recognition of printed manuscript symbols in the Azerbaijani language.

Although research on image recognition began in the middle of the last century, the results are still not at the desired level, and every effort to improve the quality of the results is commendable. Approaches used in the recognition of printed manuscript symbols are mainly artificial neural networks, fuzzy logic, methods of classification of artificial intelligence, etc. developed on the basis of.

The modern innovative theoretical and practical approaches proposed for the recognition of printed manuscript symbols have been successfully used in the recognition systems of texts, ancient alphabets, artifacts and number plates in various local languages.

Much of the research on the creation and development of existing recognition systems has focused on symbols and texts written in English or other most widely used alphabets. However, the recognition of various symbols used in a number of languages, such as Arabic, Japanese and Chinese, is still a very pressing problem. Although the alphabets of a number of local languages, such as Azerbaijani and Bulgarian, are dominated by Latin characters, the special characters used, as well as the morphological structure of the language, require a special approach. In this regard, the selection and application of the

[3] Chang S.L., Taiwan T., Chen L.S., Chung Y.C., Chen S.W., " Automatic license plate recognition" // IEEE Transactions on Intelligent Transportation Systems, 2004, Vol: 5 , Issue: 1, p. 42 – 53.

[4] Fu K. S., Mui J.K., "A Survey on Image segmentation" // Pattern Recognition, 1981, 13, p. 3–16.

[5] Storn R., Price K., "Differential Evolution – A Simple and Efficient Heuristic for Global Optimization over Continuous Spaces" // Journal of Global Optimization, 1997, p. 341–359

most informative features directly affects the recognition accuracy of a particular character.

One of the most important features of image recognition problems is the process of selecting such features. For example, patterns, geometric and graphic elements used to recognize an image can be successfully used to classify different surfaces from urban landscapes, satellite imagery, maps, and the environment[6].

A lot of work has been done in the field of image recognition in the country. Under the leadership of academician T. Aliyev, G. Abdullayeva and N. Gurbanova[7] created an electronic recognition system for writing in the Arabic alphabet in the 80s. prof. Under the leadership of R. Aliyev[8], research was conducted in the field of image recognition using fuzzy logic. Prof. A. Karimov worked to create optimal classifiers of dynamic systems, R. Mammadov[9] reviewed technical vision systems. Prof. Under the leadership of O. Nusratov, a system for recognizing handwritten letters was developed[10]. Prof. Under the leadership of K. Ayda-zade[11], handwritten letters and speech recognition systems were developed. E. Mustafayev[12] and J.

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[6] Kurtzberg J. M., Feature analysis for symbol recognition by elastic matching // IBM J Res Dev, 1987, 31(1). p. 91–95.

[7] Aliyev T. A., Abdullayeva G.G., Gurbanova N. G. Intellectual system of identification of Arabic graphics // SPIE 15th Annual International Symposium, Orlando, Florida, USA, 2001.

[8] Alyev R. A., Guirimov B.G. Handwritten Image Recognition by Using Neural and Fuzzy Approaches // Intelligent Control and Decision Making Systems. Thematic selected articles. Publishing House of Azerb. SOA, 1997, № 1, p. 3-7.

[9] Мамедов Р.Г., Акберов И.А., Аббасзаде А.А. Использование систем технического зрения для оперативного управления информационными комплексами // Известия АНАКА, 2006, т. 9, № 2, с. 82-88.

[10] Нусратов О.К., Гейдаров П.Ш. Метод распознавания рукопечатных символов и текстов // PCI 2006.The International conference “problems of cybernetics and informatics”. Volume III, October 2006, p. 81-85.

[11] Мустафаев Э.Э. Разработка систем распознавания рукопечатных форм с использованием искусственных нейронных сетей: Диссертация на соискание ученой степени кандидата технических наук. Баку, 2005.

[12] Мустафаев Э.Э. Разработка систем распознавания рукопечатных форм с использованием искусственных нейронных сетей: Диссертация на соискание ученой степени кандидата технических наук. Баку, 2005.

Hasanov[13] developed the system of recognition of printed manuscripts of the Azerbaijani language and the system of recognition of manuscripts written in the Latin alphabet in the Azerbaijani language.

One of the main problems in the construction of object recognition systems is the selection of the class of informative features. There is a lot of research work devoted not only to the recognition of images, but also to the selection of appropriate parameters for the diagnosis of diseases, financial forecasting, forecasting of various values in expert systems for calculation.

Although the selection of subset sets of signs is not a separate expert system, it is one of the most important parts of the design and improvement of recognition and classification systems. It can be said that this approach can be successfully used in many areas where artificial intelligence is applied, such as medical expert systems, business forecasting, industrial decision-making, robotics, data analysis.

The choice of the most appropriate subset of the available parameters has a direct impact on the quality of recognition. It is not possible to use analytical optimization methods because the power of the set of parameters is too large. For this purpose, the problem of binary optimization was set and solved in the dissertation. Random selection methods based on heuristic optimization algorithms were applied to solve the binary optimization problem.

In the dissertation parallel genetic algorithms were applied to select the best subgroup from the base of large-scale signs produced for the recognition of printed handwritten symbols in the Azerbaijani language, this algorithm was implemented using the capabilities of the HPC center of Azerbaijan State Oil and Industry University, and the results were interpreted.

Object of research work: Image recognition systems of different character are a set of features used in expert systems.

[13] Ayda-zadə K.R., Həsənov C.Z. Azərbaycan dilində latın əlifbası ilə yazılmış əlyazmanı tanıma sistemi // "Elm və təsildə informasiya-kommunikasiya texnologiyalarının tətbiqi" II Beynəlxalq Konfransının materialları. 2-ci kitab. Qafqaz Universiteti. Bakı, 2007. s. 662-670.

The subject of the research work: The hand printed character in the Azerbaijani language consists of symbols, some special symbols and figures.

Research methods: The research used artificial neural networks, image processing, multilevel classification, evolutionary algorithms, the method of support vectors, the theory of fuzzy sets.

Main highlights, brought forward for dissertation defense. In this dissertation the following problems are considered:

1. Processing of hand printed character symbols in the Azerbaijani language, application of segmentation and skeletalization algorithms;
2. Analysis of the results of different classes of signs and different classification methods used in recognition of hand printed character symbols in Azerbaijani language and justification of the advantages of proposed methods;
3. Development of methods and algorithms for the production of "soft" symbols based on the visual characteristics of the characters for the recognition of hand printed characters in the Azerbaijani language;
4. Application of various algorithms to select the most informative set of symbols from the large number of symbols used in the recognition of hand printed character symbols in the Azerbaijani language, their implementation in high-speed computing systems (HPC center of Azerbaijan State University of Oil and Industry).

Scientific novelty of the research.

1. Various segmentation and skeletalization algorithms were analyzed and applied for the processing of hand printed character symbols in the Azerbaijani language;
2. Algorithms for obtaining "soft" features based on the visual characteristics of objects have been proposed and applied in recognition systems;
3. Applied to the existing classification methods for the recognition of hand printed chracter symbols in the Azerbaijani language and substantiated the advantages of the support vector method;

4. Genetic algorithms for selection of optimal subset from numerous parameters in recognition systems, as well as in expert systems of different nature were proposed, implemented in parallel at the HPC center of Azerbaijan State University of Oil and Industry.

Theoretical and practical significance of the research. The proposed approach to the extraction of "soft" features for the recognition of hand printed character symbols in the Azerbaijani language in the dissertation can be successfully applied in various areas of image recognition. Also, the use of evolutionary algorithms to select the most informative features from among the many traits and their application in parallel high-speed computing systems in areas such as business forecasting, medical expert systems, natural language processing allows to obtain high results.

Approbation and application. The results of the dissertation were presented at the following international conferences and symposiums.

1. Proceedings Of the International Scientifically and Practical Conference "Information Innovation Technologies: Integration of Business, Education and Science" Almaty, Kazakhstan, November, 27-28, 2008.
2. 24th Mini EURO Conference on Continuous Optimization and Information-based technologies in the financial sector, Izmir, Turkey, June 23-26, 2010
3. International Sympozium on Innovations in Intelligent Systems and Applications, Kayseri, Turkey, 2010, June 21-24
4. 11th International Conference "Pattern Recognition and Information Processing", 18-20 may, 2011, Minsk, Belarus.
5. Innovations in Intelligent Systems and Applications (INISTA), 2012 International Symposium on, Trabzon, Turkey, 2-4 July, 2012.
6. IEEE International Symposium on INnovations in Intelligent Systems and Applications, 2014, Italy, Alberobello

7. In: 11th World Conference on Intelligent Systems for Industrial Automation - WCIS-2020. Advances in Intelligent Systems and Computing, 2020

8. The proposed methods and algorithms in the field of image recognition have been successfully tested in Arter LLC, ATL Tech and Destech Group.

The name of the organization where the dissertation work was carried out. The dissertation work was carried out at the "General and Applied Mathematics" department of the Azerbaijan State University of Oil and Industry.

Composition of the dissertation work. The total volume of dissertation work – 164499 symbols (title page – 532 symbols, contents – 1880 symbols, introduction – 15412 symbols, chapter one – 63852 symbols, chapter two – 45862 işarə, chapter three – 35384, result – 1577 symbols, 43 image, 7 table). The list of used literature consists of 91 types of literature.

Publications. The obtained results were published in 24 works including 7 papers and 17 confrans matherials.

MAIN CONTENT OF THE WORK

In the Introduction part reflects the actuality of the topic, the objectives, research methods, theoretical and practical significance of the research.

In the first chapter OCR systems are generally subsystems of object recognition, the basic concept and methodology are also related to the recognition of such objects and image processing. Writing, which for centuries was the primary method of collecting, storing, and transmitting information, is now used not only to communicate with people, but also to communicate with people and machines. Intensive research efforts in the field of OCT have been made not only to solve the problem of reading simulation, but also to solve such problems as mass processing of papers, data transfer to machines and web references, including paper documents. The search for ways to

perform common tasks, such as automating human functions and machine reading, has always been a topical issue. SOT systems can be divided into different classes according to their purpose and function.

Existing character recognition systems have been successfully applied in a variety of fields, such as document automation, license plate recognition, image and video processing. The algorithms currently used in existing systems and approaches, the stages of building recognition systems, as well as the lack of consideration of the characteristics of some local languages in research, the excessive number of characters, the volume of the required training base are explained.

The second chapter describes the methods and algorithms used in recognition systems.

Currently, there are software that can partially solve the digitalization of paper documents, but there are many problems with their operation. First of all, these software cannot fully ensure the recognition of the Azerbaijani language. Despite the use of symbols of the Latin alphabet in the language, the morphological structure of the Azerbaijani language, its unique spelling rules require a special approach[14,15].

When finding the boundary of the image sought in robotics, the model of the image obtained by the camera is first constructed. Then, after rendering the model (visualization, description), the coordinates of the objects are found. The Sobel operator was used in the dissertation to determine the first boundaries of the object.

The Sobel operator is used to calculate the approximation of the image brightness gradient. Thus, it is possible to obtain the degree of the greatest change in brightness and the degree of change in this direction. Therefore, in order to know how the brightness of the image

[14] Alieva N.T., Ismayilov E. A., About fuzzy recognition system of Azerbaijani hand-printed texts // Abstracts of the IV Congress of the Turkic World Mathematical Society. 1-3 July, 2011. p. 299.

[15] Alieva N.T., Ismayilov E. A., The analysis of how the choice of membership functions influences the quality of recognition system // Innovations in Intelligent Systems and Applications (INISTA), 2012 International Symposium on, Trabzon, Turkey, 2-4 July, 2012.

changes in each pixel, it is possible to find a point on the border of the object and to direct it. Thus, by applying the Sobel operator, we can obtain the vector of the intersection of the direction of growth with the boundary of different luminosity regions. The Sobel operator is based on extracting an image based on small integers in the vertical and horizontal directions. The operator puts two rotation masks on each pixel of the image. These masks are represented by two orthogonal 3x3 matrices.

For example, we are given the following 3x3 matrix, where z_1, ..., z_9 - shows the transparency of the corresponding pixels in the mask (figure 1, 2).

z_1	z_2	z_3
z_3	z_5	z_6
z_7	z_8	z_9

Figure 1. The degree of transparency of the pixels of the original image

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Figure 2. Application of Sobel operator

As shown in the figure, the sum of the coefficients in each mask is 0, as in the gradient operator.

$$M(x,y) = |(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)| + \\ +|(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)| \quad (1)$$

Both masks shown in Figure 3 are called Sobel operators. The coefficient of central weights is 2 to achieve a higher smoothness.

Sobel masks define vertical and horizontal borders on the image. When these masks are placed differently on the object, gradient values can be obtained in each direction, or more precisely, G_x, G_y. The final value of the gradient can be calculated by the following formula.

$$G = \sqrt{G_x^2 + G_y^2}$$

The working principle of the program written in the figure below can be seen visually. The program was implemented using Sobel masks (Figure 3).

Figure 3. The process of finding the boundaries of objects through the program

As you can see, the algorithm easily finds the boundaries of complex objects. The program is written in Java and Delphi programming languages.

One of the most important processes associated with image processing is image binary. The binary process is the process of converting color images, or more precisely, gray images, to white and black (0 and 1).

The main purpose of binary is to radically reduce the amount of data available in the form. However, it should be noted that if this process fails, it can lead to line breaks, image distortion, loss of informative parts, loss of object integrity, additional noise, etc. There will be many problems such as (Figure 4).

Figure 4. The figure shown on the household item

If we pay attention to the picture, we will see that the picture was taken when it was not lit. The picture was of a different transparency because the diodes that illuminate the home screen are not provided with a stable light. This image must be processed before it can be recognized, and it is correct to use local binary when binary. Therefore, it is possible to obtain the following image using the local binary algorithm (Figure 5).

Figure 5. The result of Christina binary.

In the dissertation, the process of binary in hand printed character symbols in the Azerbaijani language was carried out with the help of many different algorithms. Each of them is described in detail below.

Lower boundary binary process: The process of binary through the lower boundary is an easy operation, where a boundary value is used:

$$f'(m,n) = \begin{cases} 0, f(m,n) \geq t; \\ 1, f(m,n) < t, \end{cases}$$

the color value of the pixels is replaced by 0 (black) if it is greater than the t limit, and 1 (white) if it is small.

Upper border binary process: In the first case in the binary process, if the result is negative, you can alternatively use the upper boundary binary process:

$$f'(m,n) = \begin{cases} 0, f(m,n) \leq t; \\ 1, f(m,n) < t, \end{cases}$$

Binary constraint binary process: If it is known that the brightness values of the pixels can vary in a certain range, then the binary constraint method is applied ($t_1<t_2$):

$$f'(m,n) = \begin{cases} 0, f(m,n) \geq t_1; \\ 1, t_1 < f(m,n) \leq t_2; \\ 0, f(m,n) > t_2. \end{cases}$$

In addition, there are other variations of border approaches.

Incomplete border processing: The image obtained during this type of conversion is simplified for further analysis, as the image is freed from additional backgrounds and objects.

$$f'(m,n) = \begin{cases} f(m,n), f(m,n) > t; \\ 0, f(m,n) \leq t, \end{cases}$$

Multilevel boundary transformations: This operation converts a non-binary but segmented image with a different brightness.

$$f'(m,n) = \begin{cases} 1, f(m,n) \in D_1; \\ 2, f(m,n) \in D_2; \\ \cdots \\ n, f(m,n) \in D_n; \\ 0, digər\ hallarda \end{cases}$$

In addition to the above methods, local binary is also used [16]. These binary methods were also used in the dissertation.

Otsa method: this method uses a distributed brightness histogram algorithm of the pixels of the image. The histogram is based on the values $p_i=n_i/N$ where N – is the number of pixels with all the brightness levels k in the figure, and n_i – is the number of pixels in the brightness i. Depending on the values of the boundaries, the brightness range is divided into two classes (where k is an integer from 0 to L). The ratio frequency ω_0, ω_1 corresponds to each class:

$$\omega_0(k) = \sum_{i=1}^{k} p_i;$$

$$\omega_1(k) = \sum_{i=k+1}^{L} p_i = 1 - \omega_0(k);$$

[16] Chutani G., Patnaik T. and Diwedi V., "An Improved Approach for automatic denoising and Binarization of Degraded Document Images Based on Region Localization" // IEEE, 2015, p. 2272–2278.

$$\mu_0(k) = \sum_{i=1}^{k} \frac{ip_i}{\omega_0};$$

$$\mu_1(k) = \sum_{i=k+1}^{k} \frac{ip_i}{1};$$

Then, the maximum value of dividing the image into two parts is calculated:

$$\eta(k) = \max_{k=1} \left(\frac{\sigma^2_{\text{class}}}{\sigma^2_{\text{general}}} \right)$$

Here $(\sigma_{class})^2=\omega_0\omega_1(\mu_1-\mu_0)^2$, – is the variance between classes, $(\sigma_{general})^2$ – is the exact variance of the whole figure.

As for the final stage, it is advisable to bring all the images to the standard size for the selection of their features after the operation. This can be achieved using different scaling algorithms. The most widely used scaling algorithms are binary and bicubic methods.

The binary algorithm is as follows (figure 6, a):

$$\widetilde{G}(\widetilde{i}, \widetilde{j}) = (1-a)(1-b)G(i,j) + (1-a)bG(i,j+1) + \\ + a(1-b)G(i+1,j) + abG(i+1,j+1)$$

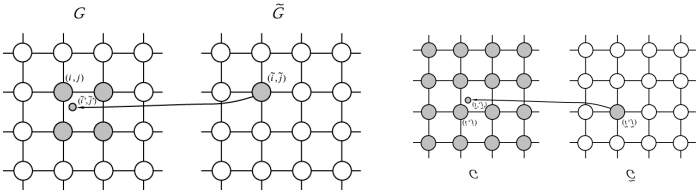
,

here $\widetilde{G}(\widetilde{i}, \widetilde{j})$ - is the scaling of the image; $G(i,j)$ - is the size of the input image; a and b - $(\widetilde{i}', \widetilde{j}')$ the distance between the points, and $(\widetilde{i}, \widetilde{j})$ is the opposite projection of the points. G closest to the image (i,j) points are determined by the following formula:

$$a = \widetilde{i}' - \lfloor \widetilde{i}' \rfloor, \widetilde{i}' = \tilde{\imath} \cdot k_h^{-1}, b = \widetilde{j}' - \lfloor \widetilde{j}' \rfloor, \tilde{\jmath} = \tilde{j} \cdot k_w^{-1},$$

here k_h and k_w- i and j due to the scaling coefficient; $\lfloor x \rfloor$ – while is the largest integer less than or equal to x.

As for the bicubic algorithm, it is calculated as follows (Figure



a) binary b) bicubic

Figure 6 scaling algorithms

6, b):

$$\widetilde{G}(\widetilde{i},\widetilde{j}) = \sum_{m=-1}^{2}\sum_{n=-1}^{2} G(i+m, j+n)\cdot R_c(m-a)\cdot R_c(-(n$$

,

$$R_c(x) = \frac{1}{6}\left((x+2)_+^3 - 4(x+1)_+^3 + 6(x)_+^3 - 4(x-2)_+^3\right)$$

,

here $(z)_+^m = \begin{cases} z^m, & z > 0 \\ 0, & z \le 0 \end{cases}$.

It should be noted that in the dissertation, the scales were taken in the form of 42x63, or more precisely, the scale was taken in the ratio of width to length of 1.5. Prior to that, the measurements were taken as a ratio of 1 to 1 of width and length. As a result of experiments, it was found that this measure is more appropriate.

Many methods have been proposed for the problem of skeletalization of objects. Skeleting itself is divided into two classes: the method of remote mapping (for example, Blum) and topological skeletonization (Rosenfeld, Zonga-Sunya, etc.). The most widely used of these, the Zonga-Sunya skeletonization algorithm, is a very

effective algorithm for the skeletonization of black-and-white images (Figure 7).

Figure 7. Image obtained after using the Zonga-Sunya skeletalization algorithm.

In general, a binary image is considered a P matrix, if the pixel is black, its value is 1, if it is white, it is 0. Thus, the object present in the image is identified by black pixels. Each p pixel is denoted by 8 adjacent pixels (p_0, p_1,…, p_7). They are written as N_8 (p) (Figure 9). The set N_4 (p) = (p_0, p_2, p_4, p_6) is called the 4 adjacent sets of p pixels. The distance between two 8 adjacent pixels is D_8 (p, q) = max (| x_p - x_q |, | y_p - y_q |) and for 4 adjacent pixels d_4 (p, q) = (| x_p - x_q | + | y_p - y_q |), where (x_p, y_p), (x_q, y_q) are the coordinates of p and q pixels.

P_5	P_6	P_7
P_4	p	P_0
P_3	P_3	P_1

Figure 8. N_8(P) pixel abundance.

The skeletalization algorithm used in the dissertation is implemented by deleting non-skeletal black pixels. To maintain the neighborhood relationship between the pixels, we divide each operation into two sub-iterations. In the first sub-iterations, we delete the boundary of point P_1 when the following conditions are met.

(a) 2 =< B(P_1) =< 6

(b) A(P_1)= 1

(c) $P_2*P_4*P_6 = 0$

(d) $P_4*P_6*P_8 = 0$

where A (P_1) is the 1st example and the others are P_2, P_3, P_4,…, P_8, P_9 8 existing neighbors of P_1 and B (P_i) is a non-zero neighbor of P_1 which is B (P_1) = $P_2 + P_3 + P_4$ It is defined as +… + $P_8 + P_9$ (Figure 9).

P_9 (i-1, j-1)	P_2 (i-1, j)	P_3 (i-1, j+1)
P_8 (i, j-1)	P_1 (i, j)	P_4 (i, j+1)
P_7 (i+1, j-1)	P_6 (i+1, j)	P_5 (i+1, j+1)

Figure 9. How to arrange pixels in a 3x3 window

If none of these conditions is met, the value of P_2, P_3, P_4, ..., P_9 occurs as shown in Figure 10, while $A(P_i) = 2$ does not remove P_1 from the figure.

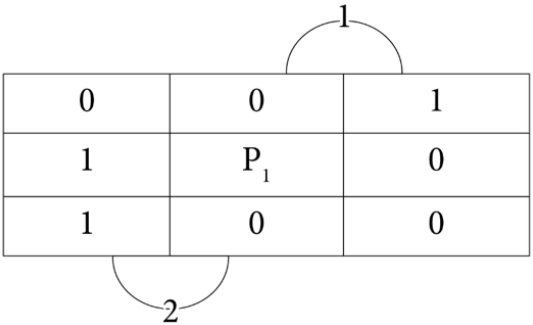


Figure 10. P_2, P_3, P_4, ..., P_8, P_9 calculation of 0 and 1 in sequence

As for the second sub-iteration, only the conditions (c) and (d) are modified as follows (Figure 11).

	P_2	
P_8	P_1	P_4
	P_6	

Figure 11. Points considered and their locations

(c') $P_2*P_4*P_8 = 0$

(d') $P_2*P_6*P_8 = 0$

Under conditions (c) and (d), the first iteration results in the maintenance of a perfect pixel only at the south-east boundary points and the north-west corner points.

Deleted points provide the following conditions:

$$(c)\ P_2*P_4*P_6 = 0 \quad (1)$$

$$(d)\ P_4*P_6*P_8 = 0 \quad (2)$$

The solution of formulas (1) and (2) will be $P_4 = 0$ and $P_6 = 0$ or ($P_2 = 0$ and $P_6 = 0$). Thus, the deleted point P1 can be an east or south boundary point or a north-west corner point. Similarly, the deleted point P_1 in the second sub-iteration can be the north-west boundary point or the south-east corner point. For example, the skeleton of the "H" symbols with both sub-iterations results in the following figure (Figure 12, a). According to the above conditions, the carcass at the end of the line is preserved. In addition, under condition (b), the points passing through the endpoints are preserved, as shown in Figure 12, b. This iteration continues until no point is erased.

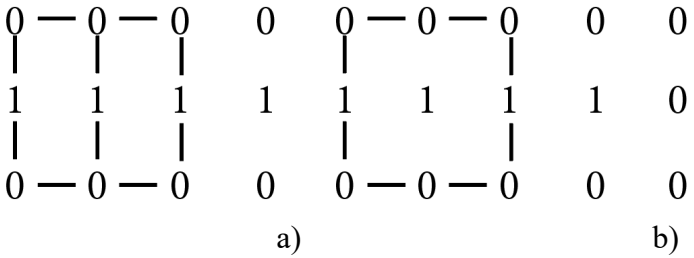


Figure 12. The process of eliminating endpoints

The Zonga-Sunya algorithm is widely used in skeletonization because it is fast and easy to calculate [17]. This method is a parallel method that requires the new value of any pixel to be calculated using the values in the iteration only one step earlier. This algorithm iteratively deletes pixels until only one pixel-thick bar is left on the eight linked skeletons. Each element is brought to a size of 3x3, which

[17] Zhang T., Suen C.,A fast parallel algorithm for thinning digital patterns // Communications of the ACM, 1984, no. 3, Vol. 27, p. 236–239.

shows its relationship with 8 neighboring pixels. The pixels in the table can be represented as a binary A matrix, respectively, where A (i, j) is either 1 or 0. Structure 1 consists of valuable pixels. Neighbors of the point (i, j) (i-1, j) (i-1, j + 1) (i, j + 1) (i + 1, j + 1) (i + 1, j) (i + 1 , j-1) (i, j-1) (i-1, j-1).

The skeletonization algorithm described above was improved and software was developed, and printed manuscripts and manuscripts were applied in the Azerbaijani language (Figure 13).

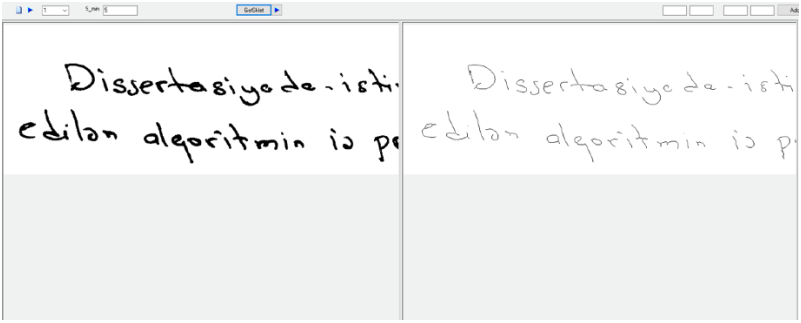


Figure 13. Skeletləşdirmə alqoritminin nəticəsi

Thus, we conclude that the correct choice of skeletonization and segmentation algorithms for the initial processing of images during character recognition has a very significant impact on the quality of recognition. Also, the fact that not all of the traits used in identification are informative or have a high correlation necessitates the use of different approaches to select the optimal subsets of traits. This chapter describes the existing approaches to the initial processing of symbols, the calculation of signs, the implementation of recognition, the selection of the optimal subset of signs, their advantages and disadvantages.

In the third chapter, work was carried out on the recognition system of Azerbaijani hand printed characters. Although most of the letters of the Azerbaijani alphabet are used in the Latin alphabet, there are some special symbols, such as "ğ", "ə" and so on. creates problems in the application of existing recognition systems. The morphological

structure of the Azerbaijani language, in turn, requires an individual approach to the recognition of symbols.

Unfortunately, the features used to classify various objects are derived from computer calculations that can be interpreted as random parameters that are incomprehensible to the human mind and undetectable to human logic and intellect. Thus, recognition requires the calculation of more functions and makes it more difficult to assess the effectiveness of the functions[18].

Therefore, in this case, the calculation of "soft" fitures is considered, in which case the signs are determined in a way that a person can understand. The main purpose of the dissertation is to save time by using fewer signs and not to damage the quality of recognition. In this study, this problem was solved by two approaches - the selection of "soft" traits for object recognition and the application of parallel genetic algorithms in high-performance computers for the selection of more informative traits.

This section describes the proposed features for the recognition of printed manuscript symbols in the Azerbaijani language and their calculation algorithms. First, each of the symbols given to the system is placed in a separate (42x63) rectangle and the skeletonization algorithm is implemented.

Degree of curvature

One of the features of "soft" is the use of the degree of curvature. Using this sign, it is possible to compare the letters "O" and "H", in addition, the sign of the closed area is used, where the number and location of the closed area is also important, through these signs the symbols "P", "B", "A" it is possible to distinguish from each other.[19]

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[18] Исмайылов Э. А., “Система распознавания текстов с применением нечетких множеств” // Professor Yəhya Məmmədovun anadan olmasının 80 illik yubileyinə həsr olunmuş “Riyaziyyat və Mexanikanın aktual problemləri” adlı Beynəlxalq konfrans. Bakı, Azərbaycan, 27 dekabr, 2010, p. 217-218.

[19] Ismayilov E. A., Feature selection method for recognition of hand-printed characters // The 5th International Conference on Control and Optimization with Industrial Applications, 27-29 August, 2015, Baku, Azerbaijan, p 208-210.

Determining the degree of curvature of a symbol occurs in two stages: first, the rectangle where the symbol is located is divided into 9 parts. The degree of curvature in each section is calculated according to the formula for calculating the Gini index known from the economy.

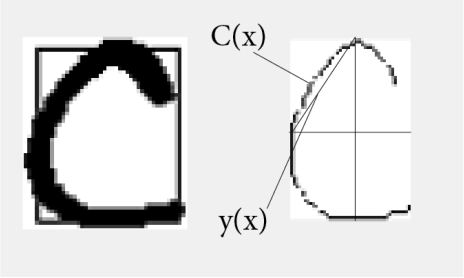

Figure 14. Determination of the degree of skeletalization and curvature

Thus, the following formula is used to determine the degree of curvature of the symbol in a given section:

$$CD = \frac{\int_{x_0}^{x_n} C(x)dx}{(x_n - x_0)(y_n - y_0)},$$

where C (x) is a function that expresses the curvature generated by the pixels. The integral of this function can be defined by the trapezoidal method of numerical integration

$$CD = \frac{y_0 + y_n + 2\sum_{i=1}^{n-1} y_i}{2(x_n - x_0)(y_n - y_0)}.$$

The calculation of the degree of curvature of the symbols is described in Figure 14 for the symbol "c". If we imagine the dividing straight lines in each part as axes of the Cartesian coordinate system and combine the first and last pixels in the considered rectangular part, we observe 2 fields: the first field is the area and peaks bounded by the O_x and O_y axes under the C(x) curve (x_0 , y_0), (x_n, y_0) and (x_0, y_n) are right-angled triangular areas.

Calculating the degree of curvature using the above formula allows you to easily classify different symbols [20].

Closed area: "P", "B", "Ö" and so on.

The number and location of closed areas are very important for the classification of characters such as The first colorless pixel is defined along with all neighboring colorless pixels and colored with a fixed color, then another colorless pixel that is not adjacent to the colored pixels is assigned and at the same time painted in a different color with neighboring pixels, this process continues until all colorless pixels are colored. If the object has two colors after the process is complete, it means that the character has a closed area (the second color is considered the background); If three colors are used, then the object has two closed areas, and so on. (Figure 15).

Figure 15. Determining the closed area

One of the most difficult issues when defining closed areas in an object is closed areas that are artificially created during processing (Figure 16). To solve this problem, it was proposed to analyze the diameters of the closed areas and the ratios of the diameters of all the closed areas in the facility.[21].

[20] Ismayilova N. T., Ismayilov E. A., Fuzzy Features Extraction for Hand-printed character/digit recognition system // IEEE International Symposium on INnovations in Intelligent Systems and Applications, 2014, Italy, Alberobello, p. 249-252.

[21] Ismayilov E. A., Feature selection method for recognition of hand-printed characters // The 5th International Conference on Control and Optimization with Industrial Applications, 27-29 August, 2015, Baku, Azerbaijan, p 208-210.

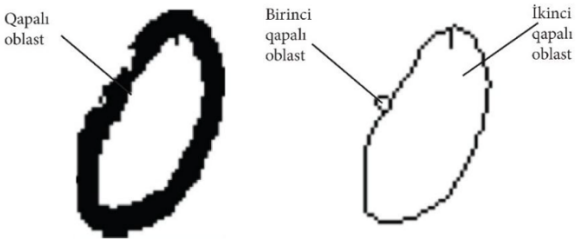

Figure 16. Artificial closed area formed after skeletalization

Given that the part where the closed area is located is also important in recognition, the location of the closed area is determined by determining the center of gravity as a sign. Symbols such as "δ" (largest closed area below) and "P" (largest closed area above) are easily classified by determining the center of gravity of the largest closed area in a given object and calculating the distance between this point and the edges of the symbol [22].

The number of points of intersection of the pixels of the symbol with the lines drawn on the rectangular part

To calculate this sign, a large number of straight lines are drawn inside the rectangle where the symbol is located. (Figure 17)

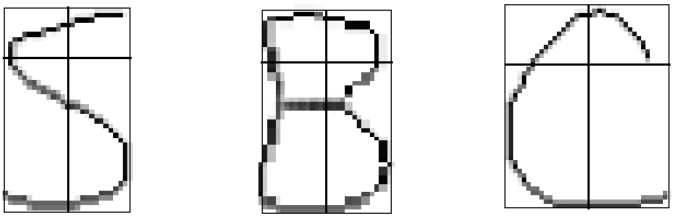

Figure 17. Classification of symbols according to the drawn lines

Then the number of points of intersection of the pixels that make up the symbol with the drawn lines is determined.

As shown in the figure, the number of points where the horizontal line intersects the symbol "S" is 1, the number of points

[22] Ismayilova N. T., Ismayilov E. A., "Soft" features and SVM for hand-printed caharcters recognition // 6th International Conference on Control and Optimization with Industrial Applications, 2018, August, p. 178-180.

where the symbol "B" intersects is 2, and the number of points where the symbol "C" intersects is 1. For a vertical straight line, this number is 3 for the "S" symbol, 3 for the "B" symbol, and 1 for the "C" symbol. Thus, it is possible to easily classify symbols by drawing such straight lines from different points and in different directions.

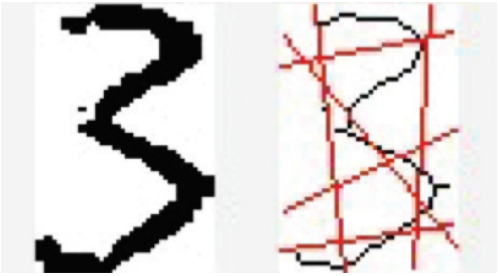

Figure 19. Straight lines drawn in different directions in the rectangle where the symbol is located

The following questions arise during the calculation of the described sign. What should be the number of these lines? How should the starting and ending points of the lines drawn, or rather the pieces, be determined?

Of course, the answers to these questions cannot be found experimentally. Thus, taking into account the dimensions of the rectangle where the symbols are located, the number of different straight lines that can be drawn is 32,634. Figure 19 shows several examples of these lines.

The problem of selecting the optimal set of subtypes from the database of signs is brought to the problem of binary optimization. Here, if the position is 0 in the optimized vector, the sign does not participate in the recognition, if it is 1, it participates.

In short, sequential selection of traits adds or deletes traits in one step, depending on the productivity of the classification. This process continues until there is a k-dimensional subset.

There are many signs that can be used to recognize printed manuscript symbols in the Azerbaijani language. Genetic algorithms

were used to select an informative trait subset within the existing set of traits[23].

Initially, this approach was applied to a vector of 37 traits, and in addition to genetic algorithms to reduce the size of the vector, backward sequencing and forward sequencing were used [24].

Figure 20 shows that the minimum error value was detected for 16 characters when using the sequential forward selection method, and Figure 20 shows that the best result was detected for 24 parameters in the backward selection method.

Figure 20 shows a graph of the dependence of the accuracy of recognition on the length of the characteristic vector when applying the forward sampling method. Here, the empty sign vector is first displayed, and the other signs are added to the vector one by one, and the accuracy of the recognition is measured. The support vector method (SVM) was used to assess the accuracy of the identification. As can be seen from the graph, the inclusion of some symbols in the system after a certain number does not change the recognition accuracy.

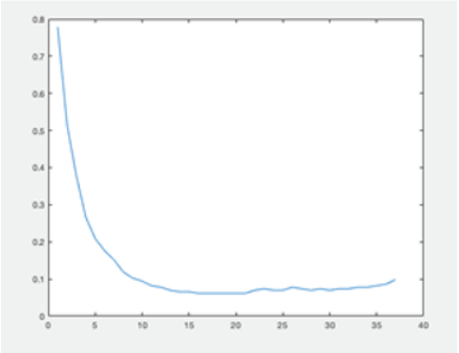

Figure 20. Recognition accuracy depends on the characteristics obtained after the application of sequential forward selection.

[23] Ismayilov E.A., Mammadov R., Parallel solution of features subset selection process for hand-printed character recognition // Azerbaijan Journal of High Performance Computing, 2019 2(2), p. 170-177.

[24] Ismayilov E. A., Application of SVM and Soft Features to Azerbaijani Text Recognition // ICTACT Journal on Image and Video Processing (Volume: 9, Issue: 2, 2018), p. 1872-1875.

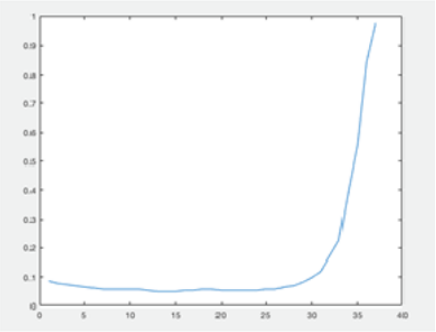

Figure 21. Recognition accuracy depends on the characteristics obtained after the application of sequential reverse selection.

Another solution to the problem is the use of genetic algorithms to determine informative traits. After using genetic algorithms for this purpose, the most accurate recognition result was obtained for 17 traits from the considered set (see Figures 22, 23).

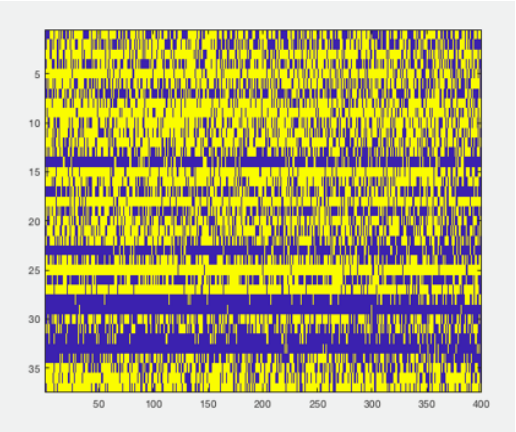

Figure 22. Optimal traits as a result of the application of genetic algorithms, 100th generation.

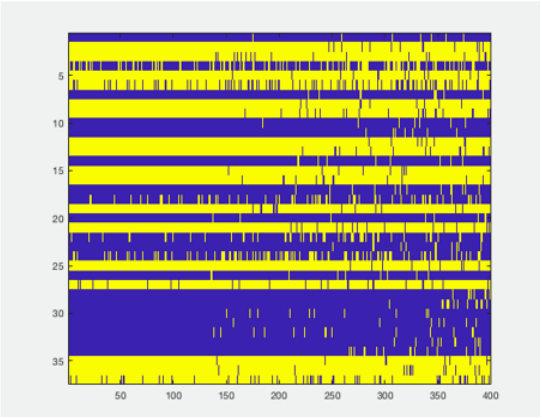

Figure 23. Optimal traits as a result of the application of genetic algorithms, 900th generation.

Table 1 describes the results of the analysis of the described methods to obtain optimal features, as well as the results that provide the most accurate recognition of Azerbaijani printed manuscript symbols by SVM.

Table 1. Character vectors obtained by applying different methods to the binary optimization problem

Method	Selected features (+ selected, - not selected)	Error
Consecutive selection	+ - + - + - - + + + + + + - + + - + + + + - + + + + + + - - - - - + + + -	0.0492
Sequential forward selection	- + + - + + - + + - - + + - + - + - - - - - + - - + + - + - - - - + + - - - +	0.0615
Genetic algorithm	- + + - + + - + + - - + + - + + - - + - + - - - + - + - - - - - - - + + +	0.0410

The approach considered was used only to select the optimal traits from a small number of traits. There is a need to use systems with more powerful computational capabilities to select the optimal set of signs from a larger database. Therefore, parallel genetic algorithms were used to select the optimal one from all the traits described earlier in the study, and the results were calculated in a

cluster calculation system at the HPC center of the Azerbaijan State University of Oil and Industry. The cluster computing center of the HPC center of the Azerbaijan State University of Oil and Industry has 21 nodes (one of these nodes is a server and the other is a client service). During the experiments, 3 types of crossover methods (1-point crossing, 3-point crossing and random crossing) and 2 types of mutation values were used. The results of the experiments are described in detail in Table 1-4.

Table 2. Accuracy of identification of the best features in the evaluation process

Number of generations	Execution time (seconds)	The length of the subset of features	Level of accuracy (%)
100	799	7682	93
250	2403	7707	94
500	4002	7650	96
1000	7963	7529	97

Table 3. Results of experiments performed on different number of computing nodes.

Number of nodes	Execution time	Number of generations	The length of the subset of features	Level of accuracy (%)
2	4232	500	7654	92
5	1703	500	7568	94
10	1143	1000	7787	96
15	837	1000	7731	95
20	799	1000	7598	97

Table 4. Results of experiments with different crossover methods and mutation rates.

Crossing method	Mutation level	Execution time (seconds)	Number of generations	The length of the subset of features	Level of accuracy (%)
Crossing 1	<0.5	800	200	7782	91
	<0.4	796	200	7674	90
	<0.3	797	200	7144	94
Crossing 2	<0.5	801	200	7689	92
	<0.4	803	200	7832	97
	<0.3	798	200	7345	93
Crossing 3	<0.5	801	200	7980	97
	<0.4	799	200	7759	90
	<0.3	787	200	7564	89

Figure 24 shows the relationship between the accuracy of the recognition system and the number of generations when applying genetic algorithms. 17 characters were optimally selected for the recognition of hand printed character symbols in the Azerbaijani language.

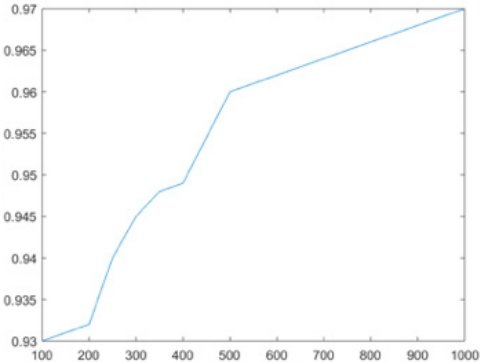

Figure 24. Graph of the dependence of the accuracy index on the number of generations

The recognition system established to substantiate the effectiveness of the process of selecting the proposed subgroups of symbols and signs was tested in the database of Azerbaijani hand printed characters symbols and in the NIST dataset forms and symbols database. As a result, higher recognition quality was achieved with fewer symptoms (Table 5).

Table 5. Comparative analysis of recognition results.

Symbols	The result of recognition (%)	Error recognized (%)	Refusal (%)
Azerbaijani hand printed characters	95,43%	2,44%	2,23%
Anchor figures	95,22%	1,68%	3,10%
Special characters	96,07%	3,14%	0,79%
Characters taken from the NIST database	98,60 %	0,2%	1,2%

This chapter provides algorithms for calculating the proposed features for the recognition of hand printed characters in the Azerbaijani language, compares them with different classification methods and different classes of signs, and demonstrates the advantages of the proposed features and DVU based on experiments. The issue of binary optimization has been solved at the ADNSU HPC center to prevent overload by selecting informative signs from the set of available signs and deleting non-informative signs by deleting them.

RESULTS

The main **scientific results** obtained in the dissertation are as follows:

1. The existing problems in the field of optical recognition of symbols are studied, the proposed approaches and methods for

the recognition of symbols used by many peoples, including those used in different local languages, are studied;
2. It has been shown that the use of a small number of "soft" features that are close to human thinking but increase the quality of recognition has been shown to be more effective in recognizing objects by algorithms that are not detected by computers.;
3. For the recognition of hand printed characters in the Azerbaijani language, the degree of curvature of the characters, the number of closed areas of the characters and their position, "soft" features symbols are proposed, algorithms for their calculation are shown;
4. Features suggested by different researchers for the recognition of hand printed characters symbols in the Azerbaijani language were tested in different ways and a comparative analysis was given;
5. Binary optimization methods - sequential forward selection, sequential backward selection, parallel genetic algorithms - were used in the recognition system to select the optimal traits from the large class of traits.;
6. Genetic algorithms for selecting a set of informative traits from numerous classes of traits used in object recognition were implemented in a cluster calculation system at the HPC Center of the Azerbaijan State Oil Oil and Industry University of and the results were compared comparatively based on various parameters.

The main content of the dissertation is published in the following works:

1. İsmayilov E. Ə., Azərbaycan Dilində Çap Əlyazma Simvollarinin Taninmasina Yeni Əlamətlər Sinfi və Dayaq Vektorlar Üsulunun Tətbiqi // İnformasiya texnologiyaları problemləri, 9 (2), 2018, s. 101-107.

2. İsmayilov E. Ə., Azərbaycan Dilində çap əlyazma simvollarının tanınmasına dayaq vektorları üsulunun tətbiqi // Riyaziyyatın nəzəri və tətbiqi problemləri Beynəlxalq Elmi Konfransı, Sumqayıt 2017, may, s. 276-277.
3. Исмайылов Э. А., "О использовании нечетких множеств в системе распознавания рукопечатных текстов Азербайджанского языка" // Материалы международной научной конференции «Нефть-газ, Нефтепереработка и нефтехимия» посвященной 90-летнему юбилею АГНА. 327-328 с.
4. Исмайылов Э. А., "Система распознавания текстов с применением нечетких множеств" // Professor Yəhya Məmmədovun anadan olmasının 80 illik yubileyinə həsr olunmuş "Riyaziyyat və Mexanikanın aktual problemləri" adlı Beynəlxalq konfrans. Bakı, Azərbaycan, 27 dekabr, 2010, p. 217-218.
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10. Alieva N.T., Ismayilov E. A., Hand printed recognition system using a fuzzy neural network // Proceedings of The second International Conference "Problems of Cybernetics and Informatics", Baku, Azerbaijan, September 6-8, 2010. p. 214-217.
11. Alieva N.T., Ismayilov E. A., Hand-printed recognition system using spline L-R type fuzzy numbers // International Sympozium on Innovations in Intelligent Systems and Applications, Kayseri, Turkey, 2010, June 21-24. p. 138-141.
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15. Ismayilov E. A., "Analysis of the effectiveness of the use features for character recognition Azerbaijani language" // Riyaziyyat və informatikanın aktual problemləri Heydər Əliyevin anadan olmasının 90 illik yubileyinə həsr olunmuş Beynəlxalq konfrans, Bakı, 2010, p. 220-222.
16. Ismayilov E. A., "Comparison of results of recognition system for Azerbaijani texts with various features classes" //

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24. Ismayilova N. T., Ismayilov E. A., “Soft” features and SVM for hand-printed caharcters recognition // 6th International Conference on Control and Optimization with Industrial Applications, 2018, August, p. 178-180.

The defense of the dissertation will be held on March 4, 2022 at 1 PM at the meeting of the Dissertation Council ED 2.02 operating under the Azerbaijan State Oil and Industry University.

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