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IMPROVEMENT OF IRIS RECOGNITION TECHNOLOGY FOR BIOMETRIC IDENTIFICATION OF A PERSON

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This topic is very relevant in the field of artificial intelligence as a direction of pattern recognition. In this work, the iris of the eye is considered as an image.

Artificial intelligence makes this technology more accessible for use in CCTV cameras, smartphones and various areas of human activity.

The article reflects the results of a study of methods and technologies of pattern recognition on the example of the human iris.

The aim of the work was to study methods and technologies for human iris recognition and iris recognition of employees of a particular organization using EyeLock equipment by comparing segmentation results with Daugman standard segmentation.

Comparison analysis of segmentation results with standard segmentation can be done by directly measuring the number of correctly segmented irises in both methods, or by indirectly measuring the effect of segmentation on iris recognition performance. The method using the Daugman integral-differential operator has the greatest efficiency. The performance of the neural network has been improved. To use a neural network to classify iris profiles, we selected sets of images (images per person) as training images, and the rest of the images were used as test images. Training time (in seconds): for the Daugman method 170.7, and for the parabolic method 204.7.

The Daugman integro-differential operator is applied to the captured image to obtain the "maximum integral derivative of the contour" with ever-increasing radius on "successively decreasing scales" in three parameters: center coordinates and radius. Finding the maximum when the search coordinates deviate along an unwinding spiral.

Methods and techniques for pattern recognition have been investigated using the human iris

Keywords: pattern recognition, segmentation method, iris recognition technology, biometric personality authentication

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1. Introduction

Over the past two decades, biometric recognition has exploded into a plethora of different applications around the globe. This proliferation can be attributed to the high levels of authentication accuracy and user convenience that biometric recognition systems afford end-users. With the increasing demand for identity authentication, iris recognition systems are gradually applied in various scenarios. Iris segmentation is the basis of the iris recognition system. The topic of pattern recognition is very relevant, especially the recognition of biometric patterns, as the results of research in this area can improve the degree of information protection in enterprises and organizations.

Like other biometric methods, iris recognition has its advantages. They can be described as follows: the retina is considered very stable and almost never changes during a person's life. Thus, in this regard, the retina is considered the most reliable biometric technology available on the market today.

Given the small file size of the retinal recognition patterns, the system confirms the person's identity very quickly; this can happen in less than two seconds.

Due to the large number of unique data points that the retina possesses, there is little to no error in confirming a person's identity that it is indeed that person. In other words, there is practically no statistical likelihood that an impostor will be falsely accepted by the retinal recognition system.

Since the retina is located within the very structure of the eye, it is not subject to the rigidity of the external environment, like hand geometry recognition and fingerprint recognition.

This topic is very relevant in the field of artificial intelligence as pattern recognition. Iris recognition is an innovative and reliable method of biometric authentication. Iris recognition is considered the most reliable and accurate biometric identification system [1].

Artificial intelligence makes this technology more accessible for use in video monitoring cameras, smartphones and other access and security controls.

In addition, such identification would reduce the risk of failure of facial recognition systems.

The biometric system is an important direction in pattern recognition.

2. Literature review and problem statement

In [1] the authors of the article propose a new approach to the classification of the iris, based on the structure of the fibers of the iris. Transfer and negligible deformation invariant local features of the iris are extracted using a network of scattering wavelets. A simple generative affine PCA classifier is used to classify the resulting invariant feature vectors. Experiments with two reference iris databases show that the proposed iris classification algorithm is successful and reliable in terms of classification accuracy. But this work does not describe the technology for implementing the iris classification algorithm.

In [2], the authors proposed an encoding-based approach called bit-passing code to solve the less studied problem of designing a biometric authentication system by combining iris and palm print modalities. The approach is based on encoding binary transitions of symmetric and asymmetric parts of the Gabor filtered image at all pixel locations. Score-level fusion is used to integrate individual characteristics of the iris and handprints. Experiments are conducted with three reference iris/handprint databases, namely the IITD iris and handprint databases and the PolyU handprint database. Performance is measured by receiver operator performance (ROC) curves and other metrics such as equal error rate and area under the ROC curves. A comprehensive comparison with several state-of-the-art approaches is presented to test the usefulness of the proposed approach. The paper does not describe enough the technology for implementing the recognition of the iris of the eyes.

In [3] the authors note that the quality of iris images varies greatly under different shooting conditions. The authors describe experimental results on two iris databases under near-infrared illumination and one iris database under visible light illumination, demonstrating that the method has good iris segmentation ability and generalization efficiency. The accuracy of iris segmentation and the efficiency of the proposed method are higher than those of the modern fusion method. This article confirms the effectiveness of the method based on the study of segmentation of the iris, which we propose in our work.

In [4] the authors write: In this article, we give an overview of each of the above open tasks. We review the work that has been done to address each of these issues and highlight issues that require further attention. Finally, we provide information on how the biometrics community can address the major design challenges of biometric recognition systems to better instill trust, fairness, and security for all. This article confirms the importance of studying the iris of the eyes, because. it has advantages over other types of biometric personal identification.

In [5] the authors write: Automatically recognition and classification of biological objects under microscope methods are shown in paper. Problem of separated of white-black and color images is studied. Method of separation of different type of objects (visual diapason of specter) with compare results is shown in the paper. Quality of segmentation methods analyses is presented in the paper. Schemes and table results of segmentation are exist. Methods of pattern recognition applicability for Computer Vision Systems of analysis and pattern recognition scenes in the visual spectrum are studied in the paper. Author analyzed several pattern recognition methods that will allow to process data of the environment for the brain. But the methods and algorithms described in this article can be used in recognition for adaptation to computer vision systems.

In [6], the authors write that there are different methods and algorithms on retinal images for optic disc detection and that they used the Grasshopper optimization algorithm to implement a new automated method for optic disc detection. But the article did not describe the technology for implementing the Grasshopper optimization algorithm.

In [7] the authors write: We design a dual-uncertainty estimation approach to measure the disagreement label noise and single-Target label noise via improved Direct Uncertainty Prediction and Monte-Carlo-Dropout.

We also release a large re-engineered database that consists of annotations from more than ten ophthalmologists with an unbiased golden standard dataset for evaluation and benchmarking. The authors focus their research on noise analysis and prediction.

The analysis of the above articles and other publications confirms the feasibility of conducting a study of pattern recognition technology by comparing the results of iris image segmentation with the standard Daugman segmentation and the iris segmentation method using the Hough transform.

3. The aim and objectives of the study

The aim of the study is to improve the human iris recognition technology for human biometric identification.

To achieve this aim, the following objectives are solved:

– to use segmentation method to identify authenticate the human iris;

– to compare segmentation results with standard Daugman segmentation using the MATLAB package;

– to use the neural network method IrisDenseNet using the example of the iris of the eyes of employees of a particular organization.

4. Materials and research methods

The object of research is the technology of recognition of the iris for biometric identification of a person.

The main hypothesis of the study is based on comparing the segmentation results with the standard Daugman segmentation using the MATLAB package.

The method of localization of biometric identification of an employee of an organization based on the Daugman integral-differential operator was used. The parameters of the circles approximating the inner and outer boundaries were calculated. In localization, the operator is used sequentially to define the inner and outer boundaries. The cell with the largest value is searched, the coordinates of which are considered to be the parameters of the desired circle.

Based on the analysis of publications on this topic, we consider it appropriate to conduct a study of pattern recognition technology by comparing the results of iris image segmentation with the standard Daugman segmentation and the iris segmentation method using the Hough transform [1].

Image recognition technology using the methods "Circular Hough Transform", "Log-Gabor Filter", "Feature Extraction using 2D Gabor Filters" by comparing the segmentation results with the standard Daugman algorithm, the iris image decomposition method using the MATLAB platform.

The device is easily integrated into an existing access control system.

Tactical and technical characteristics:

– registration and verification of compliance by the device itself – "On Board";

– identification in sunglasses or colored contact lenses;

– storage in memory "On Board" database for 20,000 people;

– create an account for 1 or 2 eyes;

– ability to connect a card reader to provide two-factor protection (eyes+card);

– types (protocols) of connection: Wiegand, F/2/F, OSDP, PAC, relay and Ethernet for easy integration with all available platforms and access control systems;

– power over PoE (IEEE 802.3af).

MYRIS is a device for controlling the possibility of users entering information sources[2].

The device provides additional protection of information resources of enterprises and reliable identification/authorization of users, this can be applicable, for example, to access bank accounts when performing high-risk actions and in other similar cases.

Experimental system software.

The experimental system software consists of two modules.

The registration module performs the following functions:

– obtaining an image of the iris of the eye;

– localization of the iris of the eye;

– normalization of the iris image;

– selection of features, their transformation into a template format, saving in the database.

Identification module performs the following functions:

– obtaining an image of the iris of the eye;

– localization of the iris of the eye;

– normalization of the iris image;

– extraction of features, their transformation into a template format and comparison with templates stored in the database;

– making a decision[3].

To achieve the goal, the following research methods were implemented:

1. Calculations to compare the implemented iris recognition system and the existing Daugman system will be performed using MATLAB.

The capabilities of MATLAB made it possible to implement a neural network for recognizing images of the iris of the eyes. To apply segmentation of the iris using the Daugman method, parameters were determined, and the Daugman integro-differential operator was determined.

2. The iris database consists of employee iris images. Images of the iris were taken using a camera. Images are acquired in color (red, green, blue) then converted to grayscale images. Only grayscale images are evaluated in our work.

3. Description of the IrisDenseNet neural network method The implemented neural network includes neurons in the input layer that correspond to the number of characteristic parameters in the normalized iris. This parabolic normalization estimation using neural network classification is performed on images of people, neurons in the output layer.

To select the number of neurons in the hidden layer, the performance of the network was tested using a variable number from 5 to 400 neurons. Low validation errors and tests have shown that 260 neurons is the best choice for the number of neurons in the hidden layer.

To analyze the effectiveness of the developed segmentation method, segmentation results are compared with standard segmentation (Daugman). This analysis can be done by directly measuring the number of correctly segmented irises in both methods, or by indirectly measuring the effect of segmentation on iris recognition performance.

5. The results of the study of pattern recognition technology by comparing segmentation results with standard Daugman segmentation

5. 1. Results of segmentation method

The iris structure consists of a boundary layer, a mesoderm (stroma layer) and an ectoderm (pigment-muscular layer). The first layer consists of cells (melanocytes) containing pigments that give an iris color. Such cells may be a likely development of ocular melanoma.

The second layer contains blood vessels and collagen fibers that perform hemodynamics of the entire iris [2].

The outer layer consists of a sphincter and dilator muscles that adjust the light streams from outside to the retina and pupil. The muscles are constantly working and automatically adjusting the received light. If the light is too bright, the pupil automatically decreases reducing the flow of light per retina. As a result, the pupil expands with a dilator in low light. Interestingly, pupil constriction also improves the sharpness of the image that is transmitted to the retina. [5].

The system offers an integral differential operator for covering two iris circles in parametric space introduced in 1993. Then it normalizes the annular area of the iris into a linearized rectangular pattern of fixed size [4, 6].

Daugman analyzes iris texture using non-orthogonal two-dimensional Gabor's wavelet complexes and generates complex coefficients whose phase is quantized in 2-bit code according to 4-quadrant encoding. Consequently, the iris is represented by a compact 256-byte binary signature called "iris". Daugman proposes a normalized Hamming distance in the matching stage, which measures the proportion of different bits between two iris codes that are in areas that do not overlap in two images simultaneously [7].

Daugman's method analyzes the iris texture using non-orthogonal 2D Gabor wavelet complexes and generates complex coefficients whose phase is quantized in 2-bit code according to 4-quadrant coding. Therefore, the iris is represented by a compact 256-byte binary signature called "iris" (Fig. 1). Daugman's method assumes a normalized Hamming distance at the matching stage, which measures the proportion of different bits between two iris codes that are in areas that do not overlap in two images at the same time [7].

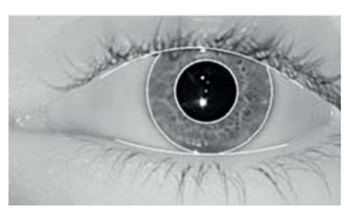


Fig. 1. Results of the iris research by Daugman's algorithm

The white contours show the results of the arrangement of the ring of the iris and the eyelid. The upper left iris code is the result of phase coding of complex two-dimensional Gabor wavelet coefficients, which are used to characterize the iris model.

In 1997, the wilds method of the iris biometric system, developed at the Sarnoff Laboratory in New Jersey, was introduced, which was completely different from the Daugman method and was based on segmentation of the iris using the Hough transform [2].

In 1998, the Boles and Boaches approach was introduced, in which texture analysis is performed by a one-dimensional transformation to eight-scaled orthogonal wavelets. The resulting signal is also one-dimensional and is obtained after normalization by virtual concentric circles during comparison of two irises. This is in order to have a constant diameter with the reference image and to guarantee, that the same iris texture points are selected regardless of the iris size in the image. The virtual circles create *n* "iris signatures" on each scale. Each of these *n* signatures is then encoded on the three lowest scales (4^{th}, 5^{th} and 6^{th}), and a smooth wavelet transform occurs by detecting the zero-crossing of the second derivative (Fig. 2). In Fig. 2 it is possible to see the results of processing the iris according to the Boles and Boashash method, which shows the reference image in Fig. 2, *a*, then Fig. 2, *b* shows the signal located on the virtual circle) of the iris, and Fig. 2, *c* shows three levels of resolution of the signature wavelet transform, Fig. 2, *d* shows the zero crossings. The comparison is provided by the energy difference and the normalized coefficient of cross-correlation between the two zero-crossing representations [8].

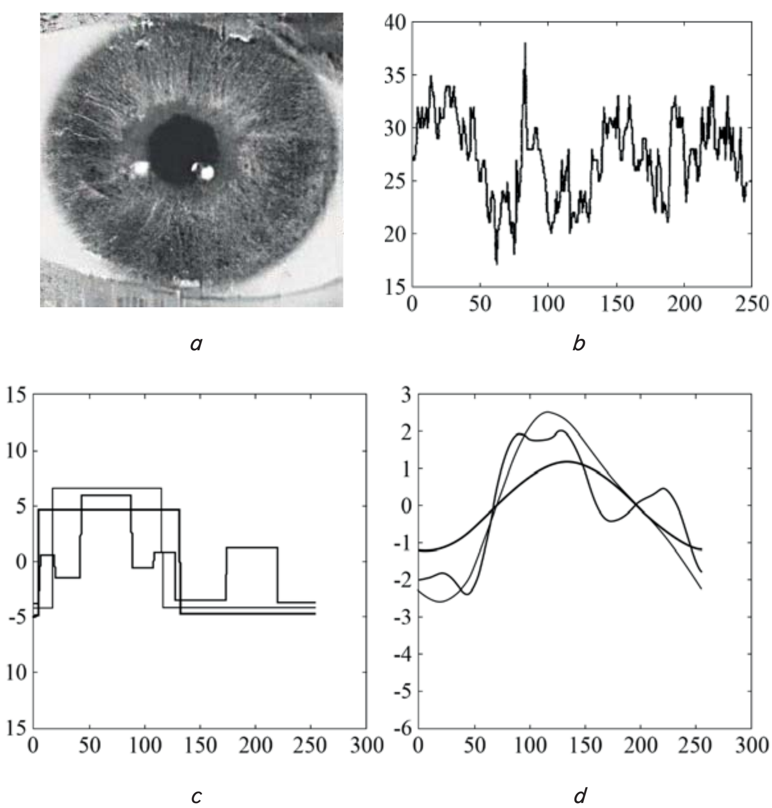


Fig. 2. Results of iris processing by Boles and Boashash method: *a* – the reference image; *b* – example of iris signature (signal located on a virtual circle) of the iris; *c* – three levels of resolution of the wavelet transform of the signature; *d* – representation of zero-crossings

Each research contributes to one or more stages of the recognition process. Some focus on obtaining an image of the iris eye, others on the segmentation of the interested area. Other articles also deal with coding and texture matching or even improving performance under different conditions [8].

The retinal ratio in the human eye is 100,000:1. The automatic scaling of the eye pupil is dependent on exposure when the human eye moves both physically and chemically (saccades) [9, 10]. In constant darkness, it takes about 4 seconds for the normal human eye to adjust to the darkness, where complete adjustment takes place. It takes 30 minutes for darkness to appear on the retina, chemically called the Purkinje effect. Therefore, if the light is interrupted by an adaptation to darkness, the adjustment process shall start over. Adaptation to darkness depends on a good blood supply to the eye. Poor blood flow can make it difficult for a person to adjust to darkness. The lens in the eye is similar to lenses in optical devices such as a camera, and the main lens in the eye is similar to lenses in cameras. The diaphragm performs the same functions in the camera as the pupil of the human eye. The retina acts as a diaphragm that acts as a stop for the diaphragm. The typical pupil size is a radius of 2 mm, which usually ranges from 1.2 mm/f/8.4 in a bright place to 4.3 mm/f/2.2 in the dark. The value of the letter varies with age, and in the case of older persons, the eye expands within 5 or 6 mm [11].

Iris recognition is the process of automatically identifying a person using a mathematical model. Recognition methods using data obtained from one or both iris images are inherently unique to human models [12]. The performance of the iris recognition system in the context of video-based remote detection [13] can be improved by deterioration effects using combined methods for quality criteria at pixel level. Various factors determine the quality of biometric iris data [7], including focus, angle, degree of occlusion, focus area, pupil dilation and degree of iris pigmentation.

The iris is a colored muscle ring that opens and covers the eyeball like a shutter in a camera. The color of this annular area around the pupil is determined by the amount of matter in it called melanin. The increased amount of melanin in the iris creates a brown pigment, the color spectrum of which typically ranges from blue, grey or greenish to various shades of brown.

Images can be obtained both in the visible wavelength of light and in the infrared part of the spectrum. Infrared images are commonly used in night photography, and that is the wavelength of the night vision devices, such as glasses and lenses. It is also a wavelength at which one can discern more subtle details in the design of brown and darker eyes.

There are several ways to recognize the iris of the eye. The methods of investigation and extraction of the iris of the eye can be classified according to the type of feature recognized by: light spots (when searching for an iris is usually a dark area of the pupil on a relatively light background of the iris or a black area of the iris on a light sclera); the edges of the region (such methods are generally based on brightness derivatives).

Using the method of factorization (extraction) of the necessary information, which can also be formulated in such a way that the images are given to the "recognizable form" [12]: methods based on the Hough approach in which exploration takes place at the location of the parameters; Design methods that reduce the space of the search; methods based on clustering and hierarchical aggregation. For example, consider Daugman's iris recognition systems. The Daugman system is the most famous and the most successful of many other systems. The Daugman system was tested through numerous studies, all of which showed no failure intensity. The Daugman system is argued to be able of accurately identifying a person with millions of capabilities [9].

The Daugman normalization method converts the localized structure of a multicolored layer from a Cartesian to an opposite concept of location. The presented method covers superfluous differences determined by the gap of the eye from the camera also by the position thereof relative to the camera. Daugman uses an integral differential operator to determine the position of the circular diaphragm and area of the pupil, as well as the arch of the upper and lower eyelids.

The variety of iris recognition systems available on the market use near infrared (NIR) light. Infrared lighting with wavelength between 700 and 900 nm is used for discrete images at distances up to 1 m. Daugman found that near-infrared light is suitable for such a device because the radiation intensity can be adjusted, which is completely harmless to the eyes [11, 13].

The Canny Edge Detector is an edge detection operator that uses a multi-stage method to detect different edges in images. Thus, useful and structured information is extracted from the various image objects and the amount of data that needs to be processed is significantly reduced [13].

The Hough Rearrangement is a common image analytic tool for tracking curves that have every chance of being assigned in a parametric form, such as lines and circles. The significance of the global form is guided by support for local models [12].

Also, it needs to be noted that not all images are taken under ideal conditions. Some examples are:

1) when the edges of the iris are closed above and below by eyelids and eyelashes. For a picture to be perfect, a man needs to keep its eyes open for a while;

2) it is extremely difficult to segment the image of the iris when light is low, as the structure of the iris may not be sufficiently underlined in such images;

3) reflection: small areas of iris image characterized by high-brightness pixels. They are usually caused by uneven directional illumination from the light source. If reflections occur at the edge of the iris, it becomes difficult to segment the iris.

Localization: A method of determining the iris by the Hough method. The inner and outer edges of the iris ring can be approximated by two non-concentric circles, which are defined according to the Hough transform in two stages:

1) to find candidate points that may belong to the circle;

2) to keep the channel receiving the maximum number of votes in the channel parameter space. Candidate points are identified by applying vertical and horizontal gradients to define the inner circle and using only vertical gradients to define the outer circle, this minimizes the effects of eyelashes and eyelids. Decomposition of the iris image at 3 scales (s=1..3) and with (n+1)=4 orientations (0, $\pi/4$, $\pi/2$ and 3 $\pi/4$) is presented in Annex 1.

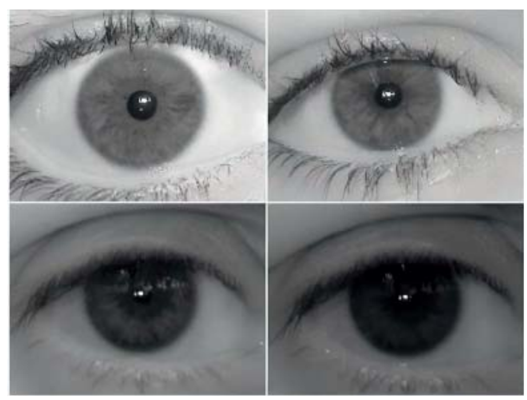
Normalization: rotate the diaphragms at different angles to compensate inconsistent rotation due to head tilting during shooting. The method then becomes invariant with respect to rotation. To compensate pupil dilation and discrepancies due to size variation (distance between eyes and camera). the iris ring is redrawn as a rectangular texture block with a fixed size after a pseudo-polar reference transformation. Then the method becomes scale-invariant [5].

5. 2. Comparison results segmentation with standard Daugman segmentation using the MATLAB package

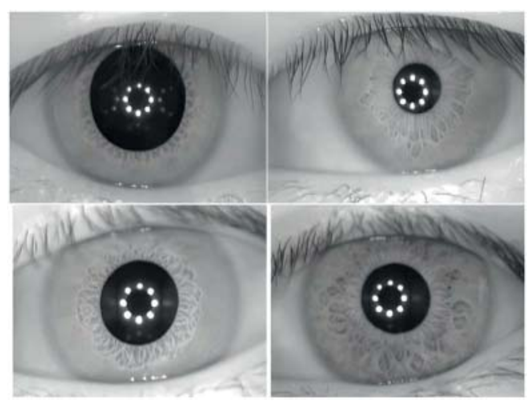
Human iris recognition technology using EyeLock equipment by comparing segmentation results with Daugman standard segmentation and using the MATLAB package.

Calculations to compare the implemented iris recognition system and the existing Daugman system will be developed using MATLAB.

The iris database consists of images of staff members' irises. Images of the iris were taken using a camera. The images are acquired in color (red, green, blue) then converted to grayscale images. Only grayscale images are evaluated in this work. Fig. 3 shows examples of iris images.



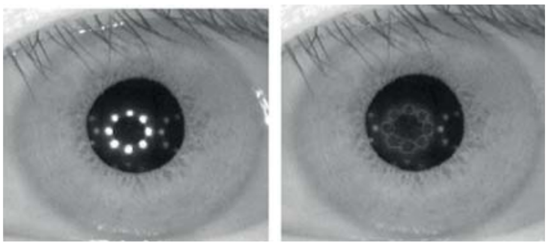
a



b

Fig. 3. Sample images of the iris: *a* — Gaussian filter; *b* — crime to obtain a smoothed image

Gaussian filter to obtain a smoothed image. Pre-processing of iris images. Prior to performing any operations with iris images, they are pre-processed to reduce the reflection of mirrors and eyelashes. The intensity threshold operation was first used to reduce mirror reflections characterized by high intensity pixels. The intensity of grayscale images varies from black to white. Let's choose a threshold value of intensity by analyzing the distribution of intensity values of iris images. Fig. 4 shows intensity analysis of iris images.



a *b*

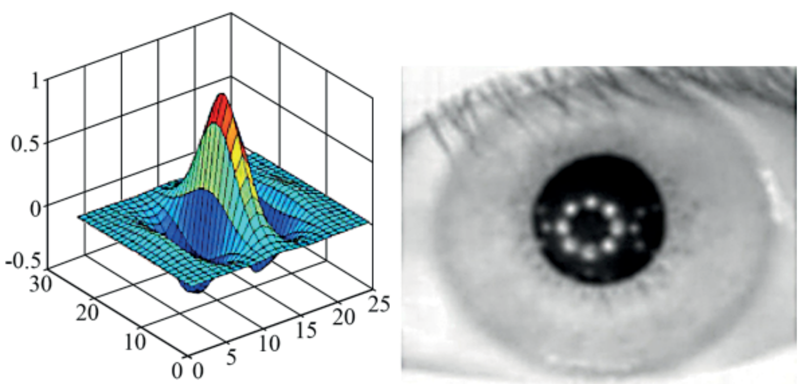
Fig. 4. Analyzing the intensity of the iris images:
a — Gaussian filter; *b* — crime to obtain a smoothed image

The original image of the iris is processed to reduce the mirror reflections and create a outline image.

Firstly, it is needed to generate using a method based on the Canny filter to apply the Hough transform. This method defines the edges of the image by finding the local maxima of the gradient of the smoothed image.

Smoothing is performed with a two-dimensional Gaussian filter.

Fig. 5, *a* shows a filtered image using a Gaussian filter, Fig. 5, *b* shows a filtered image using a filter to obtain a smoothed image. The resulting filter as well as the filtered image are shown in Fig. 5, *a*, *b* below.



a *b*

Fig. 5. The filtered image: *a* – Gaussian filter;
b – filter applied to obtain a smoothed image

The derivative of the smoothed image is then computed to create a gradient image. Two intensity thresholds are used to define the boundaries of the strong and weak gradients in this image. These gradients correspond to the zones of separation between light and dark or between dark and light, which are characteristic of the contour between two homogeneous zones. Vertical and horizontal gradients are calculated using square matrices.

The vertical gradient is used to define the outer border of the iris. The horizontal gradient is used to define the eyelid and both directions are used together to detect the edges of the pupil.

Application of the Daugman integral differential operator. In order to apply the Daugman segmentation method to the iris, it is necessary to define parameters and determine the Daugman integral differential operator. The Daugman segmentation is realized by overlaying a search interval for the centers and radii of circular approximations of the two iris boundaries. As a result of the approximation of the centers of the iris boundary, two windows around these centers define the pixels for the application of the Daugman operator. The iris will be transformed in the normalization process to a matrix representation of a fixed dimension after segmentation.

The iris region will be divided into 10 parts by uniformly distributed rings to cover the entire surface of the iris when information is located in the iris texture.

Classification of Hamming distances. Only one parameter to choose is given when measuring similarity between two diaphragm codes using Hamming distance. This parameter is the amount of translation bits that compensate the rotation of the iris.

Classification by neural networks. The implemented neural network includes neurons in the input layer that correspond to the number of characteristic parameters in the normalized diaphragm. This assessment of parabolic normalization using neural network classification is performed on images of people, which are neurons in the output layer.

Low validation errors and tests have shown that about 300 neurons are the best choice of the number of neurons in the hidden layer to select the number of neurons in the hidden layer.

The segmentation results are compared with the standard segmentation (Daugman) to analyze the efficiency of the segmentation method. This analysis can be performed by directly measuring the number of properly segmented iris in both methods, or by indirectly measuring the impact of segmentation on iris recognition performance.

Detecting iris boundaries in images. The white and green contours represent a circular approximation and the active contour detection respectively.

The success of any object recognition system lies in the use of methods, corresponding representations and appropriate characteristics. Researchers use most of something as a bandwidth decomposition, or multi-resolution analysis of iris images to create a biometric model.

Several categories to be applied according to different approaches to the texture characterization can be distinguished with consideration of various developed coding methods.

The used methods in the iris recognition can be divided into four main categories:

1) phase calculation: the phase is selected in some ways as a characteristic of the iris texture. The diaphragm characteristic extraction problem is a phase demodulation method. Based on this approach several coding techniques have been developed, such as the Daugman method;

2) zero transition representation: zero transformation transitions applied to iris images can also be used for iris coding. These methods provide meaningful information about iris texture;

3) texture analysis: many texture analysis methods are adapted for iris encoding, such as Laplacian type filters or Gaussian filters and multichannel Gabor filters;

4) representation of local variation of intensity: for the transitional signal variation locales translate its most important properties. Methods characterizing local texture variations of iris images have been developed, such as the Maetal method.

The technology is based on the use of segmentation by edgeless active contour and a circular Hough transform. It was proven that the iris boundary is well defined and that the outer iris boundary is well approximated by a circle. At the end of this step the iris is isolated from the pupil and the white of the eye after filtering the eyelashes, eyelids and reflections.

The normalization step is then applied. The segmented iris is selected according to the transformation from the Cartesian plane to the polar plane to have a representation of the iris under the shape of a square matrix of a fixed size. Rubber standardization takes into account that important distinguishing features of the iris are located at the boundary of the pupil. These sample contours differ between the free contour that defines the pupil boundary and the approaching circular contour of the iris outer boundary.

The eyelids tend to have an elliptical shape with often low contrast. When it comes to eyelashes, it is probably the most difficult noise to find in the iris texture. Indeed, eyelashes are black objects, irregular and varied in shape that can cover large areas of iris texture, especially in the case of Asian iris.

It is need to find the boundaries of the iris of pupil and the iris of eye, rather than extract from the image various elements that are considered as noise.

The system analyzes around a set of application points in the image. The iris texture is converted into binary code due to computed Gabor phases and four quadrant codes.

The Hamming distance is similar to the Masek segmentation algorithm, which uses active contour segmentation.

For a point to be taken into account in computing Hamming distance, it is necessary that the probability of the output of the image around this point coincide when it is applied to the GMM of a large decision threshold of 0.5.

It is needed then to calculate the percentage of texture of a masked iris as the ratio of the number of pixels classified by this method as belonging to eyelids and the total number of pixels of the image of the normalized iris.

Then the percentage of occlusion of the iris should be plotted.

Left iris ICE and right iris ICE.

In the above Fig., it can be seen that the left iris contains more samples with an occlusion rate greater than 20 % than the straight base of the diaphragm, while the latter contains more samples with an occlusion rate of 10 to 20 %. The two distributions behave similarly at a value above 35 % and below 10 %.

Neural network performance. In order to use the neural network to classify iris profiles, sets of images (images per person) are selected as educational images and the rest are used as test images. The performance of the neural network is as shown in Table 1, Fig. 6.

The curve from the iris recognition system using our normalization where the parabolic is more asymptotic than the Daugman normalization. This is a valid result.

The best recognition comes from our standardization method.

The search for discriminant information of the iris is carried out by separating the iris in 10 different rings. To assess the discriminatory capacity of each region, the recognition characteristics of each of the ten iris rings are evaluated. This process corresponds to the best configuration tested previously (active contour segmentation and rubber normalization on the center of CGP).

The results are also compared with those in the frame.

The recognition quality of each ring is measured by three parameters:

1. Efficiency.
2. Decidability.
3. Accuracy at equal error rate and curve.

Resolution.

Resolution obtained for each of 10 iris rings for two systems.

The comparison is shown in Fig. 7.

Table 1

Neural network performance

Parameters	Normalization method	
	Daugman	Parabolic
Learning time (in seconds)	170.7	204.7
Learning error	0.004	0.0015
Validation error	0.025	0.02
Test error	0.0209	0.0145

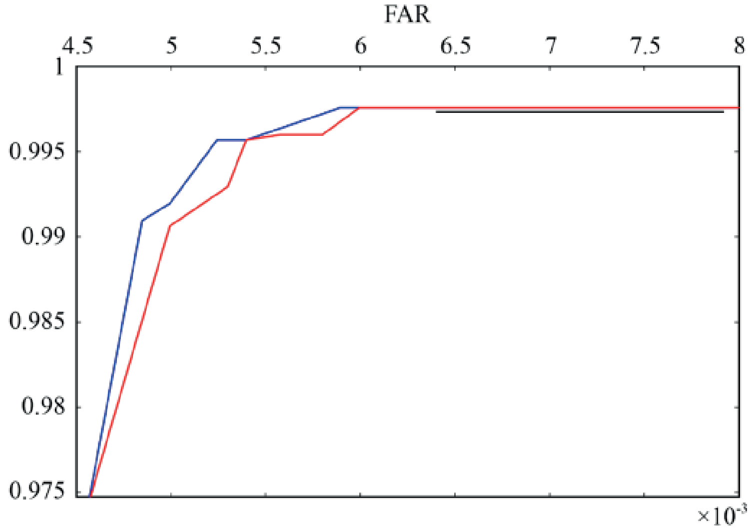


Fig. 6. The curve from the iris recognition system curves providing system recognition characteristics

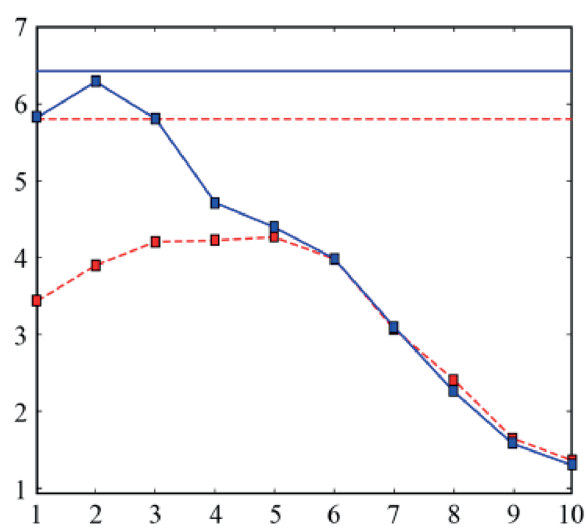
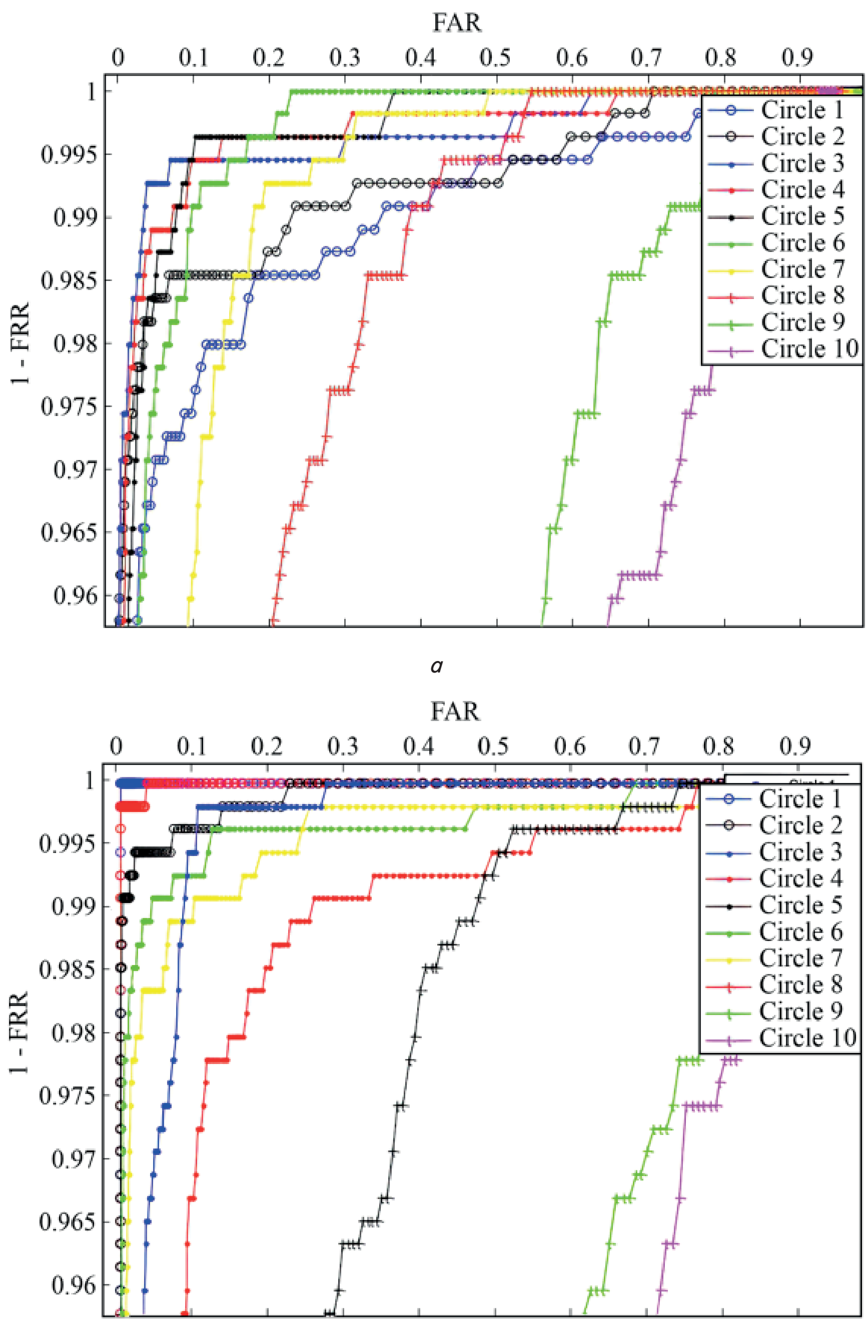


Fig. 7. Decidability of each of the iris rings obtained from the proposed system

The curve for each of the 10 diaphragm rings for the two compared systems is as shown in Fig. 8, *a*, *b*.



a

b

Fig. 8. The curve for each of the 10 iris rings: *a* – reference system; *b* – and proposed system

More accurate segmentation also leads to improved iris recognition performance, which in particular results in better resolution and detection power seen in COR curves.

The technology of iris recognition of the staff eyes of JSC organization "AudBukh" was carried out with the use of equipment and software "EyeLock" by comparing the results of segmentation with the standard segmentation by Daugman using MATLAB platform. The proposed approach to the synthesis of new recognition algorithms is based on a library of already known algorithms and methods [9].

5. 3. Results of neural network method IrisDenseNet

Describe the neural network method IrisDenseNet using the example of the iris of the eyes of employees of a particular organization. To solve this problem, the methods and technologies of the task of recognizing the images of the enterprise JSC of the organization "AudBukh" were used using EyeLock equipment by comparing the segmentation results with the standard Daugman segmentation using the MATLAB platform. The parameters of circles approximating the inner and outer boundaries are calculated. For this, the maximum derivative of the smoothed medium intensity along a circular contour. Using the image intensity function, smoothing the Gaussian function, taking into account the contour of the circle with coordinates (x, y) and radius r. In localization, the operator is used sequentially to determine the internal and outer border. To find the boundaries on the image with the maximum value of the operator, optimization methods are used. To search for a circle, a three-dimensional array is specified, each dimension of which corresponds to a certain parameter of the circle. Outlines are highlighted in the image. Each point of the contour is transferred to the parameter space, and the cells of the array are filled. The cell with the highest value is searched, the coordinates of which are considered as parameters of the required circle.

The proposed approach to the synthesis of new recognition algorithms is based on a library of already known algorithms and methods [11].

6. Discussion of the results of the study of iris recognition technology

The segmentation method used to authenticate the human iris was used, the results of the study of the iris according to the Daugman algorithm were obtained, as shown in Fig. 1.

The comparison is provided by the energy difference and the normalized the cross-correlation coefficient between the two representations of the zero crossing.

The segmentation method used to authenticate the human iris was used, the results of the study of the iris according to the Daugman algorithm were obtained, as shown in Fig. 1.

In Fig. 1, the white contours show the results of the location of the iris ring and eyelid.

The comparison is provided by the energy difference and the normalized cross-correlation coefficient between the two zero-crossing representations [8].

Unlike the Masek [4] algorithm, it does not require image-specific parameters. Daugman's method requires an exhaustive search for every pixel over the entire image area. The proposed improvement restricts the search to a limited area by finding an initial pupil center estimate using a grayscale image threshold [12]. In order for an iris recognition system to accurately identify iris images, accuracy is required at every stage of processing. This study examined segmentation and matching in relation to dilated and non-dilated pupils.

The method is quite effective if the images are of higher quality. In the future, this method can be used successfully if the image quality is high.

Comparison of segmentation results with standard segmentation can be done by directly measuring the number of correctly segmented irises in both methods, or by indirectly measuring the effect of segmentation on iris recognition performance. The method using the Daugman integro-differential operator has the highest efficiency. The Daugman integro-differential operator is applied to the captured image to obtain the "maximum integral derivative of the contour" with ever-increasing radius on "sequentially decreasing scales" in three parameters: center coordinates and radius. Let's find the maximum when the search coordinates deviate along an unwinding spiral.

The results of the implementation of the technology of a biometric human recognition system by the iris using the equipment NANO NXT, HBOX, MYRIS manufactured by eyeLock (USA) – the device is easily integrated into an existing access control system. MYRIS is a device for controlling the possibility of users entering information sources, the device provides additional protection of information resources of enterprises and reliable identification/authorization of users, experimental system software consists of two modules. The nano NXT allows to transfer iris templates to your smartphone/smart card and use it for further verification. HBOX is a personal identification and authentication device that performs real-time reading and analysis of the iris at a distance and on the move.

The registration module performs the following functions: obtaining an image of the iris, localizing the iris, normalizing the image of the iris, selecting features, converting them into a template format, and storing them in the database. The identification module performs the following functions: obtaining an image of the iris, localizing the iris, normalizing the image of the iris, extracting features, converting them into a template format and comparing them with templates stored in the database, making a decision.

The method using the Daugman integral-differential operator has the highest efficiency. The Daugman integral-differential operator is applied to the captured image to obtain the "maximum integral derivative of the contour" with ever-increasing radius on "sequentially decreasing scales" in three parameters: center coordinates and radius. Let's find the maximum when the search coordinates deviate along an unwinding spiral.

The peculiarity of the obtained results in comparison with the existing ones is that the methods of comparing the segmentation of the iris with the standard Dougman segmentation and the method of the obtained data processing using the MATLAB platform using the equipment of the eyeLock company (USA) were combined. The use of methods and technologies of pattern recognition for the enterprise JSC organization "AudBukh".

The limitations of this study were the size of the data sample, the time frame of the experiment. The limitations of the study were reflected within the chosen methods and technologies, in the set tasks.

The disadvantages of this study are the errors associated with the use of equipment and data processing using MATLAB.

The development of this study may be associated with the use of additional methods of pattern recognition.

Experimental and mathematical errors can be made during this kind of research.

7. Conclusions

1. A segmentation method was used to identify the authenticity of the human iris. Daugman method assumes a normalized Hamming distance in the matching step, which measures the proportion of distinct bits between two iris codes that are in areas that do not overlap in two images at the same time. The literature review confirms the feasibility of conducting a study of pattern recognition technology by comparing the results of iris image segmentation with the standard Daugman segmentation and the iris segmentation method using the Hough transform. To apply segmentation of the iris according to the Daugman method, it is necessary to determine the parameters, determine the Daugman integro-differential operator

Daugman segmentation is implemented by superimposing a search interval for the centers and radii of circular approximations of the two iris boundaries. I know this segmentation is designed as a result of approximating the centers of the iris borders, two windows around these centers determine the pixels for applying the Daugman Operator. To use a neural network to classify iris profiles, image sets (images per person) are chosen as training images and the rest of the images are used as test images. Comparison of segmentation results with standard segmentation can be done by directly measuring the number of correctly segmented irises in both methods, or by indirectly measuring the effect of segmentation on iris recognition performance. The method using the Daugman integro-differential operator has the highest efficiency. Neural network performance is improved. To use a neural network to classify iris profiles, we selected image sets (images per person) as training images and used the rest of the images as test images. Training time (in seconds): for the Daugman method – 170.7, and for the parabolic method – 204.7. Learning error: for the Daugman method – 0.004, and for the parabolic method – 0.0015. Validation error: for the Daugman method – 0.025, and for the parabolic method – 0.02. More accurate segmentation also results in improved iris recognition performance, which in particular results in better resolution and better detection power. Segmentation method using integral-differential the Daugman operator has the highest accuracy.

2. Comparison of segmentation results with standard Daugman segmentation using the MATLAB package. The most accurate method is using Daugman integral-differential operator. To determine the outer boundary of the iris, the idea of analyzing the function distribution of boundary points from the center of the pupil. The Canny operator is applied to the input image, resulting in an image of its boundary points. The parameters of the Canny operator for

searching for the pupil border and for searching for the iris border are different and are selected experimentally based on the available set of images. For the resulting image, the distribution function of the boundary points is calculated from the distance to the center of the pupil $f(R)$. It is assumed that this function has a local maximum in the vicinity of the desired value of the iris radius, since the pupil and iris are approximately concentric, but this maximum can be lost among others that arise due to noise Images. Further, in the loop, the local maxima of the function $f(R)$ are enumerated, starting from the most. The main stages of the implementation of the neural network: preparing data for training the network, creating a network, training the network, testing the network, using the network to solve the problem.

Choosing a network architecture. Then, in order to use the neural network to classify iris profiles, image sets (images per person) are chosen as training images and the rest of the images are used as test images. Comparing segmentation results with standard Daugman segmentation is well implemented in MATLAB. We call MATLAB. Load the demo model by typing mrefrobotarm in the MATLAB command window. This command invokes Simulink and creates a simulation window. Neural network controller based on the reference model is already placed in the model. Simulink has a standard set of neuroblocks, consisting of various activation functions, network input functions, weight functions, and neural network-based control systems. Training time (in seconds): for the Daugman method – 170.7, and for the parabolic method – 204.7. Learning error: for the Daugman method – 0.004, and for the parabolic method – 0.0015. Validation error: for the Daugman method – 0.025, and for the parabolic method – 0.02. More accurate segmentation also results in improved iris recognition performance, which in particular results in better resolution and better detection power. Segmentation method using integro-differential the Daugman operator has the highest accuracy.

3. The neural network method IrisDenseNet is described on the example of the iris of the eyes of employees of a particular organization using the MATLAB package. With the help of neural network technologies using the MATLAB extension package for neural networks Neural Networks Toolbox. Convolutional neural networks are important tools for deep learning and are particularly suitable for image recognition. The image is transferred to a convolutional neural network and the activations of the various levels of the network are displayed. Convolutional layers perform convolutions with trainable parameters. All activations are scaled so that the minimum activation is 0 and the maximum activation is 1.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, copyright or otherwise, that could affect the study and its results presented in this article.

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Data availability

The manuscript has associated data in the data warehouse

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