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ABSTRACT

Diabetes can lead to a number of serious complications, in particular, diabetic retinopathy, which occurs in patients with diabetes and can lead to vision loss. In this regard, the development of an information system for the diagnosis of diabetic retinopathy is an important task in the medical field. Such a system can greatly facilitate the diagnostic process and help doctors detect and treat diabetic retinopathy in time. As a result of the conducted research, the urgent task of increasing the accuracy of diagnosis of fundus diseases was solved by using methods of pre-processing images to improve their informative characteristics, statistical analysis and differentiation of pathologies with the help of a decision support system based on neural network technologies. A comparative analysis of the existing methods of diagnosing diabetic retinopathy and other eye diseases was carried out, according to which it is clear that intellectual analysis and pre-processing of the received images of the fundus can significantly improve the results of diagnostics, especially early screening, which is important for preventing severe stages of the disease.

Keywords: diabetes, diabetic retinopathy, neural network, image preprocessing, classification, medical diagnosis, statistical analysis, decision support system

1. INTRODUCTION

The world is witnessing a growing pandemic of diabetes, which is one of the most common chronic diseases in the world. According to the World Health Organization, at the beginning of 2020, more than 420 million people worldwide suffered from this disease[1]. Diabetes can lead to a number of serious complications, in particular, diabetic retinopathy, which occurs in patients with diabetes and can lead to vision loss (Figure 1)[2].

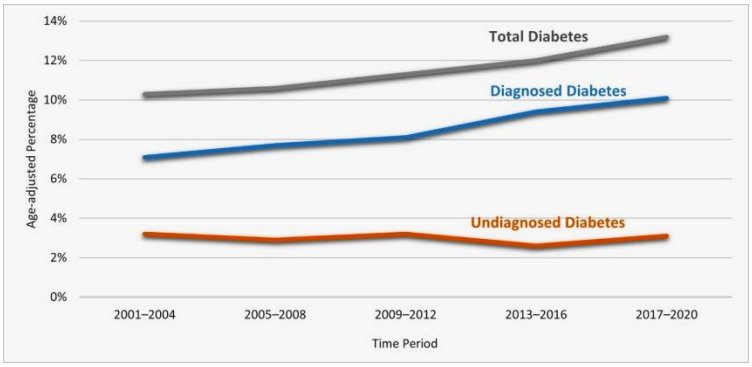

Figure 1. Trends in Prevalence of Diagnosed Diabetes, Undiagnosed Diabetes, and Total Diabetes Among Adults Aged 18 Years or Older, United States, 2001–2004 to 2017–2020

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In this regard, the development of an information system for the diagnosis of diabetic retinopathy is an important task in the medical field. Such a system can greatly facilitate the diagnostic process and help doctors detect and treat diabetic retinopathy in time [3].

Modern technologies make it possible to automate the process of diagnosing diabetic retinopathy [4,5,6] and provide quick and accurate analysis. This requires the development of a special information system that would allow diagnostics using retinal images obtained with the help of various medical devices.

The application of machine learning and image processing methods can become a powerful tool in the development of such an information system[7,8,9]. Machine learning is a branch of artificial intelligence that deals with the development of algorithms and models that can learn from data and make predictions based on new data. Image processing includes a number of methods that allow you to process and analyze images for the purpose of detecting diseases and complications.

The development of an information system for the diagnosis of diabetic retinopathy is an urgent task, because such a system can be useful for doctors and patients who are faced with the problem of diabetic retinopathy[9,10,11]. The developed system can provide fast and accurate analysis of retinal images, which will allow doctors to detect and treat diabetic retinopathy in time, preventing vision loss and blindness in patients[12,13,14]. In addition, the development of an information system for the diagnosis of diabetic retinopathy can have a significant impact on modern medicine. Diabetes is quite common, and diabetic retinopathy can lead to serious complications, including vision loss and permanent eye damage. Development of an effective diagnostic system can help detect this disease in time and prevent its development.

Therefore, this study is an important step in the development of an information system for the diagnosis of diabetic retinopathy using machine learning and image processing methods. The possibility of creating a more effective diagnostic system depends on the results of the study, which can have a significant impact on people's health and reduce the number of cases of vision loss and irreversible eye damage in diabetic patients[20,21,22].

2. ANALYSIS OF METHODS AND SYSTEMS FOR DIAGNOSING DIABETIC RETINOPATHY

Fighting the consequences and causes of diseases of the organs of vision has an important place and medical and sanitary significance in clinical practice. In particular, pathological conditions of the retina and optic nerve can be caused by many neurosurgical, cardiovascular diseases, as well as endocrine lesions, which often require combined coordinated observation and treatment by both an ophthalmologist and a doctor of any other specialty [4].

Changes in the fundus are of great diagnostic and prognostic importance, since most patients with eye diseases require not only surgical but also therapeutic treatment. Hence the need to study the general pathology of the retina and develop appropriate tactics for the combined treatment of patients [4].

The problems of DR research are the difficulty of detecting the disease in the early stages, when treatment can be more effective. At an early stage, DR can manifest itself without symptoms, which makes diagnosis difficult. Special studies such as ophthalmoscopy, fluorescent angiography, and optical cochleography are used to detect DR[15,16,17].

The consequences of DR can be serious and lead to impaired vision or even blindness. Chronic hyperglycemia, high blood pressure, and other risk factors may contribute to the development of DR[129]. If DR is detected, steps should be taken to prevent disease progression, such as diabetes management, blood pressure control, and regular fundus monitoring.

Two leading pathogenetic mechanisms play a role in the pathogenesis of diabetic retinopathy[16,18]: increased permeability of the vascular wall, which leads to the appearance of edema, hard exudates and hemorrhages on the retina; the process of formation of microthrombi and capillary occlusion, this leads to the development of areas of ischemia and hypoxia. Later, vascular endothelial growth factors are produced in these places, which cause the process of neovascularization. Pathogenic changes occurring in diabetic retinopathy are listed in Table 1.

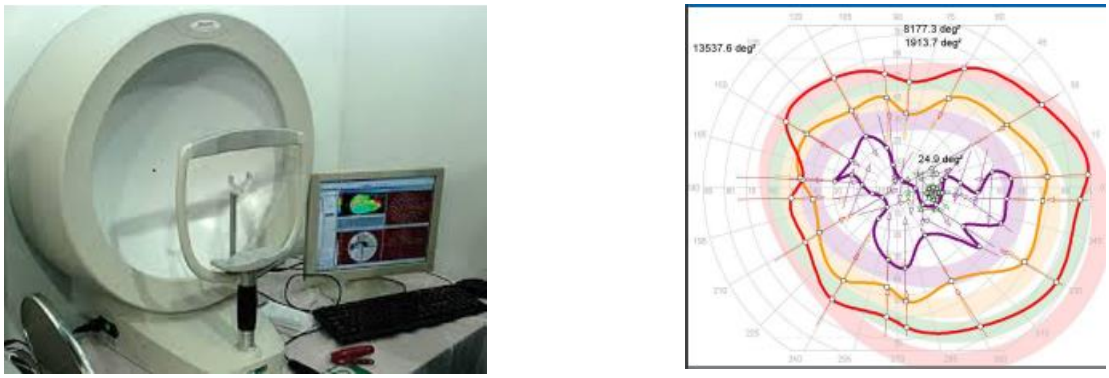
Table 1. Pathogenic changes occurring in diabetic retinopathy [4]

	Diabetes		
	angiopathy	common retinopathy	proliferative retinopathy
The optic disc is pink	+	+	+
Swelling, increasing in size	—	—	—
The boundaries of the optic disc are clear	+	+	+
Arteries are narrowed	—	—	—
The caliber of the vessels is not uniform	+	-	+
Corkscrew and tortuosity of small venous vessels in the area of the macula	—	—	—
Copper and silver wire symptom	—	—	—
Symptom of Salus-Gunn II-III centuries.	—	—	—
Whitish-yellow spots in the retina	—	+	+
Hemorrhages in the retina and its swelling	—	+	+
The shape of a "star" in the area of the macula	—	—	
Newly formed vessels	+	+	+
Proliferation	—	—	+

3. METHODS OF RESEARCHING EYE DISEASES, IN PARTICULAR DIABETIC RETINOPATHY

There are many methods of investigating eye diseases, depending on the symptoms and the pathological process to be investigated. Here are some of the more common methods:

- Eye exam: This is the first step in an eye exam, usually performed by an ophthalmologist or optometrist. During the examination, the doctor examines the visual acuity, fields of vision, refraction, condition of the eyeballs, pancreas and lower leg.
- Computer spheroperimetry of the eye is a modern ophthalmological examination that allows you to determine the limits of the visual fields and their smallest deviations from the established norms at the earliest stages, as well as to record this in the form of diagrams, graphs and a three-dimensional image (Figure 2) [17,19].



a) b)

Figure 2. Computer perimeter (a) and example of a kinetic visual field test performed on an Octopus 900 (b)

The analyzer of hydro- and hemodynamics of the eye (hereinafter tonograph) is designed to determine the intraocular pressure, the parameters of the circulation of intraocular fluid and blood in the eye.

3.1 Analysis of decision support systems

In many systems of medical diagnosis, the reliability of the results is reduced, including due to the lack of a decision support system, since the interpretation of images of biological objects by the diagnostician requires a lot of time and effort and is not always appropriate from the point of view of the final result[11,12,16]. Therefore, the development of a decision support system (DSS) for the diagnosis of BT based on the analysis of their retinal images will increase the reliability and efficiency of the assessment of pathological conditions in diabetes.

In order to correctly build an expert decision support system, it is necessary to select and determine a sufficient number of information parameters that will satisfy the accuracy and reliability of diagnosis, when analyzing polarimetric images. Statistical, correlational or fractal approaches are often used for this purpose, which is often insufficient for high reliability of diagnostic systems. Therefore, it is worth combining informative indicators such as statistical points and other types of expert systems to increase the reliability of the system.

The next stage is the selection of the rule type for the DSS system. Known methods based on statistical decision theory[8], fuzzy logic[9,11,12], decision tree methods[19] and neural network technologies[11,15,17] may be more or less appropriate for use in different conditions and methods.

3.2 Discriminant analysis

Discriminant analysis[8,9,10] is used to make decisions about which variables distinguish two or more groups. The basic idea of discriminant analysis is to determine whether the populations differ on the mean of any variable (or linear combination of variables) and then use that variable to predict for new members whether they belong to one or another group[13].

Discriminant analysis is based on the assumption that the description of objects of each kth class is the implementation of a multidimensional random variable distributed according to the normal law $N_m(\mu_k; \Sigma_k)$ with means μ_k and the covariance matrix:

$$C_k = \frac{1}{n_k - 1} \sum_{i=1}^{n_k} (x_{ik} - \mu_k)^T (x_{ik} - \mu_k); \quad (1)$$

m indicates the dimensionality of the feature space.

Within the statistical (probabilistic) approach, the Bayesian method is used[14]. According to the Bayes formula, the reliability of the conclusion about the presence of this or that pathology is determined $P(Y_j/X_i)$ [3]:

$$P(Y_j / X_i) = \frac{P(Y_j) P(X_i / Y_j)}{P(X_i)}. \quad (2)$$

Taking into account the set of features, $X_1, ..., X_K$, the Bayes formula takes the form [39]:

$$P(Y_j / X_1, ..., X_K) = \frac{P(Y_j) P(X_1, ..., X_K / Y_j)}{P(X_1, ..., X_K)}. \quad (3)$$

The decisive rule according to the Bayesian method (fig. 3) is to find the maximum of the conditional posterior probability $P(Y_j / X_1, ..., X_K)$

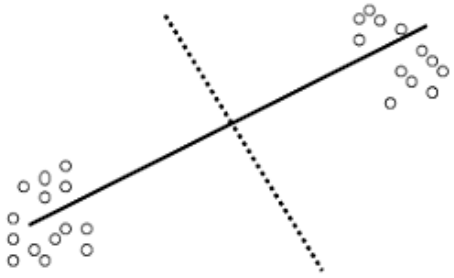


Figure 3. Division of the population into two classes using a discriminant function

The advantage of the Bayesian method lies in the possibility of using a set of signs that may have different physical origins, since not the dimensional values themselves are used, but estimates of the probabilities of their occurrence.

The main disadvantage of using the Bayesian method is the need to have a large amount of prior information. The main disadvantage of discriminant analysis is the high sensitivity to the distribution of input data, when even a small change in them leads to significant changes in the classification results.

4. EXPERIMENTAL RESULTS

An example of fundus images, images after preprocessing, their 2-D and 3-D distribution histograms are shown in the figure 4.

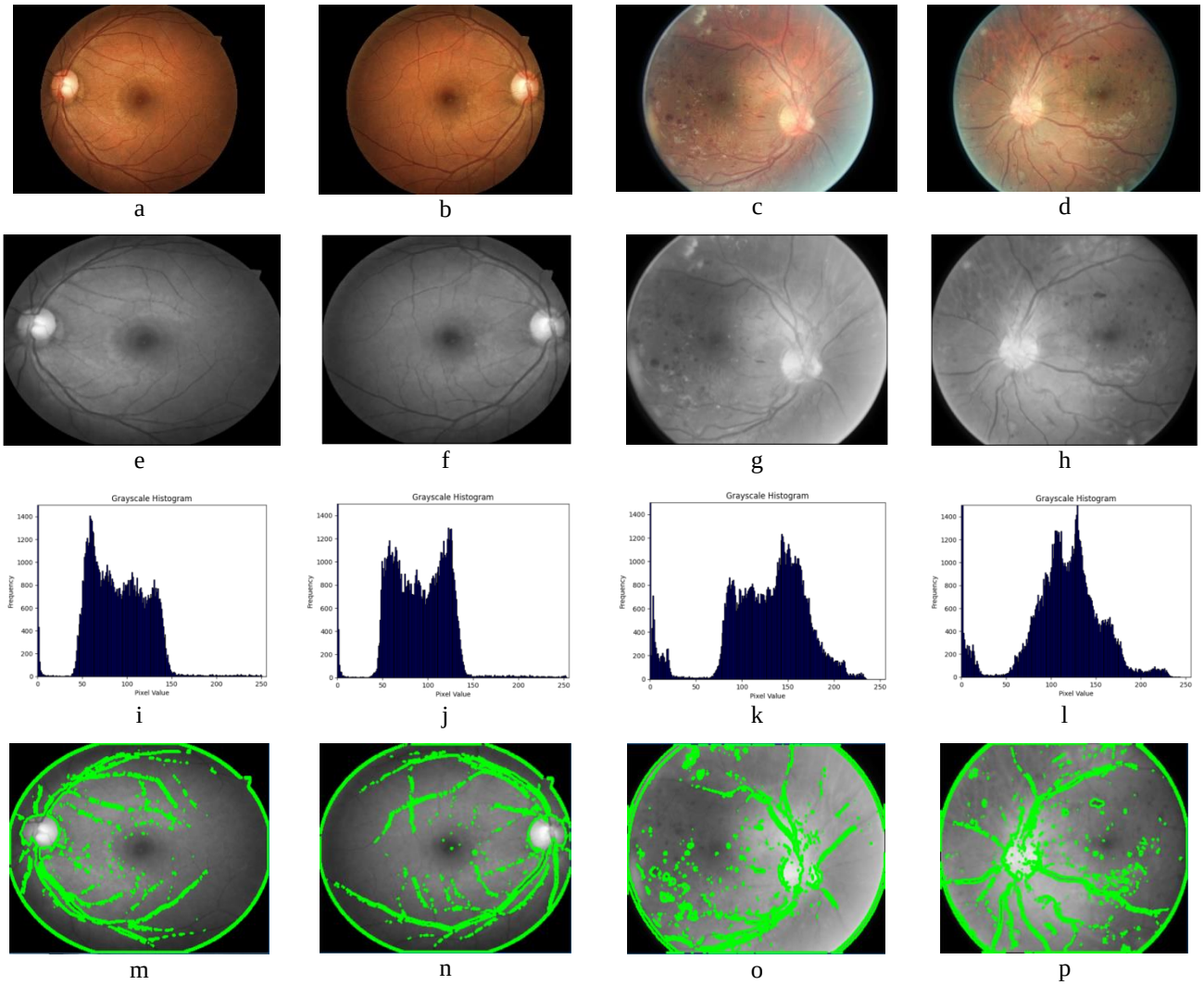


Figure 4. An example of images of a healthy and diseased retina before processing (a, b, c, d), after processing (e, f, g, h), and their two-dimensional 2*D* distribution histograms (i, j, k, l) and image with selected characteristic features (m, n, o, p)

The method of morphological heterogeneous illusion helps to improve the characteristics of the studied image by removing the bright background of the image to better determine the informative indicators of the object (Figure 5).

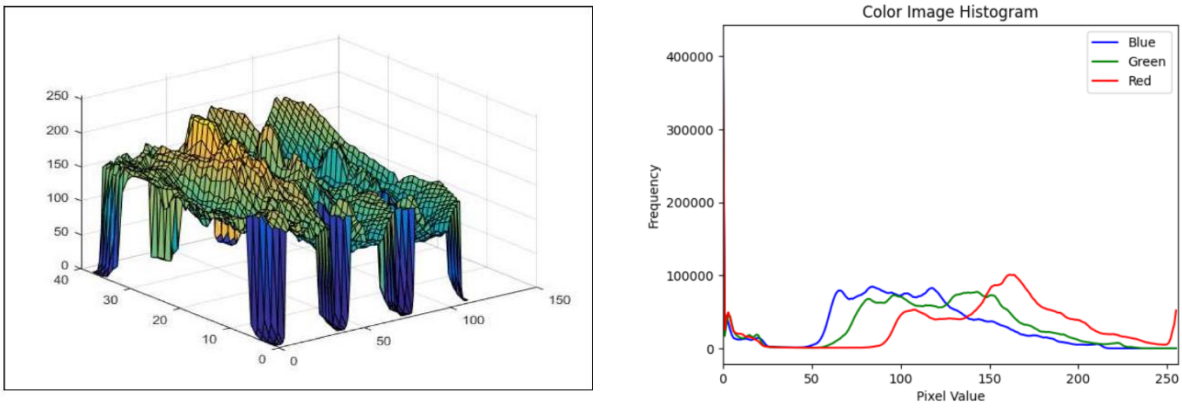


Figure 5. Three-dimensional histogram of a three-channel image

5. CONCLUSIONS

The main goal of this study is to increase the accuracy of diagnosing diabetic retinopathy using the methods of preprocessing of microscopic images followed by analysis and differentiation of pathologies using a decision support system based on neural network technologies. This system should help doctors correctly and accurately determine diabetic retinopathy even in the early stages, which will help avoid complications and save a person's vision.

The results of the dissertation research solved the urgent task of increasing the informativeness, accuracy and reliability of the classification of the information system for the diagnosis of diabetic retinopathy.

An analysis of the existing methods of diagnosing eye diseases was carried out, and it was established that in the case of early cases, diagnosis allows preventing severe stages of the disease. A comparative analysis of existing methods of medical diagnosis of gout disease is given, from which it can be seen that the reliability of diagnosing pathologies of the above-mentioned methods is significantly improved, which is possible due to the intellectualized analysis of measured images with the help of a computer decision support system. Intelligent analysis and image pre-processing to improve the informativeness of the data have expanded the capabilities of ophthalmic systems.

A number of existing methods for a decision support system were analyzed. The choice of a rule for a decision support system was justified, based on the fact that with a given number of samples and informative parameters, neural network technologies are best suited due to sufficient accuracy, simplicity of working with numerical characteristics. An analysis of existing neural network algorithms was carried out, their pros and cons were indicated.

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