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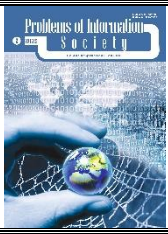

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The application of artificial intelligence technologies in medical diagnostics

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ABSTRACT

Image recognition is one of the main directions in artificial intelligence theory. Providing a universal solution for the recognition of any given image by a computer is virtually impossible. However, the characteristic features of each image indicate that it follows certain regular patterns. In this study, medical diagnosis is considered as a three-stage process, and closed sub-objects are examined based on complex image representations, which corresponds to the earliest stage of diagnosis. In modern times, medical equipment has become an integral part of medical diagnostics. The research was conducted on 238 ultrasound images obtained using the Toshiba-SAL-38B ultrasound imaging system. A preprocessing package is proposed for the initial processing of the images, which enables tasks such as boundary detection, segmentation, noise removal, and filtering. For image recognition, mathematical morphology methods and a classifier are used. In the final stage, closed or semi-closed contours are detected, and a predictor concept is introduced for their evaluation. Three new indicators characterizing the predictor are proposed: the area enclosed by the contour, the centroid of the area, the color palette of the area. A software package has been developed for image recognition. If a predictor is detected, its indicators are measured and logged. The monitoring frequency is determined by the physician.

1. Introduction

Pattern recognition is one of the main branches of artificial intelligence. In classical pattern recognition theory, this process involves the formation of informative features and the determination of a decision-making procedure. Scientific research has shown that there is a large body of work dedicated to the development of decision-making rules. Numerous new approaches and methods have been developed in this area, and a wide range of algorithms have been created, among others. However, the determination and selection of informative features are typically addressed within a narrow scope — that is, through methods and algorithms capable of covering only a specific field, and only rarely through comprehensive methodologies.

In general, it can be stated that the process of determining features with informative value for pattern recognition is of an empirical nature. This process depends on the individual's subjective opinion, experience, and personal intuition. Providing a universal solution for the recognition of any given image by a computer is virtually impossible. However, the identification of features characterizing each image indicates that it follows certain regularities. From this perspective, the preparation of an image for recognition should consist of several stages. First, the image must be filtered; then, the filtered image must undergo logical processing; and in the final stage, decision-making algorithms should be applied to the logically processed image. It is important to note that the implementation of each of these stages is not mandatory—depending on the task at hand, some of them may be used while others may not. Tasks involving image processing can be classified into three main categories (Gonzalez & Woods, 2012; Abdullayeva et al., 2004):

- Image processing tasks;
- Image analysis tasks;
- Image synthesis tasks.

Tasks involving image processing fall into one of the three aforementioned categories. The boundaries between image analysis and image processing are not clearly defined. Therefore, some researchers propose classifying these tasks into low, intermediate, and high levels. Low-level processes involve primitive tasks such as noise reduction and contrast enhancement. At this level, both the input and output are images. Intermediate-level tasks include information extraction from the image and object detection, where the output consists of features derived from the image. High-level tasks encompass the recognition of objects extracted from the image (computer vision). The separation between image analysis and processing tasks is conditional and may vary depending on the specific problem, meaning the sequence of stages can differ. Image synthesis refers to the process of creating or reconstructing images for specific purposes within the fields of computer graphics and image processing. It may involve techniques that help generate new images from existing ones or complete incomplete images. In general, image synthesis focuses on creating new visual data using existing datasets or models. Overall, image processing technologies are applied across a wide range of domains. For instance, image processing methods play a critical role in various fields, from medical diagnostics to space research, aiding in early disease detection, environmental monitoring, and solving other complex problems.

2. Related work

The problem of recognition and identification of complex closed contours has not yet been fully resolved for specific cases. Let us consider a few examples. In a study conducted at the University of Athens titled “Quantitative Image Analysis in Thyroid Gland Sonograms,” an automatic determination of the condition of glandular tissue using statistical analysis methods was proposed (Skouliakou et al., 2006).

Limitations of the method include the following: on one hand, a large amount of statistical database is required for object recognition; on the other hand, brightness-based distance estimation demands highly accurate correlation.

As an alternative example, the importance of ultrasound imaging in diagnosing benign pathologies of the mammary glands should be noted. Limitations: the timely detection of small benign tumor (with a diameter of less than 10 mm) remains an unresolved issue. Moreover, accurate data regarding even smaller tumor are still debated (Sukhareva et al., 2013).

The minimum size of a mammary gland tumor visible with ultrasound under favorable conditions is 4–5 mm; however, we should remember that even a large tumor nodule is not always visible, especially if glandular tissue is defined, and the structure of the nodule is isoechoic. The minimum size of tumors in the kidney, at which it can be visualized, is 10-15 mm (when the tumor grows beyond the contour of the kidney) (Kazakevich et al., 2016).

Malignant renal parenchymal tumors are typically characterized by large size, deformation of external contours, and structural heterogeneity. Nevertheless, the effectiveness of the method is low in detecting intraparenchymal location that do not alter the kidney contour and are smaller than 1.5 cm in size (Nikolsky et al., 2016).

Ultrasound computed tomography is of great importance in the early detection of recurrence of thyroid cancer, since, according to studies, the sensitivity of this type of examination in detecting local recurrences of thyroid cancer is 93.6%, accuracy 91%, specificity 90.2% (Abdullayeva et al., 2015). The minimum size of a growth in the thyroid gland detectable by ultrasound is 3-4 mm (Huseynov et al., 2016).

Most researchers believe that the minimal size for the visual detection of liver cysts is 3–5 mm. A number of studies conducted in recent years have noted that the differential diagnosis of large non-parasitic cysts from parasitic lesions has been simplified, and significant progress has been achieved in this area. Nowadays, it is possible to visually detect intraductal nodes larger than 2–3 mm through liver radioisotope scintigraphy and dynamic imaging of the biliary system. Studies show that the presence of tumors larger than 1 cm does not affect the sensitivity of X-ray contrast computed tomography. Sensitivity of contrast X-ray computed tomography reaches 100% for foci larger than 2 cm, 93% for growths ranging from 1 to 2 cm and 60% for tumors smaller than 1 cm with a specificity of 96%. In this regard, the use of X-ray computed tomography in the differential diagnosis between primary and metastatic liver cancer is justified (Sinyukova et al., 2016).

Zoph and colleagues (Zoph et al., 2018) demonstrated that developing scalable image recognition models requires significant resources and high costs. For this reason, the authors proposed a new dataset called the NASNet search space. Longacre, A. Jr. (Longacre et al., 2016) noted that a flattened image is typically a cropped image or one presented at a certain angle.

An analysis of conducted studies has shown that ultrasound images of tumors located in internal organs can generally be visualized when they are larger than 2–3 mm. However, obtaining information about tumors smaller than 1–2 mm is of great importance in the early stages of oncological diseases. In such cases, the internal area of the tumor may sometimes have the same echogenicity as the surrounding tissue, which complicates its visual detection. It should be noted that a considerable number of studies have been devoted to the automatic or semi-automatic recognition of ultrasound images in the field of medicine. However, an analysis of these studies reveals that there is no universal approach or algorithm for detecting complications occurring in internal organs. There is a clear need to develop an automated diagnostic system based on the recognition, identification, and measurement of lesions, closed or semi-closed contours in ultrasound images of the human body (Abdullayeva et al., 2019). The present work is aimed at addressing this issue. In the recognition of complex patterns in ultrasound imaging, one of the current and challenging problems is the detection of very small closed contours (lesions), as well as the monitoring of their development over time. If this process can be solved at the earliest stage of diagnosis, it could serve as an additional advisory tool for medical professionals. This paper proposes an approach to address this problem. Specifically, the work is dedicated to the development of an automated intelligent diagnostic system for the recognition, identification, and measurement of tumors surrounded by closed or semi-closed contours in ultrasound images obtained during the examination of the human body.

3. Materials and methods

3.1. Selection of technical tools

A significant number of articles are written about the use and prospects of artificial intelligence in various fields, including its current and future status in healthcare and medicine. Among these, particular emphasis is placed on the processing of images obtained from medical devices. The application of information technologies in this area remains a highly relevant issue. Computers are used in medical institutions for documentation, data processing and storage, and statistical analysis. Another category of computers serves as integral components of various diagnostic and therapeutic devices. In many of these areas, standard software is employed. However, another crucial direction in the informatization of medicine is ensuring timely and accurate diagnosis and the selection of effective treatment strategies. One of the information technologies that has recently been successfully applied in medicine is computer vision. This technology is widely used for image analysis and recognition.

The technical equipment and hardware used for image acquisition determine the quality, accuracy, and efficiency of imaging, as well as enable effective processing of the obtained data. Among the technical tools are scanners, digital cameras, 3D scanners, microscopes, infrared cameras, and specialized image processing devices. Each piece of equipment is selected based on specific requirements and application areas.

Ultrasound refers to high-frequency sound waves. The human ear perceives waves propagating in the environment at frequencies up to 16,000 Hz (hertz); vibrations with higher frequencies are referred to as ultrasound. US involves vibrations of sound waves exceeding 20,000 Hz, which are inaudible to the human ear. Ultrasound imaging is used to detect abnormalities in organs, especially lesions, tumors, and structural changes. Currently, this method is considered one of the safest, most sensitive, and sufficiently accurate techniques for examining soft tissues and fluid-filled organs. In US images, tumors appear clearly and can even be differentiated. In this research, we used the Toshiba-SAL-38B (Sonolayer) ultrasound device, which is equipped with electronic and mechanical high-frequency scanning transducers (PLB-505, 5 MHz) and operates in B-, B+M, and M-modes. The diagnostic depth is 20 cm, and the system is used for measuring distance, area, and growth dimensions.

3.2. Image recognition methods

Image processing is a widely applied direction in the field of medicine. With the implementation of advanced diagnostic methods, the analysis of medical images has gained particular importance, as numerous techniques are used in clinical practice to obtain such images. The majority of medical images are acquired through ultrasound imaging, which is considered safe for human health. However, due to the complexity of the images obtained via ultrasound, image recognition cannot be performed solely through algorithms based on feature extraction. In such cases, the primary objective is to capture the appearance of the organ and to perform measurements. The recognition process is carried out based on informative tasks comprising two stages with the following characteristics: Transformation of the original data into a format suitable for recognition; Actual recognition, i.e., assigning the object to a specific class. At these stages, the concept of object similarity or analogy may be introduced. Rules can be formulated based on objects recorded in various classes or within the same class. It is difficult to construct formal theories and apply classical mathematical methods to these problems, as the available data may not correspond to existing mathematical models, or the benefits derived from the model and applied methods may not be comparable to the associated costs. In this study, various methods were investigated and their effectiveness evaluated for selecting approaches and algorithms that ensure recognition accuracy. In the first step, distance-based methods in the feature space were explored. These include Euclidean, Manhattan (L1 norm), Minkowski, Chebyshev, Canberra, Cosine, Covariance (Cov), Mahalanobis, Nearest Neighbor, Farthest Neighbor, and Kolmogorov distances. In the second step, boundary-based methods were examined. The primary task in image recognition is the differentiation of the image. This requires the segmentation of the image into parts, i.e., the identification of boundaries and the separation of the inner region enclosed by those boundaries. For this purpose, several applied methods aim to solve the problem of contour detection in images. Boundary methods divide the image into two or more parts based on edge values. Two basic methods are employed: Global thresholding method; Adaptive thresholding method.

In global threshold processing, methods such as Bernsen, Eykliv, Niblack, and others are used. The adaptive thresholding method yields better results in cases of uneven illumination (Shapiro et al., 2001). In this approach, the initial image is divided into subregions, and within each of these, an individual threshold is determined for segmentation. Linear filtering (such as Sobel and Prewitt filters for edge enhancement, and Gaussian blur for smoothing the image and reducing noise) is simple and computationally efficient. It computes the weighted sum of the input signal and maintains a linear relationship between the input and output signals. Non-linear filtering, in contrast to linear filtering, creates a non-linear relationship between input and output signals, allowing for the processing of more complex data and relationships. Among the filters tested in this study are Median, Non-Local Means, Harmonic Mean, Gaussian, and Laplacian filters.

In the color palette (RGB, CMYK, HSI color models—Hue (H), Saturation (S), Intensity (I)), the grayscale model is used. There are various names and shades of gray (e.g., Gray, Trolley Grey, Chrysler Vapor Steel Gray, Volkswagen Polar Gray), which are used in different color systems and contexts. Grayscale images use varying shades of gray. In the RGB model, gray shades lie along the main diagonal of the color cube, where the red, green, and blue components have equal values.

3.3. *Problem solution*

In medicine, diagnosis refers to the identification of the type of disease, its symptoms, and associated clinical signs. The presence of asymptomatic, ambiguous, or incomplete sets of symptoms is often referred to as early diagnosis. By utilizing modern technical tools and information technologies, the concept of the earliest possible diagnosis can be introduced into the medical diagnostic process. The term earliest diagnosis refers to cases in which certain signs are detected, yet it is not possible to definitively confirm which specific pathology they correspond to. To address this, it is necessary to first define the essence of diagnosis. Diagnosis can be viewed as a three-stage process (fig. 1).

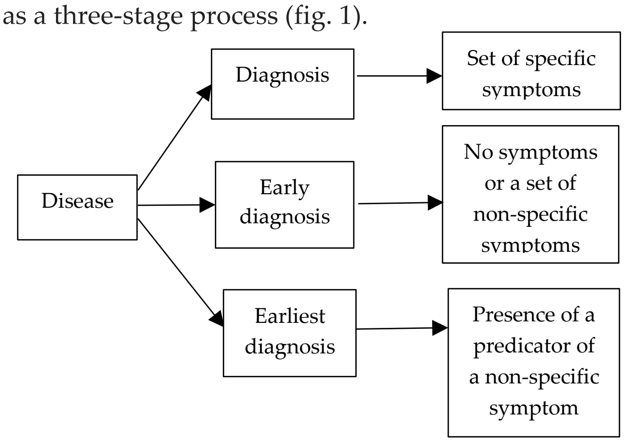

Fig. 1. Types of disease diagnosis

To obtain information about a predictor, we propose three indicators that characterize it: the area enclosed by a curved line, the centroid of the area, and the color palette of the area. To calculate the area of the figure, one can use definite integrals, as well as methods such as rectangles, trapezoids, Monte Carlo, or Green's theorem. The area of the figure serves as an informative feature that reflects the geometric dimensions of the closed contour and distinguishes it from other figures. Determining the centroid of the figure is applied using mathematical morphology methods to assess the correspondence between the newly obtained figure in a transformed plane and the original figure in the initial plane. Variation in the centroid indicates variation in the figures themselves. In addition to the mentioned indicators, the color of the figure is also considered an informative feature. For this purpose, the RGB color model is used. By applying the normal distribution law, the color distribution of the figure's points is determined. Based on the color shades of the points within the closed figure, the weighted arithmetic mean (M), variance (D), standard deviation (σ), and standard error of the mean (m) are calculated. A diagnostic system that performs analysis based on image processing must include several components. Each component is designed to fulfill specific functions. During ultrasound imaging, an image is obtained as a result of the reflection of echo-signals from the organ. The main challenge lies in analyzing this image to detect whether a pathology is present in the organ. Let us consider the operational workflow of the diagnostic system in a sequential stage-by-stage manner.

In the first stage, ultrasound images must be input into the computer, classified, and forwarded for processing. The mathematical tools required for processing must be selected and packaged. Through these tools, informative features must be identified for the recognition of complex 2D images, and relevant computations should be performed when necessary. Based on these features, it becomes possible to proceed to the diagnostic stage. Taking the above into account, the architecture of an intelligent system designed to detect lesions in ultrasound images is established.

A software package was developed for processing the images transferred from the Toshiba-SAL-38B to the computer, based on the analysis of the tools and methods mentioned in Sections IV and V. The software package serves as a structural foundation that plays a crucial role in the organization and application of modern information technologies. This package consists of a collection of programs or software components brought together to solve a specific problem. The programs within the package perform interrelated functions aimed at addressing broader and more complex tasks. Typically, these programs are managed through a unified interface, providing a more user-friendly environment. The architecture of the system is presented in fig. 2.

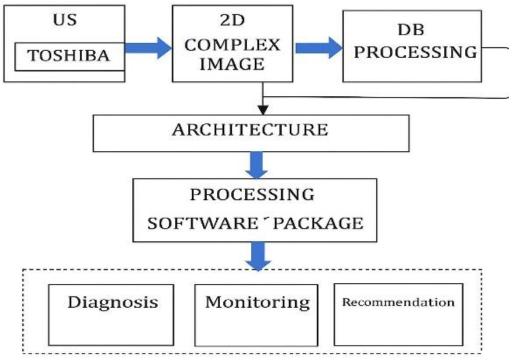

Fig. 2. System architecture

This package is a collection of several programs or software components brought together to solve a specific problem. The programs within the group perform interrelated functions and are aimed at executing broader and more complex tasks. Typically, these programs are managed through a unified interface, which creates a more user-friendly environment for the user.

Methods used in the software package include:

- k-nearest neighbor (k-NN);
- Image processing – in this technology, the following methods are applied:
- Thresholding methods;
- Canny edge detection;
- Gradient method;
- Watershed algorithm;
- Gaussian blur (noise reduction technique);
- Sobel method (edge detection);
- Grayscale image representation;
- Canny Non-Maximum Suppression;
- Binary morphology;
- Calculation of predictor indicators.

The software is developed using the Python programming language.

3.4. *Conducting experiments*

To increase the effectiveness of the experiment, it is advisable to ensure the representative selection of experimental objects. In other words, various organs should be equally represented in the experiment. In some cases, the subject of the experiment may be limited to laboratory studies. This has particular significance in our approach, as in the earliest diagnostic stages, there may exist pre-indicators that remain unchanged for years. Such cases require a systematic approach from the ultrasound imaging specialist. This type of approach can constitute a research study with high scientific value. Practice has shown that very small nodules and cysts may sometimes serve as significant indicators for the early diagnosis of more serious diseases (fig. 3).

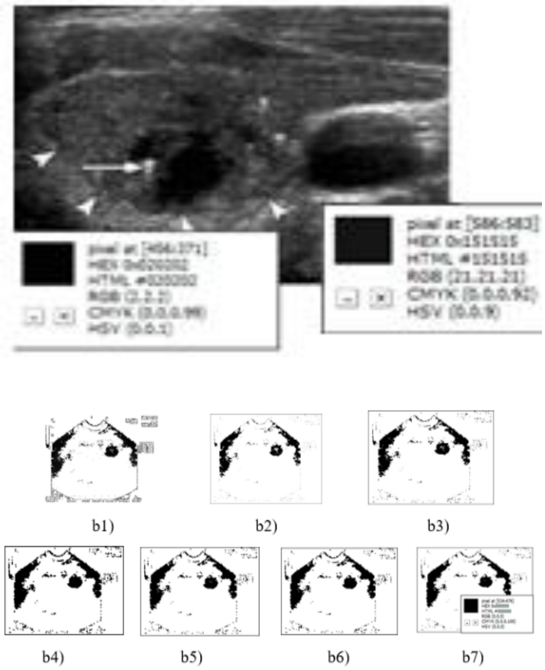

Fig. 3. Kidney imaging and processing

During the earliest stages of diagnosis, medical devices used for detecting very small lesions—such as MRI—cannot always or frequently be used due to various reasons. In particular, dynamic monitoring using such methods may pose health risks to the patient (i.e., medical examinations like MRI may not always be feasible for detecting such small lesions, as the dynamic observation process can be risky for the patient). Although ultrasound imaging allows for the detection of small lesions, these formations are often overlooked by physicians due to subjective factors. A large number of experiments (238 in total) have shown that the images obtained through the application of the methods included in the software package and mathematical morphology operations are identical to those produced by ultrasound imaging. Regardless of size, the appearance of any lesion within the general image of an organ can be captured. This demonstrates that the proposed algorithm is potentially effective even for detecting very small lesions. For the recognition of the detected lesions, a predictor is used, and three indicators characterizing it are calculated.

4. Discussion

The main distinction between the approach presented in this article and similar studies lies in the introduction of the concept of the "earliest diagnosis" in addition to early diagnosis. The developed system enables the detection of small-sized lesions (relative to other organs) in medical images during the early diagnosis of certain types of diseases. Medical images are often characterized by contrast, which corresponds to boundary contrast in human vision. Overlooking such lesions in medical imaging can lead to incorrect conclusions about the patient's condition. Experiments have shown that the accurate detection of these lesions depends on the object's contrast in the image, angle measurements, and the boundary contrast of the visual system.

To correctly detect low-contrast lesions (measured in pixels), preprocessing should be directed toward adapting image parameters to the relevant indicators. As a result, lesions can be detected both during the contrast enhancement phase and at the scaling stage. For this purpose, a new concept called the "predictor" is introduced. Future observations will reveal whether the lesion remains stable or shows progression. Protocols for the information-recognition system have been developed, and in addition to the results obtained by the physician, new characteristics (indicators) are presented. The system serves as a tool that allows for tracking the formation and developmental stages of the lesion.

5. Conclusion

To detect very small (less than 2 mm) nodules and tumors in ultrasound images, methods and algorithms from the theory of image recognition—one of the main branches of artificial intelligence—were applied, and an intelligent diagnostic system was developed. A three-stage approach to medical diagnosis was proposed for this purpose. The concept of a predictor was introduced, along with three indicators that characterize it. A software package for recognition was created, which performs classification, boundary detection, segmentation, noise reduction, filtering, mathematical morphology, and, if a predictor is identified, calculates its indicators and presents diagnostic protocols to the physician. Based on the case, the physician determines the necessity and frequency of monitoring. The experiments were conducted on 238 fragments of images obtained from the Toshiba-SAL-38B ultrasound device. The system allows for the monitoring of the dynamics of small tumors enclosed by closed or semi-closed contours. These new characteristics may be useful for physicians as well as researchers conducting scientific investigations at the biomolecular level.

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