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An Information Recognition System for Complex Images

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KEYWORD

software package; artificial intelligence; pattern recognition; ultrasonic irradiation; closed contour

ABSTRACT

An approach to objective assessment of ultrasound examination is presented. To this end, modern information technologies and a set of mathematical methods in the form of a package are proposed. In this paper, diagnosis is viewed as a three-step process, and closed sub-objects are investigated using complex images, which pertains to the earliest diagnostic stage. For this purpose, three new features related to the disclosure of a growth are included in the paper. A system that performs the detection of the growth and finds the coordinates, area, gravity center and color palette of the obtained image is developed. By means of the created software package, the image is cleared from noise, filtering operations are performed, boundaries are defined more clearly and recognition by the mathematical morphology method is completed using selected classifiers. The main purpose is to direct doctor's attention to the presence of the pre-indicator of a non-specific symptom and to control the future development of the growth. The accuracy of the system is confirmed by the detection and identification of closed growths in the images taken in an ultrasound examination of internal organs of the human body. The system's operability has been tested directly on the ultrasound images (138 cases investigated), with the result of 98.8% at the diagnostic stage, 92, 03% at the early diagnostic stage; 2 cases have been recorded at the earliest diagnostic stage in 2018 and the frequency of monitoring has been determined.

1. Introduction

The use of artificial intelligence methods in real life for solving applied problems is a challenge. The difficulties are due to the fact that two types of resources are required here: computer and human resources (the development of intelligent systems requires involving specialists from different fields of knowledge and organizing long-term projects). The first type of resources are at the appropriate level for the development of artificial intelligence systems. But since the second type of resources refers to the human factor, the achievements in this field depend on the qualifications of leading experts.

Information technology (IT) is used in many areas of society. Medicine is not an exception and the use of IT in this field is a priority. Informatization of healthcare is a fairly generalized concept and the capabilities of modern IT pertain to all aspects of medical care. IT also makes it possible to optimize the work of physicians, registration, emergency rooms and other services, including events for the dissemination of information on the scientific achievements in medical profession through information technology, along with provision of many other kinds of information. Informatization is an effective tool for training and advance training of personnel of hospitals and clinics. Because of IT, doctors can get quick access to new discoveries, inventions and latest advances in medical science. This is particularly relevant for medical personnel working in remote areas.

The development of IT has a positive impact on the identification and application of new trends in the provision of medical aid to the population. From this perspective, telemedicine, real-time monitoring and control of patient's condition, remote registration of physiological parameters, exchange of patient's records between medical institutions, real-time treatment, etc. takes medicine to a qualitatively new level. All of this improves service quality, speeds up the work of medical personnel and reduces service costs for patients.

Intensive development of medical devices and equipment has taken the science of diagnostics to a new level: ultrasonic, magnetic resonance, nuclear resonance imaging, hypobaric chambers, bedside monitors, etc. This equipmen allows medical professionals not just to diagnose but even to solve the problem of early diagnosis. Modern information technologies has led to the emergence of new technologies that allow detecting a disease in its latent stage.

By medical diagnosis, we understand the process of determining the type of disease based on patient's symptoms and signs.

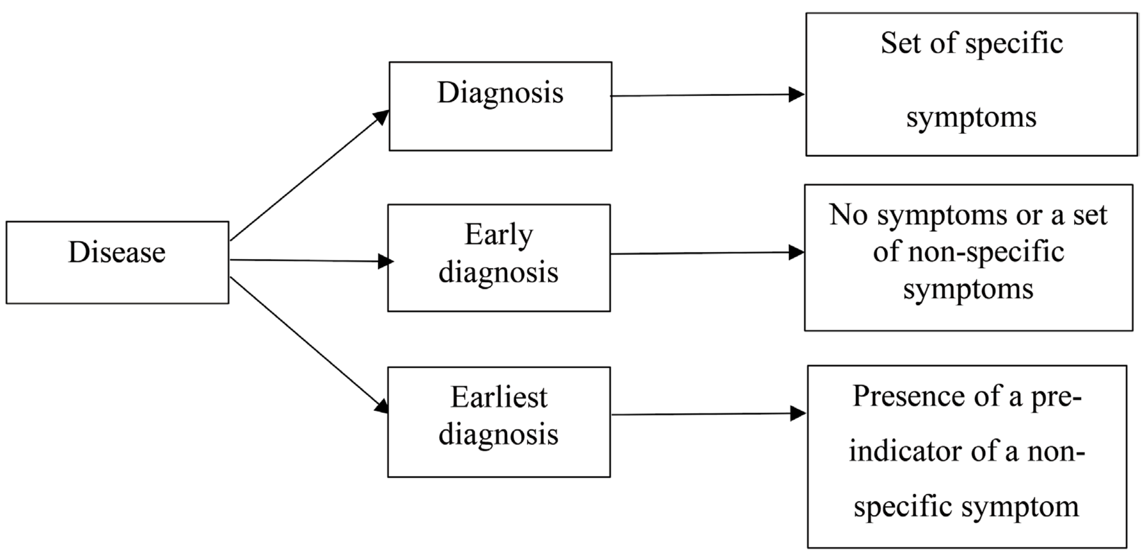

Figure 1: Types of diagnosis.

Early diagnosis identifies the early signs of a disease in a symptom-free patient (Abdullaeva & Alizadeh, 2015). In earliest diagnosis, we deal with such cases when the exact pathology is not directly confirmed despite the manifestation of some signs. We need to determine the nature of the diagnostics from the beginning. Thus, diagnosis can be perceived as a three-step process. This paper focuses on the earliest diagnostic stage, i.e. when no specific symptoms have been detected, but an ultrasound examination confirms the presence of an undefined closed contour and there is no opinion with regard to its nature. In this case, the following definition is suggested: pre-indicator of a non-specific symptom (Fig. 1).

In this study, we detect the asymptomatic period of growths that can form in internal organs, identify the signs that can characterize them, conduct measurements of those growths and place them under monitoring to keep their future development under control. This requires solving the following subtasks:

- Ultrasound (US) examination and its capabilities;
- Collecting obtained US images, systematizing them, determining the coordinates;
- Creating a database;
- Identifying informative signs;
- Choosing the mathematical apparatus;
- Building the conceptual diagram and architecture of the system;
- Software development;
- Calculating the area and gravity center of the growth, determining the color palette inside the contour;
- Creating a data bank.

2. Literature review and analysis

The problem of recognition and identification of closed contours in complex gray-scale images is yet to be resolved in concrete cases. For instance, the authors of "Quantitative image analysis in sonograms of the thyroid gland" performed at the Radiology Department of the University of Athens propose automatic recognition of the condition of the gland tissue by methods of statistical analysis (Skouroliakou *et al*, 2006).

For each patient two sonographic images are recorded in DICOM format. Based on the received matrices, contrast and uniformity can be determined. But the shortcoming of the method should be remarked upon. On the one hand, a large amount of statistical data is required for recognition; on the other hand, a very accurate correlation is required to estimate the distance based on the brightness. Let us consider another example. For instance, ultrasound examination is essential in the diagnostics of benign pathology of mammary glands. However, the issue of timely detection of small benign tumor-like growths has not been resolved yet. The most common growths are less than 10 mm in size. Proven information regarding smaller growths is open to question (Sukhareva & Ponomareva, 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. After surgical treatment, the ultrasound method is key to the detection of local recurrence, allowing us to see recurrent nodules of at least 4-5mm in size. The minimum size of tumors in the kidney, at which it can be visualized, is 10-15mm (when the tumor grows beyond the contour of the kidney) (Kazakevich *et al*, 2016).

Malignant renal parenchymal tumors compared with benign tumors are characterized by large size, deformation of the outer contours, the heterogeneity of the structure, etc. One of the drawbacks of the method is its low efficiency in detecting neoplasms of the renal parenchyma of intraparenchymal location without a deformation of the kidney contour, which are smaller than 1.5 cm (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% (Abdullaeva & Alizadeh, 2015). The minimum size of a growth in the thyroid gland detectable by ultrasound is 3-4 mm (Sinyukova *et al*, 2016).

Many researchers believe that the minimum size of a visualizable liver cyst is 3–5 mm. Many studies of recent years remark upon great achievements and the simplicity of the differential diagnosis of large non-parasitic cysts and parasitic lesions. According to a number of studies, at present, radioisotope scintigraphy of the liver and a dynamic study of the biliary system (ducts) make it possible to detect tumors up to intraductal nodes of at least 2-3 mm in size. There is data that a tumor larger than 1 cm does not affect the sensitivity of X-ray 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 (Huseynov & Huseynov, 2016).

In (Zoph *et al*, 2018), it is shown that the development of models for scalable image recognition requires significant costs. For this reason, the authors propose a new dataset called the NASNet search space. In (Longacre *et al*, 2016), the authors say that a straightened image is, as a rule, a cropped or rotated image.

Our analysis of the relevant studies showed that US images of tumors in the internal organs are detectable in the general case if they are 2-3 mm and larger. But it is very important, particularly in the early stages of oncological diseases, to have information in case of growths that are smaller than 1-2 mm. With such small sizes, the internal field of a tumor may even not change color with the environment, which makes it difficult to detect.

3. Selection of the equipment

Ultrasound has been used in medicine for over 50 years. The application of ultrasound in medical and biological studies can be divided into two categories: impact methods (low-frequency and mid-frequency ultrasound) and diagnostic methods (high-frequency ultrasound). The frequency of waves used in a US examination varies between 2 to 18 MHz. This range depends on the transmission capacities of the ultrasonic waves and the depth of their penetration: lower frequency waves have low penetration capacity but can be transmitted to smaller structures of the body. Higher frequency waves have a high transmission coefficient but they are absorbed by tissues much faster, limiting the penetration of ions into the depth of the human body. Ultrasonography is effective for the examination of soft tissues. For the body's surface structures, such as muscles, tendons, etc., high-frequency waves (7-18 MHz) are used. Deeper structures of the body, such as liver and kidneys, are examined by means of lower frequency waves (1-6 MHz) that penetrate deeper into the tissues. The main parameter characterizing the composition and properties of tissues in ultrasonography is echogenicity. Ultrasonography is based on the principle of echolocation, i.e., the ability of the tissues to reflect ultrasonic waves. Different organs of the human body reflect ultrasonic waves differently. The sonograph shows black and white images, the higher the density of an organ the whiter the image. Thus, fluids look black in a US image.

The main parameters of ultrasonography are exogenicity, structure and contour of the organ. Image on the monitor of an ultrasound machine consists of pixels, each is one of the shades of gray (0-255). Color intensity depends directly on the degree of reflectivity of untrasonic waves. Denser organs reflect the waves very well because they take on the vibrations of their surroundings and act as the second intensive source of untrasound. For this reason, the ultrasound returns to the transmitter in its original state.

Tissues have different exogenicity. There are several types of exogenicity:

- isoechogenicity – normal (tissues and organs are shown in gray color in US);
- hypoechogenicity – reduced (objects are dark, close to black);
- hyperechogenicity – increased (pixels are white or shades of light-gray);
- anechogenicity – echonegativity, i.e. absence of echogenicity (structure is black).

In the case of hyperechogenicity, bright spots on the black background show highly reflective surfaces (bones, gas).

Ultrasound imaging occurs in three stages: the formation of the ultrasound wave, the reception of echo signals and the processing of these signals. The first two stages are related to technical solution. In the third stage, the image recognition process is carried out directly.

In this study, TOSHIBA NEMIO XG SSA-580A (Japan) and TOSHIBA-SAL-38B (Japan) are used for US imaging (Fig. 2).

Figure 2: Toshiba NEMIO XG SSA-580A and Toshiba-SAL-38B ultrasound machines.

4. Methods

In image recognition, first of all, informative signs form and their differentiation is specific to each case. For this purpose, specialized methods and algorithms are used, and the choice of methods often depends on the subject's experience and intuition. The choice of an image recognition method or their combinations depends on the specifics of the case and on the simplicity and accuracy of the methods for solving it. However, an analysis of most methods, their advantages and drawbacks has shown that there is no concrete method for solving this problem. For instance, in (Abdullayeva *et al*, 2004), an artificial image of the pathology center, a composite picture, was created to recognize orthopedic X-ray grayscale images and the necessary operations were performed on it. In (Abdullayeva & Kazim-Zada), decomposition methods are proposed to provide image recognition by plotting graphs of recurrence of complex colored patterns depending on pixels on the plane. None of these methods is appropriate for our problem, because the composite image in (Abdullayeva *et al*, 2004) gave a sketch of the damaged bone, and the dimensions in (Abdullayeva & Kazim-Zada) are not necessary, as pattern recognition itself was sufficient. Our goal is to determine the contour and find its maximum correct dimensions. For instance, there can be very small (up to 2mm) nodules, which do not lead to large growth of the thyroid gland, but they can also be the initial stage of future tumors. Given this, we propose the following software package (Gonzalez & Woods, 2008):

- ***"k-nearest neighbor"*** method is based on the similarity of objects (Buy & Spitsyn, 2010). At this stage, the clustering problem is solved;
- Image processing – in this technology, we have included the following methods:
  - ***Threshold*** – thresholding is dividing an image into two or more segments based on the threshold values. There are two basic methods: global threshold method and adaptive threshold method.
  - ***Canny edge defection*** is based on discriminate criteria. Image edge processing is carried out in a variety of ways. Lower boundary binarization is the simplest operation, with two restrictive and multilevel

binary approaches related to the brightness of pixels of different fragments. The Canny operator (John F. Canny) is used to detect boundaries in the field of computer vision.

- ***Gradient*** metod is finding the local maximum in the direction of the vector of edge pixels. The edge detection algorithm based on the gradient method is implemented through the following sequence of operations: Gaussian smoothing (Gaussian blur) filtering; finding the brightness gradient in each pixel; finding maximum pixels; filtration of maximum pixels.
- ***Watershed.*** The watershed method includes three basic concepts: detection and removal of fragments; edge processing; processing of regions. In accordance with these concepts, the watershed method allows for more stable results (including uninterrupted boundaries of regions) for segmentation.
- ***Gaussian blur*** (denoising method) is reduction and removal of noise in the image means by filtering, which implies any processing procedure on the image. In this case, a raster image is input, and a raster image is generated at the output as well. However, it is often necessary to filter the image. Noise filtering is obtaining an image, whose parameters are close to those of the original "noiseless" image, after the real image has been "cleaned" by means of certain algorithms. "Noisiness" is the distortion in the image of a real object.
- ***Sobel*** method (edge detection). Sobel algorithm is used to detect the edges in image processing. It is often used as one of the steps of the more complex and accurate Canny edge detection method.
- ***Grayscale image***. Grayscale is used to convert an image to a grayscale color model. The gray color is located along the diagonal in the color cube of the RGB model, and each component receives the same values as the grayscale. **Gray colors are shades of gray with the hexadecimal code** #808080. **In the RGB color model** #808080 is comprised of 50.2% red, 50.2% green and 50.2% blue. In the HSL color space #808080 has a hue of 0° (degrees), 0% saturation and 50% lightness. The wavelength of this color is about 620 nm. This color is also known as **Gray, Gray**, **Trolley Gray**, Chrysler Vapor Steel Gray and Volkswagen Polar Gray. Grayscale is an image of a uniform row of optical densities of neutral gray fields.
- ***Binary morphology***. The word "morphology" refers the fields of science studying form and structure. In the context of computer vision, the term "morphology" refers to the parameters of the form of an image. Mathematical morphology is a tool used to extract some components of an image. Using morphology as a tool, one identifies such components of an image, by means of which it is possible to fully recognize the image. Components can include contour, convex surfaces, body, etc. Mathematical morphology uses the language of set theory. In this theory, a set refers to any objects located on the image. For instance, it would be possible to get a complete morphological picture of a binary image by means of a set of black pixels. Binary morphology refers to a binary image consisting of 0 and 1 dots (*pixels*) of adjusted black and white. By image area, we understand the subset of the points of a given image. In binary morphology, every operation is carried out on this subset. The initial data then consists of binary images of some image A in binary morphology and a preselected structuring element S. In this case, the result of the operation is also obtained as a binary image.
- ***Canny Non-Maximum Suppression***. The concept of Canny Non-Maximum Suppression means that edge pixels are the dots, in which the local maximum of the gradient in the direction of the gradient vector is reached.In the contour of the edge, only the maximum points of the gradient of the image are left, and non-maximum points lying near the edge are suppressed. The method also uses information about the direction of the edge in order to suppress the points near the edge and not to break the edge itself near the local maxima of the gradient. Then, using two thresholds, weak edges are removed.
- The area enclosed in the closed contour and the gravity center of the figure arer calculated by formulas.
- The color palette of the area in the RGB model is determined.

5. Solution of the problem

Given the above, the architecture of the information-recognition system has been developed (Fig. 3).According to the architecture, the first step is to collect and systematize images taken in an ultrasound examination. The images are divided into groups by organs and form the basis of the database. The next step is edge detection — this task is solved by separating the noise from the image. Here, the detection of the boundaries between the image and the parts that surround it is carried out.

For demonstration, in the example, the *threshold* method has been selected from among edge detection methods and used to determine the boundary values.

When the process is completed, we apply the method of binary morphology. It is important to select a structural element because through it, it is possible to detect such components in the image that can be used to perform its full recognition. These components can include contour, protuberant layers, stem, etc.

As a geometric shape, a structuring element is a binary image. It has different dimensions and structure. Mostly symmetrical elements are used. It can be a rectangle or a circle with the diameter d.

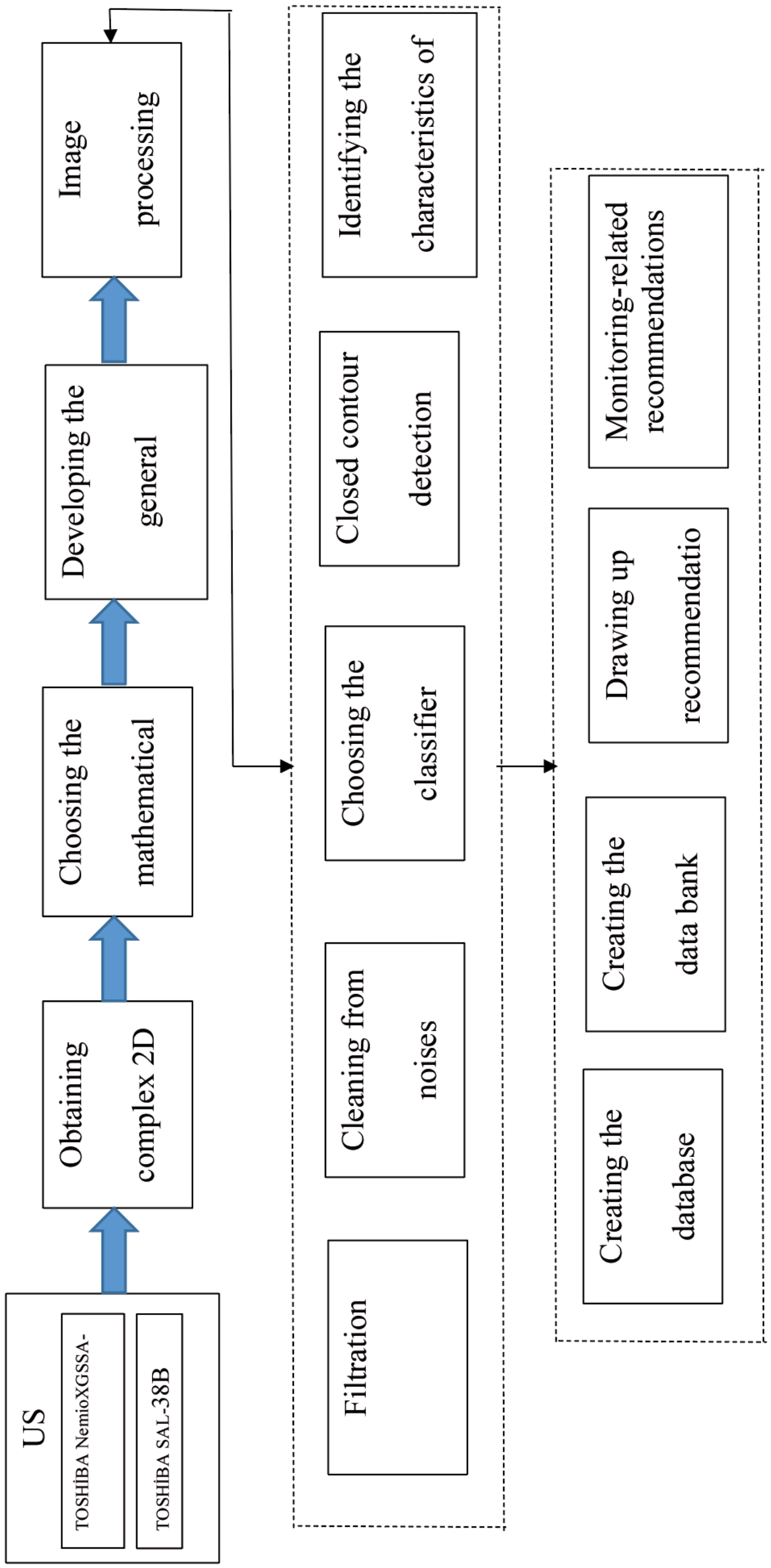

Figure 3: The artchitecture of the inteligent system.

```
package ip.methods;

import java.awt.Color;
import java.awt.image.BufferedImage;
import java.io.File;
import java.io.IOException;
import java.util.HashMap;
import java.util.Map;
import java.util.Set;
import java.util.TreeMap;
import java.util.Map.Entry;

import javax.imageio.ImageIO;

public class Threshold {
        public static Color white = new Color(255,255,255);
        public static Color black = new Color(0,0,0);
   public BufferedImage convert(BufferedImage image, int thresholdMinValue, int thresholdMaxValue){
           int height = image.getHeight();
                int width = image.getWidth();
                Map<Integer, Integer> histogram = new TreeMap<Integer, Integer>();
                Double luminosity = null;
                Color color = null;
                BufferedImage newImage = new BufferedImage(width, height, image.getType());
                 for(int i=0; i<height; i++){
                    for(int j=0; j<width; j++){
                        color = new Color(image.getRGB(j, i));
                        luminosity = 0.2126*color.getRed()+ 0.7152*color.getGreen()+0.0722*color.getBlue();
                        if(histogram.containsKey(luminosity.intValue())){
                                histogram.put(luminosity.intValue(), histogram.get(luminosity.intValue())+1);
                        }else{
                                histogram.put(luminosity.intValue(), 1);
                        }

                        //color = new Color(luminosity.intValue(),luminosity.intValue(),luminosity.intValue());
                        if(luminosity.intValue()> thresholdMinValue && luminosity.intValue()< thresholdMaxValue){
                            newImage.setRGB(j, i, black.getRGB()); //black.getRGB()
                        }else{
                                newImage.setRGB(j, i, white.getRGB());
                        }
                    }
              }
                 int prev = 0;
                 int curr = 0;
                 boolean isAscending = false;
```

A single specific point is selected for each structuring element, which is called the *origin*. This point can be located in the arbitrary spot of the element. But in symmetrical elements, this point is usually the central pixel. By the main operations in binary morphology, we understand *Basic operators*:

a. Transport – $X_1 = \{x + t/x \in X\}$
b. Dilation – $A \odot B = U_{b \epsilon B} A$
c. Erosion – $A \ominus B = [z \in A/B_z \subseteq A]$
d. Closing – $A \cdot B = \{(A \odot B) \ominus B\}$
e. Opening (opposite of closing) – $\{A \ominus B\} \odot B \quad A \circ B = \{A \ominus B\} \odot B$

Thus, the obtained two-color set will be the subset of the plane and can be regarded as two-dimensional (*x, y*) vectors. The vector coordinates show the image with black and white pixels.

The structuring element is taken sufficiently small relative to the image itself. Usually, as mentioned above, it is a rectangle, a disk or a circle with dimensions of 3x3, 4x4, 5x5. Thus, by binary morphology, we understand set operations carried out by the methods of merging, intersection, difference, parallel transport, closing, etc. To proceed to binary morphological operations, the plane of recognition is filled with zeros. Here, the structuring element is suggested as a *d=5* disk.

```
         00100
         01110
d(5) =   11111
         01110
         00100
```

Through it, the image is probed pixel by pixel or scanned.

```
public class Morphology {

    public static int[][] square = {{1,1,1},{1,1,1},{1,1,1}};
    public static int[][] square5 = {{1,1,1,1,1},{1,1,1,1,1},{1,1,1,1,1},{1,1,1,1,1},{1,1,1,1,1}};
    public static int[][] disk = {{0,1,0},{1,1,1},{0,1,0}};
    public static int[][] disk5 = {{0,0,1,0,0},{0,1,1,1,0},{1,1,1,1,1},{0,1,1,1,0},{0,0,1,0,0}};
```

Binary image is obtained using the binarization process (i.e. a grayscale image becomes black and white). Additionally, the gray color is located along the diagonal in the color cube of the RGB model, and each of its components gets the same value as the grayscale.

Let us take a US image of a kidney to demonstrate the processing of a US image by the software package.

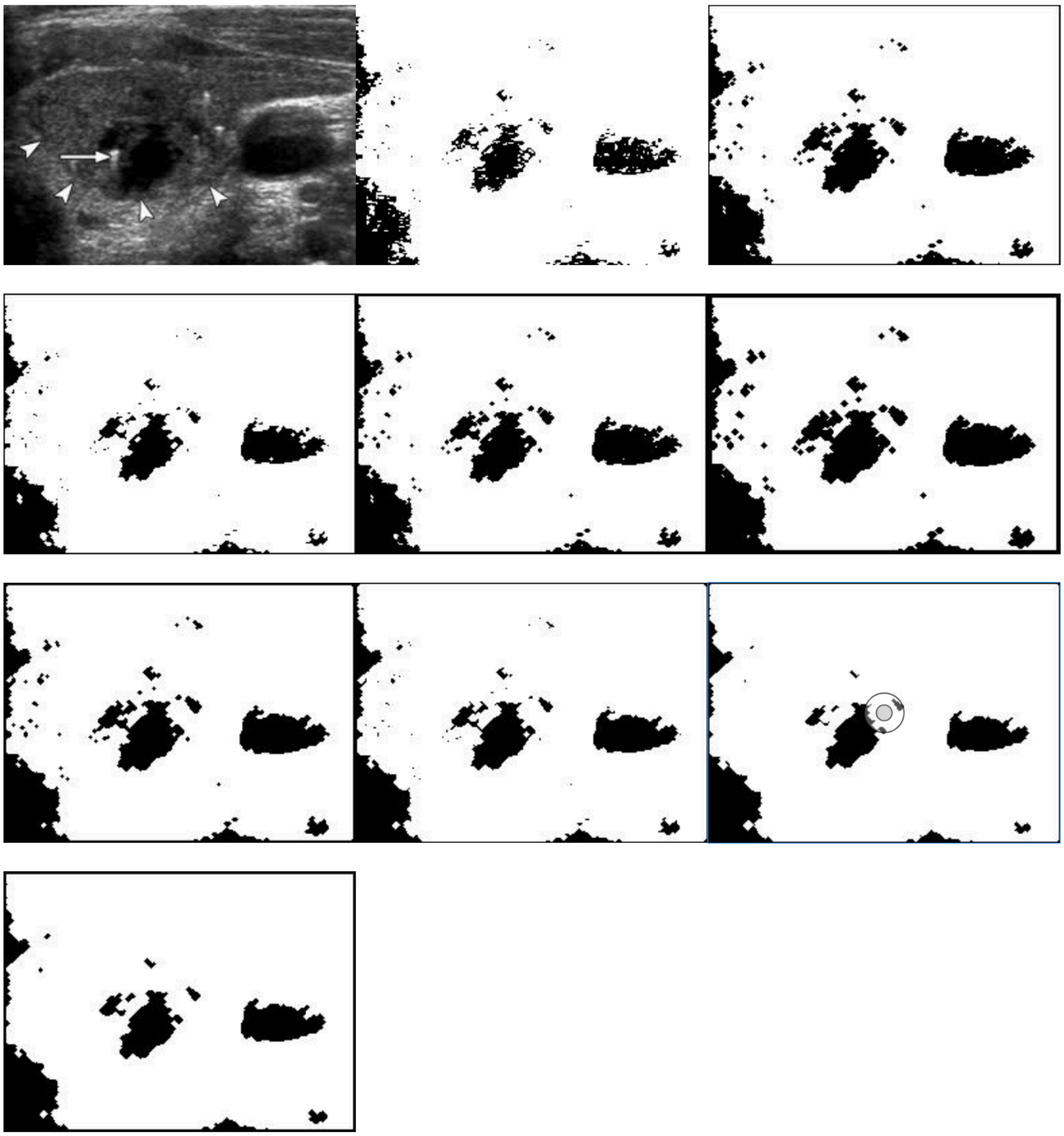

Figure 4: Processing of an ultrasound image of a kidney by the software package.

At the first stage, we apply the Threshold method. The intensity interval [0.30] is taken (max 255), i.e. black and dark (close to black) tones. Then the sequence of binary morphological operations is as follows:

1. erosion;
2. dilation;
3. dilation;
4. dilation;
5. erosion;
6. erosion.

The choice of the interval in the Threshold method and the binary morphological operations and sequences are specifically defined for each US image. After detecting the growth, we can proceed to determining its gravity center and calculating its area. Using the methods included in the software package, we determine the coordinates of the gravity center more precisely, so that different centers would not belong to one figure. This means that we made a mistake in our operations. The US image is given with *NxM* size and transported to the plane with the same dimensions. It is possible to calculate the gravity center of an arbitrary figure under the following conditions:

- The image is on the plane;
- All points have equal mass;
- The density of the figure surface is constant (i.e. single area mass is constant)

On the *0XY* coordinate grid it will be described by the points $A_1(x_1,y_1)$; $A_2(x_2, y_2)$; … $A_n(x_n,y_n)$ with masses $m_1, m_2, \ldots m_n$.. Then the coordinates of the gravity center will be calculated by formula (1) below:

$$X_0 = \frac{x_1m_1+x_2m_2+\ldots+x_nm_n}{m_1+m_2+\ldots+m_n} = \frac{\sum_{i=1}^{n} x_i m_i}{\sum_{i=1}^{n} m_i}$$
$$Y_0 = \frac{y_1m_1+y_2m_2+\ldots+y_nm_n}{m_1+m_2+\ldots+m_n} = \frac{\sum_{i=1}^{n} y_i m_i}{\sum_{i=1}^{n} m_i} \qquad (1)$$

Here, X_ixm_i $(i = \overline{1,n}w$, is the static moment of the mass *mi* relative to the *0Y* axis; *Yixmi* is the static moment of the mass m_i relative to the *0X* axis.

The obtained figure is confined by the lines $X = a$ and $X = b$ on the *0X* axis, *and* $y = f_1(x)$ and $y = f_2(x)$ on the *0Y* axis. Let us denote the surface density through *d*. Let us divide the interval [*a*,*b*] into *n* parts:

$$a = x_1, < x_2, < x_3, \ldots < x_n$$

Then the figure is divided into *n* strips with the width equal to $\Delta x_1, \Delta x_2, \Delta x_3, \ldots \Delta x_n$: $x_i = x_{i+1} = x_{i+2} = \ldots = x_n = b$, the mass of each strip equals $m_i = Si\delta$ (S_i being the area of the *i*-th strip, δ being the density of the strip). Depending on $f_1(x)$ and $f_2(x)$, each strip is a curvilinear figure. Let us substitute each strip with rectangles A_i B_i C_i D_i, here, Δx_i is the base of the rectangle, $h = f_2(\xi)-f_1(\xi)$ is the height, $\xi = \frac{x_{i-1} + x_i}{2}$ Thus, the mass of the strip equals to

$$\Delta m_i \approx \delta[f_2(\xi_i)-f_1(\xi_i),]\,\Delta x_i (i = \overline{1,n}).$$

Finally, let us proceed to the limit for the accuracy of the coordinates:

$$\lim_{\Delta x_i \to 0} x_0 = \frac{\int_a^b x[f_2(x) - f_1(x)]dx}{\int_a^b [f_2(x) - f_1(x)]dx} \qquad (2)$$

$$\lim_{\Delta x_i \to 0} y_0 = \frac{\frac{1}{2}\int_a^b [f_2(x) + f_1(x)][f_2(x) - f_1(x)]dx}{\int_a^b [f_2(x) - f_1(x)]dx} . \qquad (3)$$

After we determine the coordinates of the gravity center, we calculate the area of the obtained figure. The figure is closed by the functions *y=f(x)* at the top and *y=g(x)* at the bottom between the straight lines *x=a* and *x=b* on the *0X* axis (Fig. 5).

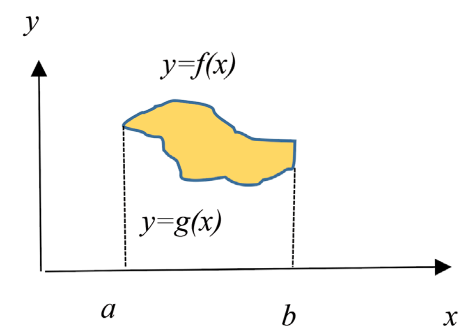

Figure 5: Obtaining the closed figure.

The area of the figure within the closed contour obtained from the US image by filtering and binary morphology method in the new coordinates is calculated using the following simple formula:

$$S = \int_a^b \big(f(x) - g(x)\big)dx$$

The proposed software package employs the "from complex to simple" principle, dividing a whole image into parts, and, using simple algorithms, detects very small growths. Detection and differentiation of one or more growths in internal organs by mathematical morphology algorithms makes it possible to simplify such complex problem as image processing. Detection of growths of this size belongs to the domain of earliest diagnosis. Using the methods included in the software package, the coordinates of the growth are found, the gravity center of the figure is determined, the area is calculated, the color palette in the RGB model is determined and, if necessary, placed under monitoring. The frequency of monitoring depends directly on the physician. The obtained information is entered into the data bank. Fragments of the information system in action are shown in Fig. 6.

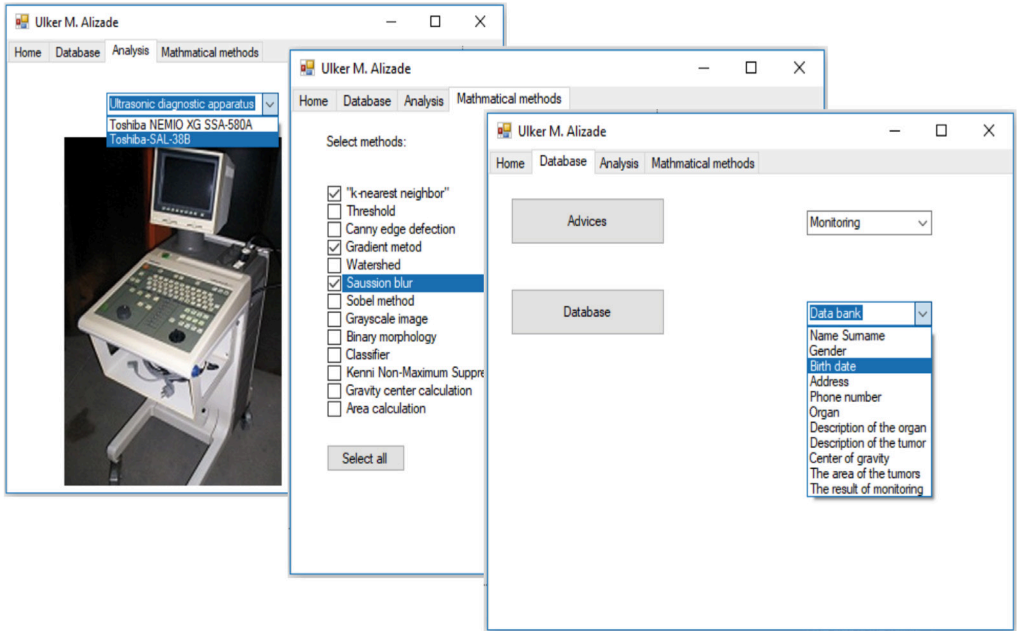

Figure 6: Fragments of the information system.

6. Discussion

The main difference between the approach we have presented in this paper and other similar studies is that we propose the concept of the earliest diagnosis besides early diagnosis. To this end, a new concept of "pre-indicator" is given. New characteristics are obtained in addition to the information obtained by US machine: precise calculation of the area enclosed in the curvilinear contour; calculating the gravity center of the obtained figure; registering the color change inside the contour in the RGB model. These characteristics are objective and far from subjective assessment. Based on this assessment, a physician establishes whether monitoring is necessary assessment is necessary and determines its frequency. Future monitoring will provide information on whether the growth remains a stationary mass or develops. The protocols of the information-recognition system have been drawn up and new characteristics are provided in addition to the results of the ultrasonographer. The system is a tool that allows one to monitor the process of formation of growths and stages of their development. New characteristics may be useful for scientists who conduct scientific research at biomolecular level to make their research more refined and accurate.

7. Conclusion

The stages of diagnostics by ultrasound examination have been investigated and a three-step recognition model has been proposed. The concept of pre-indicator has been introduced and its definition has been given.

A software package for the recognition of closed circuits in complex images obtained on the plane has been proposed. By means of the methods included here, the image is cleaned from noise, filtering operations are performed, the edges are detected and the recognition ends with the method of mathematical morphology using selected classifiers.

New characteristics are determined. The area within the curvilinear contour is calculated, the color palette and the gravity center of the closed figure are determined. The calculation of the area is more accurate as it is calculated by the formula of the area enclosed in the curvilinear boundary. The parameters of the inner color of the closed contour allow detecting the changes occurring over a certain period of time and are registered as one of the informative features of the image. The gravity center of the figure is determined to identify the figure obtained on the new plane by the method of mathematical morphology. The diversity of the center indicates the diversity of figures, i.e. the dynamic nature of any process inside.

Multi-modular system architecture has been created and the software has been developed. In the first module, the US machine is selected, a 2D image of the body is obtained, entered into the current database and sent to the processing. Filtering, denoising, selection of the classifier, detection of closed contours by means of the developed software package is carried out in the second module. At the same time, the informative attributes of the figure are identified in this module and new characteristics are proposed.

In the next module, the problem of diagnostics is solved on the basis of a three-step model, and the accuracy of the obtained result is calculated. The result is entered in the data bank (a collection of USM case records), a relevant recommendation is developed for a specific case and the frequency of monitoring is determined. A special focus is put on early and earliest diagnostic situations, i.e. cases with the presence of incomplete indicators or pre-indicators.

The system's operability has been tested directly on the ultrasound images (138 cases investigated), with the result of 98.8% at the diagnostic stage, 92, 03% at the early diagnostic stage; 2 cases have been recorded at the earliest diagnostic stage in 2018 and the frequency of monitoring has been determined. The protocols of the information-recognition system have been drawn up and new characteristics are provided in addition to the results of the ultrasonographer. The system is a tool that allows one to monitor the process of formation of growths and stages of their development. New characteristics may be useful for scientists who conduct scientific research at biomolecular level to make their research more refined and accurate.

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