International Journal of Electrical and Computer Engineering (IJECE)
Vol. 13, No. 6, December 2023, pp. 6778~6786
ISSN: 2088-8708, DOI: 10.11591/ijece.v13i6.pp6778-6786

Detection of lung pathology using the fractal method

Gulzira Abdikerimova[1], Ainur Shekerbek[1], Murat Tulenbayev[2], Bakhyt Sultanova[3], Svetlana Beglerova[2], Elvira Dzhaulybaeva[4], Kamshat Zhumakanova[5], Bakhytgul Rysbekkyzy[6]
[1]Department of Information Systems, Faculty of Information Technology, L.N. Gumilyov Eurasian National University, Astana, Republic of Kazakhstan
[2]Department of Information Systems, Faculty of Information Technology, M.Kh. Dulaty Taraz Regional University, Taraz, Republic of Kazakhstan
[3]Department of Information and Computing Systems, Faculty of Innovative Technologies, Karaganda, Technical University named after A. Saginov, Karaganda, Republic of Kazakhstan
[4]Department of Biostatistics, Bioinformatics and Information Technologies, Astana Medical University, Astana, Republic of Kazakhstan
[5]Department of Biostatistics, Pediatrics and Neonatology, Karaganda Medical University, Karaganda, Republic of Kazakhstan
[6]Department of Information Technology and Security, Innovative Technologies, Karaganda Technical University named after A. Saginov, Karaganda, Republic of Kazakhstan

Article Info

Article history:

Received Jun 21, 2023
Revised Jul 7, 2023
Accepted Jul 9, 2023

Keywords:

Chest radiograph
Digitalization
Fractal analysis
Fractal dimension
Medical imaging texture
Pathology

ABSTRACT

Currently, the detection of pathology of lung cavities and their digitalization is one of the urgent problems of the healthcare industry in Kazakhstan. In this paper, the method of fractal analysis was considered to solve the task set. Diagnosis of lung pathology based on fractal analysis is an actively developing area of medical research. Conducted experiments on a set of clinical data confirm the effectiveness of the proposed methodology. The results obtained show that fractal analysis can be a useful tool for early detection of lung pathologies. It allows you to detect even minor changes in the structure and texture of lung tissues, which may not be obvious during visual analysis. The article deals with images of pathology of the pulmonary cavity, taken from an open data source. Based on the analysis of fractal objects, they were pre-assembled. Software algorithms for the operation of the information system for screening diagnostics have been developed. Based on the information contained in the fractal image of the lungs, mathematical models have been developed to create a diagnostic rule. A reference set of information features has been created that allows you to create algorithms for diagnosing the lungs: healthy and with pathologies of tuberculosis.

Corresponding Author:

Ainur Shekerbek
Department of Information Systems, Faculty of Information Technology, L.N. Gumilyov Eurasian National University
010000 Astana, Republic of Kazakhstan
Email: shekerbek80@mail.ru

1. INTRODUCTION

According to official data, the number of patients with pneumonia is registered annually in Kazakhstan, for example, in 2020 to 3,000, in 2021 to 4,000, and in 2022 to 5,000. At the moment, there is a high probability of damage to respiratory diseases. For the timely detection of the most severe of them, each person must undergo an annual fluorography. At this stage, there is a possibility of an error-an unnoticed pathology will remain with a person for a year, turning into a more serious form and having complications. Provided that the specialist has discovered the pathology, the patient needs to undergo an x-ray, which will only increase the likelihood of a diagnosis. Therefore, the detection of pathologies on radiographs today is an urgent problem. To reduce the error in annual fluorography, as well as speed up the process and reduce the stages of diagnosis, the use of an x-ray image segmentation algorithm for its subsequent analysis is considered.

The purpose of the article is to study and evaluate the applicability of the fractal method for detecting lung pathology. It aims to determine the effectiveness and accuracy of this method in the early detection of pathologies such as lung cancer, pneumonia, or fibrosis, as well as to identify possible advantages and limitations of it is use. The article discusses various aspects of fractal analysis of lung tissues, including image segmentation methods, calculation of fractal dimension and other parameters, as well as the use of classification algorithms for the diagnosis and determination of the nature of pathologies. The main purpose of the work is to provide evidence of the effectiveness of the fractal method in detecting lung pathologies, supported by the results of experiments on real clinical data. Such information can contribute to the development of new methods of diagnosis and treatment, as well as increase the effectiveness of predicting results and applying an individualized approach to patients with lung diseases.

The solution to this problem in the article is proposed by one of the developing areas in digital image processing-fractal analysis. The development of this direction is facilitated by the fact that most images can be considered fractal or multifractal to some extent. Therefore, any image has the properties and characteristics of fractal objects, including invariance to the viewing scale and rotation, which should be used to develop new methods of fractal image processing. The fractal dimension is a measure of the complexity of a geometric shape. In healthy lungs, the geometric shapes of the bronchi and alveoli have higher fractal dimensions, indicating a higher complexity of the structure. In the case of lung pathology, the fractal dimension values may decrease, indicating a loss of structural complexity. Another approach used to diagnose lung pathology based on fractal analysis is fractal spectrum analysis, which is a plot of fractal dimension versus scale. The fractal spectrum can be used to detect changes in the structure of the lungs associated with various pathologies, such as bronchial asthma, chronic obstructive pulmonary disease (COPD), and others.

However, it is worth noting that fractal analysis is not the only method for diagnosing lung pathology and is usually used in combination with other methods, such as a doctor’s imaging analysis, lung function tests, and tests for allergic reactions. Visual analysis of the fluorogram image cannot always make it possible to determine the exact diagnosis of the patient’s condition, therefore, methods and algorithms are needed to intelligently support the analysis of fluorogram images and make the final diagnosis. Fractal image analysis involves the calculation of the fractal characteristics of the entire image or its fragments, or objects in the scanning field. The main characteristic of a fractal image is its dimension, which determines the complexity of the fractal. Improving the quality of image analysis is associated both with the expansion of the resolution of image digitizing methods; by extending the bit depth of the binary representation of intensity and contrast to the maximum possible limits, implemented in the MATLAB environment using the image processing Toolbox, and by identifying promising areas for digital processing of X-ray images of the lungs based on fractal analysis. For the study, the internal parts of the lungs were considered, except for the part near the clavicles, the outer lateral, and lower parts of the globe, therefore, the borders of the lung pattern and the area around it are subtracted.

2. LITERATURE REVIEW

Based on image processing methodologies, Archana and Kalirajan [1] presents a comprehensive study of medical image analysis and its application to various forms of medical imaging. It also discusses the challenges scientists face in successfully executing and provides an overview of the advantages and disadvantages of existing algorithms. This case study highlights key terms to watch out for or future issues to consider when developing image processing techniques.

Rashed and Popescu [2] provides an overview of machine learning used in medical image processing and focuses on two main types (supervised learning and unsupervised learning) to evaluate their importance in medical image processing and explains the most important machine learning algorithms, the most important advantages and disadvantages of machine learning are discussed. Application of machine learning methods in medical imaging. In addition, some common algorithms such as k-nearest neighbors (KNN), support vector machine (SVM), decision trees (DT), logistic regression (LR), and random forest (RF) for the medical dataset were applied to test the performance of the algorithms. Lung cancer is the leading cause of cancer death worldwide. Medical imaging is essential for the diagnosis and prognosis of lung cancer. Medical imaging techniques, such as radiomics, can extract information from these images that are not available without computational tools and can be useful in the detection and treatment of cancer. Moreno *et al.* [3] presents modern methods of image processing used in the study of lung cancer, with an emphasis on two main tasks: segmentation of nodes or tumors and extraction of useful features for classification and prediction of tumor evolution using Radiomics.

Kothari *et al.* [4] proposed a method for detecting nodules in the lungs, based on single signs. Used a stationary wavelet transform and a convergence index filter to extract texture features and used AdaBoost to generate a white knot similarity map. A single feature was defined to assess the degree of candidate isolation.

Both the degree of isolation and similarity to white nodules were used as the final score for candidates for lung nodules. Luo *et al.* [5] proposes a neural network for the diagnosis of pneumothorax based on feature fusion, where information about the frontal and lateral x-ray is combined. Their algorithm addresses the vanishing gradient problem in the pneumothorax recognition model and introduces a residual block to solve this problem. Due to the large number of channels, this model also uses channel attention mechanisms to improve model performance. Comparative experiments show that the fusion of a neural network of frontal and lateral chest images can provide higher accuracy than a single-task model. Adaptive morphological neural networks have been developed in Liu *et al.* [6] to classify chest x-ray images such as pneumonia and coronavirus disease (COVID-19). A new structure is proposed that can self-learn morphological expansion and erosion to determine the most appropriate adaptive layer depth.

This work is devoted to the development of methods for the analysis of textural images of breast cancer. The main problem addressed in the article is the increase in requirements for preprocessing results. As a result of the task, images of chest magnetic resonance imaging are considered for image processing using textural image analysis methods. The main goal of the research is the development and implementation of algorithms that allow the detection and isolation of tumors in the female breast in the image. Textural features, clustering, and orthogonal transformations are used to solve the problem. In the article, the methods of analyzing textural images of breast cancer, namely: Hadamard transformation, skew transformation, discrete cosine transformation, Daubechs transformation, and Legendre transformation, the results of their software implementation on the example of biomedical images of oncological pathologies. In the example of breast cancer, it is shown that the most informative method for image segmentation is the method based on the Hadamard transform and the method based on the Haar transform. The article provides recommendations for using the obtained results in practice, in particular, it is shown that there are clinically important indicators, and other informative parameters that contribute significantly to the assessment of the degree of pathology and the probability of the development of the disease: diameter and curvature. Therefore, the requirements for the reliability, accuracy, and speed of biomedical image processing have increased. It is difficult for radiologists to classify chest x-rays because of the noisiness. Existing models based on convolutional neural networks contain a huge number of parameters and therefore require multifunctional graphical processing units (GPUs) for deployment.

3. METHOD

The fractal approach can be used as a method for detecting pathologies in x-ray images. Fractals are geometric objects that have a self-similar structure at different scale levels. Fractal analyzes can be used to describe the structural features of images, which can help in the identification and analysis of pathologies. One possible approach to using fractal analysis to detect pathologies in x-ray images is image texture analysis. Fractal texture analysis can help determine the degree of difference between different areas of an image, which can be useful in detecting the presence of pathology. For example, changes in texture may indicate the presence of a tumor or an inflammatory process. Another possible approach is to evaluate the geometric properties of an image, such as the shape, size, and location of objects. Fractal analysis can help identify changes in these properties that may indicate the presence of pathology. For example, changes in the shape and size of the lung lobes can indicate various lung diseases. Fractal analysis can also be used to compare images and detect changes over time. For example, comparing images before and after treatment can help evaluate the effectiveness of treatment and identify possible complications [7].

The following method was used as the basis of the algorithm for detecting multifractal structures of raster images. Bitmaps have a limited size proportional to r and c, where r is the number of rows and c is the number of columns. Let's designate the minimum cell-image pixel-x_{ij}, where $i=\overline{1,r}$ and $j=\overline{1,c}$. The value x_{ij} characterizes the gradation of gray from 0 to 255, where 0 means black, and 255 means white [8]–[13]. We used a modified method for calculating generalized fractal dimensions, which assumes the presence of two types of pixels. To do this, we transform the original data set x_{ij} into a new one (1),

$$y_{ij}(\Gamma) = \begin{cases} 0, x_{ij} \notin \Gamma, \\ 1, x_{ij} \in \Gamma, \end{cases} \tag{1}$$

where $\Gamma = [\gamma_1, \gamma_2]$ is threshold brightness level; γ_1, γ_2 is specified limits of analysis γ_1, γ_2, $\Gamma \subset [0, 255]$. Table 1 shows the characteristics $r(k)$, $c(k)$, and Mk corresponding to the image partitioning.

Figure 1 shows an example of such an image splitting for $\delta = 4$. In this example N(4)=9. In each "non-empty" cell, the number of unit pixels is calculated (2),

$$M_k = \sum_{i=r(k)}^{r(k)+\delta-1} \sum_{j=c(k)}^{c(k)+\delta-1} y_{ij}(\Gamma), \quad k = \overline{1, N(\delta)} \tag{2}$$

where $r(k)$ and $c(k)$ are the number of the row and column from which the k-th cell begins.

Table 1. Cell characteristics at $\delta = 4$

k	r_k	c_k	M_k
1	1	1	5
2	1	5	5
3	1	13	6
4	1	17	3
5	5	1	6
6	5	5	6
7	5	9	4
8	5	13	6
9	5	17	5

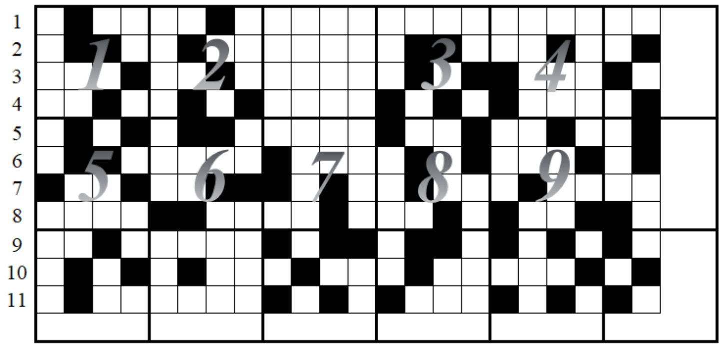


Figure 1. An example of splitting when $\delta = 4$

Calculate the number of unit pixels in an image:

$$M = \sum_{k=1}^{N(\delta)} M_k \tag{3}$$

and determine the "occupancy" of the k-th cell (4).

$$p_k = \frac{M_k}{M}, \quad k = \overline{1, N(\delta)} \tag{4}$$

Relations (3), (4) imply the normalization property (5).

$$\sum_{k=1}^{N(\delta)} p_k = \sum_{k=1}^{N(\delta)} \frac{M_k}{M} = 1 \tag{5}$$

To determine the spectrum of fractal dimensions D_q, $-\infty \le q \le \infty$, describing a multifractal, we introduce the sum

$$z(q, \delta) = \sum_{i=1}^{N(\delta)} p_i^q(\delta), \tag{6}$$

Representing the sample initial moment of the q-th order. Then the spectrum of generalized fractal dimensions is calculated by (7),

$$D_q = \frac{\tau(q)}{q-1} \tag{7}$$

where the function $\tau(q)$ has the form (8).

$$\tau(q) = \lim_{\delta \to 0} \frac{\ln Z(q, \delta)}{\ln \delta}. \tag{8}$$

The generalized fractal dimensions of a homogeneous fractal do not depend on q, that is, $D_q = D_{const}$. This follows, as indicated in [14]–[19] from the fact that for a regular (homogeneous) fractal.

$$p_i(\delta) = \frac{1}{N(\delta)} \approx \delta^D. \tag{9}$$

From where we learn the equality of dimensions. If the function D_q depends on q, then the object under consideration is multifractal [20]–[26]. Denote by $D_{q,\delta}$ the discrete analog of function (7) without passing to the limit (8), i.e., depending on the cell size δ:

$$D_{q,\delta} = \begin{cases} \frac{ln \sum_{k=1}^{N(\delta)} p_k^q(\delta)}{(1-q) ln\, \delta}, & q \neq 1, \\ \frac{ln\left(\sum_{k=1}^{N(\delta)} p_k(\delta) \cdot ln p_k(\delta)\right)}{\ln \delta}, & q = 1. \end{cases} \tag{10}$$

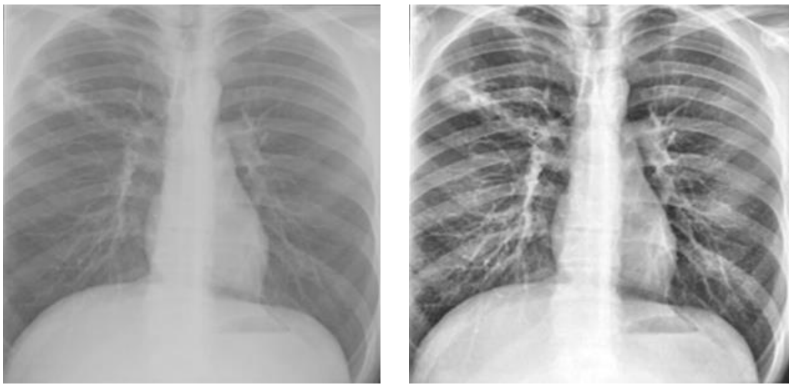
The spectrum of multifractal dimensions is calculated by (11).

$$D_q = \lim_{\delta \to 0} D_{q,\delta}. \tag{11}$$

4. RESULTS AND DISCUSSION

During the experiment, 40 images were studied. Among them, types of a healthy lung cavity, lobar pneumonia, pulmonary tuberculosis, focal tuberculosis, lobar pneumonia, echinococcosis of the lung, and segmental pneumonia were considered. As shown in Figure 2, the structure of x-ray optical images was studied, such as in Figure 2(a) an image with pathology, and the result of image processing with pathology is shown in Figure 2(b) and a table of images of the norm and some pathologies noted during x-ray diagnostics was compiled. On the images, deviations in the lung structures are visually observed with noted pathologies; these structural deviations are highlighted in the analysis of the radiograph by software. In this work, the algorithm for performing the fractal method in detecting pathology in x-ray images was performed as follows:

a) Obtaining an x-ray image from open-access databases.
b) Image processing (improvement of contrast, segmentation of the studied area).
c) Splitting the image into small blocks (windows) with a certain size.
d) Calculation of the fractal dimension for each image window.
e) Construction of the fractal spectrum for all image windows. The fractal spectrum is the dependence of the logarithm of the number of windows on the logarithm of the window size.
f) Analysis of the obtained data to identify differences in fractal properties between normal and pathological areas of the image.
g) Visualization of analysis results using color coding or other methods for a better understanding of the results.



(a) (b)

Figure 2. Processed images with (a) areas of interest, image with pathology and (b) the result of image processing with pathology

The distribution of fluorograms by classes was carried out by an experienced radiologist. The distribution was carried out according to two criteria-norm and pathology. 20 experiments with the norm and 40 pathologies were conducted. The results of the fractal dimension for each image are shown in Table 2.

Table 2. The value of the fractal dimensions of images

No.	Images title	Values	No.	Images title	Values
1	Normal 1	2.9900	21	Tuberculosis 12	2.4501
2	Tuberculosis 1	2.4036	22	Normal 10	2.9763
3	Normal 2	2.9643	23	Tuberculosis 13	2.5346
4	Tuberculosis 2	2.5525	24	Normal 11	2.8932
5	Tuberculosis 3	2.5159	25	Tuberculosis 14	2.4699
6	Tuberculosis 4	2.5109	26	Normal 12	2.9798
7	Normal 3	2.8701	27	Tuberculosis 15	2.6016
8	Tuberculosis 5	2.6738	28	Normal 13	2.9879
9	Normal 4	2.9179	29	Normal 14	2.9443
10	Tuberculosis 6	2.6881	30	Normal 15	2.8704
11	Normal 5	2.9907	31	Tuberculosis 16	2.5840
12	Tuberculosis 7	2.5920	32	Normal 16	2.9253
13	Normal 6	2.9079	33	Normal 17	2.9643
14	Normal 7	2.9924	34	Tuberculosis 17	2.6204
15	Tuberculosis 8	2.4164	35	Tuberculosis 18	2.5200
16	Tuberculosis 9	2.3530	36	Normal 18	2,9585
17	Normal 8	2.9767	37	Tuberculosis 19	2.6129
18	Tuberculosis 10	2.4271	38	Normal 19	2.9449
19	Normal 9	2.8803	39	Tuberculosis 20	2.6488
20	Tuberculosis 11	2.4047	40	Normal 20	2.9155

For the obtained values of the deviations of the fractal dimension D, distribution graphs were constructed illustrating the changes in the deviations of the fractal dimension in the order of the study. The values of the fractal dimension of norm and pathology differ well from each other. The deviation graphs of the fractal dimension $D\varphi$ are shown in Figure 3.

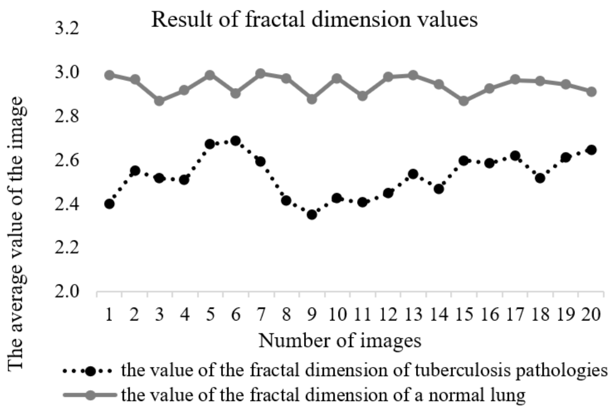


Figure 3. Graph of deviations of fractal dimensions of norm and pathology

To detect pathology, it is important to process images before applying the fractal method. Studies have shown that this limit lies in the value of $D\varphi$=2.75. Results below this limit are likely to be abnormal images. Studies have shown that this limit lies in the value of $D\varphi$=2.75. Results below this limit are highly likely to be abnormal images.

To calculate a program that uses a complex mathematical idea to analyze an image, it is necessary to develop an appropriate image, assuming the results are obtained in advance. It is most logical, given that the program analysis occurs when an object is divided into pixels of a certain size, to create such areas, which is shown in Figure 4. Table 1 shows that the conclusion of the program for such conditions, “as no pathology was detected”, coincides with the doctor’s conclusion of about 96%, there are high coincidences with the conclusions “heaviness of the roots” -100%; 100% coincidence in pneumonia, which indicates a good sensitivity of the method. Only such diagnoses as the heaviness of the roots coincide with the expert's conclusions in less than 78%. Perhaps this is due to the insufficient number of cases.

Figure 4. The result of the fractional method is the study of fluorograms with highlighted pathology boundaries

5. CONCLUSION

The proposed algorithm for calculating the fractal dimension of raster images made it possible to create software for analyzing radiographs using fractal analysis methods. The development of an algorithm for a program for fractal processing of grayscale fluorographic images is an effective research application in image processing. The developed algorithm will further automate the process of sorting and diagnosing radiographs based on fractal analysis. In general, the fractal approach can be an effective tool for detecting pathologies in x-ray images. However, it must be taken into account that fractal analysis is a complex and computationally expensive process, and its use requires experience and specialized equipment. In addition, fractal analysis can only be used as an auxiliary tool, and the final decision on the presence or absence of pathology should be made by the doctor based on a comprehensive analysis of the data.

REFERENCES

[1] B. Archana and K. Kalirajan, "A survey of medical image processing and its applications," in *2022 4th International Conference on Inventive Research in Computing Applications (ICIRCA)*, Sep. 2022, pp. 1541–1546, doi: 10.1109/ICIRCA54612.2022.9985621.

[2] B. M. Rashed and N. Popescu, "Machine learning techniques for medical image processing," in *2021 International Conference on e-Health and Bioengineering (EHB)*, Nov. 2021, pp. 1–4, doi: 10.1109/EHB52898.2021.9657673.

[3] S. Moreno, M. Bonfante, E. Zurek, and H. S. Juan, "Study of medical image processing techniques applied to lung cancer," in *2019 14th Iberian Conference on Information Systems and Technologies (CISTI)*, Jun. 2019, pp. 1–6, doi: 10.23919/CISTI.2019.8760888.

[4] S. Kothari, S. Chiwhane, S. Jain, and M. Baghel, "Cancerous brain tumor detection using hybrid deep learning framework," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 26, no. 3, pp. 1651–1661, Jun. 2022, doi: 10.11591/ijeecs.v26.i3.pp1651-1661.

[5] J. X. Luo, W. F. Liu, and L. Yu, "Pneumothorax recognition neural network based on feature fusion of frontal and lateral Chest X-ray images," *IEEE Access*, vol. 10, pp. 53175–53187, 2022, doi: 10.1109/ACCESS.2022.3175311.

[6] S. Liu, F. Y. Shih, and X. Zhong, "Classification of chest X-ray images using novel adaptive morphological neural networks," *International Journal of Pattern Recognition and Artificial Intelligence*, vol. 35, no. 10, Aug. 2021, doi: 10.1142/S0218001421570068.

[7] W. J. AL-kubaisy and M. Mahmood, "Classification of texture using random box counting and binarization methods," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 10, no. 1, pp. 533–540, Feb. 2021, doi: 10.11591/eei.v10i1.2480.

[8] R. Usha and K. Perumal, "A modified fractal texture image analysis based on grayscale morphology for multi-model views in MR Brain," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 21, no. 1, pp. 154–163, Jan. 2021, doi: 10.11591/ijeecs.v21.i1.pp154-163.

[9] G. Abdikerimova *et al.*, "Detection of chest pathologies using autocorrelation functions," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 4, pp. 4526–4534, Aug. 2023, doi: 10.11591/ijece.v13i4.pp4526-4534.

[10] A. Orazayeva, J. Tussupov, W. Wójcik, S. Pavlov, G. Abdikerimova, and L. Savytska, "Methods for detecting and selecting areas on texture biomedical images of breast cancer," *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska*, vol. 12, no. 2, pp. 69–72, Jun. 2022, doi: 10.35784/iapgos.2951.

[11] M. Yessenova *et al.*, "The applicability of informative textural features for the detection of factors negatively influencing the growth of wheat on aerial images," *Eastern-European Journal of Enterprise Technologies*, vol. 4, no. 2(118), pp. 51–58, Aug. 2022, doi: 10.15587/1729-4061.2022.263433.

[12] B. Zholmagambetova, T. Mazakov, S. Jomartova, A. Izat, and O. Bibalayev, "Methods of extracting electrocardiograms from electronic signals and images in the Python environment," *Diagnostyka*, vol. 21, no. 3, pp. 95–101, Sep. 2020, doi: 10.29354/diag/126398.

[13] F. Wang, K. Yang, J. You, and X. Lei, "Analysis of pore size distribution and fractal dimension in tight sandstone with mercury intrusion porosimetry," *Results in Physics*, vol. 13, Jun. 2019, doi: 10.1016/j.rinp.2019.102283.

[14] T. Wen and K. H. Cheong, "The fractal dimension of complex networks: A review," *Information Fusion*, vol. 73, pp. 87–102, Sep. 2021, doi: 10.1016/j.inffus.2021.02.001.

[15] G. Wang, J. Shen, S. Liu, C. Jiang, and X. Qin, "Three-dimensional modeling and analysis of macro-pore structure of coal using combined X-ray CT imaging and fractal theory," *International Journal of Rock Mechanics and Mining Sciences*, vol. 123, Nov. 2019, doi: 10.1016/j.ijrmms.2019.104082.

[16] A. Agarwal *et al.*, "Fractal dimension and optical coherence tomography angiography features of the central macula after repair of rhegmatogenous retinal detachments," *Retina*, vol. 39, no. 11, pp. 2167–2177, Nov. 2019, doi: 10.1097/IAE.0000000000002276.

[17] Y. Xia, J. Cai, E. Perfect, W. Wei, Q. Zhang, and Q. Meng, "Fractal dimension, lacunarity and succolarity analyses on CT images of reservoir rocks for permeability prediction," *Journal of Hydrology*, vol. 579, Dec. 2019, doi: 10.1016/j.jhydrol.2019.124198.

[18] X. Hongchao *et al.*, "The influence of surfactant on pore fractal characteristics of composite acidized coal," *Fuel*, vol. 253, pp. 741–753, Oct. 2019, doi: 10.1016/j.fuel.2019.05.073.

[19] O. Castillo and P. Melin, "Forecasting of COVID-19 time series for countries in the world based on a hybrid approach combining the fractal dimension and fuzzy logic," *Chaos, Solitons & Fractals*, vol. 140, Nov. 2020, doi: 10.1016/j.chaos.2020.110242.

[20] S. Yu and V. Lakshminarayanan, "Fractal dimension and retinal pathology: A meta-analysis," *Applied Sciences*, vol. 11, no. 5, Mar. 2021, doi: 10.3390/app11052376.

[21] V. Y. Ilichev, "Development of program for determination of fractal dimensions of images," *Meždunarodnyj naučno-issledovatel'skij žurnal*, vol. 4, no. 106, pp. 6–10, 2021.

[22] Z. U. Aydın, M. G. Ocak, S. Bayrak, D. G. Bulut, and K. Orhan, "The effect of type 2 diabetes mellitus on changes in the fractal dimension of periapical lesion in teeth after root canal treatment: a fractal analysis study," *International Endodontic Journal*, vol. 54, no. 2, pp. 181–189, Feb. 2021, doi: 10.1111/iej.13409.

[23] C. Porcaro *et al.*, "Fractal dimension feature as a signature of severity in disorders of consciousness: An EEG study," *International Journal of Neural Systems*, vol. 32, no. 07, Jul. 2022, doi: 10.1142/S0129065722500319.

[24] K. Gangadharan, G. R. N. Kumari, D. Dhanasekaran, and K. Malathi, "Detection and classification of various pest attacks and infection on plants using recursive backpropagation neural network with GA based particle swarm optimization algorithm," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 20, no. 3, pp. 1278–1288, Dec. 2020, doi: 10.11591/ijeecs.v20.i3.pp1278-1288.

[25] M. Ivanovici and N. Richard, "Fractal dimension of color fractal images," *IEEE Transactions on Image Processing*, vol. 20, no. 1, pp. 227–235, Jan. 2011, doi: 10.1109/TIP.2010.2059032.

[26] P. M. Silva and J. B. Florindo, "A statistical descriptor for texture images based on the box counting fractal dimension," *Physica A: Statistical Mechanics and its Applications*, vol. 528, Aug. 2019, doi: 10.1016/j.physa.2019.121469.

BIOGRAPHIES OF AUTHORS

Gulzira Abdikerimova received her Ph.D. in 2020 in Information Systems from L.N. Gumilyov Eurasian National University, Kazakhstan. Currently, she is an associate professor of the Department of Information Systems at the same university. Her research interests include image processing, computer vision, satellite imagery, artificial intelligence, and machine learning. She can be contacted at email: gulzira1981@mail.ru.

Ainur Shekerbek received a bachelor's degree in computer science in 2002 from Taraz State University named after M.Kh. Dulaty. In 2005, she received a master's degree in applied mathematics from the South Kazakhstan State University named after M. Auezov, Kazakhstan, Shymkent. Currently, she is a doctoral student at the Department of Information Systems of the Eurasian National University. L.N. Gumilev. Her research interests include image processing, computer vision, radiography, artificial intelligence, and machine learning. She can be contacted at email: shekerbek80@mail.ru.

Murat Tulenbayev Doctor of Technical Sciences, Professor, Academician of MAIN. Currently he works at the Department of Information Systems of the Taraz Regional University named after M.Kh. Dulaty. He has more than 45 years of scientific and pedagogical experience and more than 100 scientific papers, including 4 articles on the Scopus database, 7 copyright certificates for programs and developments. She can be contacted at email: mtulenbaev@mail.ru.

Bakhyt Sultanova candidate of pedagogical sciences, Professor of the Department of Information and Computing Systems. Currently working at Karaganda Technical University named after A. Saginov. She has more than 40 years of scientific and pedagogical experience and more than 10 textbooks, 80 scientific articles, 3 monographs, 19 intellectual property certificates, 12 electronic textbooks. She can be contacted at email: bk.sultanova@mail.ru.

Svetlana Beglerova candidate of technical sciences, acting Associate Professor, Department of Information Systems, Taraz Regional University named after M.Kh. Dulaty. Currently, he is the head of the distance department of the same university. She has more than 25 years of scientific and pedagogical experience and more than 70 scientific papers, including 6 articles on the Scopus database, 6 copyright certificates for programs and developments. She can be contacted at email: sbeglerova@mail.ru.

Elvira Dzhaulybaeva received her bachelor's degree in mathematics in 2008 and her master's degree in mathematics in 2010 from M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan. Currently he works at the NJSC "Astana Medical University", at the Department of Biostatistics, Bioinformatics, and Information Technologies. Her research interests include image processing, computer vision, radiography, artificial intelligence, and machine learning. She can be contacted at email: elvira22121986@mail.ru.

Kamshat Zhumakanova Ph.D. in the specialty "Medicine" currently works as an associate professor at the Department of Pediatrics and Neonatology of Karaganda Medical University. Author of more than 30 scientific papers, including 2 articles in the Scopus database and 1 copyright certificate. She can be contacted at email: kamshat_zh@list.ru.

Bakhytgul Rysbekkyzy (Zholmagambetova BR-until 2021) senior lecturer of the Department of Information Technology and Security, Karaganda Technical University named after A. Saginov. Work experience at the university is more than 20 years, more than 50 scientific papers have been published, including 1 article in the Scopus database, and 1 article in the web of science database. 5 copyright certificates for programs and developments. She can be contacted at email: bakhytgulz@mail.ru.