ANNOTATION

for the dissertation of Ryspayeva Marya Kuanyshevna entitled "Artificial intelligence for breast cancer detection using Deep Convolutional Neural Networks" submitted for the degree of Doctor of Philosophy (PhD) in the educational program 8D06102 – Information Technologies and Robotics

Relevance of the Research Topic. Breast cancer (BC) remains one of the most significant oncological challenges in modern healthcare and is the most common malignant tumor among women. According to international statistics, more than two million new cases of breast cancer are detected annually, and the number of deaths in 2022 exceeded 700 thousand. In the Republic of Kazakhstan, more than 5 thousand new cases of breast cancer are registered annually, while the problem of late diagnosis remains: according to estimates, in 10-15% of cases the disease is detected at late stages, which worsens the prognosis and increases the cost of treatment. Medical imaging plays a key role in the early detection of breast cancer, including ultrasound examination (US) and mammography. However, the interpretation of images depends on the human factor and the quality of protocols, which stimulates the development of artificial intelligence (AI) methods, in particular convolutional neural networks (CNN), which have demonstrated high effectiveness in automated medical image classification and pathology detection. In practical scenarios, the application of CNN in BC diagnostics is significantly limited by the scarcity and imbalance of clinical data, in which malignant cases are represented significantly less frequently, and the creation of high-quality annotations requires substantial expert effort.

Traditional augmentation methods (rotations, reflections, scaling) only partially compensate for the imbalance and do not provide the required clinical diversity. Therefore, the practical task is to increase the sensitivity of CNN classifiers to the malignant class. Generative adversarial networks (GAN) are considered as an auxiliary tool, enabling the generation of realistic synthetic medical images and compensating for the shortage of the minority class.

Within the framework of the present dissertation, generative synthesis is considered not as an independent goal, but as a mechanism for improving the quality of automated BC detection using CNN. For medical data, the application of stable training schemes (WGAN-GP) and the analysis of the influence of transfer learning (TL) and sources of pretraining (ImageNet, RadImageNet) on the stability of synthesis and the final performance of downstream classification are critical. Thus, the relevance of the research is determined by the need to develop and experimentally validate an approach that increases the efficiency of BC detection through synthetic expansion of the training dataset and an increase in CNN sensitivity to the malignant class.

The aim of this research is to develop and experimentally validate a method for automated breast cancer detection in medical images using CNNs. The proposed

approach addresses data scarcity and class imbalance through synthetic dataset expansion using the DGAN-WP-TL generative model.

Objectives of the Research:

1. To analyze contemporary methods for applying convolutional neural networks and generative models to breast cancer detection under conditions of data scarcity and class imbalance.
2. To justify the use of generative models for the synthetic augmentation of medical training data.
3. To develop the DGAN-WP-TL generative model with a dual-branch critic architecture for generating synthetic images of the minority class.
4. To develop a training method for CNN classifiers based on the controlled formation of the training set by varying the proportion of synthetic data.
5. To develop a methodology for evaluating synthetic data and to conduct an experimental validation of the proposed approach, including an analysis of the impact of synthetic augmentation on classification performance.

Object of the Research: Systems of automated diagnosis of breast cancer based on deep convolutional neural networks.

Subject of the Research: regularities of increasing the diagnostic efficiency of CNN classifiers of breast cancer when training on limited and imbalanced medical data under conditions of their generative synthetic expansion.

Research Methods. In the dissertation research, methods of AI and deep learning based on architectures of CNN and GAN were used. For the analysis and processing of medical images, transfer learning methods using pretrained models were applied. During the research, methods of mathematical and computational modeling, experimental methods of neural network training, as well as methods of generative synthetic expansion of training datasets were used. To evaluate the effectiveness of the proposed approaches, methods of statistical analysis and metrics of generation quality and classification of medical images were applied.

Key Findings Submitted for Defense:

1. The DGAN-WP-TL generative model with a dual-branch critic architecture, which enables the integration of pretrained and domain-adapted features and improves the quality of synthetic image generation.
2. A training method for a breast cancer CNN classifier, in which the training set is formed in a controlled manner by varying the proportion of synthetic data, making it possible to deliberately modify the data distribution and improve the model’s diagnostic sensitivity.
3. A methodology for evaluating synthetic data based on a combination of distributional, perceptual, and structural metrics, as well as an analysis of their influence on classification results, which makes it possible to assess their diagnostic significance.

Main Research Results. As a result of the conducted dissertation research, a method for automated detection of breast cancer in medical images was developed and experimentally validated. The method is robust to data scarcity and class imbalance and is based on the joint use of CNN and generative data synthesis. An approach is proposed in which the generative model is used not as an independent

goal but as an auxiliary tool for targeted synthetic expansion of training datasets in order to increase the sensitivity of CNNs to the malignant class.

The DGAN-WP-TL method was developed and theoretically substantiated, based on the Wasserstein GAN architecture with gradient penalty (WGAN-GP) and transfer learning mechanisms. The method is intended for stable generation of synthetic malignant images under conditions of limited and imbalanced datasets. A pipeline for forming a synthetically expanded training dataset and subsequent training of CNN classifiers aimed at improving the quality of downstream classification was implemented.

A set of computational experiments was carried out on the BUSI and CBIS-DDSM datasets, and cross-domain validation of the robustness of the approach was performed on Alzheimer MRI data. It was established that the use of synthetic data generated by the DGAN-WP-TL method provides a stable improvement of clinically significant metrics for detecting malignant cases (primarily Recall and F1-score, as well as AUC) compared to training on the original imbalanced datasets.

Ablation studies were performed to analyze the influence of generative model training parameters, including the gradient penalty coefficient λ, and the influence of sources of pretrained weights (ImageNet and RadImageNet) on the stability of generation and the contribution of synthetic data to subsequent classification was analyzed. It was shown that improvement of downstream classification is determined not only by minimizing distributional generation metrics but is achieved at an optimal balance between realism and intra-class diversity of synthetic images.

The scientific novelty lies in the development of a comprehensive approach to the automated detection of breast cancer, encompassing the generation, use, and evaluation of synthetic medical data. A DGAN-WP-TL generative model with a dual-branch critic architecture is proposed, in which the integration of pretrained and domain-adapted feature spaces enables a more accurate approximation of the distribution of medical images and improves the stability of generative model training. A method for training CNN classifiers is developed based on the controlled construction of the training dataset through varying the proportion of synthetic data in the minority class, thereby allowing purposeful adjustment of the data distribution and improving the diagnostic sensitivity of the model. In addition, an evaluation methodology for synthetic data is developed based on a combination of distributional, perceptual, and structural metrics, as well as an analysis of their impact on classification performance, making it possible to detect mode collapse and assess the diagnostic relevance of synthetic images.

The theoretical significance of the dissertation research lies in the development of scientific understanding of the application of AI methods, in particular CNN and GAN, for automated analysis of medical images.

The work proposes and theoretically substantiates an approach in which the generative model is used as an auxiliary tool for synthetic expansion of training datasets in order to improve classification efficiency under conditions of data scarcity and imbalance.

The obtained results expand the theoretical foundations of the application of GAN in medical imaging by substantiating their role in the formation of synthetic

training data aimed at increasing the sensitivity of CNN classifiers to rare malignant patterns. The possibility of using unconditional generation of medical images for balancing training datasets is demonstrated, which reduces the dependence of models on the volume of annotated data and forms methodological foundations for integrating generative models and CNN in tasks of automated pathology detection.

The practical significance of the dissertation research lies in the possibility of applying the developed DGAN-WP-TL method to improve the efficiency of automated analysis of medical images in tasks of breast cancer detection.

The use of synthetic data generated by the proposed model makes it possible to reduce the influence of imbalance in training datasets, increase the sensitivity of CNN to rare malignant patterns, and improve the reliability of classification of medical images.

The obtained results can be used in the development of computer-aided detection systems (CAD), as well as in research and educational projects in the fields of medical imaging, machine learning, and AI.

Implementation of Research Results. The results of the dissertation work were implemented in the educational process of the Department of Software Engineering of the Non-profit Joint Stock Company "Akhmet Baitursynuly Kostanay Regional University", which is confirmed by the Act on the practical application of the results of the dissertation research of M.K. Ryspayeva entitled "Artificial intelligence for breast cancer detection using Deep Convolutional Neural Networks" dated 03.03.2026.

Approbation of the Dissertation Research Results. The main results of the dissertation research were reported and discussed at scientific seminars of the Department of Software Engineering of the Non-profit Joint Stock Company "Akhmet Baitursynuly Kostanay Regional University", as well as at the following international scientific conferences whose proceedings are indexed in IEEE Xplore and Scopus:

– IEEE International Conference on Smart Information Systems and Technologies (SIST), Astana, Kazakhstan, 2023, 2025;

– IEEE AITU: Digital Generation Conference, Astana, Kazakhstan, 2024.

In international publications with a non-zero impact factor included in the Scopus database – 1 article. The author's contribution consists in the formulation of the scientific hypothesis, data collection and preliminary processing, development and technical implementation of the experimental part of the research, interpretation of the obtained results, and preparation of the publication:

1. Multi-domain synthetic medical image generation and dataset balancing with DGAN-WP-TL // Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization. – 2025. – Vol. 13(1). – P. 2556687. https://doi.org/10.1080/21681163.2025.2556687

Articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan – 5 articles. Within these publications the author is the developer of the research concept and methodology of data analysis.

The author directly participated in data collection, interpretation of results, formulation of conclusions, and preparation of scientific articles for publication:

1. GAN-based medical image generation for rare pathologies using transfer learning and RadImageNet weights // International Journal of Information and Communication Technologies. – 2025. – T. 6, № 3. – P. 254–269. https://doi.org/10.54309/IJICT.2025.23.3.015

2. Impact of loss function on synthetic breast ultrasound image generation // Scientific Journal of Astana IT University. – 2025. – № 24. – P. 99–112. https://doi.org/10.37943/24MMIK3887

3. Evaluation of StyleGAN2 and StyleGAN3 for synthetic medical image generation on BUSI and CBIS-DDSM datasets // Bulletin of Shakarim University. Technical Sciences Series. – 2025. – № 4(20). – P. 89–96. https://doi.org/10.53360/2788-7995-2025-4(20)-11

4. The Impact of Gradient Penalty Parameter on the Performance of Deep Convolutional Generative Adversarial Network with Wasserstein Penalty in Mammography // University Proceedings. – 2025. – № 4. – P. 427–434. https://doi.org/10.52209/1609-1825_2025_4_427

5. Synthesis and classification of ultrasound images of breast cancer using a Wasserstein generative adversarial network and transfer learning // Bulletin of KazATK. – 2025. – № 141(6). – P. 222–231. https://doi.org/10.52167/1609-1817-2025-141-6-222-231

The author's personal contribution consists in formulating the goal and objectives of the research and selecting the methodological approach to automated breast cancer detection based on CNN using synthetic data augmentation methods. The author performed an analysis of modern methods of medical image classification and generative models, developed and theoretically substantiated the DGAN-WP-TL method based on the Wasserstein GAN architecture with gradient penalty and transfer learning mechanisms.

The author implemented the developed method in software, prepared and processed experimental data, trained and tested models on BUSI, CBIS-DDSM and Alzheimer MRI medical image datasets, and conducted computational experiments and analysis of the obtained results using generation and classification quality metrics. All main scientific results and provisions submitted for defense were obtained personally by the author.

Publications on the Dissertation Topic. In total, 9 (nine) scientific works were published on the topic of the dissertation research, including 5 (five) articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 1 (one) article in an international scientific publication included in the Scopus database, 3 (three) articles in proceedings of international scientific conferences indexed in IEEE Xplore and Scopus, and 3 (three) certificates of state registration of computer programs were obtained.

Structure and Volume of the Dissertation. The dissertation consists of an introduction, four chapters, a conclusion, a list of references, and appendices. The volume of the dissertation is 116 pages (30 figures and 41 tables).

In the introduction, the relevance of the dissertation research topic is substantiated, the purpose and objectives of the work are formulated, the object and subject of the research are defined, and the scientific novelty, theoretical and practical significance of the obtained results are presented.

The first chapter presents an analytical review of the current state of research on breast cancer detection using artificial intelligence methods. Medical aspects of early diagnosis of breast cancer, the application of CNN in medical imaging tasks, and the problem of scarcity and imbalance of clinical data are considered. Particular attention is paid to generative models for medical image synthesis and existing approaches to integrating generative and classification methods.

The second chapter presents the methodological and mathematical foundations for developing the breast cancer detection method. CNN architectures and their adaptation to the task of breast cancer classification are considered, as well as the use of transfer learning and pretrained weights ImageNet and RadImageNet. The mathematical model of generative networks from classical GAN to WGAN and WGAN-GP is described. The datasets and experimental data used are presented, the two-branch architecture of DGAN-WP-TL with integration of the generative model and feature extractor in the discriminator is described, and the approach to tumor classification based on a synthetically expanded training dataset is formulated.

The third chapter presents experimental studies and results aimed at evaluating the effectiveness of automated breast cancer detection using CNN under conditions of data scarcity and imbalance. A key element of the chapter is the analysis of the influence of the synthetically expanded training dataset on downstream tumor classification quality, including evaluation of changes in clinically significant metrics Recall, F1-score and AUC. To ensure conditions for improving classification quality, experimental validation of the proposed DGAN-WP-TL method used as a synthetic data augmentation tool was performed. Results of synthetic image generation for BUSI and CBIS-DDSM datasets are presented, and additional methodological validation of the method was performed on Alzheimer MRI data. Analysis of distributions of real and synthetic images was conducted using PCA and t-SNE methods, comparison with the baseline architecture StyleGAN2 was performed, and the influence of pretrained weights ImageNet and RadImageNet and architectural parameters of DGAN-WP-TL on generation stability and quality under small datasets was investigated.

The fourth chapter presents an analytical discussion and generalization of the research results, including interpretation of experimental data, justification of architectural solutions, comparative analysis with existing approaches and baseline architectures, and formulation of limitations, practical recommendations and directions for further research.

In the conclusion, the main results of the dissertation research are summarized, conclusions based on the results of the performed work and recommendations are formulated, and prospects for further development of the proposed approach are outlined.

The appendices present supplementary materials, including the act of implementation and documents confirming the practical application of the dissertation research results.