ANNOTATION
to the dissertation of Talshyn Sarsembayeva
submitted for the degree of Doctor of Philosophy (PhD)
in the educational program
8D06114 — Artificial Intelligence in Medicine
on the topic:
"Machine diagnostic of medical imaging and its adaptation to the needs of population screening on example of Chronic Obstructive Pulmonary Disease"

Relevance of the research topic. Chronic Obstructive Pulmonary Disease is one of the major medical and social problems of modern healthcare. It is characterized by a long progressive course, a decrease in patients' quality of life, and a significant contribution to the burden of chronic respiratory diseases. A specific feature of COPD is that the disease may remain clinically underdiagnosed for a long time, while structural changes in lung tissue can develop before the appearance of pronounced symptoms. Therefore, early identification of morphological changes in the lung parenchyma is essential for timely monitoring, additional diagnostic assessment, and prevention of further disease progression.
Spirometry remains the main functional method for confirming COPD. However, it does not provide direct information about the morphological substrate of the disease. Computed tomography, in contrast, allows visualization of structural abnormalities of lung tissue, including emphysematous destruction, low-attenuation areas, signs of hyperinflation, and regional heterogeneity of lung involvement. Thus, CT images represent an important source of data for automated analysis of emphysema-related signs as one of the morphological components of COPD.

Quantitative computed tomography plays a central role in automated CT analysis. Indicators such as LAA%-950, Perc15, Mean HU, and TLV make it possible to quantify density and volume characteristics of lung tissue. However, isolated use of QCT parameters has several limitations, since the results may depend on scanning parameters, inspiratory level, segmentation quality, image noise, and selected HU thresholds. In addition, threshold-based densitometry does not fully describe the spatial and textural organization of emphysematous changes.

Deep learning methods provide an opportunity to extract complex visual and textural features from CT images. Convolutional neural networks can form latent representations reflecting heterogeneity of the lung parenchyma, distribution of low-density areas, local contrast transitions, and specific patterns of lung structure. However, fully neural network-based models often lack interpretability, which limits their use in medical practice. Therefore, the integration of neural network-derived features with physically interpretable QCT indicators is a relevant scientific and practical direction.

The relevance of this dissertation is determined by the development of a modified machine diagnostic method for automatic detection of emphysematous changes on CT images, combining deep learning and quantitative CT analysis. The proposed approach aims to improve the quality of medical image analysis while

preserving the physical interpretability of the results and creating a basis for adaptation to population screening needs.

The aim of the research is to develop a system for automatic detection of signs of Chronic Obstructive Pulmonary Disease based on CT images using a modified machine diagnostic method oriented toward large-scale population screening.

To achieve this aim, the **following objectives** were formulated:

To analyze the latent layer of a pre-trained ResNet-152 model in order to obtain a reduced subset of features while preserving diagnostic efficiency.

To implement an automatic data labeling strategy based on quantitative CT analysis using QCT indicators.

To develop a modified method combining ResNet-152 embeddings and automatic QCT-based annotation for detecting signs of pulmonary emphysema on CT images in a scalable screening scenario.

To develop a prototype system for automatic detection of emphysema signs based on CT images using the proposed modified method.

The object of research is the process of automatic detection of emphysema signs based on CT image data.

The subject of research is the modification of the method for automatic detection of signs of Chronic Obstructive Pulmonary Disease based on CT image data.

The scientific novelty of the dissertation lies in the development and experimental validation of a method for automatic detection of emphysema signs on CT images based on the integration of latent features extracted by a pre-trained ResNet-152 model and quantitative QCT indicators.

Unlike approaches based only on threshold densitometry or only on neural network classification, the proposed method combines two complementary levels of CT image representation: visual-textural and physical-densitometric. ResNet-152 is used as a feature extractor that generates embeddings describing latent visual characteristics of the lung parenchyma. QCT indicators, including LAA%-950, Perc15, Mean HU, and TLV, provide a connection between the model output and physically measurable parameters of lung tissue density.

An additional scientific aspect of the research is the use of an auto-labeling strategy to adapt the open LIDC-IDRI dataset, which does not contain specialized clinical labels for COPD and emphysema, to the task of machine analysis of low-attenuation changes in the lung parenchyma. The generated labeling has the status of Silver Standard, since it is based on reproducible QCT criteria but does not replace a clinical diagnosis.

Main provisions submitted for defense

Automatic labeling of CT examinations based on QCT indicators makes it possible to generate Silver Standard labels for model training in the absence of expert COPD annotation in the original dataset.

Embeddings extracted from the latent layer of ResNet-152 contain visual-textural features associated with low-density changes in lung tissue; reduction of the feature space makes it possible to preserve diagnostically significant information.

The proposed model combining QCT features and ResNet-152 embeddings improves classification quality compared with the isolated use of quantitative QCT indicators or embedding-based features alone.

The developed software prototype demonstrates the feasibility of implementing a complete automated CT image analysis cycle, including DICOM data upload, preprocessing, QCT metric calculation, ResNet-152 feature extraction, probabilistic assessment, and presentation of the result to the user.

The theoretical significance of the research is associated with the methodological justification of the combined use of neural network and densitometric features in CT image analysis. The dissertation considers ResNet-152 embeddings as latent visual-textural descriptors, while QCT indicators are treated as physically interpretable features associated with lung tissue density. This contributes to the development of approaches for applying artificial intelligence in medical imaging.

The practical significance of the research lies in the development of a reproducible pipeline for automatic CT data processing. The proposed approach includes DICOM series selection, conversion to the Hounsfield scale, HU range control, resampling, lung segmentation, calculation of QCT indicators, automatic labeling, extraction of ResNet-152 features, and classification. The developed prototype may serve as a basis for further development of decision support systems and preliminary CT-based screening tools.

The reliability of the obtained results is ensured by the consistent organization of the experimental pipeline, the use of reproducible CT image processing methods, and quantitative evaluation of classification quality. During data preparation, HU range control, lung segmentation, calculation of LAA%-950, Perc15, Mean HU, and TLV, as well as Silver Standard labeling were performed.
Model quality was assessed using ROC-AUC, PR-AUC, F1-score, balanced accuracy, and confusion matrices. Cross-validation and comparison of different model variants were used to analyze classification stability. Grad-CAM was applied to interpret neural network decisions and to identify CT image regions influencing the prediction.

The results confirm the main research hypothesis: combined use of CNN-derived features and QCT indicators improves classification quality compared with the isolated use of neural network features. At the same time, the dissertation correctly states that the proposed model is not an independent tool for establishing a clinical diagnosis of COPD and requires further external clinical validation on specialized COPD datasets.

Structure and brief content of the dissertation

The dissertation consists of an introduction, three main chapters, conclusion, list of references, and appendices.

The introduction substantiates the relevance of the topic, defines the aim, objectives, object and subject of research, and presents the scientific novelty, practical significance, research methods, and main provisions submitted for defense. The first chapter presents the theoretical foundations of the research. It analyzes scientific sources on COPD diagnosis, the role of CT in emphysema detection, the

significance of the LAA%-950 metric and the HU < −950 threshold, and the limitations of traditional diagnostic methods. It also substantiates the transition to artificial intelligence methods and reviews modern approaches to CT image analysis, including CNN, ResNet, U-Net, QCT, and feature fusion models.

The second chapter describes the methodology and organization of the research. It presents the aim and hypothesis, data and data preparation procedures, preprocessing stages, feature extraction, machine learning methods, architecture of the modified model, and ethical aspects of the study.

The third chapter presents the results and discussion. It describes the prepared dataset, analyzes QCT-based labeling, examines the distribution of LAA%-950, evaluates ResNet-152 embeddings, performs informative feature selection, and presents the results of the proposed modified model combining ResNet-152 and QCT features. The chapter also includes error analysis, Grad-CAM-based visual interpretation, and the implementation of a prototype system for automatic CT image analysis.

The conclusion summarizes the main results of the research, confirms that the aim has been achieved and the objectives have been fulfilled, and outlines the limitations of the study and directions for further development.

Publications based on the research results

Scientific works have been published on the topic of the dissertation and are presented in the appendix of the dissertation. These publications reflect the main results of the study, including CT image analysis, the use of ResNet-152 as a feature extractor, application of QCT indicators, development of a modified model, and approaches to automatic detection of emphysematous changes.

List of Publications:

Scopus/ WoS:

1. Sarsembayeva T., Mansurova M., Oshibayeva A., Serebryakov S. Interpretable Diagnosis of Pulmonary Emphysema on Low-Dose CT Using ResNet Embeddings. Journal of Imaging. 2026; 12(1):51. (Q1, 87th percentile) https://doi.org/10.3390/jimaging12010051

2. Sarsembayeva T., Mansurova M., Abdildayeva A., Serebryakov S. Enhancing U-Net Segmentation Accuracy Through Comprehensive Data Preprocessing. Journal of Imaging. 11 2025; (2): 50. https://doi.org/10.3390/jimaging11020050 (Q1, 87th percentile)

Journal 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. Sarsembayeva T., Oshibayeva A., Shayakhmetova A., Ospan A. ResNet embedding-based pipeline for transparent diagnosis of pulmonary emphysema on low-dose CT // Journal of Problems in Computer Science and Information Technologies. – 2026. – Vol. 4, No. 1. DOI: https://doi.org/10.26577/jpcsit4120262

International conferences:

1. Sarsembayeva, T., Mansurova, M., Shomanov, A., Sarsembayev, M., Sagyzbayeva, S., Rakhimzhanov, G. (2022). Pre-processing of CT Images of the Lungs 14th Asian Conference on Intelligent Information and Database Systems , ACIIDS 2022. // Lecture Notes in Computer Science(), vol 13758. Springer, Cham. https://doi.org/10.1007/978-3-031-21967-2_39 (Scopus Proceedings)

2. Sarsembayeva T., Shomanov A., Sarsembayev M., Mansurova M., Zhunussova A., Rakhimzhanov G. UNet model for segmentation of COPD lung lesions on computed tomography images // CEUR Workshop Proceedings. – 2022. – Vol. 3382.URL:https://ceur-ws.org/Vol-3382/Short5.pdf (Scopus Proceedings)

3. Sarsembayeva T., Mansurova M., Essengaliyeva N., Koshanova A. Өкпенің созылмалы обструктивті ауруы белгілерінің машиналық диагностикасы үшін өкпенің КТ кескінін өңдеу жүйесін жасау // Материалы IX Международной научно-практической конференции «Computer Science and Applied Mathematics» (CSAM 2024). – Алматы, 2024. – С. 419–428. – URL: https://conf.iict.kz/wp-content/uploads/2025/01/collection_CSAM_IX_2024.pdf