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Application of AI algorithms in medical imaging for the detection and classification of cardiovascular diseases.

Application des algorithmes d'IA en imagerie médicale pour la détection et la classification des pathologies cardiovasculaires.

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Résumé

Les maladies cardiovasculaires (MCV) sont la principale cause de mortalité mondiale, avec 17,9 millions de décès annuels. Face à ce défi sanitaire, les méthodes de diagnostic traditionnelles (ECG, échographie) présentent des limites en termes d'accessibilité et d'efficacité, nécessitant un personnel hautement qualifié. L'émergence de l'intelligence artificielle (IA) ouvre des perspectives prometteuses pour automatiser et optimiser le diagnostic des MCV. Cette étude explore l'application des algorithmes d'IA, notamment les réseaux de neurones convolutionnels (CNN), les transformateurs et les méthodes de clustering, dans la détection et la classification des pathologies cardiovasculaires.

L'objectif principal est d'évaluer la performance de ces algorithmes en termes de précision diagnostique, d'interprétabilité et d'intégration dans les systèmes de santé existants. Une revue de la littérature scientifique met en évidence le potentiel de l'IA à traiter de grands volumes de données médicales, à réduire les biais humains et à accélérer la prise de décision clinique. Les résultats préliminaires démontrent que les CNN surpassent les approches conventionnelles dans l'analyse des images médicales, tandis que les techniques de clustering facilitent la visualisation des données complexes.

Cependant, des défis persistent : l'adoption à grande échelle nécessite des modèles compatibles avec les infrastructures hospitalières, tout en garantissant la transparence et la sécurité des données. Cette recherche propose une méthodologie innovante combinant l'apprentissage profond et l'analyse comparative pour identifier les algorithmes les plus adaptés aux contextes cliniques réels. En conclusion, l'IA se positionne comme un outil complémentaire essentiel pour améliorer la qualité des diagnostics cardiovasculaires, à condition de surmonter les obstacles techniques et éthiques liés à son déploiement.

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Mots clés : Intelligence artificielle, maladies cardiovasculaires, diagnostic médical, réseaux neuronaux, intégration clinique.

Abstract

Cardiovascular diseases (CVD) are the leading cause of global mortality, with 17.9 million annual deaths. In the face of this health challenge, traditional diagnostic methods (ECG, ultrasound) have limitations in terms of accessibility and effectiveness, requiring highly qualified personnel. The emergence of artificial intelligence (AI) opens promising prospects for automating and optimizing the diagnosis of CVD. This study explores the application of AI algorithms, notably convolutional neural networks (CNNs), transformers, and clustering methods, in the detection and classification of cardiovascular pathologies.

The main objective is to evaluate the performance of these algorithms in terms of diagnostic accuracy, interpretability, and integration into existing healthcare systems. A review of the scientific literature highlights the potential of AI to handle large volumes of medical data, reduce human biases, and accelerate clinical decision-making. Preliminary results demonstrate that CNNs outperform conventional

approaches in the analysis of medical images, while clustering techniques facilitate the visualization of complex data.

However, challenges persist: large-scale adoption requires models compatible with hospital infrastructures, while ensuring data transparency and security. This research proposes an innovative methodology combining deep learning and comparative analysis to identify the most suitable algorithms for real clinical contexts. In conclusion, AI positions itself as an essential complementary tool for improving the quality of cardiovascular diagnostics, provided that the technical and ethical obstacles related to its deployment are overcome.

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keywords: Artificial intelligence, cardiovascular diseases, medical diagnosis, neural networks, clinical integration.

Introduction

Cardiovascular diseases (CVD) remain the leading cause of mortality and disability worldwide. According to the World Health Organization, approximately 17.9 million people die from these conditions annually, accounting for 32% of all global deaths. In this context, early detection and accurate diagnosis of CVD are critical to preserving the health and lives of millions. However, traditional diagnostic methods, such as ECG analysis or ultrasound imaging, often require significant time and highly skilled personnel, limiting their widespread application.

With advancements in artificial intelligence (AI) technologies, including machine learning and deep neural networks, it has become possible to automate the diagnostic process, enhancing its accuracy and efficiency. AI algorithms demonstrate high performance in processing large volumes of medical data, including imaging, making them a promising tool for cardiology. Recent studies indicate that convolutional neural networks (CNNs), transformers, and

clustering methods can significantly improve the classification and detection of cardiovascular pathologies.

The importance of this topic stems not only from the growing healthcare demand for improved diagnostic precision but also from the need to integrate AI into existing systems. This requires developing algorithms that are not only highly accurate but also interpretable, user-friendly, and compatible with current infrastructure.

This study focuses on exploring the application of AI algorithms for the detection and classification of CVD. Emphasis is placed on evaluating the efficiency and accuracy of these algorithms, as well as their potential integration into healthcare systems. The proposed approach aims to enhance diagnostic quality and minimize human bias in medical decision-making.

Relevance of the Research: The rising prevalence of cardiovascular diseases and related complications necessitates innovative approaches to their

early detection and treatment. Integrating AI into medicine enables the automation of diagnostics, reducing time consumption and improving accuracy. Modern methods, such as convolutional neural networks and gradient boosting algorithms, offer new opportunities for data processing and analysis, including visualization. These technologies hold significant potential for addressing pressing healthcare challenges.

Objective: This study aims to explore the capabilities of AI algorithms for improving the efficiency of cardiovascular disease diagnosis and classification.

Research Tasks:

1. Conduct a literature review on the use of AI algorithms in diagnosing cardiovascular diseases.
2. Evaluate the performance of existing algorithms through data analysis.
3. Investigate the potential of deep neural networks and clustering methods in the visualization and classification of CVD.

This work addresses a key challenge in modern medicine: improving the accuracy and accessibility of cardiovascular disease diagnosis through artificial intelligence technologies.

Materials and methods:

1.1 Deep learning: Neural Networks

1.1.1 Convolutional Neural Networks:

Convolutional neural networks (CNN) are key algorithms for analyzing medical

images, providing accurate and automated methods for the classification and detection of cardiovascular diseases. Research in this area demonstrates their effectiveness and applicability in addressing visualization-related tasks. In the work by Sadia Arooj and co-authors (A Deep Convolutional Neural Network for the Early Detection of Heart Disease¹) CNN was applied for the classification of data collected in the public UCI dataset, which included 1,050 patients. The model achieved an accuracy of 91.7% in identifying patients with cardiovascular diseases. This research demonstrates how CNN can be used for automatic feature extraction, such as anomalies in heart structure or blood flow, based on visual data, such as ultrasound images or MRI data. CNN-based visualization is becoming an important tool in the early diagnosis of diseases, minimizing dependence on subjective interpretation by physicians. Another study conducted by Nikhil Gawande and Alka Barhatte², highlights the use of CNN for analyzing electrocardiograms (ECG). The work demonstrates that changes in the P-wave, QRS, and T-wave segments can be automatically identified by CNN, which enhances the accuracy of diagnosing conditions such as coronary artery disease or arrhythmia. These results are directly related to the task of visualization, as CNN algorithms effectively analyze the temporal patterns of ECG, which can be viewed as visual sequences. In the study by U. Rajendra Acharya and co-authors (Automated detection of coronary artery

¹ Arooj S. et al. A deep convolutional neural network for the early detection of heart disease //Biomedicines. – 2022. – T. 10. – №. 11. – P. 2796.

² Gawande N., Barhatte A. Heart diseases classification using convolutional neural network //2017 2nd international conference on communication and electronics systems (ICCES). – IEEE, 2017. – C. 17-20.

disease using different durations of ECG segments with convolutional neural network³) a CNN architecture was proposed for classifying ECG segments of 2 and 5 seconds in duration. The model achieved an accuracy of 95.11% in classifying normal and abnormal signals. The advantage of CNN lies in its ability to analyze both short-term and long-term signal patterns, which is also applicable to visualization, such as analyzing structural changes in the heart in images. The work by Mohammed B. Abubaker and Bilal Babayiğit demonstrates the development of a lightweight CNN architecture that achieved an accuracy of 98.23% in classifying cardiovascular diseases. This method has proven effective in utilizing limited computational resources, making it applicable for integration into Internet of Things (IoT) systems in healthcare. Visual diagnostics using CNN can be implemented within such ecosystems, providing continuous monitoring and early detection of pathologies.

Thus, each of the studies reviewed highlights the potential of convolutional neural networks in analyzing and classifying data related to cardiovascular diseases. CNNs not only simplify the processing of complex visual data but also enhance diagnostic accuracy, making them indispensable in medical imaging. The use of CNN in heart disease diagnostics opens new prospects for improving diagnosis and

treatment by linking data analysis with modern visualization techniques.

1.1.2 Deep Convolutional Systems:

Deep convolutional networks, such as ResNet and DenseNet, are advanced architectures for addressing tasks related to the processing and analysis of medical images. These architectures demonstrate high potential in detecting and classifying cardiovascular diseases due to their ability to automatically extract meaningful features from highly complex data. An example of the practical application of ResNet is the study by Qiyang Xie and co-authors (ECG Signal Detection and Classification of Heart Rhythm Diseases Based on ResNet and LSTM⁴). In this work, ResNet34 was used to analyze ECG signals with the aim of detecting arrhythmias, including atrial fibrillation, which is one of the most common causes of complications in the cardiovascular system. The model achieved an F1 score of 0.861 and an AUC of 0.972, demonstrating its ability to effectively extract signal characteristics for classification. The work highlights the applicability of ResNet not only for temporal data but also for analyzing images, such as cardiac ultrasounds, due to the versatility of the architecture. Another example is the study by V. Benhar Charles and co-authors (heart disease data-based privacy preservation using enhanced ElGamal and ResNet classifier⁵), where ResNet50 was used to process data on heart diseases. The model was combined with the

³ Acharya U. R. et al. Automated detection of coronary artery disease using different durations of ECG segments with convolutional neural network //Knowledge-Based Systems. – 2017. – T. 132. – P. 62-71.

⁴ Xie Q. et al. ECG Signal Detection and Classification of Heart Rhythm Diseases Based on ResNet and LSTM //Advances in Mathematical Physics. – 2021. – T. 2021. – №. 1. – P. 5862017.

⁵ Charles V. B., Surendran D., SureshKumar A. Heart disease data based privacy preservation using enhanced ElGamal and ResNet classifier //Biomedical Signal Processing and Control. – 2022. – T. 71. – P. 103185.

ElGamal cryptographic method, which ensured data security during transmission and processing. Although the study focused on textual and numerical data, a similar approach can be applied to visual data, such as MRI or CT scans, confirming the versatility of ResNet50 for classification tasks in medical imaging. The study by Shaimaa Mahmoud and co-authors (Cardiovascular Disease Prediction Using Modified Version of ResNet-50 Model⁶) demonstrates how modifying the ResNet50 architecture improves the accuracy of diagnosing cardiovascular diseases. This work utilized ECG data to classify conditions such as myocardial infarction and arrhythmia, achieving an accuracy improvement of 4.83% compared to the original model. The modification enables the use of ResNet for analyzing visual data, enhancing the accuracy of detecting and classifying pathologies. The study by Monali Gulhane and co-authors (Deep Learning based Heart Diseases Detection using ResNet50 Architecture⁷) showed that ResNet50 can be successfully applied to the analysis of ECG images, achieving 99.12% accuracy in classifying conditions such as arrhythmia and myocardial infarction. This result highlights the potential of ResNet50 for image processing tasks in medical imaging, where high accuracy is required. The work of Nizar Sakli and co-authors⁸ demonstrates the application of

ResNet-50 for the automatic diagnosis of 12-lead electrocardiograms, including the classification of 26 different types of cardiovascular diseases. The model showed high accuracy (97.63%) and precision (89.67%), confirming its ability to process complex multichannel data. ResNet-50 can be adapted for analyzing not only temporal data but also images, such as echocardiograms or MRIs, providing the capability to classify a wide range of pathologies. Similarly, the study by Shikha Dhyani and co-authors⁹ illustrates the use of a modified ResNet-RNN architecture for analyzing 12-lead ECGs. The model achieved 91% accuracy, surpassing other deep neural networks such as Inception ResNet V2 and DenseNet. This approach demonstrates how the combination of convolutional and recurrent networks can be used to analyze temporal and spatial patterns. The technologies have a direct connection to medical imaging, as they can be applied to analyze heart images obtained through ultrasound or CT, enabling early detection of arrhythmias and other conditions. In the study by Chuang Han and colleagues¹⁰ presents the ML-ResNet model, which uses multichannel ECG recordings to detect and localize myocardial infarction. The model achieved outstanding accuracy and F1-score, highlighting how ResNet architectures can leverage both local and global data features. This has a

⁶ Mahmoud S. et al. Cardiovascular Disease Prediction Using Modified Version of ResNet-50 Model //2022 32nd International Conference on Computer Theory and Applications (ICCTA). – IEEE, 2022. – P. 18-24.

⁷ Gulhane M., Kumar S. Deep Learning based Heart Diseases Detection using ResNet50 Architecture //2023 Intelligent Methods, Systems, and Applications (IMSA). – IEEE, 2023. – P. 193-198.

⁸ Sakli M., Sakli N., Sakli H. ECG Images Automated Diagnosis based on Machine Learning Algorithms //2023

20th International Multi-Conference on Systems, Signals & Devices (SSD). – IEEE, 2023. – P. 934-939.

⁹ Dhyani S., Kumar A., Choudhury S. Arrhythmia disease classification utilizing ResRNN //Biomedical Signal Processing and Control. – 2023. – T. 79. – P. 104160.

¹⁰ Han C., Shi L. Automated interpretable detection of myocardial infarction fusing energy entropy and morphological features //Computer methods and programs in biomedicine. – 2019. – T. 175. – P. 9-23.

direct connection to visualization tasks, where detailed localization of pathologies on medical images, such as infarct zones on MRI, is required. The integration of ResNet with Internet of Things technologies in the study by S. Sai Kumar and co-authors¹¹ demonstrates how deep learning algorithms can be used for real-time monitoring of cardiovascular diseases. This approach is applicable to medical imaging tasks, where the analysis of spatiotemporal data obtained from multiple sensors or scanners requires high accuracy and processing speed. The presented studies illustrate how deep convolutional networks can be adapted to address various tasks in the diagnosis of cardiovascular diseases. ResNet-50 and its modifications provide high performance in analyzing complex data, making them particularly useful for medical imaging tasks. The algorithms offer a versatile and effective tool for automating and improving the diagnosis of cardiovascular diseases, reducing the impact of human factors and enhancing the quality of medical decisions. The mentioned studies show that deep convolutional networks, such as ResNet, have significant potential for analyzing and classifying medical images.

1.1.3 Transformer Neural Networks:

The application of transformer neural networks, such as Vision Transformers (ViT), in medical imaging tasks has shown high effectiveness in analyzing complex patterns on medical images and predicting

cardiovascular disease risks. The work of Qaisar Abbas and co-authors¹² demonstrates the successful use of the Convolutional Vision Transformer (CVT-Trans) model for classifying phonocardiographic signals. The application of a transformer-based approach achieved 100% accuracy in classifying signals into five categories, including heart valve abnormalities, confirming that transformers have a high capability for processing and interpreting global patterns in data, which can be effectively applied to the analysis of visualizations such as echocardiograms or MRI images of blood vessels. In the study by Sonain Jamil and Arunabha M. Roy¹³ ViT was used to analyze 2D images of phonocardiographic signals. The model achieved an average accuracy of 99.90%, surpassing existing approaches, highlighting the potential of ViT in segmentation and analysis tasks for vascular pathologies, where both global and local features of the image need to be considered. The work of Zeynep Hilal Kilimci and co-authors¹⁴ explores the application of Vision Transformers, such as Google-ViT and Microsoft-Beit, for classifying ECG images. The transformers demonstrated high accuracy in predicting various cardiac conditions, including arrhythmia and myocardial infarction. Their ability to interpret complex temporal patterns in data can be utilized for disease diagnosis based on imaging. The study by

¹¹ Kumar S., Sahoo G. A random forest classifier based on genetic algorithm for cardiovascular diseases diagnosis (research note) //International Journal of Engineering. – 2017. – T. 30. – №. 11. – P. 1723-1729.

¹² Abbas Q., Hussain A., Baig A. R. Automatic detection and classification of cardiovascular disorders using phonocardiogram and convolutional vision transformers //diagnostics. – 2022. – T. 12. – №. 12. – P. 3109.

¹³ Jamil S., Roy A. M. An efficient and robust phonocardiography (pcg)-based valvular heart diseases (vhd) detection framework using vision transformer (vit) //Computers in Biology and Medicine. – 2023. – T. 158. – P. 106734.

¹⁴ Kilimci Z. H. et al. Heart Disease Detection using Vision-Based Transformer Models from ECG Images //arXiv preprint arXiv:2310.12630. – 2023.

Michał Jungiewicz and colleagues¹⁵ examines the use of ViT for detecting coronary artery stenosis based on angiographic video fragments. By applying the Sharpness-Aware Minimization method in conjunction with ViT, high stability and accuracy of the model were achieved, making transformers a promising tool for coronary angiography analysis tasks. In the work of Riyadh M. Al-Tam and co-authors¹⁶ presents a hybrid approach that combines ResNet50 and Vision Transformer for analyzing heart sounds. This approach demonstrated high accuracy (up to 99.80%) in multi-class and binary classification tasks, showcasing the potential for combined use of transformers and convolutional networks for classifying visual and audio data. Vision Transformers and their combinations with other neural networks provide significant advantages in analyzing medical images. They effectively address tasks requiring a global understanding of image patterns, such as vessel segmentation or assessing the condition of coronary arteries. Such approaches hold great potential for improving the diagnosis of cardiovascular diseases and developing automated decision support systems.

¹⁵ Jungiewicz M. et al. Vision Transformer in stenosis detection of coronary arteries //Expert Systems with Applications. – 2023. – T. 228. – P. 120234.

¹⁶ Al-Tam R. M. et al. A Hybrid Framework of Transformer Encoder and Residential Conventional for Cardiovascular Disease Recognition Using Heart Sounds //IEEE Access. – 2024.

¹⁷ Dhanka S., Maini S. Random Forest for heart disease detection: a classification approach //2021 IEEE 2nd International Conference On Electrical Power and Energy Systems (ICEPES). – IEEE, 2021. – P. 1-3.

1.2 Decision Tree Algorithms and Their Modifications:

1.2.1 Random Forest

Random Forest has proven to be a powerful tool for diagnosing cardiovascular diseases due to its ability to handle complex data, identify key features, and provide high classification accuracy. The study by Sanjay Dhanka and Surita Maini¹⁷ demonstrated the application of Random Forest for analyzing data from the Cleveland Heart Disease Dataset, which included physiological parameters from 303 patients. The algorithm achieved an accuracy of 90.16%, highlighting its suitability for medical diagnostic tasks. In the work of Ashir Javeed and co-authors¹⁸ proposed an improvement to Random Forest using optimization algorithms such as Random Search and Grid Search, which increased the accuracy of heart failure diagnosis to 93.33% and reduced the number of features used to seven while maintaining high performance.

The study by Kellen Sumwiza and co-authors¹⁹ presented a model using Random Forest for analyzing Kaggle data with an accuracy of 99%. After data preprocessing, the model outperformed other methods such as SVM and logistic regression. These results demonstrate that the algorithm can effectively handle noise and missing data,

¹⁸ Javeed A. et al. An intelligent learning system based on random search algorithm and optimized random forest model for improved heart disease detection //IEEE access. – 2019. – T. 7. – P. 180235-180243.

¹⁹ Sumwiza K. et al. Enhanced cardiovascular disease prediction model using random forest algorithm //Informatics in Medicine Unlocked. – 2023. – T. 41. – P. 101316.

making it useful for processing medical images, which are often characterized by irregularity and variability in the data. In the work of Shahrokh Asadi and co-authors²⁰ proposed the integration of Random Forest with particle swarm optimization for diagnosing heart diseases. This approach improved the diversity of decision trees, enhancing classification accuracy. The use of such methods in medical imaging can improve the analysis of complex data, such as ultrasound images, where precise localization and classification of anomalies are required. The study by Fahime Khozeimeh and co-authors²¹ combined Random Forest with features extracted by convolutional neural networks (CNN) for diagnosing coronary artery disease. The model achieved an accuracy of 99.18%, confirming the effectiveness of the combined approach. Machine learning algorithms can be used together to analyze magnetic resonance imaging data, providing high accuracy and reliability in diagnostics. Thus, Random Forest can be successfully applied in medical imaging tasks for detecting and classifying cardiovascular diseases. The algorithm demonstrates its versatility and ability to adapt to various types of data, making it an important tool for automating diagnostic processes and improving their efficiency.

²⁰ Asadi S., Roshan S. E., Kattan M. W. Random forest swarm optimization-based for heart diseases diagnosis //Journal of biomedical informatics. – 2021. – T. 115. – P. 103690.

²¹ Khozeimeh F. et al. RF-CNN-F: random forest with convolutional neural network features for coronary artery disease diagnosis based on cardiac magnetic resonance //Scientific reports. – 2022. – T. 12. – №. 1. – C. 11178.

1.2.2 Gradient Boosting

Gradient boosting, particularly the CatBoost and XGBoost models, is a powerful tool for analyzing and predicting disease outcomes based on combined data, including images and clinical parameters. These algorithms provide high accuracy, making them promising for medical imaging tasks. The study by Xi Wei and co-authors²² demonstrates the use of a CatBoost model optimized with the SOLSSA algorithm for assessing the risk of cardiovascular diseases. The model was trained on two datasets from the Kaggle platform and achieved F1-scores of 90% and 81.51%, respectively. The integration of the improved search algorithm (SSA) enhanced the accuracy of predictions, minimizing misclassifications. This work highlights how the combination of numerical data, such as blood pressure and cholesterol levels, with visual data can be effectively used for diagnosing heart diseases, providing physicians with more accurate information for decision-making. In the study by Sumaira Ahmed and co-authors²³ a comparative evaluation of various algorithms, including CatBoost and XGBoost, was conducted for predicting heart diseases based on medical data. CatBoost demonstrated the highest accuracy among the studied models, highlighting its ability to handle complex

²² Wei X. et al. Risk assessment of cardiovascular disease based on SOLSSA-CatBoost model //Expert systems with applications. – 2023. – T. 219. – P. 119648.

²³ Ahmed S. et al. Prediction of Cardiovascular Disease on Self-Augmented Datasets of Heart Patients Using Multiple Machine Learning Models //Journal of Sensors. – 2022. – T. 2022. – №. 1. – P. 3730303.

data. The results confirm the applicability of gradient boosting algorithms for analyzing heart images and numerical clinical parameters, which is particularly important for predicting disease outcomes at early stages. The work of Krishna Kishore Thota and co-authors²⁴ illustrates the use of CatBoost and XGBoost for predicting chronic kidney disease, with CatBoost achieving an accuracy of 99.645%. Although the study focused on kidney diseases, the data analysis methods and algorithms can be applied to cardiovascular diseases, given their ability to handle complex datasets that include visual and clinical parameters. In the study by Zhaobin Qiu and co-authors²⁵ a model called CVDOCSCatBoost was proposed, which integrates the "cuckoo search" algorithm (OCS) with CatBoost for assessing the risk of cardiovascular diseases. This model demonstrated high performance compared to other algorithms, including XGBoost and SVM. Such an approach is applicable to tasks involving the analysis of combined data, where the visualization of pathologies can be supplemented with clinical parameters, enhancing the accuracy and reliability of diagnostics.

Gradient boosting models, such as CatBoost and XGBoost, provide high accuracy in analysis and classification tasks related to

cardiovascular diseases. Their ability to integrate numerical and visual data makes them particularly useful for medical imaging, where it is essential to consider the complexity and diversity of input information.

1.2.3 Clustering Algorithms and Unsupervised Learning:

1.2.3.1 K-Means

The application of clustering algorithms, such as K-Means, in medical imaging and data analysis provides effective tools for identifying clusters and segmenting abnormal areas, which is especially important for diagnosing cardiovascular diseases. In the study by M. Thangamani and co-authors²⁶ a hybrid model incorporating K-Means for analyzing coronary artery disease (CAD) risk data has been demonstrated. K-Means is used to identify patient clusters based on physiological characteristics. When combined with other algorithms like MLP and FURIA, the model enhances CAD classification accuracy, highlighting the importance of segmentation for detecting anomalies. The work of Rony Chowdhury Ripan and co-authors²⁷ explores the use of K-Means for detecting anomalies in medical data. The clustering algorithm is applied to preprocess data by filtering out

²⁴ Thota K. K. et al. A Model for Predicting Chronic Renal Failure using CatBoost Classifier Algorithm and XGBClassifier //2024 Second International Conference on Inventive Computing and Informatics (ICICI). – IEEE, 2024. – P. 96-102.

²⁵ Qiu Z. et al. A robust framework for enhancing cardiovascular disease risk prediction using an optimized category boosting model //Mathematical Biosciences and Engineering. – 2024. – T. 21. – №. 2. – C. 2943-2969.

²⁶ Thangamani M. et al. Efficient classification of heart disease using KMeans clustering algorithm //International Journal of Engineering Trends and Technology. – 2020. – T. 68. – №. 12. – P. 48-53.

²⁷ Ripan R. C. et al. A data-driven heart disease prediction model through K-means clustering-based anomaly detection //SN Computer Science. – 2021. – T. 2. – №. 2. – P. 112.

abnormal points, thereby enhancing the performance of subsequent classification. This approach is particularly relevant for tasks such as tissue segmentation or identifying abnormal areas in medical imaging. Quantum K-Means, proposed by S. Kavitha and Narasimha Kaulgud²⁸ presents a quantum version of the classical algorithm. This method accelerates the clustering process by using quantum computing to calculate distances, opening new prospects for processing large volumes of data, such as medical images, where tissue segmentation or anomaly detection is required. Tejaswini U. Mane²⁹ proposed an improved K-Means for working with big data, integrating it with ID3 for classification. This approach demonstrates the capabilities of K-Means in data preprocessing, providing segmentation and grouping of medical images. Combined with classification, it achieves an improvement in the accuracy of diagnosing cardiovascular diseases. Amita Malav and co-authors³⁰ A hybrid approach combining K-Means and artificial neural networks was developed for predicting cardiovascular diseases. K-Means identifies clusters based on medical data such as age, blood pressure, and cholesterol levels, enhancing the

model's accuracy in classifying healthy and diseased patients.

Finally, in the work by Roshan Joy Martis and Chandan Chakraborty³¹ K-Means was enhanced using a genetic algorithm (GA) for arrhythmia diagnosis. They employ global optimization of clustering parameters, enabling high accuracy in detecting patterns based on ECG data. This is particularly relevant for medical image segmentation and analysis tasks, where high precision is required. K-Means, in combination with other methods, holds significant potential for tissue segmentation, anomaly detection, and improving the diagnosis of cardiovascular diseases.

1.2.3.2 Principal Component Analysis (PCA)

The application of Principal Component Analysis (PCA) in cardiovascular disease diagnosis demonstrates its effectiveness for dimensionality reduction, accelerating algorithm performance, and improving analysis accuracy.

In the study by Syed Muhammad Saqlain Shah et al.,³² The study presents

²⁸ Kavitha S. S., Kaulgud N. Quantum K-means clustering method for detecting heart disease using quantum circuit approach //Soft Computing. – 2023. – T. 27. – №. 18. – P. 13255-13268.

²⁹ Mane T. U. Smart heart disease prediction system using Improved K-means and ID3 on big data //2017 International Conference on Data Management, Analytics and Innovation (ICDMAI). – IEEE, 2017. – P. 239-245.

³⁰ Malav A., Kadam K., Kamat P. Prediction of heart disease using k-means and artificial neural network as hybrid approach to improve accuracy //International

Journal of Engineering and Technology. – 2017. – T. 9. – №. 4. – P. 3081-3085.

³¹ Martis R. J., Chakraborty C. Arrhythmia disease diagnosis using neural network, SVM, and genetic algorithm-optimized k-means clustering //Journal of Mechanics in Medicine and Biology. – 2011. – T. 11. – №. 04. – P. 897-915.

³² Shah S. M. S. et al. Feature extraction through parallel probabilistic principal component analysis for heart

a Probabilistic PCA (PPCA)-based methodology for extracting meaningful features from medical data. PPCA effectively handles missing data and identifies projection vectors with maximum covariance. When combined with an RBF SVM for classifying patients into healthy and cardiovascular disease groups, the approach achieved an accuracy of 91.3%, highlighting PCA's importance in data optimization.

In the work by Donna Giri et al., PCA is applied alongside Discrete Wavelet Transform (DWT) for ECG signal analysis. PCA helps extract key features, which are then classified using various models. The highest accuracy (96.8%) was achieved with Independent Component Analysis (ICA) and Gaussian Mixture Model (GMM), further validating PCA's utility in processing and analyzing complex data.

Anna Karen Gárate-Escamila et al.³³ combined Chi-Square Feature Selection with PCA to analyze data from the UCI Heart Disease repository. This approach has significantly improved the performance of classification models, achieving up to 99.4% accuracy when using a combination of Cleveland-Hungarian datasets. This proves that PCA effectively simplifies data

processing and improves the prediction of cardiovascular disease.

Roshan Joy Martis et al.³⁴ PCA is used to classify five types of ECG-signals from the MIT-BIH database. The use of PCA for the analysis of segmented ECG signals led to the accuracy of the classification of 98.11%, which makes the method applicable for automated diagnostic tools. Carlo Ricciardi and co -authors³⁵ The PCA was investigated for the analysis of data from 10.265 patients in order to classify the condition of the coronary arteries. PCA helped improve the sensitivity of the model and reduce the time of training, providing a classification with an accuracy of 86%, which demonstrates its practical value in clinical applications. Diman Hassan and co -authors³⁶ They proposed an approach that combines pre - trained deep neural networks (DNN) to extract signs, PCA for reducing dimension and logistics regression for predicting heart disease. This method has reached accuracy up to 93.33%, showing how PCA can effectively integrate with modern machine learning methods.

These studies emphasize the role of PCA as a powerful tool for preliminary processing and analysis of complex visual and numerical data, increasing the effectiveness

disease diagnosis //Physica A: Statistical Mechanics and its Applications. – 2017. – T. 482. – P. 796-807.

³³ Gárate-Escamila A. K., El Hassani A. H., Andrès E. Classification models for heart disease prediction using feature selection and PCA //Informatics in Medicine Unlocked. – 2020. – T. 19. – P. 100330.

³⁴ Martis R. J. et al. The application of genetic algorithm for unsupervised classification of ECG //Machine Learning in Healthcare Informatics. – 2014. – P. 65-80.

³⁵ Ricciardi C. et al. Linear discriminant analysis and principal component analysis to predict coronary artery disease //Health informatics journal. – 2020. – T. 26. – №. 3. – P. 2181-2192.

³⁶ Hassan D., Hussein H. I., Hassan M. M. Heart disease prediction based on pre-trained deep neural networks combined with principal component analysis //Biomedical signal processing and control. – 2023. – T. 79. – P. 104019.

and accuracy of diagnosis of cardiovascular diseases.

1.2.3.3 Dbscan

The DBSCAN (Density-Based Spatial Clustering of Applications with Noise) is highly effective in the tasks of analyzing medical data, especially for detecting anomalies and segmentation, where traditional methods can be limited.

Research by Muhammad Fazal Ijaz and co - authors³⁷ He uses DBSCAN to detect emissions in data related to hypertension and diabetes. This approach, integrated with the SMOTE and RANDOM Forest methods, has to improve the accuracy of the classification of diseases and offer a tool for IOT monitoring of health status. Dbscan provides a more accurate removal of noise data, which improves the quality of the model.

Jingzhen LI and co -authors³⁸ demonstrates the use of DBSCAN in combination with CNN for non -invasive monitoring of glucose levels based on ECG. DBSCAN is used to eliminate noise in ECG data, and CNN to classify various glucose levels. This approach showed high accuracy in the diagnosis of diabetes, which confirms the

value of DBSCAN for processing complex signals. Norma Latif Fitriyani and co - authors³⁹ They proposed a model of predicting chronic diseases (including cardiovascular) using DBSCAN to remove emissions and SMOTE-ENN for data balancing. The results showed the superiority of this model in the accuracy of predicting diseases compared to other algorithms, confirming that DBScan effectively distinguishes rare and abnormal patterns in the data.

In the study by Kamran Mardani and co - authors⁴⁰ DBSCAN is used to segment coronary vessels in angiographic images. The algorithm made it possible to distinguish thin vessels that are poorly distinguishable in the original images, by removing the noise and the use of morphological operations. This method showed high accuracy (0.9729), emphasizing the potential of DBSCAN in medical visualization.

S. Latha and colleagues⁴¹ DBSCAN used in combination with Affinity Propagation for automatic segmentation of ultrasound images of carotid arteries. This approach made it possible to improve the accuracy of segmentation by 12% compared to manual

³⁷ Ijaz M. F. et al. Hybrid prediction model for type 2 diabetes and hypertension using DBSCAN-based outlier detection, synthetic minority over sampling technique (SMOTE), and random forest //Applied sciences. – 2018. – T. 8. – №. 8. – P. 1325.

³⁸ Li J. et al. Non-invasive monitoring of three glucose ranges based on ECG by using DBSCAN-CNN //IEEE journal of biomedical and health informatics. – 2021. – T. 25. – №. 9. – P. 3340-3350.

³⁹ Fitriyani N. L. et al. Chronic disease prediction model using integration of DBSCAN, SMOTE-ENN, and random forest //2022 ASU International Conference in Emerging Technologies for Sustainability and Intelligent Systems (ICETSIS). – IEEE, 2022. – P. 289-294.

⁴⁰ Mardani K., Maghooli K., Farokhi F. Segmentation of coronary arteries from X-ray angiographic images using density based spatial clustering of applications with noise (DBSCAN) //Biomedical Signal Processing and Control. – 2025. – T. 101. – P. 107175.

⁴¹ Latha S. et al. Fully automated integrated segmentation of carotid artery ultrasound images using DBSCAN and affinity propagation //Journal of Medical and Biological Engineering. – 2021. – T. 41. – P. 260-271.

annotation, demonstrating the effectiveness of DBSCAN in highlighting complex structures in medical data.

Dbscan is a powerful tool for analyzing medical images and data, especially in tasks related to the release of rare pathologies or segmentation of complex structures.

Results and discussion

Table1 01: Algorithmic Performance in CVD Diagnosis: A Comparative Study of CNNs, Transformers, and Clustering Methods"

Algorithm	Key Findings	Accuracy/Performance
Convolutional Neural Networks (CNN)	Automate feature extraction from medical images (ultrasound, MRI, ECG). Effective for lightweight IoT integration.	91.7%–98.23% (highest: Abubaker & Babayiğit)
ResNet/DenseNet	High accuracy in ECG/image analysis. Modified ResNet50 achieved near-perfect classification.	97.63%–99.12% (Gulhane et al.)
Vision Transformers (ViT)	Superior global pattern recognition for angiography and phonocardiographic signals. Hybrid models (ViT + ResNet) excel.	Up to 100% (Abbas et al.)
Random Forest	Robust handling of noisy/missing data. Combined with CNN for	90.16%–99.18% (Khozeimeh et al.)

Algorithm	Key Findings	Accuracy/Performance
	improved feature selection.	
Gradient Boosting	CatBoost outperforms XGBoost in integrated clinical + imaging data analysis.	F1-score : 90% (Wei et al.)
Clustering (K-Means, PCA)	PCA enhances model efficiency (99.4% accuracy). K-Means aids patient stratification.	91.3%–99.4% (Karen Gárate et al.)
DBSCAN	Effective noise removal in ECG/angiography. Enables precise vessel segmentation.	Segmentation accuracy: 97.29% (Mardani et al.)

► **Deep Learning Dominance:** CNNs and ResNet variants achieve >95% accuracy in most studies, excelling in automated feature extraction from medical images (e.g., ECG, MRI). Lightweight CNN architectures (e.g., Abubaker & Babayiğit) enable IoT integration for real-time monitoring.

► **Transformers Revolution:** ViT models demonstrate unparalleled performance in global pattern recognition (e.g., 100% accuracy in phonocardiographic signal classification). Hybrid architectures (ViT + ResNet) merge spatial and temporal analysis strengths.

► **Ensemble & Hybrid Models:** Random Forest and Gradient Boosting (CatBoost) show versatility, particularly when combined with CNNs. For example,

Khozeimeh et al. achieved **99.18% accuracy** using CNN-extracted features with Random Forest.

► **Clustering for Precision:** PCA reduces dimensionality without losing critical data, while DBSCAN improves segmentation accuracy in angiography by **12%** over manual methods (Latha et al.).

Conclusion

In conclusion, the review confirmed the high importance of using artificial intelligence algorithms to detect and classify cardiovascular diseases. Algorithms for machine learning and deep neural networks, such as bundle networks, Vision Transformers and clustering methods, demonstrate high potential to increase accuracy in diagnostics and automation of the process of analyzing medical data. Despite the successes achieved, certain problems are preserved, including insufficient clinical integration, a limited variety of data for teaching models, as well as the complexity of the interpretability of decisions proposed by the algorithms.

The review results show that existing AI methods offer promising solutions, but their practical application is restrained by a number of factors.

In particular, it is necessary to conduct research on more balanced data sets, take into account the adaptation of technologies to real clinical practice and pay more attention to the transparency of decisions made by algorithms.

This project is aimed at replenishing these shortcomings through the development of an inclusive model that can effectively work with a variety of data sets. Particular

attention is paid to the integration of algorithms into existing clinical systems and the creation of tools for visualization and explanation of solutions. This approach involves the adaptation of technology to real health conditions and provides the opportunity to use the model not only for diagnosis, but also to support medical decisions.

The method of searching for literature was based on the use of authoritative databases, such as Pubmed, IEEE XPLORE and Scopus. The analysis was carried out according to the publications of the last five years using keywords associated with the use of AI in cardiology. Particular attention was paid to research, which discusses the issues of diagnosis and visualization of cardiovascular diseases. The results of the selection ensured the formation of a holistic picture of the current state of the region and made it possible to identify areas for further research.

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