ABSTRACT
of the dissertation by Nurdaulet Tasmurzayev on the topic:
"Development of an intelligent system for detecting ischemic heart disease based on the Internet of medical things (IoMT) and machine learning",
submitted for the degree of Doctor of Philosophy (PhD)
in the educational program "8D07116 – Intelligent Control Systems"

Relevance of the research. Ischemic Heart Disease (IHD/CAD) remains the leading cause of mortality and disability worldwide, including the Republic of Kazakhstan. According to the World Health Organization, cardiovascular diseases claim the lives of more than 17 million people every year. Early and accurate diagnosis of CAD is a critically important prerequisite for effective treatment and the prevention of complications. At the same time, clinical practice faces persistent systemic constraints: a shortage of qualified specialists, the high cost of diagnostic procedures, and unequal access to medical care, especially in remote and resource-limited regions. In this context, the development of intelligent systems based on machine learning to support clinical decision-making is of paramount importance.

Traditional machine learning methods, including logistic regression and ensemble algorithms such as XGBoost, CatBoost, and RandomForest, are widely used for CAD classification based on clinical data. However, these methods have significant limitations. First, clinical datasets are typically characterized by substantial class imbalance. Second, traditional models treat features as independent input variables, which prevents adequate modeling of complex interactions among demographic indicators, laboratory data, ECG results, and echocardiography data. Third, the limited size of available clinical cohorts increases the risk of overfitting when high-parameter architectures are applied.

Transformer architectures based on the self-attention mechanism open fundamentally new opportunities for analyzing structured medical data by allowing the model to explicitly account for relationships among features. Nevertheless, with small datasets, standard transformer architectures are prone to overfitting, while ignoring the clinical structure of the input data leads to the loss of clinically significant information.

A separate problem concerns the confidentiality and security of medical data. Transmitting clinical records to cloud computing environments creates risks of violating patient privacy. Consequently, the practical deployment of intelligent medical systems requires fully local, on-device data processing, which in turn calls for compact models adapted to the resource constraints of embedded edge computing platforms.

Thus, the development of an intelligent system that combines a hierarchical transformer architecture accounting for the clinical structure of features, robust training on imbalanced and small datasets, and an efficient model compression and edge deployment strategy with decision transparency is an important scientific task of both theoretical and applied significance.

The aim of the dissertation is to develop an intelligent system based on a hybrid transformer architecture and a model for edge devices in order to improve the accuracy and efficiency of coronary artery disease detection.

To achieve this aim, the following tasks are addressed in the work:

1) Development of a hybrid transformer architecture (HG-Former) incorporating the ADASYN algorithm to eliminate class imbalance and training optimization using Adaptive Sharpness-Aware Minimization (ASAM) to improve the accuracy of CAD detection;

2) Development of a model for transferring and efficiently deploying the model on edge devices, including knowledge distillation and SHAP.

Research methods: machine learning and deep learning methods for tabular data classification, and edge deployment methods.

The object of the research is the process of intelligent analysis of clinical medical data for detecting coronary artery disease using machine learning, explainable artificial intelligence, and edge computing methods.

The subject of the research comprises machine learning models, methods, and algorithms for CAD detection, including the HG-Former hybrid transformer architecture (with the ASAM optimizer) and model compression algorithms for deployment on edge devices.

The scientific novelty of the obtained results is as follows:

− an algorithm for detecting coronary artery disease is proposed, based on a new hybrid architecture that combines a hierarchical transformer architecture with the Adaptive Sharpness-Aware Minimization method, which ensured effective model training under conditions of a limited dataset;

− a model for detecting coronary artery disease on edge devices is proposed, based on the joint application of knowledge distillation and SHAP-driven feature selection. This made it possible to significantly reduce the number of features used while maintaining high classification accuracy.

Provisions submitted for defense:

− the developed algorithm for detecting coronary artery disease, based on the HG-Former hybrid transformer architecture and the Adaptive Sharpness-Aware Minimization method and trained on the Z-Alizadeh Sani dataset, ensures high CAD classification performance with an accuracy of 96.72%, which exceeds existing alternative methods by 10% on average;

− the developed model for detecting coronary artery disease on edge devices, using knowledge distillation and SHAP-driven feature selection, achieves a classification accuracy of 91.80%, which is on average 5-8% higher than baseline compact models. At the same time, the number of features used is reduced from 56 to 16.

Theoretical and practical significance of the research. An intelligent system for detecting coronary artery disease has been developed, combining the high-accuracy HG-Former hybrid transformer architecture, robust training on small and imbalanced

medical data, and the possibility of local deployment of the model on edge devices. The proposed approach improves the accuracy and reliability of CAD classification, reduces the risk of overfitting, ensures decision transparency through SHAP analysis and attention mechanisms, and also makes it possible to process medical data without transmitting it to the cloud, which enhances the confidentiality, accessibility, and practical applicability of intelligent medical systems. The practical applicability of the developed system is confirmed by its implementation in the ZhurekAI intelligent diagnostic platform at JSC "Research Institute of Cardiology and Internal Medicine".

Reliability of the scientific results is ensured by the application of advanced deep learning methods, including hybrid transformer architectures (HG-Former) and edge computing (Edge ML). The results are confirmed by computational experiments on real clinical data, external validation on an independent cohort from the MIMIC-IV database, the successful application of knowledge distillation and SHAP analysis, as well as the successful comparison of the proposed models with existing methods for classifying coronary artery disease.

Relationship of the topic to research program plans. The dissertation was carried out within the framework of research projects of the Ministry of Science and Higher Education of the Republic of Kazakhstan (funding source: the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan):

− grant funding (GF) AP26103523 "Development of an intelligent system for monitoring and diagnosing sleep disorders using blockchain technology and IoMT (Internet of Medical Things)" for 2025-2027.

Structure and content of the dissertation. The dissertation consists of an introduction, four main chapters, a conclusion, and a list of references.

The introduction substantiates the relevance of the topic, clearly defines the aim and objectives of the research, identifies the object and subject of the research, discloses the scientific novelty and practical significance of the work, and sets out the main provisions submitted for defense.

The first chapter presents a literature review covering classical machine learning methods for CAD diagnosis, modern artificial intelligence methods in cardiology, the mathematical foundations of transformer architectures, model optimization and compression algorithms, as well as a critical analysis of existing hybrid and combined approaches.

The second chapter sets out the mathematical models of the proposed system, describes the datasets and their preprocessing methods, the main technical components of the HG-Former architecture, and the training and optimization procedures, and also presents the results of preliminary comparative experiments based on the sequential removal (ablation) of architectural components.

The third chapter describes the HG-Former hybrid architecture, including the grouping of clinical features and the tokenization mechanism, intra-group and inter-group transformer encoders, the integration of the ASAM algorithm, the results of

experiments on the Z-Alizadeh Sani dataset, SHAP analysis, and interpretation of the attention mechanism. The full HG-Former configuration, trained jointly with the ASAM optimizer, achieved on the held-out test set an AUC of 0.9755, accuracy of 0.9672, F1-score of 0.9762, Macro Recall of 0.9767, and PR-AUC of 0.9919, substantially outperforming ten classical baseline machine learning models, including CatBoost, XGBoost, RandomForest, and FT-Transformer, as well as five stacking ensembles optimized with swarm algorithms. External validation on an independent cohort of 800 patients extracted from the MIMIC-IV database showed an AUC of 0.9620 and accuracy of 0.9038.

The fourth chapter presents an optimized algorithm for deployment on edge devices, including knowledge distillation into the compact ProtoNN student model, SHAP-driven feature selection, quantization and pruning, and TFLite deployment on a Raspberry Pi Zero 2W. The joint application of knowledge distillation and SHAP-based feature selection made it possible to reduce the input feature space from 56 to 16 clinically informative variables, while compressing the model to a size of 4.35 KB in TFLite format. The student model achieved a classification accuracy of 91.80% and an AUC of 0.9651, reducing inference latency to 0.0740 ms per prediction – approximately 400 times faster than the original teacher model.

The conclusion sets out the main results and conclusions of the dissertation.

Publications. The results of the dissertation research have been published in 6 works. Among them are 5 articles in international scientific journals indexed in Web of Science and Scopus, 1 article 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, as well as 2 copyright certificates and 1 utility model patent resulting from the practical implementation of the dissertation research.

Scientific publications:

1. Tasmurzayev, N.; Amangeldy, B.; Imankulov, T.; Imanbek, B.; Postolache, O.A.; Konysbekova, A. A Wearable IoT-Based Measurement System for Real-Time Cardiovascular Risk Prediction Using Heart Rate Variability. Eng 2025, 6, 259. https://doi.org/10.3390/eng6100259 (IF: 0.4, Scopus Percentile: 58%, Q2).

2. Tasmurzayev, N.; Amangeldy, B.; Imanbek, B.; Baigarayeva, Z.; Imankulov, T.; Dikhanbayeva, G.; Amangeldi, I.; Sharipova, S. Digital Cardiovascular Twins, AI Agents, and Sensor Data: A Narrative Review from System Architecture to Proactive Heart Health. Sensors 2025, 25, 5272. https://doi.org/10.3390/s25175272 (IF: 3.5, Scopus Percentile: 88%, Q1).

3. Tasmurzayev, N.; Imanbek, B.; Boltaboyeva, A.; Dikhanbayeva, G.; Zhussupbekov, S.; Saparbayeva, Q.; Amirkhanova, G. Explainable AI for Coronary Artery Disease Stratification Using Routine Clinical Data. Algorithms 2025, 18, 693. https://doi.org/10.3390/a18110693 (IF: 2.3, Scopus Percentile: 78%, Q1).

4. Tasmurzayev, N.; Baigarayeva, Z.; Amangeldy, B.; Imanbek, B.; Kurmanbek, S.; Dikhanbayeva, G.; Amirkhanova, G. Interpretable Machine Learning for Coronary

Artery Disease Risk Stratification: A SHAP-Based Analysis. Algorithms 2025, 18, 697. https://doi.org/10.3390/a18110697 (IF: 2.3, Scopus Percentile: 78%, Q1).

5. Tasmurzayev, N.; Amangeldy, B.; Baigarayeva, Z.; Boltaboyeva, A.; Imanbek, B.; Maeda-Nishino, N.; Zhussupbekov, S.; Baidauletova, A. Enhancing Cardiovascular Disease Classification with Routine Blood Tests Using an Explainable AI Approach. Algorithms 2025, 18, 708. https://doi.org/10.3390/a18110708 (IF: 2.3, Scopus Percentile: 78%, Q1).

6. Tasmurzayev, N.; Turmakhanbet, D.; Kakharov, A.; Aitkazin, M.; Baidauletova, A.; Kozhamberdiyeva, M. CVD Prediction from HRV Derived from Wearable PPG. JPCSIT, vol. 3, no. 4, Dec. 2025. https://doi.org/10.26577/jpcsit202542.

7. Copyright certificate: Turmakhanbet D. N., Tasmurzayev N. M., Maulenbekov M. A., Ibashova A. B., Saparbayeva K. Zh., Imanbek B. T., Boltaboyeva A. K., Aitkazin M. K., Iskakova A. M., Kudyarova Zh. B., Amangeldy B. S., Baigarayeva Zh. E., Zholdybayeva Zh. K., Baidauletova A. I. Method for determining the level of mental stress based on analysis of heart rate variability and PPG pulse wave amplitude. Certificate of state registration of rights to a copyright object No. 62846 dated October 9, 2025.

8. Copyright certificate: Turmakhanbet D. N., Tasmurzayev N. M., Maulenbekov M. A., Ibashova A. B., Saparbayeva K. Zh., Imanbek B. T., Boltaboyeva A. K., Aitkazin M. K., Iskakova A. M., Kudyarova Zh. B., Amangeldy B. S., Baigarayeva Zh. E., Zholdybayeva Zh. K., Baidauletova A. I. Software package for assessing vascular age and arterial stiffness based on photoplethysmogram analysis. Certificate of state registration of rights to a copyright object No. 63527 dated October 29, 2025.

9. Utility model patent: Imanbek B. T., Boltaboyeva A. K., Amangeldy B. S., Tasmurzayev N. M., Nurlanov Yu. Yu., Kopenov A. B., Ibrasheva Z. S., Omirbekova Zh. Zh., Mansurova M. Ya., Baigarayeva Zh. E., Amirkhanova G. A. Cardiovascular system parameters monitoring system. Utility model patent No. 10282 dated November 7, 2025.