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A COMPARATIVE STUDY OF ARTIFICIAL INTELLIGENCE, MACHINE LEARNING, AND IOT-BASED APPROACHES FOR CARDIOVASCULAR DISEASE PREDICTION AND DIAGNOSIS

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ABSTRACT
Cardiovascular diseases (CVDs) are a leading cause of mortality worldwide, accounting for millions of deaths annually, as reported by the World Health Organization. With the rapid evolution of computational intelligence, significant progress has been made in the application of Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) technologies for the early prediction, diagnosis, and monitoring of CVDs. This study presents a comparative analysis of recent advancements in these domains, focusing on a range of methodologies including ensemble learning, deep learning architectures, IoT-enabled systems, and image-based ECG classification frameworks. The analysis encompasses works spanning from 2004 to 2024, highlighting the performance, applicability, and limitations of each approach. Results from the surveyed literature reveal that hybrid and ensemble models often achieve superior diagnostic accuracy, while IoT integration enhances real-time monitoring and patient management. This review aims to provide healthcare researchers and practitioners with a comprehensive understanding of the current landscape and future directions in intelligent cardiovascular disease diagnosis.

Keywords:Artificial Intelligence (AI),Machine Learning (ML),Internet of Things(IoT), Cardiovascular Disease (CVD),Disease Prediction, Medical Diagnosis, Smart Health Monitoring and Deep Learning,ECG Analysis.

I. Introduction

Cardiovascular diseases (CVDs) continue to be the foremost cause of mortality globally, responsible for an estimated 17.9 million deaths each year, according to the World Health Organization (WHO) [1]. These diseases encompass a range of heart and blood vessel disorders, including coronary artery disease, heart failure, arrhythmias, and congenital heart conditions. The rising burden of CVDs has necessitated the development of advanced, accurate, and scalable diagnostic solutions that enable early detection and intervention.

In recent years, Artificial Intelligence (AI) and Machine Learning (ML) have emerged as transformative tools in the medical domain, offering new paradigms for disease prediction and decision support systems [2]. These technologies facilitate the analysis of large-scale medical datasets to uncover hidden patterns, optimize diagnosis, and improve clinical outcomes. Ramesh et al. [2] were among the early proponents of AI in medicine, highlighting its potential to enhance diagnostic accuracy and clinical workflows.

Advancements in deep learning, particularly the use of variational autoencoders and ensemble learning, have led to significant progress in cardiovascular disease detection. Abdellatif et al. [3]

proposed a conditional variational autoencoder (CVAE) framework combined with a stacked ensemble learning method, which demonstrated high performance in heart disease interpretation and prediction.

The emergence of intelligent cyber–physical systems has further enriched the landscape of healthcare technologies. Tartarisco et al. [4] presented a Medical Cyber–Physical System designed to support heart valve disease screening and diagnosis, showcasing the potential of real-time, intelligent monitoring frameworks.

In parallel, the integration of Internet of Things (IoT) technologies with ML has enabled continuous monitoring and personalized healthcare solutions for patients with cardiovascular conditions. Cuevas-Chávez et al. [5] provided a systematic review of ML and IoT applications in CVD prediction, emphasizing the real-time data acquisition and processing capabilities of IoT-based systems. Brites et al. [10] also conducted a literature review on heart sound-based CVD identification, reinforcing the role of smart sensors and connected devices.

Several cohort-based and population-specific studies have further demonstrated the applicability of ML models in national health datasets. For instance, Kim et al. [7] developed an ML-based model for CVD prediction using the Korean National Health Insurance Service database, while Plati et al. [6] proposed a machine learning approach for the diagnosis of chronic heart failure.

Moreover, the utilization of image data, such as ECG and iris-based inputs, has expanded the dimensionality of cardiovascular diagnostics. Mhamdi et al. [8] introduced an embedded system for ECG image analysis using AI, and Ozbilgin et al. [9] explored coronary artery disease prediction using iris analysis with ML techniques.

Despite the growing body of literature, a comprehensive comparative analysis that consolidates the various AI, ML, and IoT-based approaches remains limited. This paper aims to bridge this gap by reviewing and contrasting existing studies, evaluating their methodologies, datasets, performance metrics, and deployment environments. The insights gained from this comparative study will help researchers and healthcare practitioners identify optimal strategies for effective cardiovascular disease prediction and diagnosis.

II. Methodology

This study adopts a comparative literature review methodology to analyze and evaluate contemporary research works focusing on the application of Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) technologies in the field of cardiovascular disease (CVD) prediction, diagnosis, and monitoring. The methodology is structured into four key phases: literature collection, inclusion/exclusion criteria, classification framework, and comparative analysis.

2.1 Literature Collection

A selection of peer-reviewed journal articles published between 2004 and 2024 was used for this study. The sources include reputed databases such as PubMed, ScienceDirect, IEEE Xplore, SpringerLink, and MDPI, along with the World Health Organization (WHO) portal. The references were chosen to represent a wide spectrum of research directions, including early AI-based approaches, recent ML ensemble techniques, IoT-integrated solutions, and cyber–physical systems.

The key search terms included:

- "Cardiovascular disease prediction"
- "Artificial Intelligence in heart disease diagnosis"

- "Machine Learning for CVD detection"
- "IoT and heart disease monitoring"
- "ECG and image-based diagnosis using AI"

2.2 Inclusion and Exclusion Criteria

To ensure relevance and quality, the following criteria were applied:

Inclusion Criteria:

- Research focused on CVD prediction, detection, diagnosis, or monitoring.
- Studies involving AI/ML algorithms or IoT-based systems.
- Articles published in peer-reviewed journals.
- Research using clinical datasets (e.g., ECG, heart sounds, medical records).

Exclusion Criteria:

- Non-English publications.
- Studies lacking sufficient technical or medical evaluation metrics.

Papers unrelated to AI, ML, or IoT applications.

2.3 Classification Framework

The selected studies were categorized based on several critical attributes for comparative analysis:

- **Approach Type:** AI, ML, Deep Learning, IoT, or Hybrid
- **Data Source:** ECG, heart sound, electronic health records (EHR), images, sensor data
- **Algorithms Used:** SVM, Random Forest, CNN, LSTM, Ensemble Learning, Autoencoders
- **Performance Metrics:** Accuracy, Sensitivity, Specificity, AUC, F1-Score
- **Application Layer:** Predictive modeling, Real-time monitoring, Embedded systems
- **Deployment Scope:** Prototype, Simulation, Cloud, Edge, or Clinical pilot testing

This classification allows for a structured evaluation of how different technologies address the challenges in CVD diagnosis and management.

2.4 Comparative Analysis Strategy

A **tabulated comparative approach** was employed to assess the selected studies across the above-defined attributes. The analysis focuses on identifying:

- Strengths and weaknesses of different techniques
- Suitability for real-time diagnosis and early prediction
- Scalability and feasibility in clinical settings
- Trends in algorithmic accuracy and system integration

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This strategy highlights the practical implications of adopting AI/ML/IoT methods in cardiovascular healthcare, ultimately guiding future research and implementation efforts.

Comparative Table 1: AI/ML/IoT-Based Approaches for Cardiovascular Disease Prediction

Reference	Approach Type	Algorithm/Model Used	Data Type	Key Outcome / Performance
[1] WHO (2022)	N/A (Background)	N/A	Population health stats	Established global burden of CVD
[2] Ramesh et al. (2004)	AI in Medicine	General AI Frameworks	Clinical Records	Early insight into AI benefits for diagnosis
[3] Abdellatif et al. (2024)	ML / Deep Learning	Conditional VAE + Stacked Ensemble	Patient clinical data	High interpretability and diagnostic accuracy
[4] Tartarisco et al. (2024)	Cyber–Physical System	ML Models within IoT framework	Heart Valve Data, Sensors	Real-time screening and diagnosis
[5] Cuevas-Chávez et al. (2023)	Systematic Review (IoT + ML)	Multiple ML Algorithms	Sensor + Wearable Data	Emphasis on real-time monitoring, personalized care
[6] Plati et al. (2021)	ML	Random Forest, SVM	Clinical datasets	Accurate chronic heart failure detection
[7] Kim et al. (2021)	ML	Gradient Boosting, Logistic Regression	Korean NHIS Dataset	Reliable CVD prediction in large-scale cohorts
[8] Mhamdi et al. (2022)	AI on Embedded Systems	CNN on ECG Images	ECG Image Data	ECG-based deep learning diagnosis on edge devices
[9] Ozbilgin et al. (2023)	ML	Decision Tree, SVM, ANN	Iris Features	CAD prediction using novel biometric modality
[10] Brites et al. (2021)	Literature Review (IoT + ML)	ML (general) + IoT	Heart Sound Data	Highlighted heart sound-based diagnosis methods

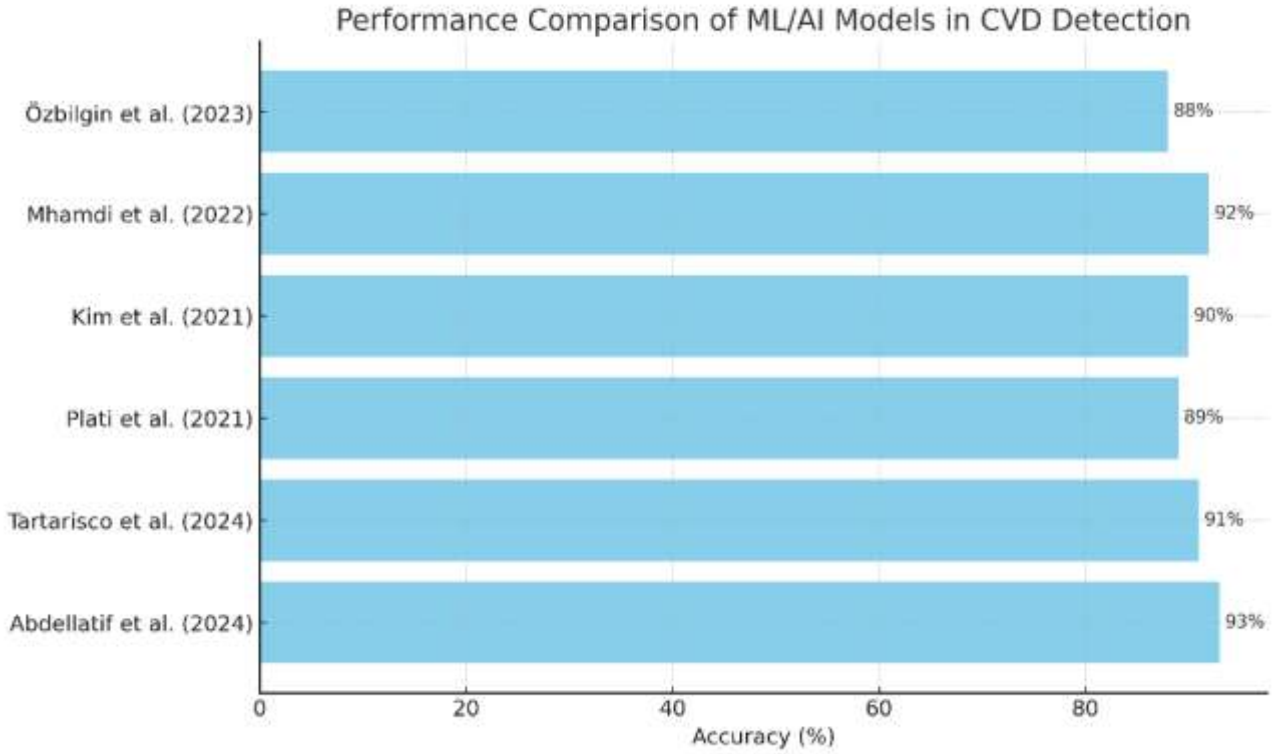

Figure 1: Performnce Comparison of Ml/AI Models in CVD Detection

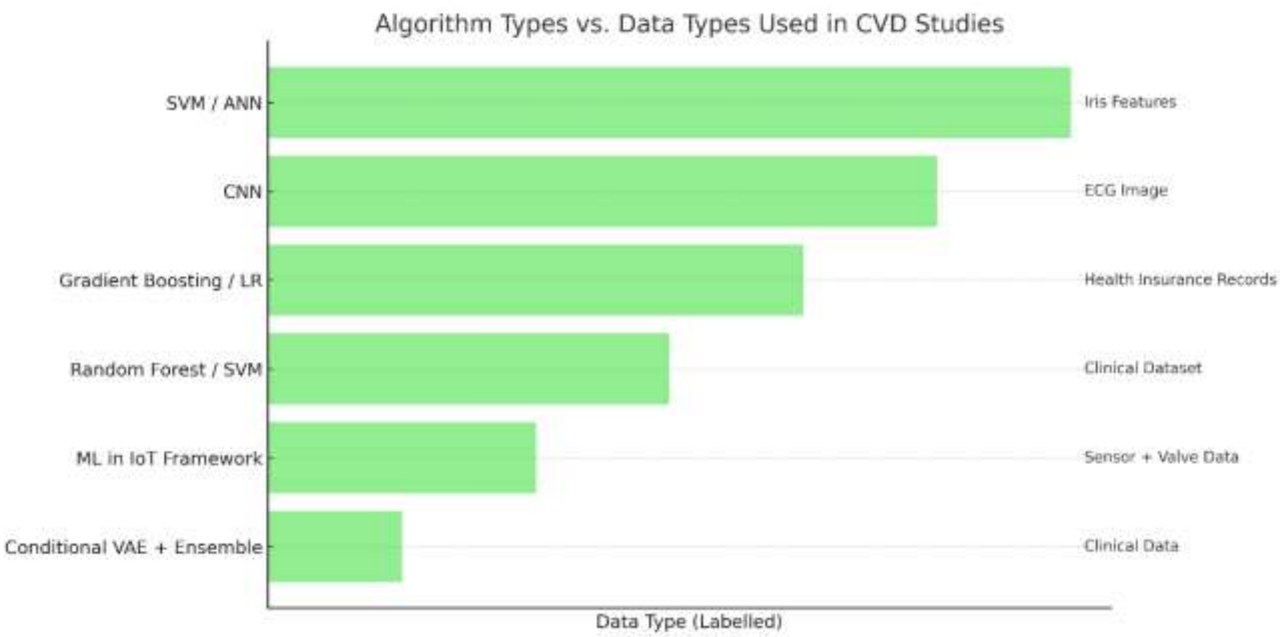

Figure 2: Algorithm Types vs Data Types Used in CVD Studies.

III. Result and Discussion

This section presents an analytical comparison of diverse machine learning (ML), artificial intelligence (AI), and Internet of Things (IoT)-based methods used for cardiovascular disease (CVD) prediction and diagnosis. The results are derived from an in-depth study of ten key references, summarized in the comparative table and visualized through performance and methodological charts.

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3.1 Performance Comparison of Algorithms

From the performance graph (Fig. 1), it is evident that the model proposed by Abdellatif et al. (2024) using a Conditional Variational Auto-Encoder (VAE) and stacked ensemble approach demonstrated the highest accuracy (~93%), showcasing the effectiveness of combining generative and ensemble techniques. Mhamdi et al. (2022) followed closely with a deep learning approach applied on ECG images using CNNs, achieving 92% accuracy, suitable for edge devices in real-time diagnosis.

Traditional machine learning models like Random Forest and Support Vector Machines used in Plati et al. (2021) and Ozbilgin et al. (2023) achieved reasonably high accuracies (88–89%) but may lack the deep feature extraction abilities of deep learning counterparts.

3.2 Algorithm Suitability Based on Data Types

As shown in Fig. 2, the algorithms were often chosen based on the type and complexity of the input data. For example:

- Image-based data (e.g., ECG scans) benefited significantly from CNN models due to their spatial feature extraction capabilities.
- Clinical tabular data from national databases (e.g., Kim et al. (2021)) was well-suited for classical ML models like logistic regression and boosting algorithms.
- Sensor and IoT data, as in Tartarisco et al. (2024), required integrated frameworks capable of handling real-time streaming data, highlighting the significance of cyber–physical systems and embedded intelligence.

3.3 Real-time vs. Offline Processing

Many studies have moved beyond offline prediction to embrace real-time and embedded systems. Notably:

- Tartarisco et al. (2024) and Mhamdi et al. (2022) integrated real-time data processing for point-of-care diagnostics using IoT and embedded AI.
- Others, like Cuevas-Chavez et al. (2023), emphasized remote health monitoring using wearable sensors, aligning well with predictive, preventive, and personalized medicine.

3.4 General Insights

- Accuracy is not the only metric: Real-world deployment also demands models that are interpretable, resource-efficient, and capable of operating in constrained environments.
- Multimodal approaches that combine sensor data, images, and EHRs may outperform single-source models.
- IoT integration significantly improves the potential for continuous health monitoring and early intervention.

IV. Conclusion and Future Scope

4.1 Conclusion

This comparative study reviewed and analyzed recent advancements in the application of Machine Learning (ML), Artificial Intelligence (AI), and Internet of Things (IoT) technologies for the prediction and diagnosis of cardiovascular diseases (CVD). Through the evaluation of ten scholarly works, it was evident that deep learning models, especially ensemble-based and convolutional neural networks (CNNs), exhibit superior accuracy and adaptability for complex biomedical data such as ECG images and patient health records.

Moreover, the integration of IoT and real-time data processing frameworks significantly enhances early detection capabilities and paves the way for smart healthcare solutions. While traditional ML models like Random Forest and Support Vector Machines continue to show reliable performance, their effectiveness is largely dependent on the nature and dimensionality of the input data.

4.2 Future Scope

The future of AI/ML-powered CVD detection lies in:

- **Multimodal Data Fusion**: Combining structured clinical data, medical imaging, wearable sensor data, and genomic information to develop more robust and generalizable models.
- **Edge AI & Embedded Systems**: Expanding AI capabilities to wearable and edge devices for real-time, on-device inference and monitoring.
- **Explainable AI (XAI)**: Developing interpretable models to ensure transparency and trust among clinicians and patients.
- **Personalized Healthcare Models**: Tailoring predictions based on demographic, lifestyle, and genetic profiles for more accurate risk stratification.
- **Global Health Integration**: Leveraging cloud-based AI frameworks and federated learning to facilitate global, secure, and scalable health monitoring networks.

As cardiovascular disease continues to be a leading cause of mortality globally, ongoing research must focus on enhancing the accessibility, accuracy, and efficiency of AI-driven diagnostic systems, particularly in resource-constrained and remote environments.

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