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Review of Heart-Risk Monitoring System

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ABSTRACT

Cardiovascular diseases continue to be among the major causes of death globally, hence making early diagnosis and monitoring crucial to enhance the quality of care. Systems that utilise electrocardiogram (ECG) signals together with artificial intelligence,e such as machine learning, deep learning, and the Internet of Things (IoT), together with wearable health devices, have revolutionised cardiac diagnostics in the contemporary age. In this literature review, there will be an extensive evaluation of new developments in ECG signal processing and arrhythmia detection techniques, wearable ECG monitors, and intelligent health applications. This work assesses different machine learning algorithms that include SVM, CNN, LSTM, MLP and hybrid deep learning algorithms that can be applied to classify ECG signals. Other areas that are covered include remote IoT healthcare systems, cloud computing based on ECG monitoring, explainable artificial intelligence models, FHIR interoperability standards and others. The strengths, limitations, data sets, pre-processing techniques, and results achieved by recent studies are reviewed.

Keywords: *Heart Risk Monitoring, ECG, SpO_2, AD8232, MAX30102, ESP32, Machine Learning, IoT Healthcare, Cardiovascular Disease Prediction, Real-Time Monitoring.*

INTRODUCTION

Cardiovascular diseases represent one of the significant global health challenges leading to the death of millions of individuals each year. The electrocardiogram (ECG) represents one of the most used methods for assessing heart abnormalities and arrhythmias. The interpretation of ECG results normally relies on cardiologist experts, which is sometimes time-consuming, particularly in case of long-term monitoring. Hence, the use of AI technology for automatic ECG interpretation has been extensively researched.

Recent developments in machine learning (ML), deep learning (DL), wearables sensor technology, as well as IoT-powered healthcare systems, have made it possible to carry out real-time monitoring of ECG data and detect the presence of arrhythmias automatically. Various scientific papers suggest that it is possible to classify ECG signal data using AI models based on the MIT-BIH Arrhythmia Database.

Smart healthcare devices empowered with artificial intelligence, as well as the use of cloud technology, enhance the availability of cardiac treatment and diagnosis.

FUNDAMENTALS OF ECG AND ARRHYTHMIA DETECTION

An ECG signal represents the electrical activity of the heart and contains several important wave components:

i. P-wave
ii. QRS wave complex
iii. T-wave

Abnormalities in these waveforms may indicate different forms of arrhythmia such as:

i. Atrial Fibrillation (AF)
ii. Ventricular Tachycardia (VT)
iii. Premature Ventricular Contractions (PVC)
iv. Left Bundle Branch Block (LBBB)
v. Right Bundle Branch Block (RBBB)

Automated ECG analysis systems primarily focus on:

i. Signal acquisition

ii. Noise filtering
iii. Feature extraction
iv. Classification
v. Real-time alert generation

ECG SIGNAL PROCESSING TECHNIQUES

Accurate ECG classification depends on signal preprocessing and feature extraction methods. Researchers have employed several techniques including:

a. NOICE REMOVAL AND FILTERING

Common ECG noises include:

i. Baseline wander
ii. Motion artifacts
iii. Power-line interference

Studies utilized:

i. Wavelet Transform
ii. Savitzky-Golay filtering
iii. Recursive Least Square filtering
iv. Band-pass filtering

For example, wearable ECG systems implemented recursive least square adaptive filters and Savitzky-Golay smoothing to improve signal quality before classification.

b. FEATURE EXTRACTION TECHNIQUES

Feature extraction transforms ECG signals into meaningful representations for ML models.
Popular methods include:

i. Fast Fourier Transform (FFT)
ii. Discrete Fourier Transform (DFT)
iii. Welch's spectral analysis
iv. PQRST feature extraction
v. RR interval analysis
vi. Wavelet decomposition

FFT and Daniell's Periodogram were used for arrhythmia classification in comparative ML and DL studies.

MACHINE LEARNING APPROACHES FOR ECG CLASSIFICATION

Machine Learning models are widely used due to their interpretability and lower computational requirements.

a. SUPPORT VECTOR MACHINE (SVM)

SVM is one of the most used classifiers for ECG analysis. Studies reported classification accuracy ranging from 70% to 97%.
A study comparing CNN and SVM approaches achieved:

i. CNN Accuracy: 87–90%
ii. SVM Accuracy: 70–76%

Another study demonstrated strong generalization capability using SVM and MLP models under leave-out patient validation protocols.

b. K-NEAREST NEIGHBOUR (KNN)

KNN classifiers showed promising performance in wearable healthcare systems.
A personalised ECG monitoring framework achieved over 97% classification accuracy using KNN models integrated with IoT healthcare interoperability standards.

c. RANDOM FOREST AND DECISSION TREES

Random Forest and Decision Tree models are also widely used due to their robustness and interpretability in healthcare environments.

DEEP LEARNING APPROACH

Deep Learning models automatically learn hierarchical features from raw ECG signals, eliminating the need for manual feature engineering.

a. CONVOLUTIONAL-NEURAL NETWORKS (CNN)

CNNs are among the most effective DL models for ECG classification.
Several studies reported:

i. 89% accuracy for arrhythmia classification using CNNs
ii. 92.6% accuracy for wearable ECG analysis
iii. 98.2% accuracy using explainable CNN frameworks

CNNs effectively extract temporal and morphological ECG features directly from raw signals.

b. HYBRID CNN-LSTM MODELS

Hybrid architectures combine CNN feature extraction with LSTM temporal learning.
A hybrid CNN-LSTM approach outperformed traditional models for SVEB and VEB arrhythmia classification.
Another advanced BLSTM-CNN framework achieved 98.75% accuracy for atrial fibrillation detection.

c. EXPLAINABLE AI (XAI)

Deep learning systems are often criticized for their "black box" behaviour. Explainable AI techniques such as Grad-CAM help visualize decision-making processes.
An interpretable CNN framework highlighted clinically important ECG regions such as QRS complexes during arrhythmia classification.

PORTABLE/WEARABLE ECG MONITORING SYSTEM

Portable/wearable ECG devices have revolutionised cardiac monitoring by enabling continuous patient observation outside hospital environments.

Key Features:

i. Lightweight wearable sensors
ii. Real-time ECG acquisition
iii. Wireless data transmission
iv. AI-based anomaly detection
v. Emergency alert systems

Wearable/portable systems using IoT platforms and cloud services enable continuous patient monitoring and timely intervention. A portable heart monitoring system integrated ECG, heart rate, and temperature sensing into a wearable vest system.

IoT AND CLOUD BASED HEALTHCARE INTEGRATION

IoT technology allows ECG devices to transmit real-time physiological data to cloud servers and healthcare providers.

Applications:

i. Remote patient monitoring
ii. ICU monitoring systems
iii. Telemedicine
iv. Smart home healthcare
v. Cloud analytics

An IoT-based ECG monitoring system utilised Arduino, ESP32, and Ubidots cloud for remote ECG visualisation and analysis. FHIR and SNOMED interoperability standards were also integrated into wearable ECG systems to enable Electronic Health Record (EHR) communication.

COMPRATIVE ANALYSIS OF EXISTING STUDIES

Study	Method	Dataset	Accuracy
Evaluation of ECG based Recognition of Cardiac Abnormalities using Machine Learning and Deep Learning	CNN vs SVM	MIT-BIH	87–90%
Personalized Wearable Systems for Real-time ECG Classification and Healthcare Interoperability	KNN + Neural Net	MITDB	>97%
Comparison Analysis for Life-Threatening Arrhythmia Classification from ECG Data Using Machine Learning and Deep Learning Methods	CNN	MVED	89%
Alimbayeva et al.	CNN	ECG Wearable Dataset	92.6%
Subhashini et al.	Explainable CNN	MIT-BIH	98.2%
Advanced Deep Learning Approaches for Automated Diagnosis of Cardiac Arrhythmia in Multi-lead ECG Signals	Dense Net + BLSTM	AF Dataset	98.75%

CHALLENGES AND RESEARCH GAP

Despite significant progress, several challenges remain:

i. DATA IMBALANCE

Many ECG datasets contain uneven distributions of arrhythmia classes.

ii. EXPLAINABILITY

Deep learning systems still lack sufficient transparency for clinical trust.

iii. REAL-TIME CONSTRAINTS

Wearable devices require low-power and computationally efficient models.

iv. NOISE SENSITIVITY

Motion artifacts and environmental noise reduce signal quality.

v. PRIVACY AND SECURITY

Cloud-connected healthcare systems face cybersecurity concerns.

FUTURE DIRECTIONS

Future ECG monitoring systems are expected to focus on:

i. Federated Learning for privacy-preserving AI
ii. Tiny ML for low-power wearable devices
iii. Explainable AI integration
iv. Multi-modal healthcare monitoring
v. Edge AI processing
vi. Personalized healthcare systems
vii. Real-time emergency prediction systems

The integration of AI, IoT, cloud computing, and wearable biosensors will continue transforming the next generation cardiac healthcare systems.

CONCLUSION

This review paper analysed recent developments in ECG-based cardiac monitoring and arrhythmia detection using Machine Learning, Deep Learning, wearable devices, and IoT technologies. Deep learning approaches, particularly CNN and hybrid CNN-LSTM architectures, demonstrated superior classification accuracy compared to conventional ML methods. Wearable ECG systems integrated with IoT, and cloud healthcare platforms provide continuous monitoring, real-time alerts, and improved patient accessibility.

However, challenges related to explainability, computational efficiency, security, and data quality still require further research. Future intelligent healthcare systems will increasingly rely on explainable, lightweight, and personalised AI-powered ECG monitoring solutions for accurate and proactive cardiac care.

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