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TECHNICAL PAPER

A novel enhanced spiking sheaf attention neural network for real-time health monitoring based on internet of things

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Abstract

Intelligent healthcare monitoring systems are emerging as a result of the proliferation of portable medical devices with Internet of Things (IoT) capabilities. Deep learning (DL) and the IoT help the healthcare sector by facilitating telemedicine, which lowers disease. It is imperative to identify and categorize arrhythmia stages early to diagnose the disease, since heart arrhythmia is a fatal condition that puts many lives at risk. Due to its poor accuracy, arrhythmia identification and classification remain very difficult in the medical field. A unique hybrid DL-based Internet of Things-enabled health surveillance system is suggested in this regard, offering better accuracy and fewer error rates in the prediction and classification of arrhythmias. Initially, the input Electrocardiogram data collected from the databases are subjected to a pre-processing stage in which irrelevant noise components are suppressed. Secondly, the useful critical features needed for disease prediction are selected using a Hybrid Leopard Seal Circle-Inspired Optimization approach. Next, a Hybrid Enhanced Spiking Sheaf Attention Neural Network is employed to predict and categorize arrhythmias according to the selected critical features. The Hybrid Enhanced Spiking Sheaf Attention Neural Network model's hyperparameters are optimized through the use of Artificial Rabbits Optimization. Lastly, the effectiveness of the proposed model is assessed using two publically accessible datasets: the Atrial Fibrillation Database (AFDB) and the MIT-BIH Arrhythmia Database. Experimental results show that the stated model achieves 99.4% accuracy on the AFDB and 99.2% accuracy on the MIT-BIH Arrhythmia Database.

1 Introduction

The World Health Assembly of the WHO estimates that cardiovascular disease accounts for 32% of the total deaths globally, making it the most significant cause of mortality. Similarly, sudden cardiac death (SCD) and 15–20% of all deaths worldwide and is caused by arrhythmia. Occasionally, arrhythmias are discovered after problems manifest; familiarity with the distinctive ECG abnormalities may provide preliminary indicators of these conditions, which, if identified early, may be life-saving. Consequently, to provide those suffering from cardiac arrhythmias with an appropriate course of treatment, early diagnosis requires continuous cardiac monitoring (Cañón-Clavijo et al. 2023). Cardiac arrhythmias need to be detected promptly since they might pose a serious risk to a person's life. While there are several techniques for detecting arrhythmias, the electrocardiogram, or ECG, is the one that is most frequently employed (Irfan et al. 2022). An ECG is a vital instrument for precisely capturing the electrical activity of the heart over an extended length of time. Worldwide, more than 300

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million medical ECG records are kept in clinics. ECG is the most significant, practical, and beneficial routine assessment technique (Dhyani et al. 2023a, b). The signals generated by an ECG machine, which is connected to the body of a person, are represented as waves. To obtain a precise image of the heart, 10 electrodes are required to record 12 leads, or signals. Because electrocardiograms measure and evaluate the electrical activity of the heart, which is represented in the data from the device, practitioners utilize them to identify specific cardiovascular disorders (Madan et al. 2022). Each of the six electrode configurations depending on the limbs and the chest makes up these signals. At varying angles, each electrode records a constant flow of electrical impulses produced by the heart that extends both horizontally and vertically (Irfan et al. 2022). In the ECG plot, a normal heartbeat is regular, whereas an arrhythmic heartbeat is erratic (Jamil and Rahman 2022). Cardiac arrhythmias can cause variations in the rhythm, consistency, transmission, or source of electrical signals, depending on the severity and aggressiveness of the illness. Signs may vary from mild sensations to heart pain that can cause a person to unexpectedly faint and die (Ramkumar et al. 2023). IoT-based healthcare systems facilitate the delivery of various healthcare services by enabling machine-to-machine (M2M) communication, interoperability, data mobility, and information exchange. Wearing or implanting this wireless IoT device allows patients to effortlessly collect their medical records remotely (Zamani et al. 2024; Kim et al. 2022). The caretaker can monitor patients' health conditions thanks to IoT and communication technology. Moreover, they deliver information precisely when needed, without expert assistance, making them more effective in rural areas. By tracking body temperature, blood pressure, heart rate, and a number of other physical fitness metrics, portable clinical devices seek to lower the fatality rates associated with heart disease arrhythmias (Kumar et al. 2023a, b). Previous studies integrated additional traditional Machine Learning (ML) techniques. The Naive Bayes approach is essential to ML and data mining. It is widely utilized in medical diagnostics and text categorization, among other ML classification problems. On the training dataset, the ML method performed exceptionally well; however, on the testing dataset, it performed less well (Dhyani et al. 2023a, b). DL technology (Sun 2023) offers a new and valuable example of the use of pathophysiological data in the process of therapeutic decision-making. DL techniques have recently conquered some hurdles that were faced by the traditional ML methods. The capacity to automatically extract important details from the data without the requirement for specialized feature selection and extraction approaches is its primary distinction from traditional ML. Several recent research have effectively used DL-based cardiac rhythm signal classification (Daydulo et al. 2023). The technique of manually labeling ECG data to identify cardiac rhythm abnormalities is time-consuming and prone to errors. DL may turn out to be a more realistic option for rapid, automatic classification with better training. DL is a potential method for the detection of cardiac arrhythmias, as it can discover important features on its own and then utilize that knowledge for self-learning and class differentiating. Moreover, DL is capable of working with large and noisy datasets and also be able to feature dimensionality reduction automatically. As a result, the DL has lit up many areas like image processing, healthcare, and malware detection (Ahmed et al. 2023). Signal pre-processing, extraction of features, and classification of patterns are the three methods typically used to categorize ECG signals. Eliminating various disturbances, including ECG signal drift, is the primary goal of signal pre-processing. The ECG waveforms are then used to derive several feature indicators after pre-processing. A feature subset is then selected to uncover the most essential details from the ECG data. Finally, a suitable classifier is adopted for the classification of different arrhythmia types (Golande and Pavankumar 2023). On the down side, the low magnitude and irregularity of ECG data make classification challenging. Consequently, most traditional ML classifiers do not work well because the connection between the learning variables is not well illustrated, particularly with high-dimensional data features (Hassaballah et al. 2023). To address the drawbacks of ML classifiers, the suggested study offers an effective arrhythmia classification method that combines a DL classifier with a hybrid meta-heuristic optimization technique. The three components of the suggested method include pre-processing the ECG signal, selecting key characteristics, and predicting disease before classifying different arrhythmia stages.

1.1 Motivation

IoT-based real-time health monitoring necessitates the continuous collection and quick analysis of physiological signals, such ECG, in order to identify significant cardiac events quickly. This project is motivated by the rapidly increasing demand for real-time, precise, and dependable health-monitoring systems in the IoT-based healthcare sector. Generally, the traditional methods for detecting arrhythmia suffer from delays in response, high computational requirements, and low accuracy when processing the ECG signals in real-time from the wearable devices. Such drawbacks slow down the diagnosis and consequently the intervention in severe cardiac diseases. Thus, the need for a low-latency, innovative system that can effectively manage large-scale, dynamic biomedical data is very pressing. The proposed hybrid DL model bridges this gap by combining cutting-edge neural network and optimization techniques to offer

Table 7 Ablation study results

Model variant	Description	Accuracy (%)	F1-score (%)	Error rate (%)
M_1: Baseline ESNN	Plain enhanced spiking neural network without DOST, HLSCIO, or ARO	94.8	94.1	0.052
M_2: ESNN + DOST	Adds DOST-based denoising only	96.7	96.1	0.038
M_3: ESNN + DOST + HLSCIO	Adds optimized feature selection using HLSCIO	98.5	98.2	0.021
M_4: Full HESSANN (DOST + HLSCIO + ARO)	Proposed complete framework	99.6	99.2	0.013

4.3 Discussion

Real-time ECG signal collection is made possible by the proposed IoT platform, which uses wearable sensor nodes to continuously record cardiac signals and send them to local edge gateways via energy-efficient wireless communication techniques like Bluetooth Low Energy (BLE) or Wi-Fi. The gateways use simplified versions of the DOST algorithm to perform on-device pre-processing and noise elimination, ensuring low latency and offload transmission. Afterwards, the refined signals are directed towards the edge computing layer where a HESSANN model that is locally optimized will allow for rapid arrhythmia detection and classification without the need for cloud access. Low latency, efficient bandwidth utilization, and strong data security are provided by the distributed architecture, enabling real-time health monitoring and prompt patient and doctor input.

5 Conclusion

Detecting cardiac arrhythmia which is a serious condition should be done correctly and early to prevent life-threatening complications. This is the challenge that HESSANN highlighting Hybrid Enhanced Spiking Sheaf Attention Neural Network powered by Artificial Rabbits Optimization (ARO) proposed for the prediction and classification of arrhythmia in an IoT-empowered real-time health monitoring system. The model was created using a 1:1 ratio of attention mechanisms and spiking neuron dynamics based on the features of the ECG data. The accuracy of the suggested approach was 99.4% and 99.2%, respectively, when compared to the conventional DL techniques when the pe-stage's performance was assessed using the AFDB and MIT datasets. However, the model did have certain shortcomings that need to be addressed. First off, real-time synchronization and communication overhead may impact responsiveness, which may limit the system's scalability when deployed over extensive IoT networks with diverse devices. Second, the data diversity is restricted to publicly available ECG databases; thus, testing for generalizability is required across wider demographic and multimodal physiological datasets. Third, while HESSANN is highly accurate, model interpretability remains an issue owing to the intricate nature of spiking and attention-based interactions and needs to be augmented with explainable AI (XAI) modules to represent and explain predictions visually. Lastly, hardware implementation on low-power embedded or FPGA platforms requires additional optimization of computational burden and memory usage to achieve energy-efficient real-time processing.

6 Future scope

In subsequent work, the model can be expanded by integrating multi-sensor fusion (e.g., blending ECG, PPG, and EEG signals) to increase robustness, investigating federated and edge learning paradigms for privacy-preserving scalability, and incorporating explainability layers to enhance clinical trust. Additionally, hardware-aware neural optimization and neuromorphic circuit integration can be pursued to implement the HESSANN model in low-cost wearable devices, leading towards a completely autonomous and interpretable IoT healthcare ecosystem. The developed model will eventually be utilized to forecast certain renal and diabetic illnesses using sophisticated neural network and meta-heuristic techniques to improve the accuracy of disease prediction and classification. Additionally, the proposed model is expanded to include suitable encryption mechanisms to safeguard healthcare data from different types of cyberattacks.

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Data availability Data sharing applicable to this article. URL: https://www.kaggle.com/datasets/protobioengineering/mit-bih-atrial-fibrillation-database and https://www.kaggle.com/datasets/taejoongyoon/mitbit-arrhythmia-database.

Declarations

Ethics approval This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate All the authors involved have agreed to participate in this submitted article.

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