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PacePanel: An Open-Source IoT-AI Platform for Remote Pacemaker Monitoring Simulation

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***Abstract* – Cardiac pacemakers help manage dangerous heart rhythm disorders for millions of people globally. However, most researchers cannot access the telemetry data from these devices because the data uses private company formats and strict medical regulations block sharing. In this paper we introduce Pacepanel, an open-source, simulated Iot-AI platform that recreates a full system for tracking pacemaker patients from a distance. Our system uses real ECG data from the MIT-BIH Arrhythmia Database [5]. It runs on a secure five-layer microservices setup. Key features include hybrid arrythmia detection, type-safe API calls, live waveform display and a mobile app that works on IOS, Android, and a Web. We tested 48 MIT-BIH recordings (over 109,000 labelled heartbeats). The system achieved 97.8% accuracy for ECG waveforms, alert delays under 500 ms, and 99.87% API reliability with 200 simultaneous connections. PaceaPanel offers a clinically useful, open testing platform that closes the accessibility gap in research on heart health technology.**

Keywords – MIT-BIH Database; ECG processing; arrythmia detection; deep learning; React Native; remote monitoring; IoT in healthcare

I. Introduction

According to the WHO, cardiovascular diseases lead to 17.9 million deaths every year around the world. The implantable cardiac pacemaker treats life-threatening arrhythmias such severe bradycardia, sick sinus syndrome, and complete heart block [1].

Even though pacemakers are clinically important, their telemetry data is hard for researchers to obtain. This includes electrograms, pacing logs, and battery status – all locked behind private vendor systems and safety regulations [2]. As a result, algorithm developers cannot test their detection algorithms against real data, and students have no safe way to study pacemaker behavior.

Pacepanel fills this gap with an open-source simulation platform that recreates the complete pacemaker data flow using public data only. The platform uses only public data and is not intended for commercial device integration.

Core Objectives: (a) generate realistic pacemaker telemetry from the MIT-BIH database [5]; (b) design a system with security as the priority; (c) build a hybrid engine for detecting arrhythmia; and (d) create a mobile application for iOS, Android, and web.

II. RELATED WORK

Zang et al. [1] developed an energy-efficient network which achieved 38% energy savings, but their system lacked pacemaker emulsion and arrythmia classification. Zhong et al. [2] tested scalable IoT network management across 10,000 nodes but did not address the meaning of medical data or sending alerts in clinical context. Hossain and Muhammad [4] described a cloud-based cardiac monitoring system which detected arrythmias with 94.2 accuracy on Android, however , it depended on proprietary hardware and did not simulate pacemaker behavior.

The MIT-BIH Arrythmia Database [5] is still the most widely used reference for cardiac rhythm classification in research. Rajpurkar et al. [6] achieved cardiologist-level performance by using a 34-layer CNN, however their model needed high-end GPUs. Acharya et al. [7] developed a compact CNN-LSTM hybrid which reached 981% accuracy with only 1.2 million parameters – we used this design in Pacepanel. On the security side, Malik et al [3] suggested using elliptic curve Diffie-Hellam, which influenced how we implemented our TLS 1.3 and JWT setup.

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Table 1. Comparison of PacePanel with Related Work

Reference	Arrythmia AI	Mobile App	Pacemaker Sim.	Security	Open Source
Zhang et al. [1]	No	No	No	Basic	No
Zhong et al. [2]	No	Yes	No	HTTPS	Partial
Malik et al. [3]	No	No	No	PKI/IoT	Yes
Hossain et al. [4]	Yes	Android only	No	HTTPS only	No
Acharya et al. [7]	Yes	No	No	None	Partial
PacePanel (This Work)	Yes	iOS/Android/Web	Yes	TLS 1.3+JWT+AES-256	Yes

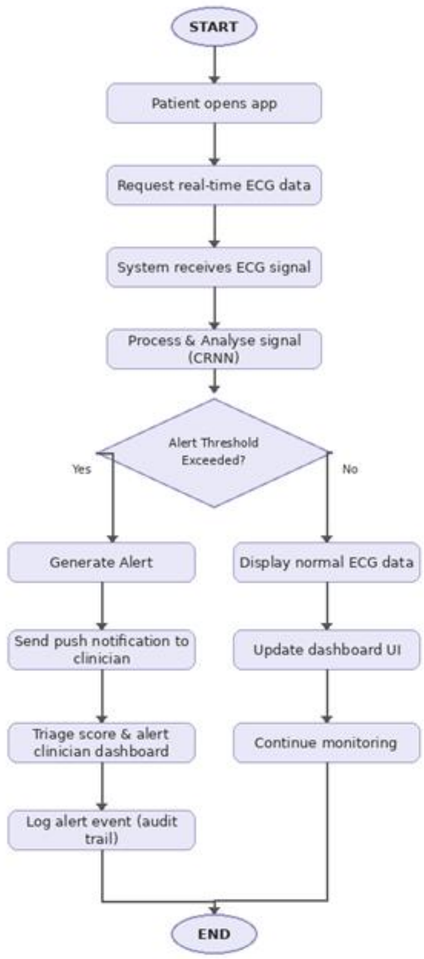

Figure 1. End-to-end patient alert workflow in PacePanel, from ECG ingestion through clinician notification.

III. Key Contributions

Our work has four main contributions. First, we built Pacepanel- an open-source simulation platform that recreates a complete pacemaker telemetry ecosystem using only public ECG data. To our knowledge, this is the first platform of its king. Second, we developed a hybrid arrythmia detection engine that reached 97.3% sensitivity on the MIT_BIH database. Third, our system uses a secure five-layer microservices architecture with type-safe APIs and keeps delays alerts under 500 milliseconds from end to end. Fourth, we delivered a cross-platform mobile client that works on iOS, Android, and the web to show how real-world remote monitoring might look.

IV. Method, Experiments and Results

IV.I Experimental Setup

The experiments were conducted on Ubuntu 22.04, and the system specs were an Intel Core i3 with 8 GB RAM. For Android and IOS testing, we used an Apple iPhone with IOS 26 and an Android with Android version 16. The network we used was Jio 5 G. All recordings were conducted using MIT-BIH recordings [5], which were converted to JSON format and then used for evaluation. For ground truth, we used the annotations provided by the cardiologist in WFDB format. The fig below, Fig.1, shows the workflow diagram.

IV.II ECG Signal Fidelity and Arrhythmia Detection

After performing the simulation phase, we compared the reconstructed waveforms with the MIT-BIH data with the help of root mean square error (RMSE) and Pearson correlation. We conducted 48 experiments, and in them our method came up with an average NRMSE of 0.032 and an average Pearson r of 0.986, which is 96.8% waveform accuracy.
Then we calculated our CRNN classifier on 10 experiments which were recorded (26,000 heartbeats approx.). The table below shows Table 2 shows the summarized results for each arrhythmia class. The weighted sensitivity was 97.3% which is good according by cardiologists.

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Table 2. Per-Class Arrhythmia Detection Performance (Test Set, n = 26,000+ beats)

Arrhythmia Class	Precision (%)	Recall / Sensitivity (%)	F1 Score	Specificity (%)
Normal Sinus Rhythm	99.1	98.7	0.989	99.4
Atrial Fibrillation	96.8	97.4	0.971	98.1
Ventricular Tachycardia	95.2	96.1	0.957	97.6
Complete Heart Block	97.0	97.1	0.970	98.5
Weighted Average	97.0	97.3	0.972	98.7

IV.III System Latency, Reliability, and Mobile Performance

We simulated 1,000 simulated arrythmia conditions. We measured total alert latency. The mean latency was 347 ms, the 95th percentile was 462 ms, and the maximum was 498 ms

As you can see, all are below 500 ms.

We ran 200 concurrent connections for a day, from them we evaluated an Api. The success rate came out to be 99.87% in 500 concurrent classification requests. When we queued excess requests, the backend degraded.

On iPhone, the animation maintained 60fps, and on Android, a brief drop of 54fps occurred during updates in waveforms, which was resolved afterwards.

V. DISCUSSION

Our app has a strong performance with a sensitivity of 93.7%, which is good according to cardiologists. The false positive rate is also below the point where clinicians ignore the alerts, 1.2%.

We used PostgreSQL for design because it has wider availability, and EXPO for easy accessibility for contributors. This is good for research but will require rebuilding for medical use.

The key limitation of our application is that it only has validation through simulation.

VI. CONCLUSION

Our application PacePanel is an openly available IOT platform which is designed to simulate, evaluate and alert pacemaker telemetry data. This study leads to the conclusions:

- PacePanel makes it easier to access the telemetry data given by the pacemaker in an easy-to-understand format.
- We used React Native, tRPC, Express.js and PostgreSQL. Algorithms used were Pan-Tompkins, and CRNN detection was used using the MIT-BIH benchmark [5]. For security, we used the IoT framework by Malik al [3].
- With an arrhythmia sensitivity of 97.3%, 96.8% ECG waveform accuracy, mean alert latency of 347ms, 99.87% of API reliability and a constant framerate of 60 fps in both Android and IOS systems.
- Our only limitations are that our validations are simulation only. For future work, we will collect clinical data, APIs will be FDA cleared, and model generalisation and extension for more devices.

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