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VitaLink: IoT Based Real-Time Health Monitoring System

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Abstract

The VitaLink project introduces an IoT-based health monitoring system capable of real-time, non-invasive monitoring of vital signs including Electrocardiogram (ECG), Electromyography (EMG), temperature, SpO2, and heart rate. The system utilizes the AD8232 and EMG sensors to detect Atrial Fibrillation (AF) and muscle abnormalities. Integrated with an ESP32 microcontroller, the device transmits data to a mobile application via Wi-Fi, enabling remote tracking. By combining signal processing and lightweight machine learning, VitaLink provides early detection, real-time alerts, and a user- friendly interface, offering a cost-effective solution for personalized and preventive healthcare.

Keywords: Atrial Fibrillation; EMG; ECG; IoT; ESP32; Wearable Health Monitoring; Machine Learning

Introduction

The increasing prevalence of chronic diseases, particularly cardiovascular and neuromuscular disorders, has led to a growing demand for real-time health monitoring solutions. Conditions such as Atrial Fibrillation (AF) and muscle abnormalities, if not detected early, can result in severe complications including stroke, heart failure, and long-term disability. Traditional diagnostic methods, although effective, are often costly, cumbersome, and impractical for continuous monitoring, especially in remote or home-based settings.VitaLink is an innovative, IoT-based health monitoring system developed to bridge this gap. It integrates biomedical sensors like AD8232 for Electrocardiogram (ECG) and Electromyography (EMG) sensors for muscle activity, enabling the continuous, real-time detection of vital health parameters including heart rate, Oxygen Saturation (SpO2), body temperature, and muscle function. Designed as a compact, wearable device, VitaLink supports wireless data transmission via the ESP32 microcontroller, allowing remote access to health data through a mobile application. The system not only enables early detection of AF and neuromuscular irregularities but also reduces the need for in-person medical visits. By leveraging machine learning and real-time signal processing techniques, VitaLink promotes proactive health management and enhances patient comfort. Its low power consumption and user-friendly interface make it ideal for long-term, non-intrusive use across various healthcare settings.

Literature Survey

Recent advancements in healthcare technology, particularly in arrhythmia and EMG-based diagnostics, increasingly leverage machine learning and deep learning. For arrhythmia detection, Yaqoob Ansari et al.[1] and Qiao Xiao et al.[2] have systematically reviewed the superior performance of deep learning methods, especially CNNs, in ECG-based classification. Felipe Meneguitti Dias et al.[3] and Matteo Gadaleta et al.[4] have focused on automated systems for continuous monitoring and predicting AF onset from single-lead ECGs.

In the domain of EMG sensing, Niti Petranon et al.[5] developed devices for translating sign language into text using sEMG and IMU sensors, while Huiqi Niu et al.[6] proposed EMG-based models for real-time muscle fatigue assessment. Amlan Deep Mohapatra et al.[7] showcased deep learning approaches for hand gesture recognition using multichannel EMG data.

Beyond specific applications, various IoT-based health monitoring systems integrate diverse sensors for comprehensive patient care. Ali Nur Fathoni et al.[8] designed assistive dispensers for the visually impaired, and Thangam S et al.[9] developed wearable systems for monitoring vital signs like ECG, pulse, temperature, and SpO2. These systems, often using sensors like AD8232, MAX30102, and DS18B20, enable real-time data transmission to the cloud. Suliman Abdulmalek et al.[10] reviewed the broader impact of IoT in healthcare.

Proposed Methodology

The methodology for the VitaLink IoT-based health monitoring system is centered around the development of a compact, wearable, and non-invasive device capable of real-time detection of critical health parameters such as AF and muscle abnormalities. The system integrates both analog and digital biomedical sensors—specifically the AD8232 ECG sensor, an EMG sensor, MAX30102 (for SpO2 and heart rate), and DS18B20 (for temperature)—to acquire physiological signals. The ESP32 microcontroller serves as the central unit, handling signal acquisition, preprocessing, and wireless communication. Analog signals from the ECG and EMG sensors are filtered to remove noise, while digital sensors provide clean outputs directly. These signals are normalized and segmented where necessary before feature extraction.

The methodology uses rule-based and statistical techniques for detecting AF, such as analyzing RR interval variability and R-peak detection from ECG signals. For EMG signal classification, time-domain features like Zero Crossing (ZC), Mean Absolute Value (MAV), and Root Mean Square (RMS) are extracted to assess muscle activity. While the system avoids computationally heavy deep learning models on-device, it optimizes simpler algorithms for quick and accurate decision-making in real-time. The ESP32 transmits the processed data via Wi-Fi to Firebase, enabling remote monitoring through a mobile application built with Flutter. The user interface offers visualizations of ECG, SpO2, temperature, and EMG data, alongside alerts for abnormalities.

The overall methodology emphasizes low power consumption, real-time performance, and modular scalability. This approach ensures high user comfort, cross-platform accessibility, and the potential to integrate future sensors or enhanced analytics, making VitaLink suitable for both clinical and home healthcare applications.

System Design

The VitaLink system design is a comprehensive integration of hardware and software components that work together to provide real-time, non-invasive monitoring of key health parameters. The system architecture is modular, scalable, and optimized for wearable deployment, ensuring ease of use, energy efficiency, and accurate biomedical signal processing as shown in Figure 1.

1. Hardware System Design

At the core of the system is the ESP32 microcontroller, which serves as the central processing and communication hub. The ESP32 is chosen for its dual-core processor, integrated Wi-Fi/Bluetooth capabilities, low power consumption, and sufficient GPIOs to handle multiple sensor inputs. The hardware design incorporates the following sensors and modules:

- AD8232 ECG Sensor: Captures the heart's electrical activity through three electrodes (RA, LA, RL). It provides analog ECG waveforms, which are crucial for detecting cardiac arrhythmias, especially AF.
- EMG Sensor: Measures electrical signals generated by skeletal muscles. It helps identify neuromuscular abnormalities by analyzing variations in muscle signal amplitude and frequency.
- MAX30102 Pulse Oximeter: Measures SpO2 and heart rate using optical sensing with red and infrared LEDs. This sensor operates over I^2C and is essential for monitoring respiratory and cardiac health.
- DS18B20 Temperature Sensor: A digital, single-wire sensor used to measure body temperature. It provides continuous temperature data to identify conditions like fever.
- OLED Display Module: A small, high-contrast screen that shows real-time health metrics like heart rate, SpO2, ECG, Temperature and EMG allowing users to get immediate feedback without relying on a mobile device.

Based on the reading from ECG Sensor, EMG Sensor, Pulse Oximeter, and Temperature Sensor, various diseases like arrythmia, hypothermia, fever, low oxygen level and muscle abnormalities can be detected.

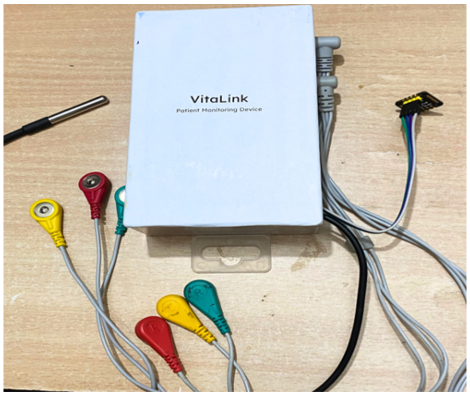

Fig 1. Project with Enclosure

The system is powered by three 18650 Li-ion batteries connected to a voltage regulator (AMS1117 5V), which ensures stable power supply across all components. The compact, custom-designed PCB integrates all modules while maintaining signal integrity and minimal electromagnetic interference through careful routing and dual-layer layout.

2. Software System Design

The software system complements the hardware by enabling data acquisition, signal processing, decision-making, and user interaction. The software stack includes firmware written in C++ for the ESP32, and a mobile application developed using React Native for cross-platform access.

Signal Acquisition & Preprocessing:

- Analog and digital signals from ECG, EMG, SpO2, and temperature sensors are acquired in real time at a sampling rate of 128 Hz.
- Preprocessing involves filtering (high-pass and low-pass) to remove noise, normalization for uniform scaling, and segmentation to extract meaningful portions for analysis.

Feature Extraction & Analysis:

- ECG: R-peak detection and RR interval calculation are used to analyze Heart Rate Variability (HRV) and detect signs of AF.
- EMG: Features such as amplitude, zero crossing, and frequency are extracted to identify abnormal muscle activities.
- SpO2 and Pulse: Sudden drops in oxygen levels or irregular pulse rates are flagged.
- Temperature: Values are classified into hypothermia, normal, fever, and hyperpyrexia.

Algorithm:

Step 1: Initialization:

● Set up communication with sensors and connect the device to a network.

● Calibrate sensors based on patient-specific baseline values.

Step 2: Get Data:

● Collection continuous data:

○ EMG: Muscle activity signal.

○ SpO2: Blood oxygen saturation levels and pulse rate.

○ ECG: Heart rate and waveform data.

● Sampling rate: Collect samples at predefined intervals (e.g., every 1 second)

Step 3: Data Preprocessing:

● Filter noise from raw signals (low-pass and high-pass filters).

● Normalize data to improve accuracy

● Segment data if necessary for further analysis.

Step 4: Feature Extraction:

● From ECG:

○ Detecting R-peaks to measure heart rate.

○ Calculate RR intervals for Arrhythmia detection.

● From SpO2:

○ Extract oxygen saturation and identify drops below a certain threshold (e.g., <90%).

● From EMG:

○ Analyze the signal's amplitude and frequency to detect any abnormal muscle activity.

Step 5: Condition Detection:

● AF:

○ Check for irregularities in RR intervals.

○ If there are frequent irregular heartbeats, flag as potential AF.

● Muscle Abnormalities:

○ If EMG signals show unusually high/low amplitudes or irregular patterns, flag as abnormal.

Step 6: Data Storage and Analysis:

● Store flagged events and timestamps locally or on a remote server for further analysis.

● If required, implement predictive analytics on historical data to assess health trends.

Step 7: Alerts and Notifications:

● Send an alert to the connected mobile device or cloud if any condition is detected.

● It provides specific details, such as the time of detection and type of abnormality.

Step 8: Continuous Monitoring and Adaptation:

● Continuously monitor the data and adjust detection thresholds based on past readings.

3. Communication and User Interface

The processed data is transmitted wirelessly using Wi-Fi (ESP32) to a Firebase cloud server, enabling real-time remote access. A Flutter-based mobile application serves as the main interface for users and healthcare providers. It includes dashboards for:

1. ECG waveforms and cardiac event flags.
2. SpO2 and pulse trends.
3. Temperature history.
4. EMG graph and activity insights.
5. PDF health reports and real-time alerts.

4. Power Efficiency and Modularity

- The entire system is designed to operate efficiently on battery power for extended durations.
- Power management is achieved through optimized code loops, sleep modes, and efficient sensor polling.
- The modular nature of the system allows for easy integration of future sensors and updates to algorithms.

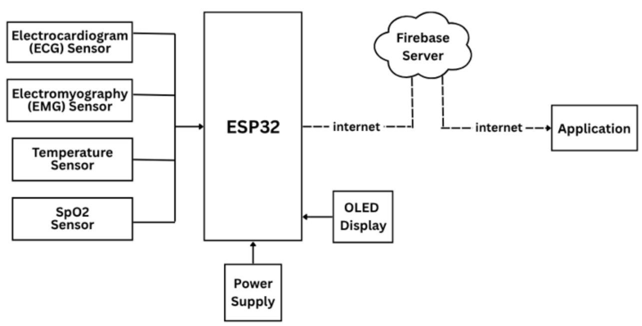

Fig 2. Block Diagram of VitaLink System

The VitaLink system is built around modular hardware and flexible software architecture to ensure scalability, ease of integration, and reliability as shown in Figure 2.

Specification

- Controller: ESP32 with dual-core CPU (240 MHz) and built-in Wi-Fi for real-time cloud communication.
- Power: Runs on 3×18650 batteries (2500 mAh each) with 5V regulation; optimized for long-duration use.
- Sensors: Integrates ECG, EMG, SpO2, and Temperature sensors for complete vital monitoring.
- Performance: Real-time data capture at 128 Hz with on-board processing for early AF and muscle abnormality detection.
- Connectivity: Data is uploaded to Firebase using Wi-Fi; which can be then accessed via a cross-platform mobile app.
- User Interface: OLED display + mobile app with live graphs, reports, and alerts.
- Design: Compact (~25 g), low power, wearable, modular, and suitable for long-term use.

Result and Discussion

The IoT-based health monitoring system was successfully designed and implemented using key biomedical sensors such as the AD8232 ECG sensor, EMG sensor, and MAX30102 pulse oximeter. The system efficiently collected real-time biomedical data, processed it via the ESP32 microcontroller, and displayed results on an OLED screen. Additionally, the data was transmitted wirelessly to a cloud platform, enabling remote health monitoring.

1. Login Page: The application opens with a login page where users are prompted to enter their email and password. There's also an option labelled "Don't have an account?" to guide new users to the sign-up page as shown in Figure 3.

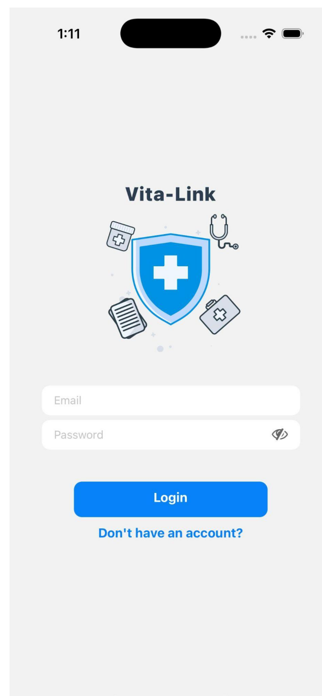

Fig 3. Login Page

2. Role and Registration: Users must choose whether they are a doctor or patient, then proceed to fill in their full name, age, email, and password. A password instruction note is displayed, stating that it must be at least 8 characters long and contain an uppercase letter, lowercase letter, number, and special character as shown in Figure 4.

3. Password Validation: The system validates the password in real-time and highlights any conditions that are not met to guide the user in creating a strong password.

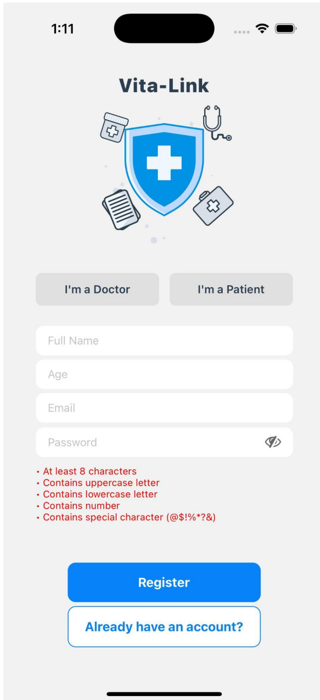

Fig 4. Role and Registration

Once all password conditions are fulfilled, the user can click the register button to complete the sign-up process as shown in Figure 5.

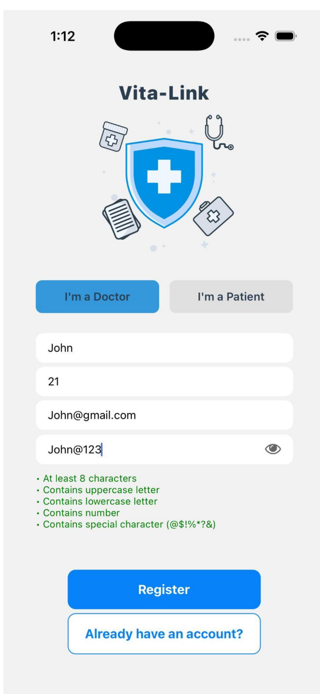

Fig 5. Password Validation

4. Email Verification Prompt: A warning message appears asking the user to verify their email before accessing the app. If the email remains unverified after one minute, a popup appears reminding the user to verify their email and informing them that a verification email has been sent as shown in Figure 6.

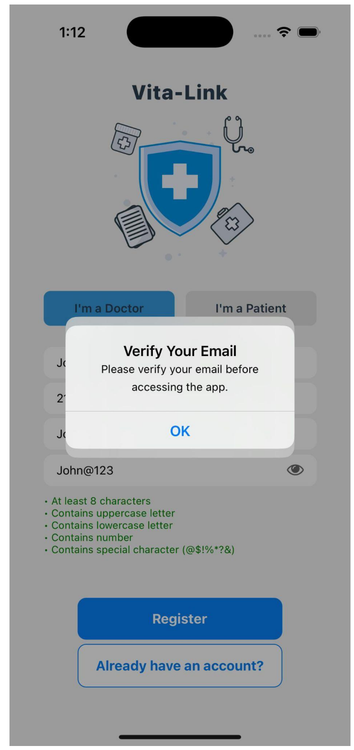

Fig 6. E-mail Verification

5. Home Page: After successful email verification, the user is redirected to the home page featuring a "Sign Out" button and separate buttons for each health parameter: ECG Monitor, Temperature, HR/SpO2, EMG Scan, and Report as shown in Figure 7.

6. ECG Monitoring: On pressing the ECG Monitor button, users see a live graph displaying ECG signals with the sampling rate and descriptions of healthy heart parameters including HR, P-wave, QRS complex, and QT interval as shown in Figure 8.

7. Temperature Monitoring: The body temperature is displayed along with an indication of the temperature category such as hypothermia, normal, fever, or hyperpyrexia. A note about core body temperature measurement is included as shown in Figure 9.

8. HR/SpO2 Monitoring: This section shows vital signs—heart rate and SpO2—along with color-coded indicators (red for abnormal values, green for normal). A description highlights reference ranges for SpO2 and resting heart rate as shown in Figure 10.

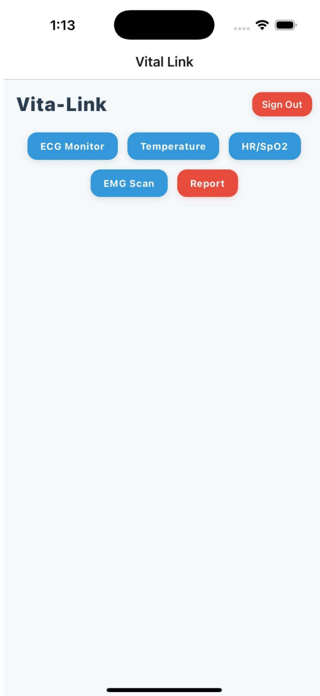

Fig 7. Home Page

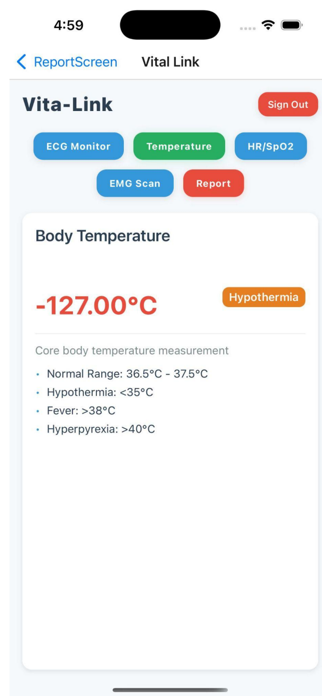

Fig 9. Temperature Monitoring

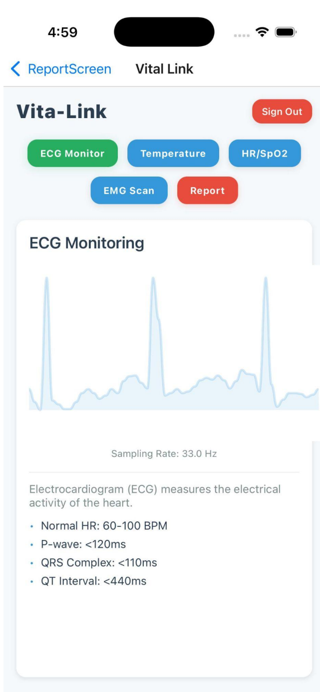

Fig 8. ECG Monitoring

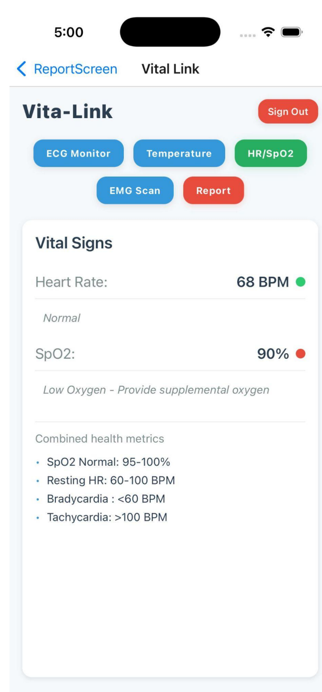

Fig 10. HR/SpO2 Monitoring

9. EMG Monitoring: Users can view a real-time EMG graph along with its sampling rate and a description explaining how muscle activity is detected and interpreted in below Figure 11.

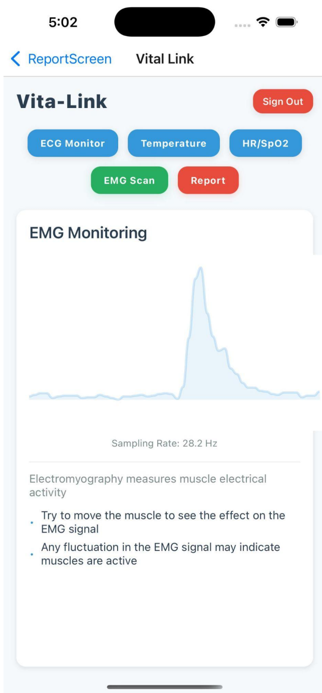

Fig 11. EMG Monitoring

10. Comprehensive Health Report: The final section compiles all measured data into a report, including the patient's name, age, and the date and time the report was generated in below Figure 12. It displays:

1. Cardiac Analysis (Avg, Peak, and Low ECG
2. Body Temperature (Avg, Maximum, Minimum)
3. Vital Signs (Heart Rate, SpO2)
4. Muscle Activity (Avg, Peak, and Low EMG
5. Medical Assessment based on the results

11. Download and Sign Out: Users can download the report as a PDF using the provided button and exit the app with the 'Sign Out' option. Users are informed that their report is saved in their device's file system as shown in Figure 13.

Conclusion

VitaLink successfully developed a compact, IoT-based wearable system for real-time monitoring of AF, muscle abnormalities, and vital health parameters. Integrated with ECG, EMG, SpO2, temperature, and pulse sensors, the system demonstrated reliable performance in detecting cardiovascular and

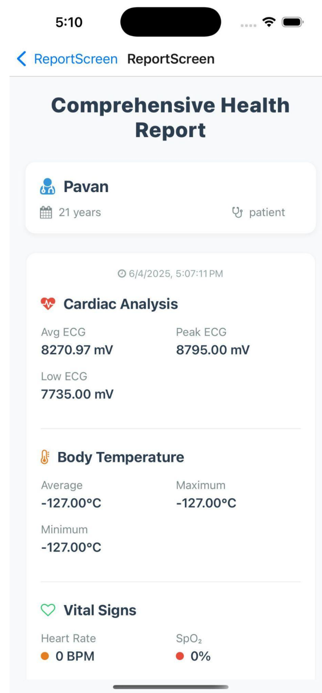

Fig 12. Comprehensive Health Report

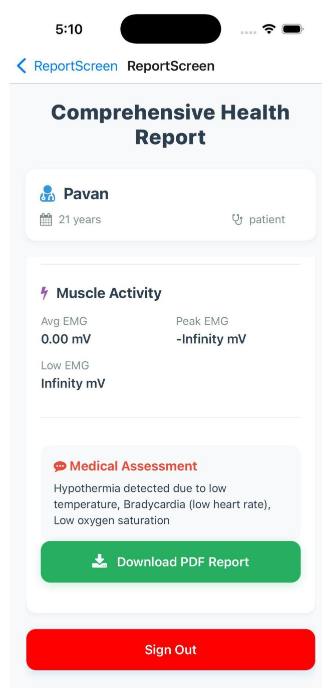

Fig 13. Download and Sign Out

neuromuscular conditions. Powered by an ESP32 microcontroller, it supports wireless data transmission and remote monitoring via a mobile app. Its low-power, user-friendly design ensures long-term usability and promotes proactive healthcare management.

Anomaly prediction using machine learning can be the next step for the current VitaLink system.

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