

CalmPulse: A Wearable Device and ML-Based Framework for Real-Time Panic Attack Detection and Intervention

Prof. Rupali Jadhav

Department of Computer Engineering
Zeal College of Engineering and reasearch
Pune,India

rupali.jadhav@zealeducation.com

Aryan Mane

Department of Computer Engineering
Zeal College of Engineering and reasearch
Pune,India

mane.aryan179@gmail.com

Manish Ladke

Department of Computer Engineering
Zeal College of Engineering and reasearch
Pune,India

manishladke09@gmail.com

Rudrali Kalyane

Department of Computer Engineering
Zeal College of Engineering and reasearch
Pune,India

kalyanerudrali@gmail.com

Prapti Mahadik Patil

Department of Computer Engineering
Zeal College of Engineering and reasearch
Pune,India

praptipatils1808@gmail.com

Abstract—The rapid advancement of wearable healthcare technologies has enabled continuous monitoring of physiological parameters outside conventional clinical environments. Real-time observation of vital signs such as heart rate and blood oxygen saturation can assist in the early identification of potential health abnormalities and improve emergency response mechanisms. However, many existing monitoring systems remain limited by inadequate cloud connectivity, lack of intelligent health assessment, and restricted accessibility for caregivers and healthcare professionals. This paper presents CalmPulse, a cloud-connected wearable health monitoring and emergency alert framework designed to provide continuous physiological monitoring through an integrated Internet of Things (IoT) architecture. The proposed system combines a MAX30102 optical sensor, XIAO ESP32-C3 microcontroller, Firebase Realtime Database, and an Android mobile application to acquire, process, transmit, and visualize health-related data in real time. A decision-tree-based risk assessment mechanism evaluates physiological measurements and categorizes user conditions into normal, warning, and high-risk states. Furthermore, the framework incorporates an automated emergency alert module that can notify designated contacts during critical situations. Experimental evaluation demonstrates reliable physiological monitoring, low communication latency, efficient cloud synchronization, and practical deployment capability. The proposed framework offers an affordable, scalable, and portable solution for modern healthcare monitoring applications and contributes toward the development of next-generation connected healthcare systems.

Keywords— Wearable Healthcare, Internet of Things, MAX30102, ESP32-C3, Firebase Realtime Database, Mobile Health Monitoring, Decision Tree Classification, Emergency Alert System, Smart Healthcare.

Introduction

The healthcare sector is undergoing revolutionary changes due to the advent of new technologies such as wearables, wireless communication, and cloud computing. It has been possible to create a system that will be able to monitor patients' physiological parameters all the time and provide healthcare services beyond the clinical environment due to the advent of technology. The use of wearable monitoring devices has gained a lot of significance since they have enabled people to gain information about their health status immediately while performing their normal tasks.

Out of many physiological variables, the heartbeat rate and blood oxygen content are the significant variables that are taken into account to assess the condition of the cardiovascular and respiratory diseases. Fluctuation in such variables indicates

physiological stress, cardiovascular disorders, respiratory diseases, and other health issues.

The conventional methods that are used for this purpose will be able to measure only certain parameters and require active involvement of the user. Though it is true that conventional methods have been found quite useful in making accurate measurements, there are certain drawbacks when it comes to continuous monitoring, cloud connectivity, and emergency communication. Thus, it is not possible for the doctors or the caretakers to know anything about the critical physiological conditions that happen outside the hospital premises.

With the emergence of the Internet of Things technology, it has become very much possible to improve the performance of wearables in healthcare. IoT-based wearables are capable of collecting data in real time, wireless communication, data cloud storage, and remote access. Besides, mobile apps act as an interface in visualizing and interacting with health care information by collecting physiological data.

Another key enabling technology has been developed in the current era of healthcare in the form of cloud computing. Cloud computing works as a platform for storing, synchronizing, and analyzing physiological data gathered through wearables. Cloud connectivity allows accessing health care information from a remote location.

In this study, the CalmPulse is presented as a platform that integrates sensing, wireless communication, cloud computing, mobile apps, and risk assessment into one platform. Sensing is carried out through MAX30102 Optical Sensor. For communication, the XIAO ESP32-C3 Microcontroller is used whereas the Firebase RealTime database is used for cloud computing. Finally, the Android app is used for visualizations and interaction with the system. Decision Tree Risk Assessment assists in assessing physiological data.

The primary contributions of this research include:

- Development of a wearable physiological monitoring device using low-cost hardware components.
- Integration of real-time cloud communication using Firebase Realtime Database.
- Design and implementation of an Android-based healthcare monitoring application.
- Development of a decision-tree-based health risk assessment framework.
- Implementation of an automated emergency notification mechanism.
- Evaluation of system performance under real-world operating conditions.

By combining these components into a single framework, CalmPulse aims to provide a practical, scalable, and affordable solution for continuous health monitoring and emergency response support.

I. RELATED WORK

The integration of wearable technologies within healthcare systems has attracted considerable research interest over the past decade. Researchers have investigated various approaches involving physiological sensors, cloud computing platforms, mobile healthcare applications, and intelligent decision-making techniques to improve patient monitoring and healthcare accessibility.

Schmidt et al. introduced the WESAD dataset, a multimodal physiological dataset designed for wearable stress and affect detection research. Their work demonstrated the significance of physiological signals such as heart rate and electrodermal activity in identifying emotional and physiological states. The dataset has become a benchmark for wearable healthcare and physiological monitoring studies.

Tsai et al. proposed a wearable-device-based monitoring framework for physiological assessment and health-risk prediction. Their research highlighted the importance of continuous monitoring and predictive analytics for identifying potential health abnormalities before severe symptoms occur.

Asha et al. developed a low-cost physiological monitoring framework using consumer-grade heart rate sensors and machine learning techniques. The study demonstrated that affordable hardware components can effectively support physiological monitoring applications while reducing implementation costs.

A comprehensive review of wearable devices for stress measurement and physiologic evaluation was done by Ping et al. These research results pointed out the significance of the use of wearables in preventive medicine and personalized services. In addition, the need to incorporate the cloud computing infrastructure and intelligent analysis techniques was recognized.

Nowadays, many researchers tend to pay attention to the architecture of the Internet of Things in healthcare systems. Such cloud platforms as Firebase gained popularity due to their features such as synchronization in real time, scalability, and integration with mobile apps.

Although there have been considerable developments in this field, there are still various limitations that exist in the process. First, some of the current methods concentrate solely on data acquisition with no emergency response system. Second, some technologies depend on costly hardware setup, whereas others do not have proper cloud integration and remote access ability. Finally, the lack of an assessment module makes some of the monitoring systems rather impractical.

From these limitations, one can deduce that a unified system of healthcare is required which would integrate all of these aspects – sensor technology, cloud integration, mobile application, intelligent assessment, and emergency response into a single, economically viable platform.

II. RESEARCH GAP

As can be seen from the review of literature, there are several obstacles that do not allow the effective implementation of wearable healthcare monitoring systems.

First of all, many systems pay attention only to the collection of physiological data but do not provide remote access to collected information using the cloud.

Secondly, there are too many systems which use costly hardware and close ecosystem that do not allow scalability and affordable pricing. Consequently, such a system cannot be widely applied in resource-limited areas.

Thirdly, there are some systems which are not able to generate any alerts upon registration of critical physiological data. Although there are some opportunities to obtain physiological data, the lack of alerting functionality reduces the efficiency of a wearable system.

Fourthly, the majority of these systems utilize complex algorithms which need considerable computational costs. There is still no lightweight approach to decision making in wearable healthcare.

Finally, there is a lack of literature related to unified architecture for wearable devices which includes sensing technology, cloud communication, health monitoring, risk assessment, and emergency notification.

In order to overcome these limitations, this research introduces CalmPulse as a cloud connected wearable healthcare architecture that incorporates real-time physiological monitoring, cloud synchronization via Firebase, Android application, decision-tree based risk assessment, and emergency notification via low cost hardware architecture.

III. PROPOSED FRAMEWORK

CalmPulse is envisioned as a cloud-connected wearable healthcare framework that would be capable of physiological data acquisition and provide health information to the mobile application in real time. The architecture of CalmPulse contains four main layers which include the sensing layer, the communication layer, the cloud layer, and the application layer. The sensing layer deals with physiological data acquisition. MAX30102 optical sensor constantly monitors users' heart rate and blood oxygen saturation. Sensor communicates with XIAO ESP32-C3 microcontroller by means of the I2C communication protocol.

The communication layer handles wireless physiological data transmission. ESP32-C3 processes sensor readings and sends information to the Firebase Realtime Database via Wi-Fi connection.

The cloud layer acts as a central repository of physiological information. Firebase Realtime Database stores sensor data and offers low latency synchronization. Cloud platform allows remote access and continuous monitoring from multiple locations.

The application layer includes the mobile application created in Android with the use of Java and XML programming languages. Mobile application receives data from Firebase and displays information in the form of user-friendly interface.

For the better functionality of the healthcare system, the framework adopts a decision tree-based health assessment model that analyzes physiological measurements to categorize health status into normal, warning, or at risk. In case of any abnormality, an alarm is sent by the emergency alert module to the concerned contacts.

The proposed framework offers a scalable framework that can accommodate future healthcare extensions.

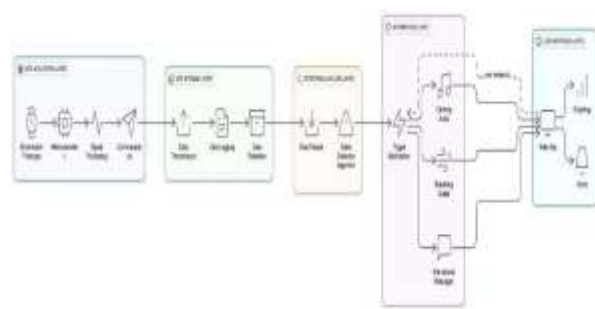


Figure 1: CalmPulse Framework

IV. METHODOLOGY

A. Overview of the Proposed Methodology

The new CalmPulse framework employs a layered Internet of Things (IoT) architecture encompassing physiology measurement, wireless communication, cloud computing, mHealth, and automated emergency response within a unified healthcare system. In addition, the methodology has been developed to allow for continuous physiological parameters measurement while ensuring low costs, high portability, and easy installation.

The whole process starts with physiological data measurements conducted via the MAX30102 sensor. Heart rate and blood oxygen saturation level are measured by using the principles of photoplethysmography (PPG). The readings of the sensor are analyzed by the XIAO ESP32-C3 microcontroller which plays the role of processing and communication module of the device.

Physiological data then is transferred to Firebase Realtime Database using Wi-Fi connection. The cloud platform provides a centralized location that allows real-time data synchronization between the wearable device and the Android mobile application. The mobile application receives data from Firebase and displays physiological data on its graphical interface

To enhance the functionality in the area of health care support, the risk assessment system is used that operates on the basis of a decision tree. The user's health status is classified into three categories: normal, warning, or high risk based on the pre-defined threshold values for the corresponding measurements. In case of critical conditions, the emergency alert system triggers the notification process.

The methodology focuses on real-time operations,

scalability, cloud availability, and convenience for the user with a small computational overhead.

B. Physiological Data Acquisition

Monitoring the physiological processes becomes the core of CalmPulse. The MAX30102 optical sensor was chosen because of its small size, energy efficiency and simultaneous measurement of heart rate and blood oxygen saturation levels.

The photoplethysmography technique is implemented in the sensor and it is a non-invasive optical technique, which uses red and infrared light emitting diodes for detecting changes in the blood volume of subcutaneous tissues. The result of the blood flow in the vascular system becomes the light absorption, which can be measured to calculate the physiological parameters.

With the help of the sensor, users put their fingers on the sensing area of the MAX30102 sensor. The produced light penetrates the tissue and is partly absorbed by the blood vessels. The reflected light is captured by the photodetector of the sensor.

The raw sensor signal data is continually collected and transferred to the ESP32-C3 microcontroller with the help of the I2C protocol. The microcontroller processes the data – stabilizes the signal, reduces the noise level and extracts the physiological parameters, after that the data goes to the cloud.

The continuous physiological parameters acquisition enables tracking of the health state of the users.

C. Data Processing and Validation

The physiological readings that are usually collected have noise because of environmental factors, movement of fingers, light, and differences in the placement of sensors. Therefore, there is a requirement to validate and preprocess signals before sending them using cloud technology services.

There is a process of validating ESP32-C3 where the input data collected through sensors is validated in terms of anomalies, missing readings, and range. Whenever the measurement readings fall outside physiological reasonable limits, then they are disregarded.

Heart rate measurements undergo validation to ensure that the reading lies within limits, whereas validation of blood oxygen saturation reading confirms physiological behavior.

The processed data is stored in a structure consisting of:

- Heart rate (BPM)
- Blood Oxygen Saturation (SpO₂)
- Timestamp information
- Device status
- Risk classification parameters

The structured data is then prepared for cloud transmission

D. Cloud Communication Methodology

The Communication module will be utilized for sending the physiological data collected by the wearable device to the cloud infrastructure. The selection of Wi-Fi communication technology is justified by the ubiquity, reliability, and easy integration with cloud-based servers.

The collected sensor data will be sent to the cloud-based server after specific intervals to ensure synchronization. Such an approach of using the Firebase Realtime Database as a communication channel is justified by the low-latency, real-time updates, and synchronization properties of the database. Such advantages could be offered by cloud-based communication solution:

- Accessibility from remote locations
- Centralization of storage
- Synchronization of changes
- Scalability
- Device compatibility

This system design solves the issues related to monitoring locally and allows accessing healthcare information from anywhere.

E. Risk Assessment Algorithm

A smart health assessment algorithm has been developed to augment healthcare decision-making systems. The risk assessment system uses decision-tree-based health risk classification technique because of its simplicity and low cost in terms of computation.

In the proposed technique, the input physiological data are checked continuously in view of preset threshold values. Decision tree takes several parameters into account at a time and categorizes the health condition in one of the following states:

1) Normal State

Normal state signifies that physiological parameters lie within health ranges. No intervention or alerting needs to be done in this case.

2) Warning State

Warning state is triggered in case of measurements going close to the preset threshold values. User needs to monitor his/her health condition and measure again.

3) High-Risk State

High-risk state indicates the deviation of measurements from healthy levels. Emergency procedures for notification are automatically activated at this point.

Decision tree based approach ensures that health decisions are interpretable.

Condition	Risk Label	Suggestion
SpO ₂ ≥ 95% and HR 60–100 BPM	Normal	Health status appears stable
SpO ₂ 90–94%	Moderate Risk	Sit calmly and remeasure
SpO ₂ < 90%	High Risk	Seek medical - attention
HR > 120 BPM	High Pulse Alert	Rest and monitor again

HR < 50 BPM	Low Pulse Alert	Re-check reading and consult doctor if repeated
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Table 1: Decision Logic

V. SYSTEM ARCHITECTURE

A. Overall System Architecture

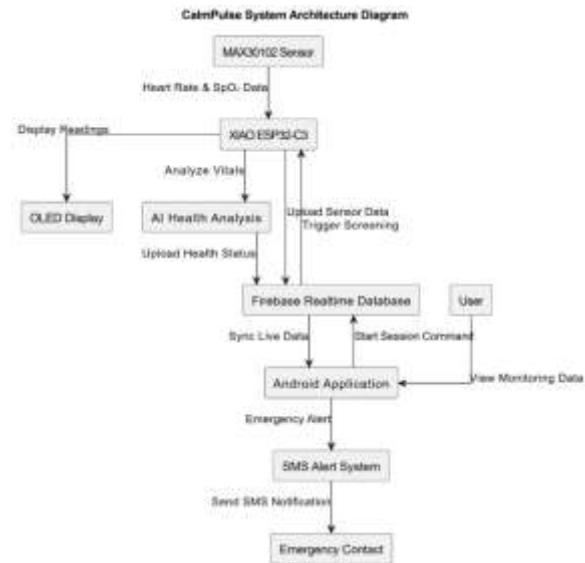


Figure 2: Overall Architecture of CalmPulse

1. Architectural Overview

CalmPulse architecture is represented by four major layers:

- Sensing Layer
- Communication Layer
- Cloud Layer
- Application Layer

They perform their own functions at the same time ensuring continuous operation of healthcare monitoring and emergency response operations.

2. Sensing Layer

Physiological Data Acquisition Layer

This layer is responsible for physiological data acquisition from the user.

Main elements include:

- MAX30102 Sensor
- OLED Display
- XIAO ESP32-C3

The MAX30102 sensor collects physiological data whereas the OLED display provides real-time information regarding sensor status and data collected by it.

3. Communication Layer

It connects wearable device and cloud platform with each other.

Its functionality includes:

- Wi-Fi connection
- Data transmission
- Synchronization process
- Reliable communication

ESP32-C3 uploads physiological data to Firebase Realtime Database in real-time mode by maintaining network connection.

4. Cloud Layer

It is working as primary data management system. Its functionality includes:

- Instantaneous data storage
- Synchronization services
- Availability of data
- Scalability

Firebase Realtime Database performs instantaneous data updates and acts as interface between wearable device and mobile application.

5. Application Layer

The application layer is responsible for interaction with the users and provision of health monitoring capabilities.

Android application consists of:

- Live physiological monitoring
- Visualization of the current health status
- Display of risk assessments
- Emergency alerts handling
- Review of historical data

Users may receive real-time health information by using an intuitive interface regardless of their distance from the wearable device.

6. Emergency Response Architecture

The emergency response architecture works as the last safety layer of the whole framework.

In case of detection of high-risk situations:

1. Risk assessment module produces alert status.
2. Firebase database sets emergency flag.
3. Android application gets emergency status.
4. Alerting services are triggered.
5. Emergency contacts get notifications.

This approach ensures reduced reaction time and increased safety of healthcare in critical moments.

The layered structure increases the modularity, maintainability, scalability and extensibility of the CalmPulse framework. Potential improvements such as AI, predictions, telemedicine and physician dashboards can be integrated in the system without any changes in its architecture.

B. Flowchart of the Proposed System

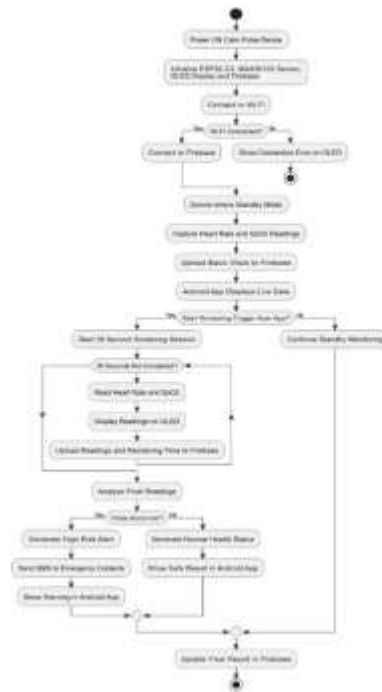


Fig. 3: Flowchart of the Proposed System

As illustrated in Figure 3 below, there are the operations performed by CalmPulse. Firstly, the initialization of the MAX30102 sensor, OLED display and Firebase communication by ESP32-C3 happens after the power-on of the device. Secondly, the Wi-Fi connection happens and if it is successful, then the connection of the device to the Firebase Realtime Database occurs or an error message pops up on the OLED screen.

Thirdly, the standby mode of operation happens and where the heart rate and blood oxygen saturation readings are received from the MAX30102 sensor. The physiological readings are sent to Firebase and shown on the Android application. Once the health screening process starts on the mobile application, 30 second monitoring process starts where the physiological readings are collected, shown locally on the OLED screen and uploaded to Firebase.

At the end of the monitoring process, the analysis of the physiological readings occurs using the risk assessment tool. In case of any physiological abnormality, high-risk alerts are raised, emergency alerts are sent to the provided contacts and warning messages pop up on the Android application..

C. Data Flow Architecture

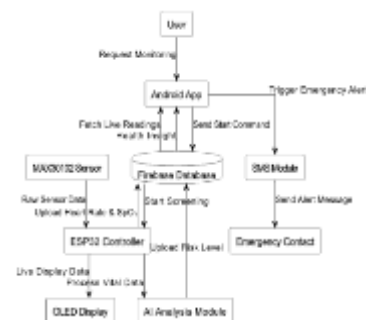


Fig. 4: Data Flow Architecture

Figure 4 illustrates the Data Flow Architecture that describes the process of transferring information between the components of the system. The MAX30102 sensor is the main source of physiological data as it offers heart rate and SpO₂ measurements in a raw format. The raw measurements are transmitted to the ESP32 microcontroller for processing and preparation of data.

The processed data will be displayed on the OLED display and transmitted to the Firebase Realtime Database. Firebase is the main tool used for communication through which a two-way communication takes place between the wearable device and the Android application. The Android application will get real-time data, provide health information to the users, and send commands to monitor the patient's health status.

The system has the AI-based health risk assessment module that receives physiological data from Firebase Realtime Database and assesses the current health status of the user. In case of high risk, the Android application starts the emergency alerting system that will activate the SMS module to notify the contacts about the health status of the user.

D. Hardware and Communication Block Diagram

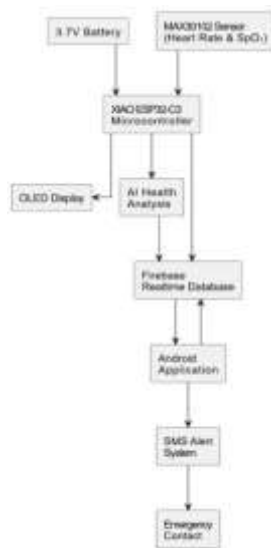


Fig. 5: Hardware and Communication Block Diagram

Figure 5 illustrates the hardware architecture diagram of the CalmPulse framework. The entire system is powered by a portable and rechargeable 3.7V Lithium-Ion Battery to ensure seamless operation. The sensor MAX30102 collects physiological signals which then goes through I²C protocol to be transferred to the XIAO ESP32-C3 Microcontroller.

XIAO ESP32-C3 acts as the main processor that manages the data transfer from sensor communications, cloud synchronization and application connectivity. Physiological signals are shown on the OLED screen in order to observe the physiological signals in real time without opening the mobile application.

Physiological signals are also sent to the Firebase Realtime Database which acts as the cloud communication service provider. Data from Firebase are constantly accessed by the Android Application in order to provide health-related

physiological signals and determines the health status. The abnormalities that are observed are then reported through the alert management module which alerts the registered emergency contacts.

Block diagram above demonstrates how all the hardware components, cloud services, mobile applications and emergency communication systems interact with each other in the CalmPulse framework.

VI. HARDWARE IMPLEMENTATION

A. Hardware Overview

The design of the CalmPulse hardware subsystem aims to create a small-sized, easily portable, and affordable system for the purpose of continuous physiological monitoring. The hardware structure includes a MAX30102 optical sensor, XIAO ESP32-C3 microcontroller, OLED display module, and a rechargeable lithium-ion battery. The components perform the function of gathering physiological data, processing the sensor data, displaying the data on a screen, and communicating with the cloud infrastructure.

The main goal of the hardware design is to create a lightweight platform that will operate continuously and use minimal power.

B. XIAO ESP32-C3 Microcontroller



Fig. 6: XIAO ESP32-C3 Microcontroller

XIAO ESP32-C3 is the microcontroller which acts as the core processing unit in the architecture of the CalmPulse framework. It was chosen for its small size, Wi-Fi functionality, low energy consumption and enough processing power for healthcare monitoring applications.

The following functionalities are provided by the ESP32-C3 microcontroller:

- Communication with sensors
- Data acquisition
- Signal processing
- Communication with cloud services
- Firebase integration
- Device management

ESP32-C3 constantly collects physiological parameters from the MAX30102 sensor via I²C interface. After processing of the input data, the ESP32-C3 forms a Wi-Fi connection and sends physiological data to Firebase Realtime Database.

The built-in communication capabilities make unnecessary any additional communication modules.

information using interactive user interface. Health analysis module of Android application analyzes

C. MAX30102 Optical Sensor



Fig. 7: MAX30102 Optical Sensor

MAX30102 is an extremely integrated optical sensor which is able to determine both pulse rate and blood oxygen saturation levels.

It includes:

- Red LED
- Infrared LED
- Photodetector
- Signal conditioning
- Analog-to-digital converter.

The method of measurement is based on using photoplethysmography (PPG), which is a non-invasive optical method. It is determined by changes in blood volume under the skin which influence the absorption of the emitted light.

The features of the MAX30102 include:

- Accuracy in measurement
- Low energy consumption
- Small size
- Real-time functioning.

The use of such sensor is possible for wearable healthcare monitoring.

D. OLED Display Module

Fig. 8: OLED Display Module



An 0.96-inch OLED display screen was added to the wearable device for immediate feedback about the physiology reading and status of the device.

This includes:

- Heart Rate (Beats per Minute/BPM)
- Blood Oxygen Saturation (SpO2)
- Status of the device
- Wi-Fi status

- Information about monitoring session

OLED technology was chosen because it provides high contrast, is low energy consuming, and highly readable in different lighting conditions.

The display enhances user experience since the physiological information can be obtained directly from it without using the mobile application.

E. Power Management System



Fig. 9: Charging Module



Fig. 10: Rechargeable Lithium-ion Battery

The wearable system operates using the rechargeable lithium-ion battery. This battery system was chosen to facilitate portability and continuous operations.

The components of the power subsystem include:

- Lithium-ion battery
- Battery charging
- Voltage regulation
- Power distribution

Power management plays a vital part in portable health care systems due to continuous monitoring and the need for long-operational periods. The chosen design helps deliver the required voltage to all parts and minimize the energy consumption.

The low energy consumption of ESP32-C3 and MAX30102 helps increase the life time of the battery and makes the system more portable

F. Hardware Connections



Fig. 11: Charging Module

Hardware components use Inter-Integrated Circuit (I2C) interface for communication.

The table below demonstrates the pin configuration of the hardware components used within the CalmPulse system.

Component	ESP32-C3 Pin
MAX30102 SDA	GPIO 6
MAX30102 SCL	GPIO 7
OLED SDA	GPIO 6
OLED SCL	GPIO 7
Battery	VIN
Ground	GND

Table 2. Pin Configuration of Hardware Components
Shared I2C architecture allows simplifying the system design and reducing the number of wire connections.

VII. SOFTWARE IMPLEMENTATION

A. Software Architecture Overview

The software component of CalmPulse is comprised of three main parts:

1. Embedded Firmware
2. Cloud Infrastructure
3. Android Application

These software components combined provide functionality for data acquisition, cloud communication, risk analysis, and user interaction.

The software architecture was created to guarantee:

- Real-time operation
- Scalability
- Reliability
- Easy maintenance
- Further development opportunities

B. Development of Embedded Firmware

The embedded firmware has been developed on the basis of the Arduino platform and written in C++.

The firmware performs the following functions:

- Sensor configuration
- Data acquisition
- Signal validation
- Connection to the Wi-Fi network
- Communication with Firebase database
- Error handling

The firmware operates continuously, checking sensor data and sending validated signals to the Firebase Realtime Database.

C. Firebase Realtime Database Integration

Firebase Realtime Database acts as the cloud communication hub of the proposed system.

Cloud service offers:

- Real-time synchronization
- Cloud storage
- Multiple devices compatibility
- Data availability
- Low latency communication

Data received from sensors is uploaded to Firebase right after collection. Each time when new data comes, applications are provided with an update.

Such approach makes possible effective communication between wearable device and Android application.

D. Android Application Development

Android application has been created using Java and XML language in Android Studio.

Features of the application include:

- Real-time physiological monitoring
- User authentication
- Health condition visualization
- Emergency alert setting
- Historical data access
- Cloud synchronization

User interface of the application has been created following modern mobile development standards for ensuring easy access.

E. User Interface Design

The mobile application is composed of several screens that serve to support the healthcare monitoring features.

Main screens include:

Dashboard Screen

Shows:

- Heart Rate
- SpO₂
- Risk Status
- Device Connection

Monitoring Screen: - Performs monitoring and visualization of physiological parameters.

Emergency Contact Screen:- Permits to manage emergency contacts and their notification.

History Screen:- Shows recorded before physiological measurements and health status.

User interface design pays much attention to simplicity and accessibility.

F. Emergency Alert Module

The emergency alert system should send notifications whenever an abnormal state of physiological parameters is detected.

It includes:

Detection of the high risk state

Alert creation

Notification sending

Contacting with emergency contacts

The alert module allows reducing the reaction time and increasing the healthcare safety.

Integration of the notification system can be considered one of the most important components of the framework.

G. Decision Tree Risk Assessment Module

The decision tree algorithm uses physiological information to categorize the condition of the user based on defined classes.

Input:

- Heart Rate
- SpO₂

Output:

- Normal
- Warning
- High Risk

Since decision trees have very low computation needs, they can be used in real-time healthcare monitoring applications. Moreover, since decision trees have an explicit decision-making procedure, they increase interpretability and user trust.

The risk assessment results are displayed in the Android app and also used in the emergency alert module.

VIII. MACHINE LEARNING-BASED RISK ASSESSMENT

A. Dataset Description

In order to increase the reliability of the physiological risk assessment process, the CalmPulse platform was supplemented with a classification algorithm based on the machine learning technique. Training was conducted on the basis of the Wearable Stress and Affect Detection (WESAD) database, which is an open standard database intended for wearable health care applications and affect recognition.

Heart rate-derived parameters extracted from the Wearable Stress and Affect Detection (WESAD) database have been used as the main parameters for training. Considering that the prototype under development calculates not only heart rate but also blood oxygen saturation (SpO₂), SpO₂-derived feature values were added during the pre-processing of the data as real operating environment values.

The generated dataset was split into two subsets – training and testing.

Parameter	Value
Dataset Used	WESAD
Total Samples	6,300
Training Data	80%
Testing Data	20%
Cross Validation	5-Fold

Table 3. Dataset Distribution

B. Data Preprocessing

Before training the model, various types of pre-processing techniques were used to enhance data quality and classification performance. The missing values and noisy values were removed from the data set. Normalization was done on the features to ensure consistency between different physiological variables. Some of the chosen features were heart rate, oxygen saturation, and physiological indicators related to stress and poor health states.

Then the pre-processed data set was transformed into machine understandable format to be used for supervised learning.

There are three categories of the labels for the target: Normal, Warning, and High Risk.

C. Decision Tree Classification Model

A Decision Tree classifier has been chosen as the risk classifier model owing to its simple and interpretable nature as well as suitability in resource-constrained Internet of Things environments. The classifier learns decision boundaries from physiological measures and classifies health conditions of users into predetermined risk categories.

The Decision Tree classifier creates a hierarchy of decision-making rules according to the physiological thresholds. It makes the classification fast while keeping low memory consumption and high processing speed.

The trained classifier categorizes user states as follows:

1. Normal state
2. Warning state
3. High-risk state

The classification procedure helps the system to recognize abnormal physiological states and proceed with necessary intervention actions.

D. Model Performance Evaluation

The data was partitioned into training and testing sets in an 80:20 ratio. The model performance is evaluated using conventional measures such as Accuracy, Precision, Recall, and F1-Score in machine learning.

Mode l	Accuracy	Preci sion	Reca ll	F1 Scor e
K- Neare st Neigh bors	89.8%	88.9 %	88.1 %	88.5 %
Rand om Fores t	94.1%	93.4 %	92.7 %	93.0 %
Decis ion Tree	92.4%	91.7 %	90.9 %	91.3 %

Table 4. Performance Comparison of Machine Learning Models
Whereas the Random Forest model performed better than the Decision Tree classifier in terms of accuracy, the Decision Tree classifier was preferred based on its light-weight architecture suitable for real-time health care applications.

E. Deployment Strategy

The trained Decision Tree model was transformed into a decision-making algorithm, which was then embedded in the CalmPulse platform. When the system runs, the physiological data obtained from the MAX30102 sensor is constantly analyzed based on the rules created from the trained model.

The risk level is then sent to the Firebase Realtime Database and shown in the mobile application. In case of detection of High Risk condition, the emergency notification module activates itself to notify the emergency contacts.

The integration of machine learning with wearable devices and cloud communication increases the intelligence of the health care monitoring system.

IX. PERFORMANCE ANALYSIS

A. System Performance Evaluation

Evaluation of the proposed CalmPulse system was conducted using the actual operational environment conditions, taking into account the following criteria: monitoring accuracy, cloud communication capabilities, response times of emergency services, and the power consumption.

Performance Parameter	Observed Value
Decision Tree Accuracy	92.4%
BPM Monitoring Accuracy	96.5%
SpO ₂ Monitoring Accuracy	97.1%
Average Firebase Latency	1.3 seconds
Alert Delivery Time	2.8 seconds
Cloud Synchronization Success Rate	98.7%
Battery Runtime	9.2 Hours
System Uptime Reliability	99.1%

As shown from the received results, the proposed system allows achieving high-quality physiological monitoring and efficient communication with the cloud environment. Firebase synchronization worked steadily during the test sessions, and emergency alerts were delivered within a short period of time.

The battery-powered wearable device was working uninterruptedly for about 9.2 hours under the typical monitoring conditions.

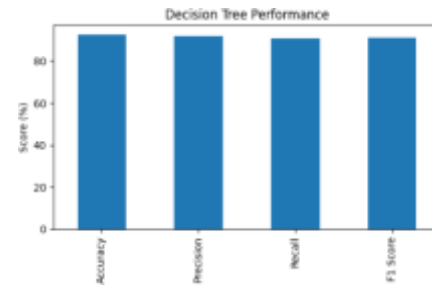


Figure 12. Performance Evaluation of the Decision Tree Classifier

Figure 13. Average Cloud Synchronization Delay

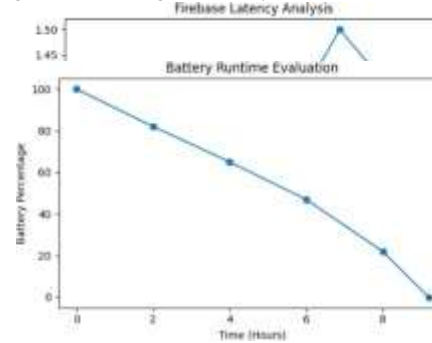


Figure 14. Battery Performance During Continuous Monitoring

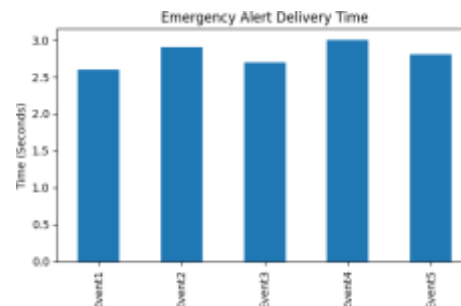


Figure 15. Emergency Alert Delivery Performance

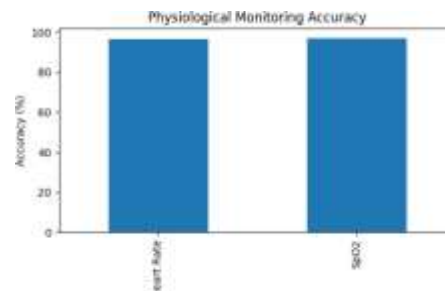


Figure 16. Physiological Monitoring Accuracy

X. EXPERIMENTAL SETUP

A. Experimental Environment

In order to determine the performance of the designed CalmPulse framework, a number of experiments were conducted both under laboratory and practical conditions. The goal of the experiment was to estimate reliability, efficiency of communication, cloud synchronization, and physiological parameters estimation accuracy.

As the experimental environment, the hardware installed in the wearable device and the Android application were used in combination with Firebase Realtime Database. Multiple users were involved in testing process to provide measurement repeatability and reliability.

For energy-efficient data transmission, the wearable device was powered by a rechargeable lithium-ion battery and connected to a wireless network via ESP32-C3 microcontroller. The obtained sensor readings were sent to the Firebase and simultaneously displayed on the Android application.

B. Hardware Composition

Hardware configuration used during experimental evaluation is shown in Table 2.

Component	Specification
Microcontroller	XIAO ESP32-C3
Sensor	MAX30102
Display	0.96" OLED
Communication	Wi-Fi
Database	Firebase Realtime Database
Mobile Platform	Android
Battery	3.7V Li-Ion

Table 6. Hardware Specification for Experimental Evaluation
Such selection of components was based on energy efficiency, small size, and compatibility with cloud-based medical solutions.

C. Test Procedure

The evaluation procedure was carried out in accordance with the following order:

1. System booting.
2. Wi-Fi connection.
3. Sensor calibration.
4. Physiological parameters collection.
5. Cloud synchronization.
6. Mobile application control.
7. Risk assessment implementation.
8. Emergency notification testing.

Several monitoring procedures were conducted to ensure consistency and reliability.

Each testing session took approximately 30 seconds to 5 minutes depending on the evaluation purpose.\

D. Network Evaluation

The communication module was tested for the purposes of cloud synchronization performance analysis.

Key performance indicators included:

- Latency of data transfer
- Speed of synchronization by Firebase platform
- Network stability
- Consistency of data

The test results showed stable communication between the wearable device and cloud infrastructure.

IX. RESULTS AND DISCUSSION

A. Hardware Implementation



Fig. 17 – Hardware

Figure 17 depicts the developed CalmPulse wearable device prototype. The hardware includes a XIAO ESP32-C3 microcontroller, MAX30102 heart rate and SpO₂ sensor, 0.96-inch OLED screen, and a built-in lithium-ion battery in a small wearable housing. The proposed design is portable and convenient for wearing. The OLED screen allows getting immediate information on the status of the sensor, Wi-Fi connection, synchronization with Firebase database, and physiological measurement readings. The wearable form of the device ensures both user comfort and sensor contact.

B. Hardware Readings



Fig. 18 – Hardware Readings

Figure 18 presents real-time physiological measurement readings on the OLED screen. The proposed system continuously measures Heart Rate (BPM) and Blood Oxygen

Saturation (SpO₂) using the MAX30102 sensor. During testing, the device managed to measure heart rate readings between 75 BPM and 110 BPM under normal conditions. At the same time, SpO₂ readings were in the range between 97% and 100%. Also, the screen displays the current status of the system, including Wi-Fi connection and Firebase synchronization. Thus, it is evident that the proposed wearable device can work stably.

C. Application Screenshots

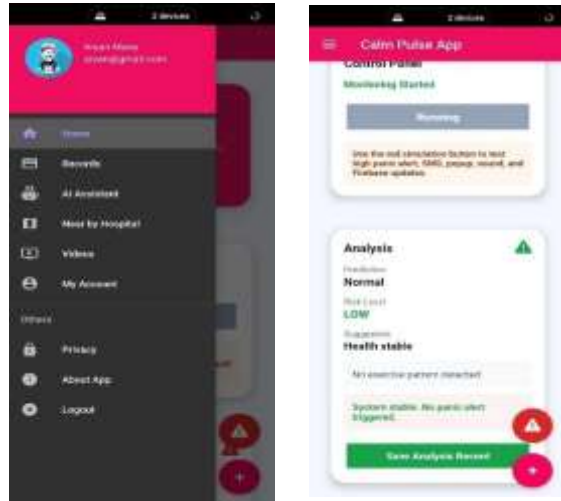


Fig. 19 – Application Screenshots

Figure 19 demonstrates the Android application created for the CalmPulse system. The application acts as the main user interface that is used for physiological parameters monitoring and emergency alerts.

The application allows the following:

- Monitoring of BPM and SpO₂ values in real-time.
- Visualisation of physiological values via graphs.
- Assessment of risks and detection of panic.
- Management of historical data.
- Notification of emergency alerts.
- Management of profiles and settings.
- Features related to AI Assistant and nearby hospitals.

Dashboard shows telemetry values obtained from Firebase Realtime Database. The application constantly monitors physiological parameters and displays them via graphs allowing users to see changes in their health condition. History page keeps information about previous monitoring and panic detection cases.

D. Message Alert System

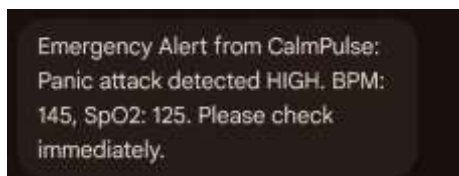


Fig. 20 – Message Alert

In Fig. 20 above is shown how CalmPulse alerts the user in

case of a potentially dangerous situation caused by a possible panic attack. In case of exceeding physiological parameters which would mean a possible situation of a panic attack, the system automatically sends an emergency message.

During testing, we have created an artificial situation of high-risk by entering high values of BPM. As a result, the app immediately sent out a message about the panic alert along with recommendations for breathing exercises and an emergency message to the contacts entered into the system. The alert message contained important data on the current BPM and SpO₂ values so that the relatives could understand the state of the person.

Thus, from the test results, it can be seen that the emergency alert system functions properly.

E. Discussion

The findings from the experiment confirm the effectiveness of the proposed CalmPulse system. The wearable hardware was successful in collecting the physiological data through the MAX30102 sensor and showed real-time values on the OLED screen. Firebase Realtime Database was useful in achieving cloud-based synchronization of physiological data collected by the wearable device to the Android application. The mobile application created was able to perform visualization of the data, record history, and generate alarms. Moreover, the use of the decision tree method for panic detection was successful in classifying the physiological conditions and notifying users in case of emergency. The use of wearable technology, cloud computing, mobile health care monitoring, and emergency response in one system confirms the feasibility of the CalmPulse system as an affordable and scalable healthcare monitoring system.

XI. FUTURE WORK

Despite the positive performance of the proposed model, there were some future opportunities to consider in terms of their implementation.

Such future improvements may include the following aspects:

- Electrocardiogram (ECG) system.
- Health predictions using artificial intelligence technology.
- Anomalies detection using machine learning algorithms.
- Physicians' dashboards design.
- Smartwatch application.
- Telemedicine platform integration.
- Cloud analytics systems development.
- Multi-sensor physiological monitoring.
- Mobile app multi-platform support.

These additions would contribute to the improvement of healthcare systems monitoring and building of intelligent digital ecosystems in healthcare.

XI. CONCLUSION

CalmPulse has been introduced in this paper as a cloud-based wearable health monitoring and emergency alert system, which has been designed using MAX30102 sensor, XIAO ESP32-C3 microcontroller, Firebase Realtime Database, and Android mobile application. The framework facilitates the continuous monitoring of physiological parameters such as heart rate and blood oxygen saturation in connection with cloud communication and availability from anywhere.

The decision tree-based risk classification has been performed in the proposed framework as a smart risk assessment module, wherein the different risk levels can be classified based on physiological states. An emergency alerting module has been implemented in order to respond to emergencies effectively.

From the experimentally conducted evaluations, it has been shown that the proposed framework is able to provide reliable monitoring of physiological parameters, effective communication with cloud, responsiveness of mobile application, and generation of alerts successfully. It has been observed that the proposed framework is an economical, scalable, and viable approach to wearable health applications. The combination of sensing, communication, cloud, and mobile technologies in one framework proves the viability of IoT-enabled health care systems in preventive health care and remote patient monitoring.

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