Iot-Based Smart Band for Continuous Epileptic Seizure Monitoring

Mr. S R Khot[1], Sejal D Kurade[2], Sushant P Retare[3], Pruthviraj P Bhosale [4], Sanika D Patil[5], Pranavi D Fatak[6], Rujavi H Jathar[7]

[1,2,3,4,5,6,7]*D. Y. Patil College of Engineering and Technology, Kolhapur, Maharashtra*

Abstract—The disorder of epilepsy produces unpredictable seizures that occur repeatedly and require urgent treatment because they can cause severe injuries or death. Electroencephalography (EEG) monitoring devices function only within medical facilities because they cannot provide ongoing assessment throughout the entire day. The research introduces a smart band which serves as an IoT wearable device that enables epileptic patients to detect seizures through its Internet of Things (IoT) capabilities. The system employs an ESP32-C3 Super-Mini microcontroller together with an MPU6050 accelerometer-gyroscope sensor and a MAX30102 photoplethysmography (PPG) sensor to track users' body movements and heart rate and oxygen saturation levels. The embedded algorithms use real-time sensor data processing to detect seizure-related activities. The device uses Wi-Fi to transmit data which reaches a cloud platform that enables remote monitoring through a mobile application and delivers emergency alerts to caregivers via Firebase services. The product features a small design which consists of a lightweight PCB and a display and a rechargeable battery that enables users to operate it throughout their daily activities. The system demonstrates accurate detection capabilities which operate with minimal delay according to experimental findings which show it can provide low-cost continuous seizure monitoring outside hospital settings.

I. INTRODUCTION

Epilepsy is a chronic neurological disorder which causes people to experience multiple spontaneous seizures that can happen at any time during their normal daily activities. The episodes result in people losing consciousness which leads to uncontrolled body movements and falls that produce serious injuries while in emergency situations they lead to Sudden Unexpected Death in Epilepsy (SUDEP) conditions. The electroencephalography (EEG) system and in-hospital observation methods serve as conventional monitoring techniques which operate exclusively within medical facilities and permit only brief monitoring intervals. The self-reported seizure diaries current requires accurate information because they miss tracking seizures which happen during the night and when no one observes them.

The latest progress in embedded systems together with Internet of Things (IoT) technology has resulted in the creation of wearable health monitoring devices which can collect data in real time and transmit data wirelessly. The wearable systems which include inertial and physiological sensors such as accelerometers and photoplethysmography (PPG) sensors demonstrate strong potential to achieve ongoing seizure identification outside hospital environments. The existing solutions require offline analysis and rely on proprietary systems while they produce excessive false alarms which restrict their effective usage by users.

This work presents a smart band for epileptic patients as a solution to these challenges. This device functions as a compact and affordable wearable device that enables real-time monitoring of seizures. The system uses an ESP32-C3 Super-Mini microcontroller together with motion and physiological sensors to conduct on-device analysis of seizure-related patterns. The device establishes Wi-Fi or mobile hotspot connections to transmit alerts and real-time data to a cloud platform after it has detected an incident, which enables remote monitoring through a Firebase-based mobile application. The proposed solution aims to provide a scalable, accessible, and reliable assistive technology for continuous seizure surveillance in everyday environments.

II. LITERATURE REVIEW

[1] Abdullah Ahmed et al. "Seizures and Epilepsy: An Overview for UK Medical Students." (2024)

The study delivers an in-depth examination of epilepsy which serves as a medical condition that causes people to experience multiple unprovoked seizures. The paper studies the pathophysiology and classification systems and treatment methods for epilepsy while explaining the differences between seizures and epilepsy. The study presents essential information about risk factors and clinical symptoms and diagnostic methods and treatment methods which follow established guidelines from the National Institute for Health and Care Excellence (NICE) and the World Health Organization (WHO). The research investigates methods for controlling acute seizures while exploring both drug-based and non-drug-based treatment options. The research presents theoretical and clinical content but lacks functionality for real-time monitoring or wearable technology, which demonstrates the requirement for operational systems that track patient status on an ongoing basis.

[2] H. Smajic et al. "Hardware Design of a Smart Wristband Used for Epileptic Seizure Detection." (2022)
This research study investigates the development of a smart wristband which uses accelerometers to detect motion patterns and includes additional physiological sensors to achieve better detection accuracy. The embedded microcontroller enables real-time seizure detection through onboard data processing while the system supports wireless data transmission to enable instant communication with caregivers and monitoring systems. The design prioritizes low power consumption and extended battery life while achieving high wearability standards to ensure the device remains comfortable for users throughout the day.

[3] V. Sangeetha et al. "A Wearable System Design for Epileptic Seizure Detection." (2021)
The study develops the wearable wristband system which enables doctors to monitor epileptic patients throughout their treatment. The system uses Myoware muscle sensors which track muscle movements together with SpO_2 sensors which assess pulse rate and oxygen saturation. Doctors and caregivers can monitor patients continuously because the system sends collected data to a cloud server. The system uses an Android application for sending alerts about seizure events while the alarm system delivers immediate local alerts. The approach enables better emergency response and real-time monitoring but needs cloud infrastructure for operation while it fails to show proper embedded processing methods to optimize power consumption in wearable devices.

III. PROPOSED SYSTEM

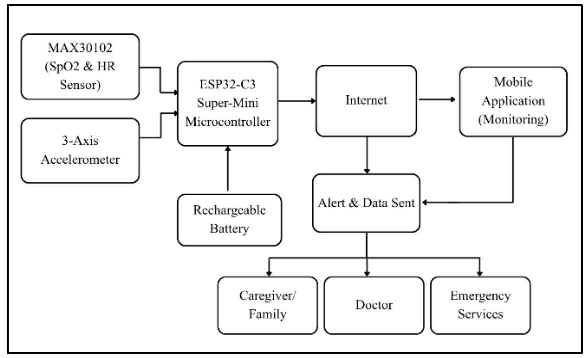

Fig No.1: Block Diagram

The recommended system consists of a wrist-worn smart band which enables continuous seizure monitoring through its combination of motion detection and vital sign monitoring with Internet of Things-based alert system. The device uses an ESP32-C3 microcontroller to connect with an MPU6050 accelerometer–gyroscope module that tracks movement and a MAX30102 photoplethysmography (PPG) sensor which measures heart rate and oxygen saturation (SpO_2). The system displays real-time information through a small OLED screen which operates from a custom-built printed circuit board (PCB) that runs on a rechargeable Li-polymer battery for flexible use and energy-efficient operation.
The ESP32-C3 performs on-device processing by continuously acquiring sensor data and extracting relevant motion and physiological features. These parameters are analyzed using lightweight, threshold-based algorithms to identify seizure-like patterns such as abnormal body movements combined with sudden changes in heart rate or oxygen levels. The system achieves faster response times because it processes data locally while saving resources that would need to run ongoing computation tasks in the cloud.
The device sends alerts and timestamps together with the latest sensor information to a Firebase-based cloud platform through its Wi-Fi and mobile hotspot connections when it detects a potential seizure. The mobile application which connects to the database

offers real-time monitoring to caregivers and clinicians while delivering instant notifications which allow them to supervise patients remotely without needing mobile applications or GSM modules. The system delivers cost-effective benefits through its real-time operational capabilities and its ability to scale while maintaining simple usability, which makes it an effective solution for continuous seizure monitoring, which can be used in daily life.

IV. METHODOLOGY

The proposed smart band for epileptic patients operates through four primary stages which include sensor data acquisition and on-device data processing and seizure detection and cloud-based alert transmission and visualization. The system runs in a continuous loop which monitors real-time data to provide immediate detection and response capabilities.

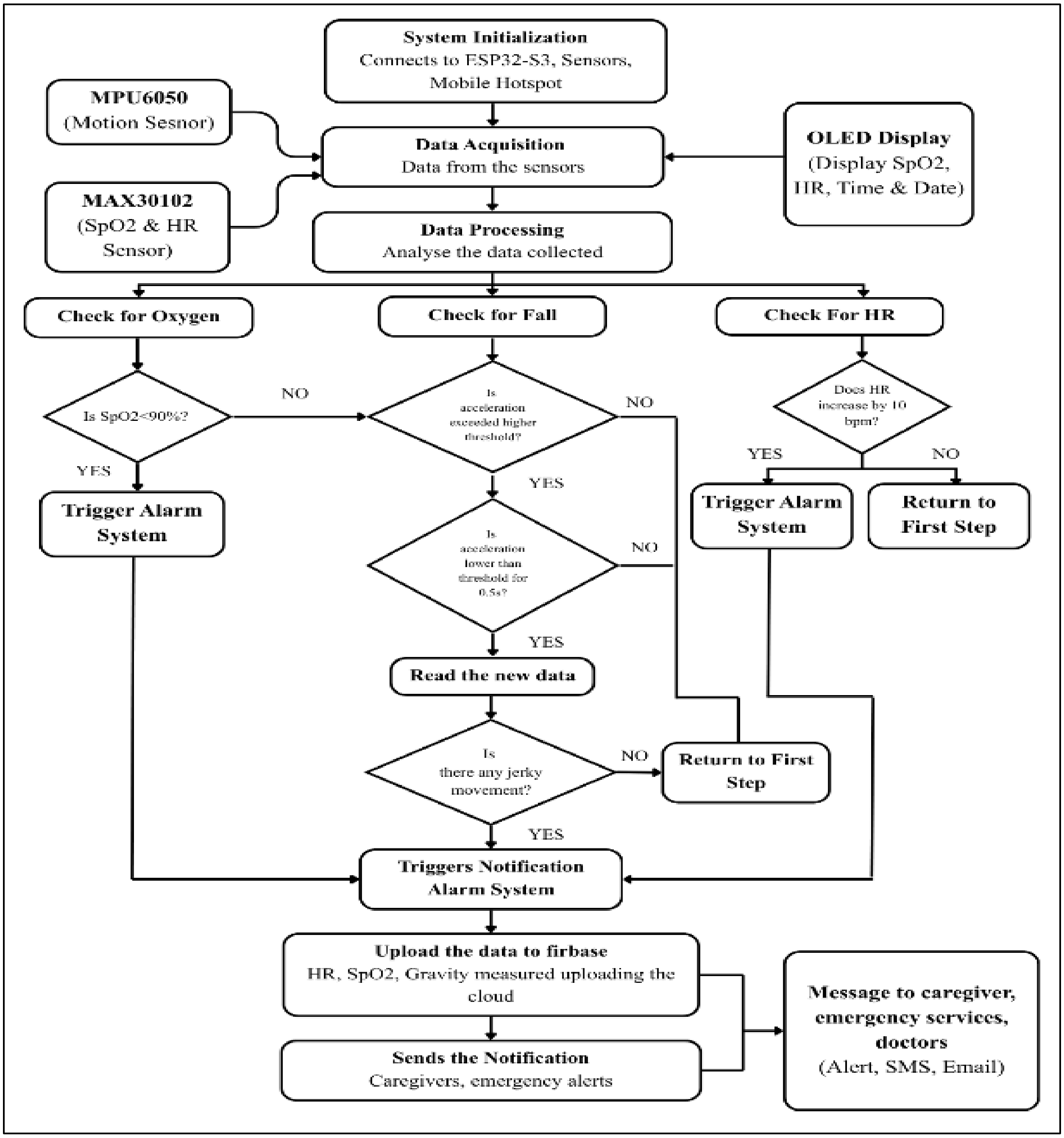

Fig No 2: Methodology

A. Sensor Data Collection

The integrated sensors of the wearable device function to collect both motion data and physiological information. The MPU6050 device) detects body movements and tremor patterns through its ability to capture tri-axial acceleration and angular velocity. The MAX30102 photoplethysmography (PPG) sensor simultaneously records optical signals which research scientists used to calculate heart rate and peripheral oxygen saturation (SpO_2) levels. The ESP32-C3microcontroller establishes I²C protocol connections with both sensors while it records timestamps for each data sample to enable synchronized analysis.

B. Data Processing

The system processes raw sensor data through on-device preprocessing operations which utilize basic filtering methods that include moving average and low-pass filters to eliminate noise and eliminate motion artifacts. The motion data provides information through which researchers extract features that include resultant acceleration and variance and activity patterns used to identify sudden movements and repetitive jerks. Peak detection methods estimate heart rate from physiological data while researchers analyze signal amplitude and consistency to derive SpO_2 values and ensure data reliability.

C. Seizure Detection

The system detects seizures through threshold-based algorithms which operate over sliding time windows. The system evaluates multiple parameters which include sudden acceleration spikes and abnormal motion patterns and elevated or irregular heart rate and drops in SpO_2 levels. A seizure event occurs when the combination of these features exceeds the established threshold limits. The system uses hysteresis and debounces mechanisms to enhance its detection capabilities by reducing false positive results which occur from short-term anomalies.

D. Alert Transmission and Monitoring

The ESP32-C3system generates an alert containing the event status, timestamp, and recent sensor summaries when it detects a seizure-like event. The system transmits JSON data through Wi-Fi or mobile hotspot connections to a Firebase Realtime Database. A mobile application connected to the database provides live data visualization along with instant visual and audible alerts for caregivers. The notification system can be further enhanced through the addition of email and push alert mechanisms. The system maintains continuous monitoring by updating status information at regular intervals to ensure uninterrupted observation.

V. SYSTEM ARCHITECTURE

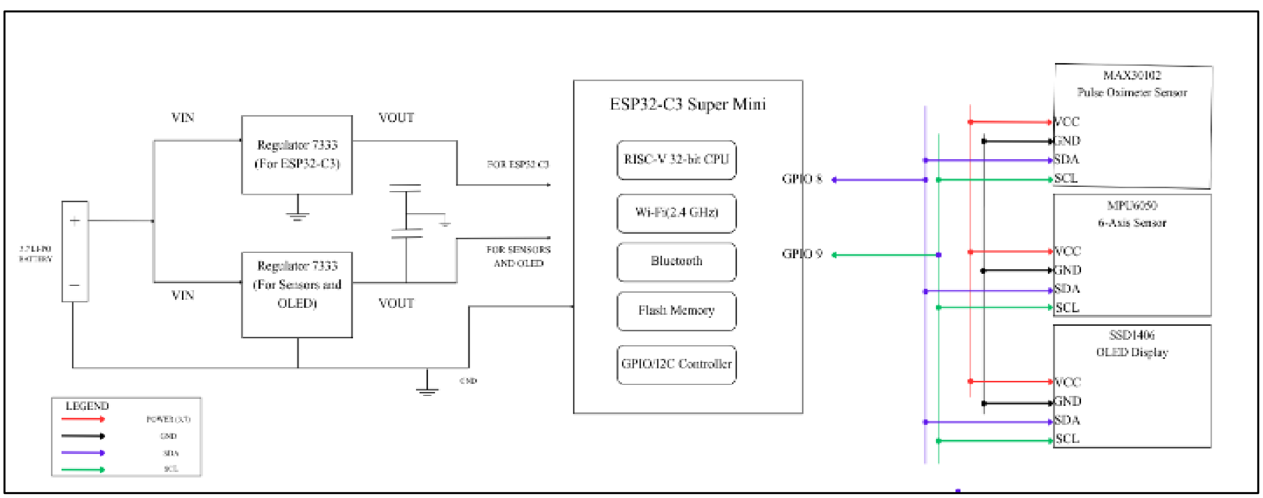

Fig No 3: System Architecture

The system architecture installation uses the Espressif Systems ESP32-C3 Super Mini microcontroller as its main processing unit which controls all functions of the smart wearable system. The system receives its electrical power from a 3.7 V lithium-ion battery which supplies power to two HT-7333 voltage regulators. The first regulator generates a 3.3 V output which powers only the ESP32-C3 module whereas the second regulator provides electricity to the sensor modules and OLED display. The system uses two voltage regulators which help decrease electrical interference while maintaining consistent power supply to both the main controller and its connected devices. Decoupling capacitors connect to the output and ground terminals of every regulator to decrease voltage changes and enhance power system stability.

The ESP32-C3 Super Mini contains a 32-bit RISC-V single-core processor with integrated Wi-Fi and Bluetooth capabilities which enables real-time wireless communication and IoT functionality. The controller connects to multiple biomedical and motion sensing devices through I²C communication protocol. The circuit design uses GPIO8 to operate as SDA line while GPIO9 serves as SCL line which creates an I²C bus system that connects all devices. The MAX30102 pulse oximeter and heart-rate sensor continuously measures physiological parameters such as heart rate and blood oxygen saturation. The MPU6050 six-axis motion sensor detects body movement and acceleration together with any unusual motion patterns. The system also connects an SSD1306-based OLED display to the same I²C bus which allows users to see sensor readings and device status in real time.

The system collects constant physical and movement data through its linked sensors which it processes in the ESP32-C3 microcontroller to show essential information on the OLED display. The system processes data through the ESP32-C3 microcontroller which uses its built-in Wi-Fi and Bluetooth capabilities to send data to external applications and cloud platforms for emergency monitoring and alert creation. The system uses a common ground configuration to establish correct reference voltage levels while maintaining stable communication among its various modules. The system presents a compact solution which consumes minimal power while delivering high performance for use in wearable healthcare and emergency monitoring systems.

VI. SYSTEM DESIGN

The proposed smart band system for epileptic patients includes two primary design elements which operate through hardware architecture and software architecture to support their sensing processing and communication functions.

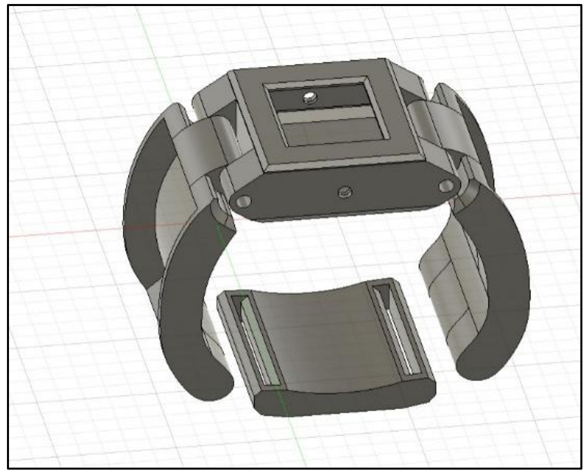

Fig No 4: Band Design

A. Hardware Architecture

An ESP32-C3 microcontroller is the core of the proposed smart band system, providing central processing and control for the entire system. The smart band will continuously collect data from sensors that are connected to the system; after processing this data via embedded algorithms, the smart band will make real-time decisions regarding seizure detection. The ESP32-C3 also interfaces with peripheral devices using I2C and GPIO, allowing it to communicate with both input devices (like an MPU6050) and output devices (like an OLED display). The ESP32-C3 has embedded Wi-Fi and BLE capability for sending critical health-related data via the Internet or Bluetooth to cloud computing platforms for remote monitoring and immediate notification of users. The low-power mode of operation on the ESP32-C3 makes it a perfect microcontroller for wearable applications requiring an efficient use of battery power.

The MPU6050 sensor is an important part of tracking motion and orientation by incorporating a 3-axis gyroscope and a 3-axis accelerometer. The sensor constantly records movement data to be sent to the ESP32-C3 via I2C, where it is analyzed for abnormal motion types like sudden jerks or repetitive motions that occur with epilepsy seizures. The usage of both accelerometer data and gyroscope data increases the accuracy of the detection; additionally, the sensor's built-in Digital Motion Processor (DMP) minimizes the amount of computation required for motion detection on the microcontroller by performing early-stage motion detection tasks on the sensor level.

Like the motion sensors, the MAX30102 sensor uses a photoplethysmography (PPG) technology to capture vital signs of the user (heart rate, blood oxygen saturation (SpO_2)). The MAX30102 does this by sending a beam of light through the skin and measuring how the light absorption changes while the blood flows through. The MAX30102 constantly sends data to the ESP32-C3, which is correlated with data generated by the MPU6050 to provide a more reliable detection of seizure events through the inclusion of both movement data and vital sign irregularities thus reducing the numbers of false positive seizure events.

Charging for the Li-Po battery in this system is accomplished using a TP4056-based charging module that allows for safe and efficient operation during charging. A CC-CV charging scheme has been used with several protection features (overcharging/over-discharging/short circuit) included within this device, therefore permitting the wearable device to be used reliably over a long period of time.

The OLED display used in the system provides a user-friendly interface for displaying heart rate, SpO2 levels and system information in real time. The I2C interface also maximises the speed of processing from an effective contrast ratio to a minimal amount of power. These elements all work together in synchronisation as per the requirements of a smart, secure and energy efficient wearable device for continuous health monitoring and seizure detection.

B. Software Architecture

The Arduino IDE together with its ESP32-C3 board support package establishes the environment needed for developing firmware. The software system uses a modular design that consists of different components to perform system startup and sensor data collection and signal processing and seizure detection and display control and network data transfer.

The embedded algorithms work to analyze sensor data which helps them identify motion patterns and physiological changes through threshold-based logic used for detecting seizures. The system shows essential information on an OLED display while it transmits data through wireless channels for immediate transmission.

The device uses Firebase Realtime Database to store live sensor data and detected events which enables it to connect with cloud services without interruptions. A mobile application connects to the database which enables users to monitor current data and receive alert notifications while they examine past information. The design enables staff members to monitor patient health through wearable devices which provide them with instant access to patient updates.

VII. WORKFLOW

The designed smart band system for epileptic patients uses the ESP32-C3 microcontroller to run its lightweight real-time algorithm. The system achieves dependable seizure detection through its operational design which needs minimal computational power and shows reduced time delays.

1. System Initialization

The ESP32-C3 initializes all peripherals including the MPU6050 (accelerometer–gyroscope), MAX30102 (PPG sensor), OLED display and establishes a Wi-Fi or mobile hotspot connection for cloud communication.

2. Continuous Data Acquisition

The system enters a monitoring loop where it periodically samples tri-axial acceleration and angular velocity and raw PPG signals at predefined intervals.

3. Signal Preprocessing

The system employs moving average and low-pass filters to filter acquired sensor data which helps eliminate noise and motion artifacts for accurate feature extraction.

4. Feature Extraction

The system uses motion features which include resultant acceleration magnitude and variance and peak patterns to detect sudden movements and rhythmic jerks. PPG signals undergo processing to determine heart rate and SpO_2 levels while quality checks remove unreliable readings from the data.

5. Seizure Detection Logic

The system assesses threshold conditions through its sliding time window implementation which evaluates two conditions. The first condition requires users to maintain high acceleration levels. The second condition requires users to repeat their motion patterns. The system detects fall-like events which include a high peak followed by a period of inactivity. The system identifies abnormal heart rate patterns which deviate from the established baseline. The system detects drops in SpO_2 levels which reach beyond the established threshold.

6. Multi-Parameter Fusion

A seizure event is confirmed only when motion anomalies coincide with at least one physiological abnormality within a defined time window, which enhances detection accuracy while it decreases detection errors.

7. Event Handling and Alert Generation

Upon detection, a seizure flag is triggered and all relevant data, which includes timestamp information, sensor summaries, and device status, gets logged. The system processes information by converting it into a JSON payload, which gets sent to the Firebase database through Wi-Fi connection.

8. Notification and System Continuity

The cloud platform processes updates and delivers real-time alerts to caregivers through a mobile application. The system continues monitoring after a brief refractory period, preventing duplicate alerts.

The algorithm processes data efficiently by using multiple sensor inputs to detect seizures with high accuracy and reliability in actual environment conditions.

VIII. LIMITATIONS

Seizures without common motor symptoms or autonomic symptoms show decreased detection ability because of the system's dependence on motion detection together with PPG signal processing. Heuristic threshold-based detection may not generalize optimally across diverse patients and could still produce false positives during vigorous non-seizure activities such as sports.

The system requires stable network connection through Wi-Fi and mobile hotspots for its operation but network interruption causes delays or complete cloud alert failure while the band can still show local alerts. The battery life remains limited because of ongoing sensor operations and Wi-Fi data transmission which requires users to recharge their devices frequently since power management requires extreme optimization to achieve user compliance.

The prototype needs to receive both clinical validation and regulatory approval because current research designates it as an assistive safety device instead of a medical diagnostic instrument.

IX. CONCLUSION

The research introduced a smart wristband system for epileptic patients which operates through IoT technology and includes an ESP32-C3 microcontroller with an MPU6050 inertial sensor and a MAX30102 PPG sensor to achieve continuous seizure detection and Wi-Fi-based notification. The system operates continuously to gather both motion and physiological measurements while it processes lightweight fusion algorithms on-device to detect seizure-like patterns and sends alert notifications together with status updates to a web application which uses Firebase technology to be accessed by caregivers and clinicians. Testing of the prototype with simulated seizure events shows that the system provides accurate detection of convulsive events because it operates with quick response times while using standard IoT equipment to improve patient safety in non-hospital settings. The proposed design provides a practical and affordable solution for developing wearable seizure detection systems which enable remote patient monitoring although it does not serve as a substitute for clinical assessment.

REFERENCES

[1] Ahmed *et al.*, “Seizures and Epilepsy: An Overview for UK Medical Students,” 2024.

[2] H. Smajic *et al.*, “Hardware Design of a Smart Wristband Used for Epileptic Seizure Detection,” 2022.

[3] V. Sangeetha *et al.*, “A Wearable System Design for Epileptic Seizure Detection,” 2021.

[4] World Health Organization (WHO), *Epilepsy: A Public Health Imperative*. Geneva, Switzerland: WHO, 2019.

[5] National Institute for Health and Care Excellence (NICE), *Epilepsies: Diagnosis and Management*, NICE Guideline NG217, 2022.

[6] U. R. Acharya, S. V. Sree, G. Swapna, R. J. Martis, and J. S. Suri, “Automated EEG Analysis of Epilepsy: A Review,” *Knowledge-Based Systems*, vol. 45, pp. 147–165, 2013.

[7] ESPRESSIF Systems, *ESP32-S3 Series Datasheet*, 2023.

[8] InvenSense (TDK), *MPU6050 6-Axis Motion Tracking Device Datasheet*, 2019.

[9] Maxim Integrated, *MAX30102 Pulse Oximeter and Heart-Rate Sensor Datasheet*, 2021.

[10] Google Firebase, “Firebase Realtime Database Documentation.” Available: https://firebase.google.com/docs

[11] J. R. Williamson *et al*., “A Wearable Sensor System for Detecting Seizures,” *IEEE Transactions on Biomedical Engineering*, vol. 62, no. 6, pp. 1500–1510, 2015.

[12] M. Shoeb and J. Guttag, “Application of Machine Learning to Epileptic Seizure Detection,” in *Proc. International Conference on Machine Learning (ICML)*, 2010.

[13] A. Page *et al*., “A Wearable System for the Detection of Epileptic Seizures,” in *Proc. IEEE Engineering in Medicine and Biology Society (EMBS) Conference*, 2015.

[14] Arduino, “Arduino IDE Documentation.” Available: https://www.arduino.cc

[15] K. Van de Vel *et al*., “Non-EEG Seizure Detection Systems and Potential SUDEP Prevention,” *Seizure*, vol. 22, no. 5, pp. 345–355, 2013.