Configurable FIFO Buffer ASIC Flow with Gate-Level Simulation & Assertions

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***Abstract*:** Continuous observation of patient health conditions is essential for early detection of medical emergencies and timely intervention. However, conventional monitoring systems often require frequent hospital visits or rely heavily on internet-based infrastructures, which may not always be available in remote or resource-limited environments. To address these challenges, this paper presents a Real-Time Patient Health Monitoring System using an ESP32 microcontroller integrated with GSM-based notification technology. The proposed system continuously measures vital physiological parameters including heart rate, blood oxygen saturation (SpO_2), and body temperature, while also incorporating a fall detection mechanism to identify accidental movements or patient collapse. The collected data from biomedical sensors is processed in real time using the ESP32 controller. The monitored parameters are displayed on a 16×2 LCD screen, allowing patients and caregivers to easily observe health conditions locally. To enhance patient safety, the system includes a threshold-based alert mechanism. When any monitored parameter exceeds predefined safe limits or when a fall event is detected, an audible buzzer alert is triggered locally. Simultaneously, the integrated GSM communication module automatically sends SMS notifications containing patient status information to caregivers, medical staff, or emergency contacts. Unlike many IoT-based monitoring systems that depend on continuous internet connectivity, the proposed solution operates using cellular communication, ensuring reliable alert delivery even in remote areas. The system is particularly beneficial for elderly individuals, patients with chronic illnesses, and home healthcare monitoring environments. Experimental evaluation demonstrates that the system provides stable real-time monitoring, rapid alert response, and reliable emergency notification, making it a cost-effective and practical solution for modern remote healthcare applications.

1. Introduction

In the present healthcare system, patients are often required to visit hospitals or clinics frequently for regular health checkups, even for basic vital parameter monitoring. This becomes difficult for elderly people, chronic patients, and individuals living in remote areas. Existing systems mainly depend on manual measurements or internet-based applications, which may not provide instant alerts during emergencies and can increase stress, time consumption, and hospital expenses.

To overcome these limitations, this mini project proposes a Real-Time Patient Health Monitoring System using ESP32 with GSM notification. In the proposed system, the ESP32 microcontroller is used to continuously monitor important vital parameters such as heart rate, SpO_2 level, body temperature, and fall detection. The measured values are displayed in real time on an LCD screen for easy observation by the patient or care taker.

For emergency situations, a buzzer is used to provide an immediate local alert to the patient when any parameter exceeds predefined safe limits or a fall is detected. Additionally, a GSM module sends instant notification messages to caretakers or nearby clinics, ensuring quick medical response without relying on internet connectivity.

This system is highly useful in real-world applications such as home healthcare, elderly monitoring, and remote patient supervision. It reduces the need for frequent hospital visits, lowers stress for patients and caregivers, saves time, and enables timely medical attention, thereby improving overall healthcare efficiency.

2. Literature Review

Recent advancements in embedded systems and Internet of Things (IoT) technologies have enabled the development of various patient health monitoring solutions aimed at improving healthcare accessibility and early detection of medical conditions.

In 2022, researchers proposed an **IoT-based remote patient monitoring system** that utilizes wearable biomedical sensors to collect physiological parameters such as heart rate, body temperature, blood oxygen saturation, and environmental conditions. The collected data is transmitted wirelessly to a cloud server where it is analyzed and presented through a remote monitoring interface. The system also generates health alerts based on computed criticality scores, enabling medical professionals to respond quickly to abnormal conditions.

A **Smart Healthcare Monitoring System using IoT**, introduced in 2023, implemented a Raspberry Pi-based architecture integrated with biomedical sensors to monitor body temperature, heart rate, and SpO_2 levels. The measured data was transmitted to cloud storage and visualized through a mobile application. Additionally, the system incorporated GSM/GNSS modules to provide patient location information during emergencies, improving the ability of caregivers to respond effectively.

In 2024, a **Real-Time Patient Monitoring System** was developed using IoT sensors and the Blynk mobile platform. The system collected patient physiological parameters and transmitted them to a mobile dashboard for real-time visualization. Alert notifications were generated through mobile messages and emails when abnormal readings were detected. While this system provided effective remote monitoring

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capabilities, it relied heavily on internet connectivity for operation.

Another research study presented an **Arduino-based health monitoring system** designed for personal health tracking. The system used sensors such as the MAX30100 pulse oximeter and temperature sensors to measure vital parameters and display them on an LCD screen. Although the system was cost-effective and easy to implement, it lacked wireless communication capabilities for remote alert notification.

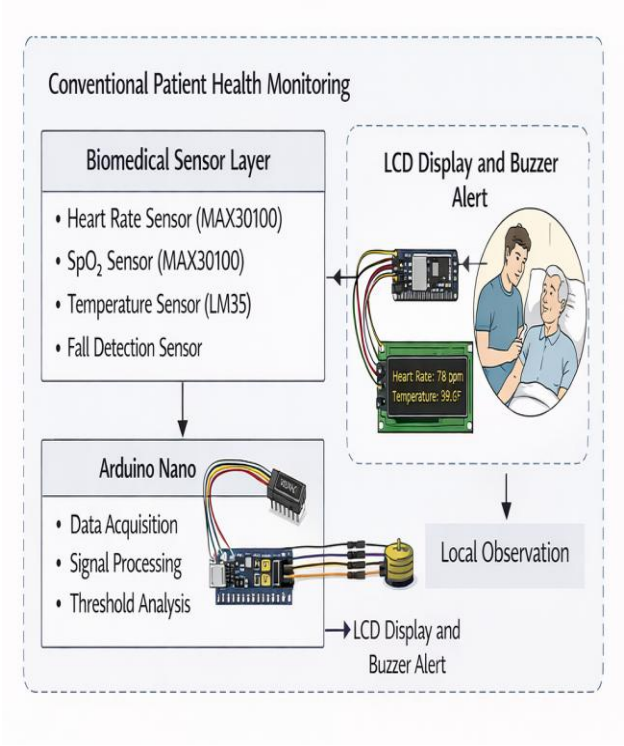
More recent studies have focused on integrating **IoT-enabled healthcare architectures** that combine sensor networks, cloud computing, and data analytics for continuous health monitoring. These systems enable physicians to remotely monitor patient health conditions, detect abnormalities early, and provide timely medical intervention.

Despite these advancements, many existing systems still face challenges such as **dependence on internet connectivity, limited emergency alert mechanisms, and lack of fall detection features**. Therefore, there is a need for a **reliable and internet-independent patient monitoring system** that can provide real-time alerts and ensure immediate caregiver notification.

The proposed system addresses these limitations by integrating **ESP32-based sensor monitoring with GSM communication**, allowing emergency alerts to be transmitted via cellular networks even in environments without internet access.

3. Existing System

Overview of Existing System



Conventional patient health monitoring systems typically rely on microcontroller platforms such as **Arduino Nano** to measure basic physiological parameters. These systems commonly employ sensors like the **MAX30100 pulse oximeter** for measuring heart rate and blood oxygen saturation (SpO_2), along with temperature sensors such as **DHT11** to monitor body temperature.

In these systems, sensor readings are processed locally by the microcontroller and displayed on an LCD interface for direct observation by the patient or caregiver. A buzzer is often used to indicate that the measurement process has been completed or to provide simple alert indications.

Although such systems are useful for personal health monitoring, they generally operate as **standalone devices** without wireless communication or remote alert functionality.

Limitations of Existing Systems

Despite their simplicity, traditional health monitoring systems exhibit several limitations:

- Lack of **remote communication mechanisms** to notify caregivers or medical professionals during emergencies.
- Absence of **GSM or wireless alert systems** for transmitting critical health information.
- Inability to **detect sudden patient falls or accidents**, which are particularly important for elderly patients.
- Dependence on **manual observation**, which may delay medical intervention during emergencies.
- Limited functionality in providing **real-time remote healthcare supervision**.

These limitations highlight the need for an improved monitoring system capable of providing **automated alerts and remote healthcare support**.

4. Proposed System

The proposed system introduces an **ESP32-based real-time patient monitoring architecture integrated with GSM communication** to provide continuous health monitoring and emergency alert functionality.

The system collects physiological parameters such as **heart rate, blood oxygen saturation (SpO_2), and body temperature** using biomedical sensors connected to the ESP32 microcontroller. Additionally, a **fall detection sensor** is integrated into the system to detect sudden patient movements or accidental falls.

The ESP32 acts as the **central processing unit**, responsible for acquiring sensor data, analyzing the measurements, and determining whether the patient's condition falls within normal physiological limits. The analysis is performed using predefined threshold values for each parameter.

If any monitored parameter exceeds the safe threshold range or if a fall event is detected, the system activates a **two-level alert mechanism**:

1. **Local Alert System** – A buzzer is triggered and warning messages are displayed on the LCD screen.
2. **Remote Alert System** – The GSM module sends an SMS notification containing patient health status to registered emergency contacts.

This architecture ensures that caregivers and healthcare providers receive immediate notifications without requiring internet connectivity.

The proposed solution provides several advantages including **real-time monitoring, fast emergency response, reliable**

communication, and suitability for remote healthcare environments.

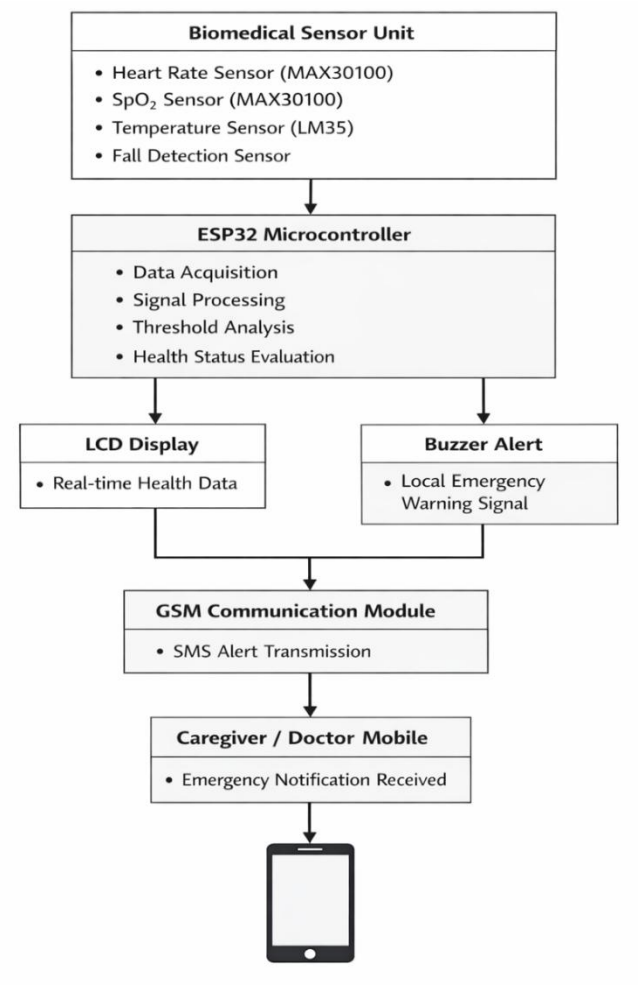


Fig 4.1 System Architecture of ESP32-Based Real-Time Patient Health Monitoring System

5. System Architecture

5.1 Architecture Overview

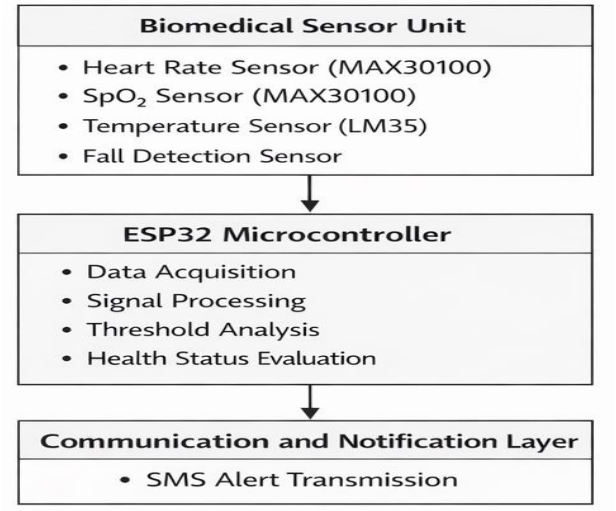
The architecture of the proposed **Real-Time Patient Health Monitoring System** is designed to provide continuous observation of patient health parameters, real-time data processing, and immediate emergency notifications. The system integrates biomedical sensors, an ESP32 microcontroller, and a GSM communication module to ensure reliable health monitoring without the need for continuous internet connectivity.

The system architecture is divided into three major functional layers:

1. **Biomedical Sensor Layer**
2. **Data Processing and Control Layer**
3. **Communication and Notification Layer**

These layers work collaboratively to collect physiological data, analyze patient conditions, and transmit alerts when abnormal health situations are detected.

The primary objective of the architecture is to ensure **continuous monitoring, reliable data processing, and rapid alert delivery**, which are essential for effective healthcare supervision in both home and remote medical environments.



5.1 System Architecture

5.2 Biomedical Sensor Unit

The biomedical sensor unit is responsible for collecting real-time physiological data from the patient. This unit consists of multiple sensors that measure critical health parameters.

The key sensors used in the system include:

- **Heart Rate and SpO_2 Sensor (MAX30100 / MAX30102)**
  Measures the patient's heart rate and blood oxygen saturation levels.
- **Temperature Sensor (LM35)**
  Monitors the patient's body temperature continuously.
- **Fall Detection Sensor**
  Detects sudden body movement or accidental falls, which are particularly important for elderly patients or individuals with mobility issues.

These sensors continuously acquire physiological signals and convert them into electrical data that can be interpreted by the processing unit. The sensor outputs are transmitted to the ESP32 microcontroller using appropriate communication interfaces such as **I2C and ADC channels**.

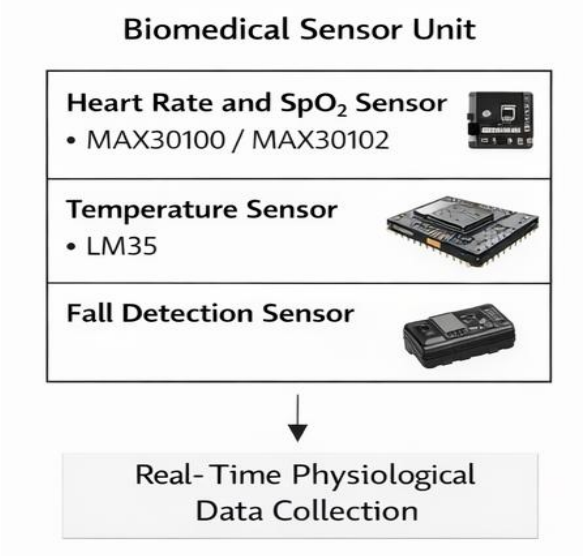


Fig 5.2 Biomedical Sensor Unit

5.3 ESP32 Processing Unit

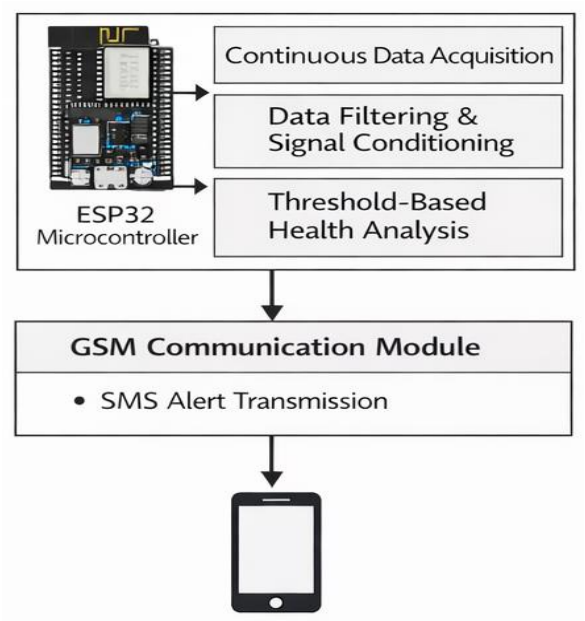


Fig 5.3 ESP32 Processing Unit

The ESP32 microcontroller functions as the **central processing unit of the monitoring system**. It is responsible for acquiring sensor data, performing real-time analysis, and controlling the alert mechanisms.

The ESP32 performs several critical tasks including:

- Continuous acquisition of sensor readings
- Data filtering and signal conditioning
- Threshold comparison for abnormal health detection
- Classification of patient health status
- Activation of local and remote alert mechanisms

Based on the processed data, the ESP32 categorizes the patient's health condition into three states:

- **Normal Condition**
- **Critical Condition**
- **Emergency Condition**

When abnormal readings are detected, the ESP32 immediately initiates an emergency response by activating the buzzer and sending SMS alerts through the GSM module.

5.4 GSM Notification Unit

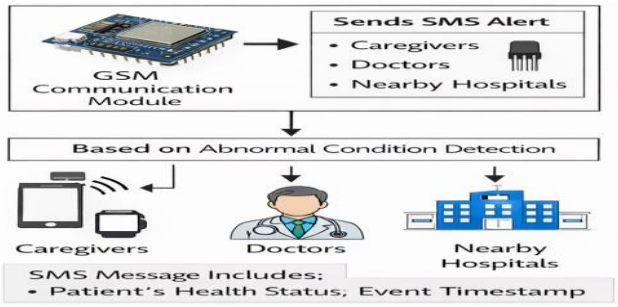


Fig 5.4 GSM Notification Unit

The GSM communication module enables remote notification without requiring internet connectivity. The module communicates with the ESP32 using **UART serial communication**.

When an abnormal health condition or fall event is detected, the GSM module automatically sends an **SMS notification** to predefined emergency contacts such as:

- Caregivers
- Family members
- Doctors
- Nearby hospitals

The SMS message may include:

- Patient health status
- Abnormal parameter values
- Alert notification message
- Timestamp of event detection

The use of GSM communication ensures that emergency alerts can be transmitted even in **rural or remote areas where internet connectivity may be limited**.

6. METHODOLOGY

The methodology of the proposed system focuses on **real-time health monitoring, data analysis, and automated emergency alert generation**. The overall methodology is divided into several operational stages.

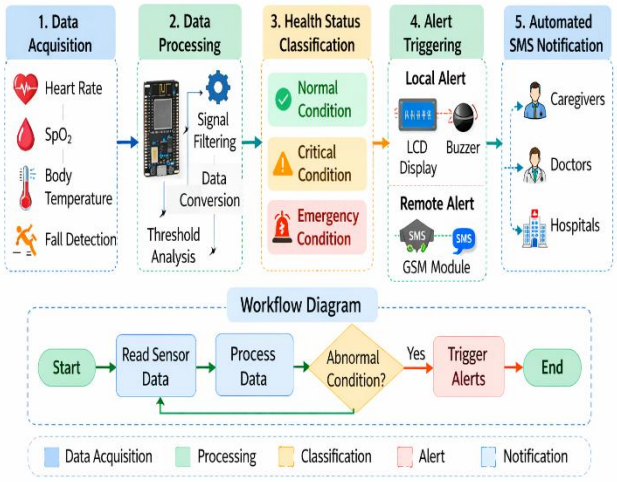


Fig 6.1 : ESP32 health monitoring system

6.1 Data Acquisition

In the first stage, biomedical sensors continuously collect physiological data from the patient. The collected parameters include:

- Heart rate
- Blood oxygen saturation (SpO_2)
- Body temperature
- Fall detection data

The sensors transmit these readings to the ESP32 microcontroller, where they are converted into digital values suitable for analysis.

6.2 Data Processing and Health Condition Analysis

Once the data is received, the ESP32 processes the sensor readings using predefined threshold values. The system compares each parameter with safe medical limits to determine whether the patient's condition is normal or abnormal.

Examples of threshold-based analysis include:

- **Heart rate** outside the normal physiological range
- **Body temperature** exceeding fever threshold levels
- **SpO_2 levels** dropping below safe oxygen saturation limits
- **Sudden motion patterns** indicating a possible fall

To prevent false alerts, the system also performs **data validation and consistency checks** before triggering emergency notifications.

6.3 Health Status Classification

After processing the sensor data, the system classifies the patient's health condition into different categories.

- **Normal Condition** – All physiological parameters remain within safe limits.
- **Critical Condition** – One or more parameters show abnormal values.
- **Emergency Condition** – Severe abnormal readings or fall detection events occur.

This classification helps determine whether an alert should be generated.

6.4 Alert Triggering Mechanism

If the system detects abnormal health conditions, it activates the alert mechanism. The alert process consists of two stages:

1. **Local Alert Activation**
   A buzzer is triggered and a warning message is displayed on the LCD screen.
2. **Remote Alert Transmission**
   The GSM module sends an SMS alert to caregivers or healthcare providers.

This dual alert mechanism ensures that both nearby individuals and remote caregivers are informed about the emergency situation.

6.5 Automated Emergency Notification

The system automatically sends SMS notifications under the following conditions:

- When physiological parameters exceed safe threshold limits
- When sudden abnormal fluctuations are detected
- When fall detection sensors identify accidental movements
- When abnormal conditions persist for a predefined duration

This automated notification mechanism enables caregivers to respond quickly and provide timely medical assistance.

7. Module Description

The system is implemented using a **modular architecture**, where each module performs specific functions while interacting with other modules.

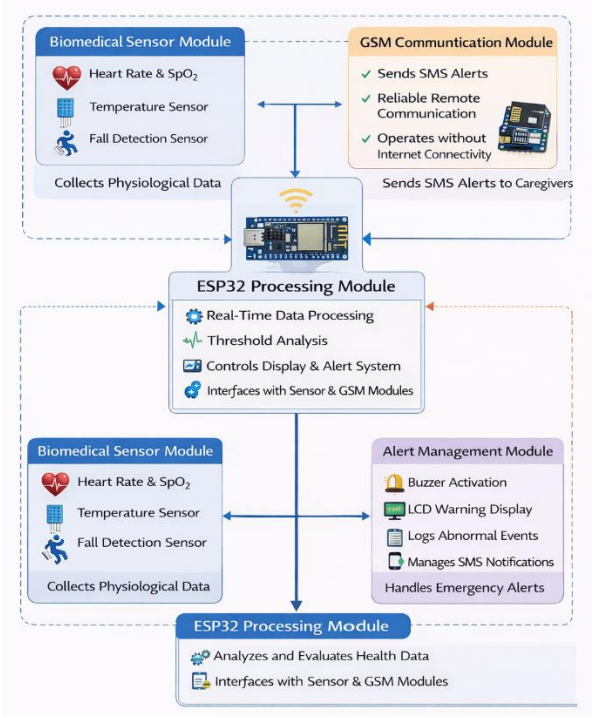


Fig 7.1 Real-time health monitoring system flowchart

7.1 Biomedical Sensor Module

The biomedical sensor module collects physiological signals from the patient. The module includes sensors for heart rate monitoring, blood oxygen measurement, body temperature detection, and fall detection.

These sensors continuously monitor the patient's condition and transmit real-time readings to the ESP32 controller.

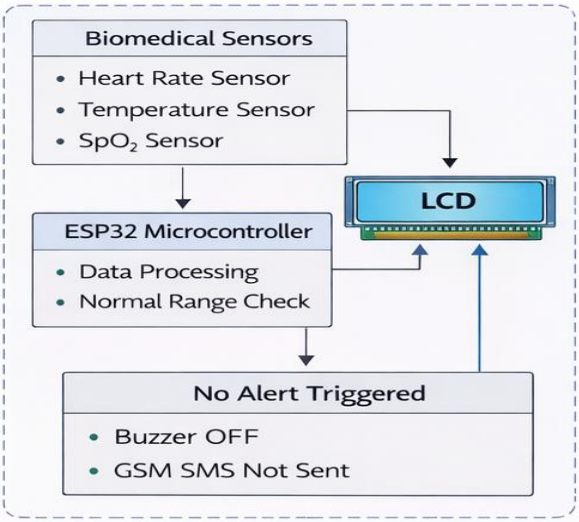


Fig 7.1 Normal Monitoring Scenario of the Patient Health Monitoring System

7.2 ESP32 Processing Module

The ESP32 module acts as the core processing unit of the system. It receives sensor data, performs real-time analysis, and determines whether the patient's health parameters fall within acceptable limits.

The module also controls other components of the system such as:

- LCD display
- Buzzer alert
- GSM communication module

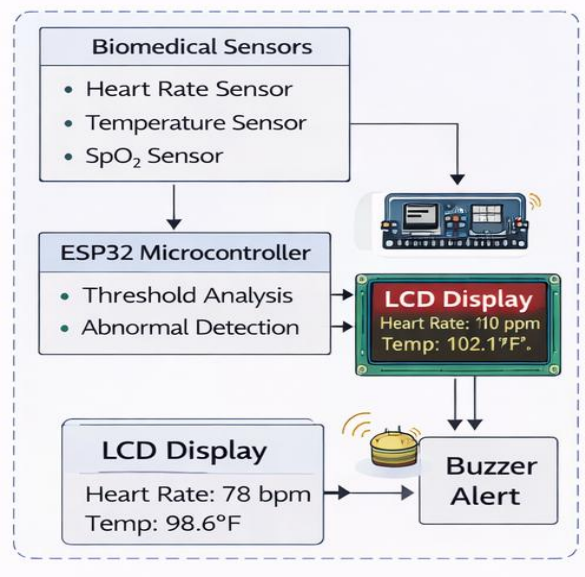


Fig 7.2 Detection of Abnormal Health Conditions and Alert Generation

7.3 GSM Communication Module

The GSM module enables remote communication between the monitoring system and caregivers. When abnormal health conditions are detected, the GSM module sends SMS alerts containing patient health information.

The GSM module provides several advantages including:

- Reliable communication in remote locations
- Instant alert transmission
- No dependency on internet connectivity.

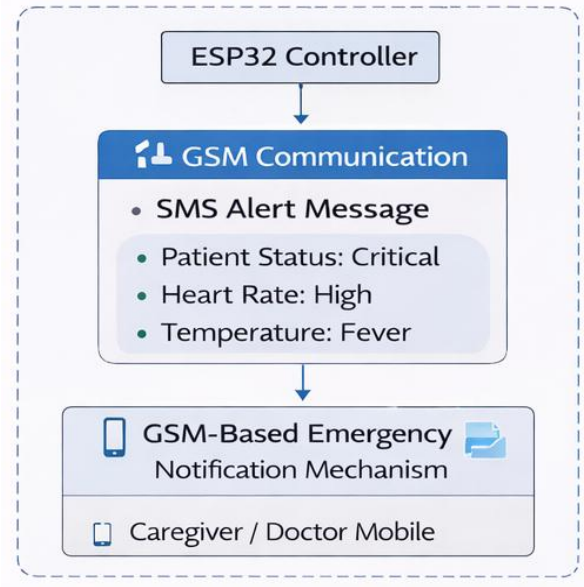


Fig 7.3 GSM-Based Emergency Notification Mechanism

7.4 Alert Management Module

The alert management module ensures that appropriate responses are generated during abnormal health conditions.

The module performs the following functions:

- Activates the buzzer during emergencies
- Displays warning messages on the LCD screen
- Sends SMS notifications through the GSM module
- Logs abnormal health events

Fig 7.4 System Reliability and Continuous Monitoring Performance

8. Results and Discussion

The performance of the proposed system was evaluated through real-time testing using different health monitoring scenarios.

8.1 Normal Monitoring Scenario

During normal operation, the biomedical sensors continuously collect physiological data from the patient. The ESP32 processes the readings and updates the LCD display with real-time information.

Example test case:

Heart Rate: **78 bpm**

Body Temperature: **98.6°F**

In this scenario:

- Sensor readings were successfully processed by the ESP32.
- The LCD displayed the measured values correctly.
- No buzzer alert was triggered.
- No SMS notification was sent.

These results confirm that the system performs normal monitoring without generating unnecessary alerts.

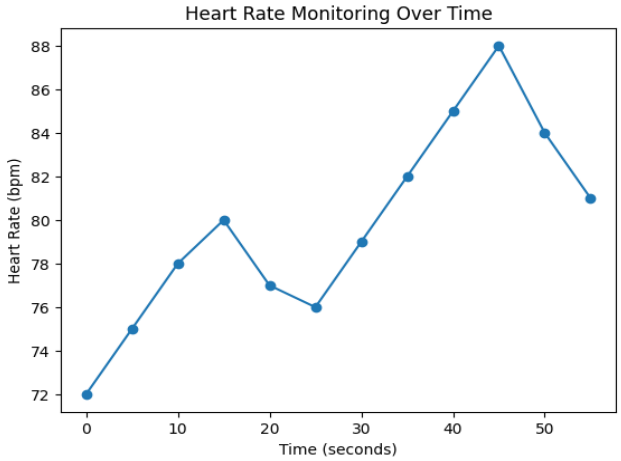


Fig 8.1 Heart Rate Monitoring Over Time

8.2 Abnormal Health Condition Detection

The system was further tested under simulated abnormal health conditions. When sensor readings exceeded predefined threshold limits, the ESP32 immediately detected the abnormal parameters.

The following actions were observed:

- The LCD displayed a **critical health alert message**.
- The buzzer produced an audible alarm.
- The GSM module successfully transmitted an SMS alert to the caregiver.

This demonstrates that the system can accurately detect abnormal health conditions and trigger emergency notifications.

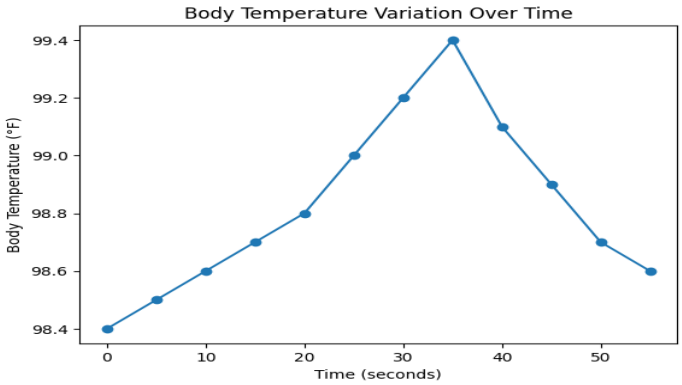


Fig 8.2 Body Temperature Variation Over Time

8.3 System Reliability

The system showed stable performance during continuous monitoring tests. Sensor readings were processed in real time without communication delays, and GSM alerts were delivered successfully.

The results confirm that the proposed system provides:

- Reliable physiological monitoring
- Accurate abnormal condition detection
- Immediate emergency alert transmission

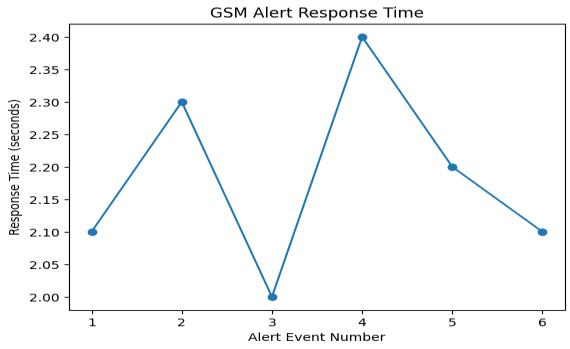


Fig 8.3 GSM Alert Response Time

9. Conclusion and Future Scope

This research presented the design and implementation of a **Real-Time Patient Health Monitoring System using ESP32 with GSM notification**. The proposed system integrates biomedical sensors, embedded processing, and cellular communication to enable continuous monitoring of patient health conditions.

The system successfully measures vital physiological parameters such as heart rate, body temperature, and blood oxygen saturation while also incorporating fall detection functionality. The ESP32 microcontroller processes sensor data in real time and evaluates the patient's health condition using predefined threshold limits.

When abnormal health conditions are detected, the system automatically activates a local buzzer alert and sends SMS notifications to caregivers using the GSM communication module. This dual alert mechanism ensures that emergency situations are identified and communicated immediately.

Experimental evaluation shows that the system provides **accurate monitoring, reliable alert delivery, and minimal response delay**, making it suitable for real-world healthcare applications.

The proposed solution offers several advantages including:

- Continuous patient monitoring
- Real-time emergency alert generation
- Reduced dependency on internet connectivity
- Cost-effective implementation for home healthcare systems

Future Scope

Although the current system provides reliable monitoring capabilities, several improvements can enhance its functionality in future developments.

Future enhancements may include:

- Integration with **cloud-based healthcare platforms**
- Use of **machine learning algorithms for predictive health analysis**
- Multi-patient monitoring support for hospital environments
- Secure data encryption for patient privacy protection
- Integration with **Electronic Health Record (EHR) systems**

These improvements could transform the system into a comprehensive **intelligent healthcare monitoring platform** capable of supporting advanced medical diagnostics and personalized healthcare services.

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