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Physical Healthcare Model for Continuous Vital Sign Tracking and Live Location Detection of Dementia Patients

J. Kaviya[1], M. Harini[2], M. Santhiyalakshimi[3], S. Susmitha[4], Mrs. K. Solangkili[5]

[1,2,3,4]UG Scholars, Department of Electronics & Communication Engineering, Arasu Engineering College, Kumbakonam, India

[5]Assistant Professor, Department of Electronics & Communication Engineering, Arasu Engineering College, Kumbakonam, India

Abstract:

The increasing number of elderly people suffering from Dementia has created a critical need for continuous monitoring systems that ensure their safety, health, and well-being. Dementia patients frequently experience memory loss, confusion, and disorientation, which can lead to wandering away from safe environments and facing difficulties in communicating their health conditions during emergencies. Human trafficking and forced human transport remain critical global challenges due to the absence of reliable real-time victim detection mechanisms, especially in GPS-denied environments. To address these multifaceted challenges, an AI-Driven Wearable Rescue Beacon System is proposed for continuous vital sign tracking and live location detection. The proposed physical healthcare smart wearable watch integrates multiple biometric and motion sensors, including a MAX30102 heart rate and SpO2 sensor, a MEMS accelerometer (MPU6050), and an iBeacon BLE module, all governed by an AI-capable 32-bit microcontroller (ESP32). The device continuously learns the user's normal activity patterns and physiological behavior. If abnormal vital signs are detected or if the patient moves outside a predefined safe area, the system automatically triggers a silent rescue mode and transmits an encrypted distress signal via IoT communication modules to caregivers. This comprehensive system ensures real-time patient monitoring, providing peace of mind to healthcare providers and promoting independent living for dementia patients.

Keywords — **Dementia, Wearable Sensors, IoT Healthcare, Fall Detection, SpO2 Monitoring, GPS Tracking, AI-Driven System, iBeacon BLE.**

1. INTRODUCTION

Healthcare technology has rapidly evolved with the development of smart wearable devices, which allow continuous monitoring of physiological parameters and provide real-time health information. These technologies play a crucial role in assisting elderly individuals and patients suffering from neurological disorders such as Alzheimer's disease and dementia. Dementia is a progressive cognitive disorder that affects memory, thinking ability, and daily functioning. Patients suffering from dementia often experience confusion about time and location, which significantly increases the risk of wandering and getting lost. This condition poses serious safety concerns for both the patients and their respective caregivers.

Traditional healthcare monitoring systems mainly rely on periodic medical checkups or manual supervision by caregivers. However, such approaches fail to provide continuous monitoring of the patient's physical condition or immediate location. In many instances, sudden health problems, cardiac anomalies, or wandering incidents may occur without immediate detection, leaving the patient vulnerable. Therefore, there is a growing, critical need for an intelligent healthcare system that can continuously track both vital health parameters and the geographical location of dementia patients simultaneously.

Recent advancements in wearable technology, sensor systems, and the Internet of Things (IoT) have made it possible to develop smart healthcare devices capable of real-time patient monitoring. A wearable watch equipped with health monitoring sensors can seamlessly collect vital data such as heart rate, body temperature, physical activity, and movement patterns. These sensors work synergistically with embedded microcontrollers to process the data and identify abnormal health conditions autonomously.

Furthermore, integrating a MAX30102 biosensor allows continuous monitoring of cardiovascular activity and oxygen saturation levels. Another major concern in dementia care is patient wandering; many patients unintentionally leave their homes due to confusion. To mitigate this, the proposed wearable watch integrates advanced GPS-based location tracking technology alongside iBeacon BLE mod- ules. By leveraging these wireless communication systems, the patient's real-time location is transmitted to caregivers through mobile applications or cloud platforms, enabling swift intervention and preventing potentially dangerous situations.

2. IDENTIFICATION OF THE PROBLEM

Dementia patients face severe difficulties in their daily lives due to persistent memory loss and confusion. One of the primary problems identified is wandering behavior, where patients may leave their homes or care centers and for- get how to return, leading to accidents, severe injuries, or becoming permanently lost.

Another critical issue is the lack of continuous health monitoring. Vital signs such as heart rate, body temperature, and blood oxygen levels are not monitored regularly when the patient is at home. Sudden physiological changes often go unnoticed, precipitating serious medical emergencies. Furthermore, caregivers and family members face immense psychological and physical strain in providing 24/7 constant supervision. Traditional GPS tracking fails in indoor, underground, or metal-enclosed areas, leaving patients untraceable. Emergency alert systems often require manual activation, which is impossible if the patient is confused, restrained, or incapacitated.

LITERATURE SURVEY Extensive research has been conducted in the field of IoT-based healthcare and fall de- tection systems:

1. **Health Monitoring Using IoT (2018):** Alekya V. and Priyanka M. proposed an IoT-based system to continuously measure heart rate and body temperature us- ing wearable sensors. Data was transmitted to a cloud platform for remote monitoring. This forms the basis for integrating SpO_2 sensors in our project.

2. **Wearable Fall Detection System (2007):** Noury N. et al. developed a system using accelerometers to identify sudden body movements and falls in elderly individuals by analyzing acceleration patterns. This supports our use of the MEMS accelerometer for fall detection.

3. **Smart Health Monitoring Using Sensors (2012):** Patel S. and Park H. introduced wireless monitoring for physiological parameters, inspiring the use of beacon-based emergency alerts in our proposed model.

4. **IoT-Based Smart Healthcare System (2015):** Islam S. M. R. et al. presented a framework for collecting patient data via internet-based communication systems, emphasizing real-time remote diagnosis.

5. **Smart Wearable Device (2010):** Pantelopoulos A. reviewed wearable systems, focusing on integrating accelerometers and heart rate monitors into compact devices.

6. **Real-Time Heart Rate Monitoring (2007):** Allen J. explained the working principle of photoplethysmography (PPG) technology, supporting our integration of the MAX30102 sensor.

3. EXISTING SYSTEM

The existing methodologies for patient and victim tracking rely heavily on outdated, manual, or highly constrained technologies.

3.1 Drawbacks of the Existing System

- **Manual Surveillance:** Monitoring relies primarily on CCTV and manual observation, which is highly ineffective in enclosed vehicles, blind spots, or iso- lated environments.
- **GPS Limitations:** Traditional GPS tracking fails completely in indoor environments, underground transits, or metal-enclosed transport areas, leaving patients and victims untraceable during critical moments.
- **Manual Activation Required:** Current emergency alert systems require the user to manually press a panic button. This is practically impossible if the dementia patient is severely disoriented, having a medical emergency, or incapacitated.
- **Lack of Integrated Intelligence:** Current solutions do not integrate physiological stress signals (like sudden spikes in heart rate) with abnormal motion detection to identify emergencies autonomously.

4. PROPOSED SYSTEM

To overcome the limitations of the existing infrastructure, we propose an AI-driven wearable smartwatch that integrates a heart rate and SpO2 sensor (MAX30102), a MEMS accelerometer (MPU6050), and an iBeacon BLE module to monitor physiological and motion patterns continuously.

4.1 Advantages of the Proposed System

- **Continuous Physiological Monitoring:** The system provides real-time tracking of critical parameters and motion patterns, enabling the early detection of wandering, falls, or forced transport scenarios.

- **AI-Driven Pattern Recognition:** The embedded AI logic learns the user's normal behavior, daily ac- tivity, and stress patterns. This allows for highly accurate identification of abnormal movements or distress conditions while drastically reducing false alarms.
- **Autonomous Rescue Mode:** The system automatically triggers a silent rescue mode upon detecting a potential emergency, eliminating the need for manual user intervention and ensuring patient safety even if they are incapacitated.
- **Robust Connectivity:** It broadcasts encrypted iBeacon distress signals and uploads motion and biometric data to authorized receivers whenever a network is available, ensuring covert protection even in GPS-denied environments.

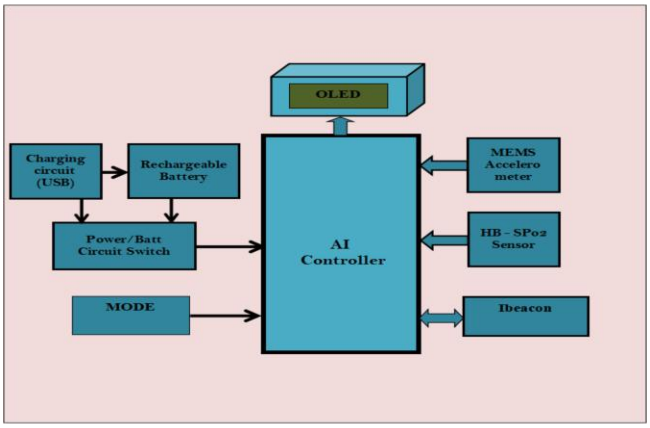

Figure 1: Block Diagram of the Proposed AI-Driven Wear- able System

5. METHODOLOGY AND SYSTEM ARCHI- TECTURE

The architecture of the proposed system is designed for high reliability and low power consumption.

When the device is powered ON, the rechargeable lithium- ion battery (3.7V, 6600mAh) supplies power to the en- tire system via a TP4056 charging circuit and a 3.3V voltage regulator. The AI controller (ESP32) initializes all connected peripherals, including the OLED display, MPU6050, MAX30102, and beacon module via I2C/SPI protocols.

5.1 Sensor Data Acquisition

The controller continuously polls the sensors for data:

- **MEMS Accelerometer (MPU6050):** Measures acceleration along the X, Y, and Z axes to detect body orientation, movement, and sudden impacts (falls).
- **Heart Rate & SpO2 (MAX30102):** Utilizes photoplethysmography (PPG). An infrared LED emits light into the skin, and a photodetector measures the reflected light. Blood volume variations correspond to heartbeats, allowing the controller to calculate BPM and SpO2 percentage.

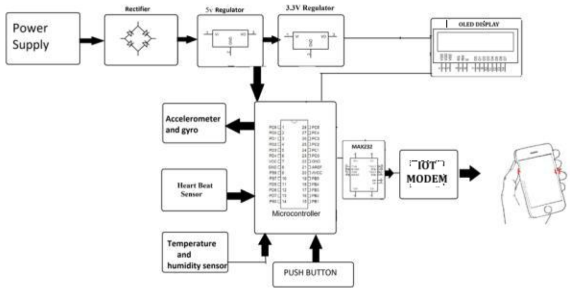

Figure 2: Detailed Circuit Diagram of the Proposed System

5.3 Data Processing & Fall Detection

The AI controller acts as the central processing unit. It filters sensor noise, calculates physiological levels, and analyzes motion data against predefined thresholds (e.g., Normal Heart Rate: 60-100 BPM; Normal SpO2: 95-100%). For fall detection, the controller monitors the accelerometer for a specific pattern:

1. Sudden drop in acceleration (free fall).
2. An extreme impact spike detected by the accelerometer.
3. Lack of movement for several seconds post-impact.

Mathematically, the total acceleration vector is calculated as:

$$A_{total} = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (1)$$

If A_{total} exceeds the defined critical threshold accompanied by immobility, a fall event is registered.

5.4 Emergency Alert Transmission

Upon detecting a fall, critical SpO2 drop, or severe wandering, the controller activates the IoT modem and iBeacon module. The beacon transmits a Bluetooth Low Energy (BLE) signal containing an encrypted alert message, which is detected by nearby receivers or transit checkpoints. Simultaneously, data is pushed to the cloud dashboard for caregivers to view via their mobile application.

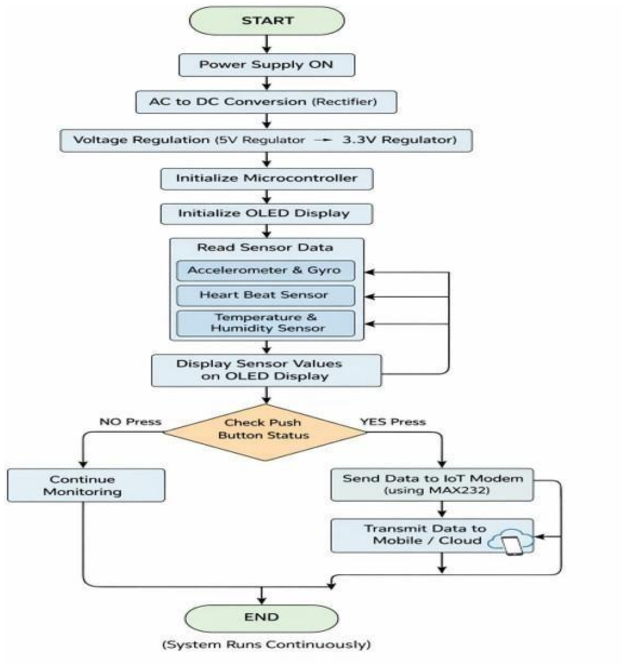

Figure 3: Flow Chart of the System Operation

6. HARDWARE COMPONENTS

6.1 AI 32-bit Controller (ESP32)

The ESP32 is a dual-core, 32-bit microcontroller operating at up to 240 MHz. It features built-in Wi-Fi and Bluetooth capabilities, making it the perfect core for IoT applica-tions. It handles multiple I2C sensor inputs simultaneously and supports Edge AI processing for pattern recognition.

6.2 MAX30102 Pulse Oximeter

This sensor integrates red and IR LEDs with a highly sensitive photodetector to measure SpO2 and heart rate. It operates on ultra-low power, ensuring the wearable device maintains a long battery life.

6.3 MPU6050 MEMS Accelerometer

A 3-axis accelerometer and 3-axis gyroscope combined on a single chip. It captures intricate motion data with 16-bit resolution, crucial for accurate fall and orientation detection.

6.4 iBeacon BLE Module

Using Bluetooth 4.0/5.0 Low Energy, this module broadcasts the patient's unique identifier and distress status over a 10-50 meter range with minimal power draw (¡10 mA).

6.5 OLED Display & Power Supply

A 0.96-inch OLED display provides a crisp, low-power interface showing real-time BPM, SpO2, and system status. Power is managed via a TP4056 module ensuring safe charging and over-discharge protection for the Li-ion battery.

7. SOFTWARE IMPLEMENTATION

The software architecture is primarily developed in **Embedded C/C++** using the Arduino IDE framework and **Python** for specific backend data processing.

7.1 Algorithm Logic

The primary loop reads data sequentially:

```
void loop()
  { readHeartSensor();
  readAccelerometer();
  detectFall();
  displayData();

  if(fallDetected || spo2 < 92 || heartRate
    > 120) { sendEmergencyBeacon();
    uploadToCloud();
  }
  delay(1000);
}
```

The cloud platform stores historical data, offering web and mobile dashboards for caregivers. Alerts are pushed via HTTP/MQTT protocols instantly.

8. RESULTS AND DISCUSSION

The hardware prototype was successfully assembled and tested under various simulated conditions.

8.1 Hardware Results

The MAX30102 accurately monitored heart rates within the 72–85 BPM normal range and SpO2 levels between 95–100%. The MPU6050 fall detection algorithm successfully identified sudden impacts, differentiating between regular walking and actual falls without triggering false positives.

8.2 Software Results

The mobile dashboard displayed live vital signs clearly, updated in real-time. The GPS tracking feature accurately pinned the patient's location on the map interface.

When abnormal conditions were simulated, the system instantly generated an ”EMERGENCY ALERT: FALL DE- TECTED” notification, successfully transmitting the pay- load to the caregiver’s device.

Figure 4: Mobile Application Dashboard Displaying Real- Time Location and Alerts

8.3 System Comparison

A comparison between the existing infrastructure and the proposed model clearly demonstrates the superiority of the AI-driven wearable approach (Table 1).

Table 1: COMPARISON BETWEEN EXISTING AND PROPOSED SYSTEM

Criteria	Existing System	Proposed System
Monitoring	Relies mainly on CCTV and manual monitoring	AI-driven wearable smartwatch for automatic monitoring
Tracking Tech	Uses standard GPS (fails indoors/underground)	Uses BLE iBeacon + mo- tion sensors (works in GPS-denied areas)
Detection Method	No intelligent abnormal pattern detection	AI learns normal activity & detects abnormal stress/motion
Physiological Monitoring	Does not monitor heart rate or stress signals	Monitors heart rate (MAX30102) and motion (MPU6050)

9. APPLICATIONS

This system extends beyond basic dementia care. Its robust feature set makes it highly applicable for:

- Wearable Health Monitoring Systems for the general public.
- Remote Patient Monitoring in post-operative care.
- Elderly Safety, Fall Detection, and assisted living facilities.
- Anti-human trafficking and forced transport detection via covert beacon broadcasting.
- General Smart Healthcare Devices and automated emergency alert frameworks.

10. CONCLUSION

The Physical Healthcare Model for Continuous Vital Sign Tracking and Live Location Detection of Dementia Patients provides a highly effective, low-latency solution for improving patient safety and remote health monitoring. By intelligently integrating sensors like the MEMS accelerometer and MAX30102 SpO2 sensor with an ESP32 AI controller, the system successfully analyzes the user’s health condition autonomously. It detects emergency situations such as sudden falls or abnormal vital signs without requiring user intervention.

The implementation of OLED displays ensures real-time visualization, while the iBeacon module guarantees that caregivers are notified instantly, even in GPS-denied environments. The device successfully promotes independent living for dementia patients while dramatically reducing the psychological burden on caregivers. In the future, this system can be further enhanced with more advanced Edge-AI predictive algorithms, expansive cloud data analytics for long-term health trending, and deeper integration with national emergency medical service (EMS) dispatch systems.

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