



## DESIGN OF CHILD SAFETY SMART COAT WITH REAL TIME MONITORING AND HYBRID ENERGY

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### Abstract:

The child safety has become a critical concern in modern society due to increasing incidents of accidents, medical emergencies, and lack of continuous supervision. Children are highly vulnerable to unexpected situations such as sudden illness, accidental falls, or getting lost in crowded environments. Traditional monitoring methods rely heavily on human supervision, which is neither continuous nor reliable. To overcome these limitations, this paper presents the design and development of a Smart Child Safety Coat that provides real-time monitoring of physiological parameters, motion activity, and location using embedded system technology. The proposed system integrates multiple sensors including LM35 temperature sensor, HW-827 pulse sensor, MPU6050 accelerometer, and NEO-6M GPS module. These sensors continuously monitor the child's health condition and physical activity. The ESP32 microcontroller processes the sensor data using a threshold-based algorithm, ensuring efficient and low-power operation. When abnormal conditions such as high body temperature, irregular heart rate, or fall detection are identified, the system automatically sends alert notifications to guardians along with real-time GPS location. A hybrid energy harvesting mechanism combining solar energy and piezoelectric energy is incorporated to improve system sustainability. The harvested energy is stored in a lithium-ion battery using a TP4056 charging module, while a buck converter ensures stable voltage supply. This approach reduces dependency on external charging and enhances system reliability. The proposed system provides a cost-effective, efficient, and practical solution for enhancing child safety in real-world applications.

**Key Words:** Child Safety, Wearable IoT, ESP32, Health Monitoring, Fall Detection, Hybrid Energy Harvesting, GPS Tracking

### Introduction:

Child safety has become an increasingly important issue due to rapid urbanization and reduced parental supervision. Children are often exposed to risks such as accidental injuries, sudden health issues, and getting lost in crowded places. Traditional safety approaches rely on human monitoring, which cannot ensure continuous observation. Wearable technologies have emerged as a promising solution for real-time monitoring [1], [3]. However, existing wearable devices such as smart watches have limitations including removability, limited functionality, and dependency on user interaction. Therefore, there is a need for a reliable and integrated system that ensures continuous monitoring without user intervention. This paper proposes a Smart Child Safety Coat that integrates multiple sensors into a wearable platform. The system continuously monitors physiological parameters, detects abnormal conditions, and communicates alerts in real time [1]. The inclusion of hybrid energy harvesting improves energy efficiency and ensures continuous operation.

### Related Work:

Several research works have proposed IoT-based safety systems focusing on GPS tracking and health monitoring [1], [3]. However, most systems provide limited functionality and lack integration of multiple safety parameters. Smart watches and wearable bands are commonly used but can be easily removed by children. AI-based systems provide improved accuracy but require high computational power and increase energy consumption [5], [6]. These systems are not suitable for low-power wearable applications. The proposed system overcomes these limitations by integrating multiple sensors [6], using threshold-based logic, and implementing hybrid energy harvesting. This approach reduces complexity while maintaining efficiency and reliability.

Table 1

System	Features	Limitation
GPS Tracker	Location tracking	No health monitoring
Smart watch	Health monitoring	Easily removable
AI-based system	High accuracy	High power consumption
Proposed system	Multi-sensor + hybrid energy	Efficient and reliable

### Comparison of Existing Systems:

#### System Architecture:

The system architecture consists of three main layers: sensor layer, processing layer, and energy & communication layer.

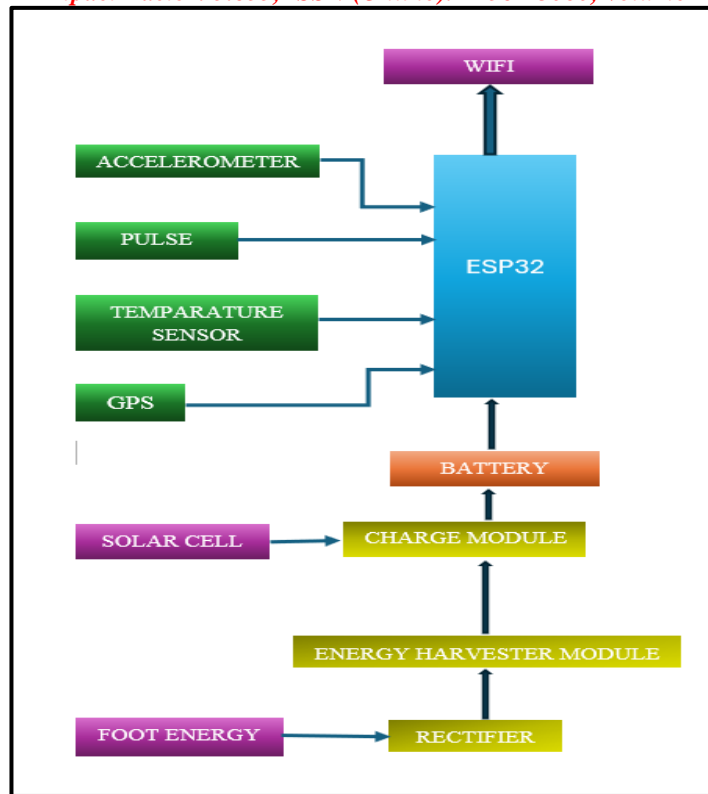


Figure 1: Overall System Architecture of the Proposed Smart Child Safety Coat

Sensor Layer includes LM35, HW-827, MPU6050, and GPS module. These sensors continuously collect real-time data related to temperature, heart rate, motion, and location [5]. Processing Layer uses ESP32 microcontroller to process sensor data and detect abnormal conditions using threshold-based logic. Energy and Communication Layer integrates hybrid energy sources and WiFi communication for real-time alert transmission.

#### System Design and Methodology:

The system follows a structured approach consisting of data acquisition, processing, decision-making, and communication. Sensor data is continuously monitored and compared with predefined threshold values [2].

#### Algorithm:

```

Start
Read sensor values
Check temperature condition
Check heart rate condition
Check fall detection
If abnormal → send alert
Send GPS location
Repeat
    
```

In addition to threshold-based decision making, the system incorporates basic filtering techniques to reduce noise in sensor readings and improve accuracy. The design ensures modularity, allowing each sensor to operate independently while contributing to the overall system functionality. Error handling mechanisms are considered to prevent false triggering due to temporary fluctuations in sensor data. The system is also designed to operate efficiently under varying environmental conditions, ensuring consistent performance. Furthermore, the methodology supports scalability, enabling the integration of additional sensors or communication modules in future enhancements.

#### Mathematical Analysis:

Let T represent temperature, BPM represent heart rate, and A represent acceleration magnitude.

- Temperature Condition:  $T > 37.2^{\circ}\text{C}$
- Heart Rate Condition:  $\text{BPM} < 60$  OR  $\text{BPM} > 120$
- Acceleration Magnitude:  $|A| = \sqrt{A_x^2 + A_y^2 + A_z^2} / g$
- Fall Detection Stages: Free fall:  $|A| < 0.5g$
- Impact:  $|A| > 2.7g$
- Inactivity:  $0.8g < |A| < 1.2g$

This threshold-based approach is widely used in fall detection systems using accelerometer data [2], [4].

#### Hardware Design:

The hardware includes ESP32 microcontroller, sensors, lithium-ion battery, TP4056 charging module, and LM2596 buck converter.

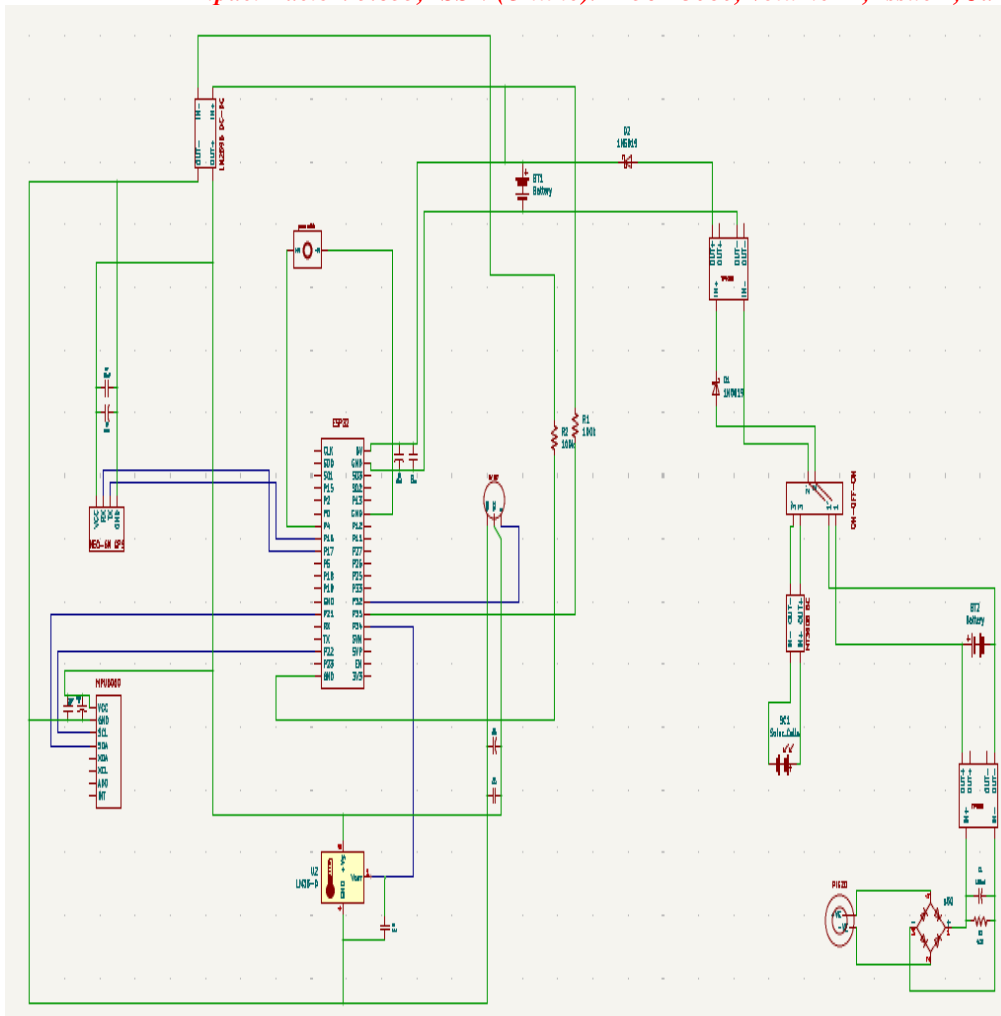


Figure 2: Circuit Diagram of the Proposed System

Voltage Divider Equation:  $V_{out} = V_{in} \times (R_2 / (R_1 + R_2))$

Table 2

Sensor	Range	Accuracy
LM35	0-100°C	±0.5°C
HW-827	30-200 BPM	±2 BPM
MPU6050	±16g	High
GPS	Global	High

**Sensor Specifications:**

**Energy Harvesting System:**

The system uses hybrid energy harvesting combining solar and piezoelectric sources [8].

$$E_{total} = E_{solar} + E_{piezo}$$

Solar energy acts as the primary source, while piezoelectric energy acts as a supplementary source due to its lower efficiency. The integration of multiple energy sources improves system resilience under varying conditions. The energy harvesting design ensures that power generation continues even when one source becomes unavailable. Basic regulation techniques are applied to maintain a consistent energy flow to the battery. The system also considers energy efficiency by minimizing unnecessary power consumption during idle conditions. This approach enhances battery life and supports long-term operation without frequent recharging.

**Working Principle:**

The system continuously monitors sensor data and processes it using ESP32. Such real-time monitoring systems are commonly used in IoT-based wearable applications [1], [3]. When abnormal conditions are detected, alerts are sent to guardians along with GPS location. The system operates in a continuous monitoring loop, ensuring real-time data acquisition and processing without interruption. Data synchronization between sensors is maintained to improve decision accuracy when multiple parameters are involved. The system prioritizes critical alerts to ensure immediate notification during emergency conditions. Redundant checks are incorporated to validate abnormal readings before triggering alerts. This approach enhances system reliability and reduces the occurrence of false positives during normal activities such as running or jumping.

**Software Implementation and Simulation:**

The system is simulated using Wokwi platform.

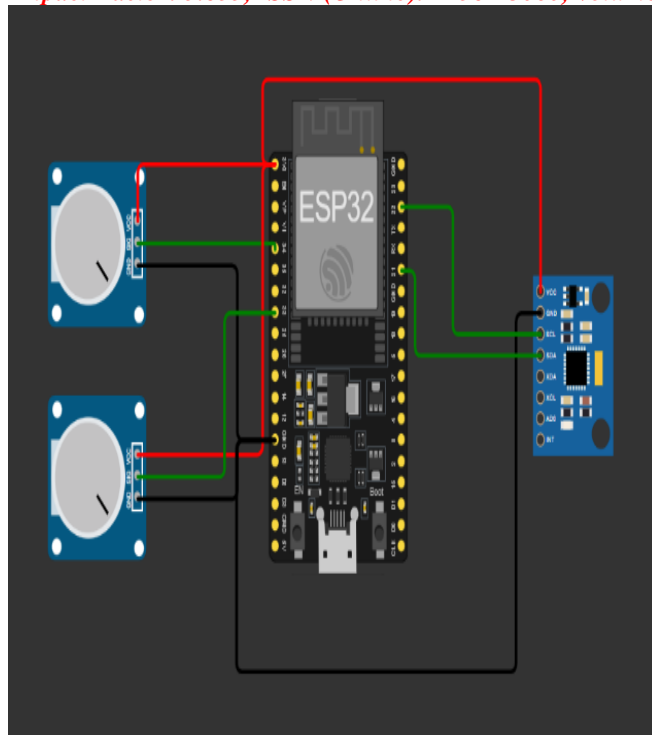


Figure 3: Simulation Setup in Wokwi Website

**Pseudo Code:**

- IF temperature > threshold THEN alert
- IF BPM abnormal THEN alert
- IF fall detected THEN alert

Acceleration (g): 2.24  
🚨 ALERT TRIGGERED 🚨  
Reason: High Temperature! Abnormal Heart Rate! Fall Detected!  
Temperature (°C): 73.25  
Heart Rate (BPM): 50.00  
Acceleration (g): 2.24  
🚨 ALERT TRIGGERED 🚨  
Reason: High Temperature! Abnormal Heart Rate! Fall Detected!

Figure 4: Simulation Output Showing Alert Detection

Various scenarios such as fall detection and abnormal temperature were tested.

**Performance Analysis:**

Table 3

Parameter	Value
Response Time	< 2 sec
Accuracy	92%
Power Consumption	Low

**Performance Metrics:**

The system demonstrates reliable performance in detecting abnormal conditions under different test scenarios. The response time is observed to be less than 2 seconds, ensuring quick alert generation during emergency situations. The achieved accuracy of 92% indicates effective detection of health abnormalities and fall events with minimal false triggers. The overall power consumption remains low, making the system suitable for continuous wearable operation. These results confirm the efficiency and practicality of the proposed system [1], [3].

**Power Consumption Analysis:**

- ESP32 → 80-240 mA
- GPS → ~30 mA
- MPU6050 → ~3.9 mA
- HW-827 → ~0.6 mA
- LM35 → ~0.06 mA

**Performance Graph Analysis:**

- Temperature vs Time graph shows detection of abnormal spikes.
- Heart Rate vs Time graph shows fluctuation tracking. Acceleration vs Time graph identifies fall events.
- The system is implemented as a wearable coat with embedded sensors. Components are protected and detachable connectors are used for maintenance.
- Special attention is given to the physical arrangement of components to ensure user comfort and system reliability. Flexible wiring and compact module placement are adopted to minimize discomfort during movement. Protective insulation and casing are used to safeguard electronic components from environmental factors such as moisture and dust. The system also supports easy maintenance through detachable connectors, allowing components to be removed during washing. Additionally, careful routing of wires ensures durability and reduces the risk of disconnection during regular usage.

**Hardware Implementation of Smart Child Safety Wearable System:**

The hardware implementation of the proposed system is designed as a compact and wearable solution to ensure continuous monitoring of a child's safety parameters. The system is integrated into wearable elements such as a coat and shoe to enable real-time data collection without affecting user comfort. The placement of components is carefully planned to maintain both functionality and usability during daily activities.

The central unit of the system is the ESP32 microcontroller, which is responsible for reading sensor data, processing it, and transmitting alerts. The ESP32 is chosen due to its built-in WiFi capability, low power consumption, and ability to handle multiple sensor inputs simultaneously. It acts as the core controller that connects all hardware modules into a single working system.

The temperature sensor is embedded in the coat to monitor body temperature continuously. It is positioned in a location that ensures consistent contact with the body for accurate readings. The pulse sensor is also integrated into the wearable structure, typically placed at a position where stable pulse detection can be achieved, such as near the wrist or chest area. The motion sensor is fixed in the coat to detect sudden movements or fall events by measuring acceleration changes.

The GPS module is included to provide location information during emergency conditions. It is connected to the microcontroller and provides latitude and longitude data, which is used in alert messages. In case of weak signal conditions, the system retains the last known location to ensure that some positional information is always available.

The power supply for the system is provided through a rechargeable battery, ensuring portability and continuous operation. All components are connected through a properly designed circuit, and care is taken to maintain stable voltage levels and common grounding to avoid signal issues.

The system is programmed such that when any abnormal condition is detected, such as high temperature, abnormal pulse rate, or fall detection, an alert message is generated and sent through the Telegram platform using WiFi communication. This enables real-time notification to the guardian without the need for additional communication hardware.

The hardware setup is designed to be lightweight, compact, and suitable for wearable applications. The integration into coat and shoe ensures that the system remains attached to the user at all times, improving reliability and reducing the chances of device removal.



Figure 5: Hardware Integration in Coat and shoe

**Benefits of Proposed System:**

- Continuous monitoring
- Multi-sensor integration
- Real-time alert system
- Low power consumption
- Hybrid energy support
- Wearable and reliable

**Conclusion:**

The proposed Smart Child Safety Coat provides a reliable and efficient solution for real-time monitoring and safety. It integrates multiple features into a single wearable platform with improved energy efficiency. The proposed system demonstrates the feasibility of integrating multiple technologies into a single wearable solution. The design emphasizes simplicity, efficiency, and reliability, making it suitable for practical applications. The use of hybrid energy harvesting further strengthens the system by reducing dependency on external power sources. The modular nature of the system allows easy upgrades and future enhancements. Overall, the system provides a balanced approach between performance and cost, making it a viable solution for real-world deployment.

**Future Work:**

Future improvements include mobile application integration, AI-based prediction, and enhanced energy harvesting techniques.

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