



# Design and Implementation of a Plug-And-Play Power-Based Safety System for Detecting Unattended Children in Vehicles

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## Abstract

Leaving children unattended in parked vehicles poses a serious safety risk, particularly in hot climates, where cabin temperatures can rise rapidly. This paper presents the design and functional demonstration of a plug-and-play IoT-based safety prototype using an ESP32 microcontroller, DHT22 temperature sensor, passive infrared (PIR) motion sensor, and MQ-2 environmental gas sensor. The PIR sensor provides occupancy-related motion input, while the DHT22 and MQ-2 provide environmental inputs. The MQ-2 serves as an auxiliary indicator of combustible-gas or smoke-related conditions and is not treated as a direct measure of human presence or respiration. When PIR-detected motion coincides with either the temperature threshold or the programmed MQ-2 threshold, the system activates audible and visual alarms, sends a Telegram notification, and logs the event in Google Sheets. The power architecture uses the vehicle supply while the vehicle is running and a rechargeable lithium-ion battery to maintain monitoring after the vehicle supply is switched off. Selected development-stage observations from the cloud log demonstrated the operation of the sensing, classification, logging, and alert pathways. However, because the demonstration did not use a predefined ground-truthed trial protocol, these observations are not presented as accuracy or reliability dataset. The prototype is therefore presented as a functional proof of concept that requires further controlled performance evaluation and testing under automotive-environment conditions.

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## I. INTRODUCTION

Leaving children unattended in parked vehicles remains a serious safety concern worldwide, particularly in hot and humid climates, where cabin temperatures can rapidly reach life-threatening levels. In Malaysia and similar regions, environmental conditions significantly increase the risk of heat-related injuries and fatalities among infants and young children left inside enclosed vehicles. Despite public awareness campaigns and increasing media attention, such incidents continue to occur, often due to caregiver distraction, fatigue, or unexpected changes in routine.

Exposure to elevated temperatures within confined vehicle environments can lead to rapid heat stress, dehydration, and heatstroke. These conditions develop more quickly in young children due to their limited thermoregulatory capacity. To mitigate these risks, various child-presence detection and reminder systems have been proposed, including integrated automotive safety features and aftermarket devices. However, many existing solutions are restricted to newer vehicle models, involve high costs, or require complex installation procedures, thereby limiting their accessibility and long-term adoption[1].

Recent advances in embedded systems and Internet of Things (IoT) technologies have enabled the development of low-cost platforms capable of monitoring environmental

conditions and motion-related inputs while delivering remote alerts. However, many published implementations remain proof-of-concept systems evaluated under limited conditions. [2]. Therefore, practical aspects such as backup power following vehicle shutdown, installation requirements, communication availability, and quantitative false-alarm performance require careful consideration.

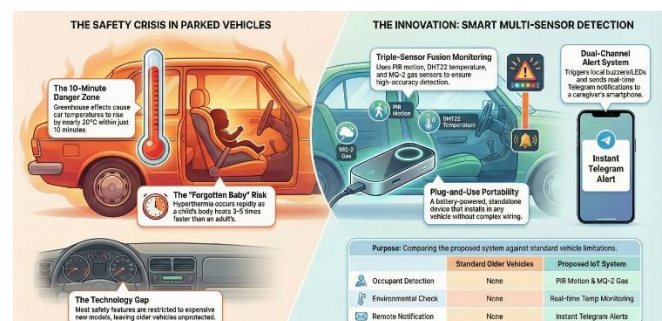


Figure 1. An IoT Plug-and-Play Child Safety System for Vehicles

Figure 1 summarizes the motivation and system concept of this study. It develops a portable ESP32-based prototype that combines PIR motion sensing with temperature and MQ-2 environmental monitoring, local audible and visual warnings, Telegram notification, and Google Sheets data logging. The

device is designed to receive power from the vehicle's electrical supply while the vehicle is running and to continue monitoring from a rechargeable battery after the vehicle supply is switched off. The work is positioned as a functional proof of concept for an aftermarket safety aid rather than as a validated replacement for an automotive child-presence detection system.

## II. LITERATURE REVIEW

Research on preventing child fatalities in parked vehicles has gained increasing scholarly attention in recent years, driven by the continuing occurrence of vehicular heatstroke deaths worldwide. This concern has led to the development of various child-presence detection (CPD) and reminder systems designed to identify occupant presence and alert caregivers when a child is left unattended under unsafe thermal conditions.

Table 1  
Summary of Related Child Presence Detection and Safety Systems

| Ref.      | Techniques                         | Alert Mechanism                      | Key Strengths                                                                        | Limitations                                                                           |
|-----------|------------------------------------|--------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| [3]       | Radar, weight, temperature sensors | Vehicle-integrated alerts            | Provides overview of regulatory and commercial CPD development                       | Lacks experimental or prototype validation                                            |
| [4]       | Motion, temperature, sound sensors | GSM / Wi-Fi alerts                   | Comprehensive overview of IoT-enabled safety systems                                 | Limited discussion on hardware deployment and validation                              |
| [6]       | 24 GHz radar, breathing analysis   | On-board alerts                      | Non-intrusive detection with high sensitivity                                        | Sensitive to sensor placement; relatively high cost                                   |
| [8]       | 79–81 GHz radar                    | Simulated passive detection          | Demonstrates radar feasibility for CPD                                               | Requires ECU integration; lacks portability                                           |
| [7]       | 60 GHz radar, XENSIV kit           | IoT-based caregiver notification     | Reliable detection using advanced sensing                                            | Expensive components; complex design                                                  |
| [9]       | Motion and temperature sensors     | GSM (SMS alert)                      | Simple and affordable prototype                                                      | Limited testing and communication range                                               |
| [12]      | Temperature sensor, NodeMCU        | Mobile notification                  | Context-specific and user-centred design                                             | Relies on single-parameter detection                                                  |
| [11]      | IR and motion sensors              | Mobile notification                  | Improves object–human differentiation                                                | Calibration required; potential false alarms                                          |
| This work | PIR, DHT22, MQ-2                   | Buzzer/L ED, Telegram, Google Sheets | Portable; includes backup battery after vehicle shutdown and local and remote alerts | PIR detection depends on movement; Wi-Fi dependent; lacks automotive-grade validation |

As summarized in Table 1, existing approaches can be broadly grouped into three main categories: integrated

automotive systems, advanced sensor-based research prototypes, and low-cost aftermarket or IoT-enabled solutions [3][4].

Several studies have explored multi-sensor-based child detection systems that combine motion, temperature, sound, and gas sensing to improve reliability and reduce false alarms. Sensor-fusion approaches integrating environmental and motion parameters have demonstrated better detection accuracy than single-sensor configurations. For example, hybrid systems that combine force-sensing resistors (FSRs), motion sensors, and respiration monitoring have shown high precision and rapid response for real-time detection under dynamic in-vehicle conditions [5]. Similarly, radar-based methods, including 24 GHz and 60 GHz millimeter-wave systems, have successfully detected subtle breathing patterns or micro-movements of stationary infants, offering high accuracy and potential compatibility with automotive safety standards [6, 7]. However, most of these systems are tailored for specific vehicle platforms or require direct integration with vehicle electronic control units (ECUs), restricting their application to newer or high-end models. These design dependencies limit retrofitting feasibility and increase the overall cost [3][8].

In parallel, other studies have focused on low-cost and aftermarket reminder systems, including weight-based seat sensors, wearable tags, and mobile alert mechanisms. Weight and pressure-based detectors can sense a child's presence even in the absence of movement but typically require customized installation or power interface adapters, thereby limiting their universality [9].

Wearable or tag-based devices, although conceptually simple, depend heavily on user compliance and battery maintenance, which may reduce long-term reliability [10]. Recent IoT-enabled prototypes have demonstrated promising results using Arduino-based platforms and networked sensors for occupant detection and mobile alerts while maintaining affordability and enhancing privacy protection [11].

Rapid advances in embedded systems and Internet of Things (IoT) technologies have further supported the development of portable and remotely monitored safety systems. IoT-based solutions using microcontrollers and wireless communication have successfully delivered real-time temperature and occupancy alerts through mobile platforms [12]. Similarly, intelligent IoT architectures combining environmental, motion, and connectivity modules have shown scalable designs suitable for integration into both passenger and fleet vehicles[13][14]. Nevertheless, many of these implementations rely on single-parameter detection or assume continuous connectivity, overlooking real-world considerations such as independent power supply, ease of deployment, and hardware robustness in the parked-vehicle environment.

The literature indicates a continuing trade-off among direct occupant-sensing capability, cost, installation complexity, and communication method. Radar and seat-based approaches provide stronger evidence of a stationary occupant but generally require more specialized sensing technologies or installation procedures [3][6]–[9]. Low-cost IoT systems are easier to prototype and retrofit but remain dependent on sensor placement, network availability, and the quality of experimental validation [4][11][12]. Recent studies have also investigated millimeter-wave radar, thermal imaging, and Wi-Fi-based deep learning methods for in-vehicle occupant or child-presence detection [15][17]. These

methods provide stronger stationary-occupant detection capabilities but generally require specialized hardware, extensive datasets, or more complex processing. The present study addresses the implementation gap by integrating low-cost sensing, local and remote alerts, cloud-based logging, and backup-battery operation in a single portable prototype, while explicitly recognizing the limitations of PIR-based motion detection and development-stage functional testing.

### III. METHODOLOGY

This study employed a prototype-development approach involving the design, integration, and functional verification of a portable, plug-and-play Internet of Things (IoT)-based child safety system. The methodology comprised three main stages: (i) system design and conceptualization, (ii) system development, and (iii) prototype development. The demonstration was conducted in a stationary vehicle using simulated inputs and was intended to verify system operation rather than to establish detection accuracy or reliability under real-world operating conditions.

#### A. System Design and Operation

The prototype uses a hybrid vehicle-and-battery power arrangement. While the vehicle is running, the system receives power through the vehicle supply connection and the charging circuit supports the rechargeable lithium-ion battery. When the vehicle supply is switched off, the battery and boost converter maintain the regulated supply to the ESP32, sensors, and alert components. Figure 2 shows the five functional modules.

- **Sensing Module:** This module incorporates a DHT22 sensor for ambient temperature monitoring and a passive infrared (PIR) sensor for detecting occupant motion. The MQ-2 is included as an auxiliary environmental sensor responsive to combustible gas or smoke-related conditions. It is not used as a direct measure of human presence or respiration.
- **Processing Module:** The ESP32 microcontroller serves as the core processing unit, responsible for sensor data acquisition, decision logic execution, and wireless communication. The ESP32 was selected due to its integrated Wi-Fi capability, low power consumption, compact form factor, and compatibility with open-source development environments.
- **Alert Module:** This module provides immediate local warnings by activating an audible buzzer and a visual LED indicator when predefined safety thresholds are exceeded.
- **Communication Module:** Utilizing the ESP32's Wi-Fi functionality, this module transmits real-time remote alerts to caregivers via the Telegram messaging platform and logs sensor data to Google Sheets for monitoring and historical analysis.
- **Power Supply:** During vehicle operation, the vehicle power connection supplies power to the system and supports battery charging through the charging module. After the vehicle supply is switched off, a single 3.7 V UltraFire TR 18650 lithium-ion cell and boost converter maintain the system's power supply. The cell was labelled and advertised by the seller as having 9800 mAh; however, this capacity and the resulting operating duration were not independently verified.

This arrangement supports continued monitoring after vehicle shutdown without requiring permanent modification of the vehicle's wiring. Performance under different vehicle electrical loads, alternator noise, voltage transients, and extended battery discharge was outside the scope of the functional demonstration.

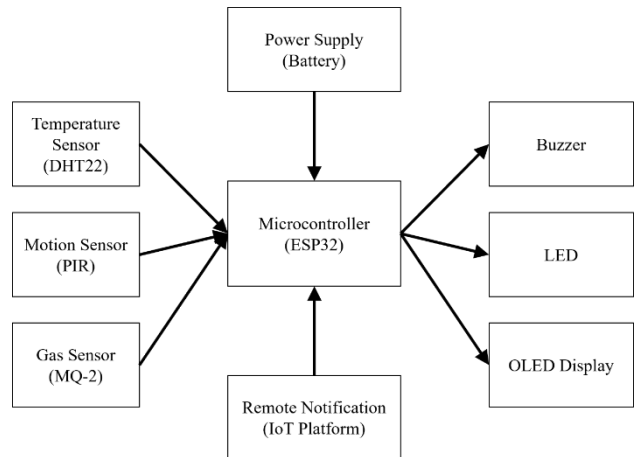


Figure 2. Block diagram of the proposed plug-and-play IoT-based child safety system, illustrating the integration of multi-sensor inputs, ESP32 processing unit, local alert mechanisms, and remote notification platforms.

The operational logic of the proposed child safety system is illustrated in Figure 3. Upon power-up, the ESP32 initializes the PIR, DHT22, MQ-2, display, and communication functions. It then monitors the sensor inputs and establishes Wi-Fi connectivity for Telegram notifications and Google Sheets logging. Local sensing and alarm control are implemented by the ESP32, whereas remote notification and cloud logging require network availability.

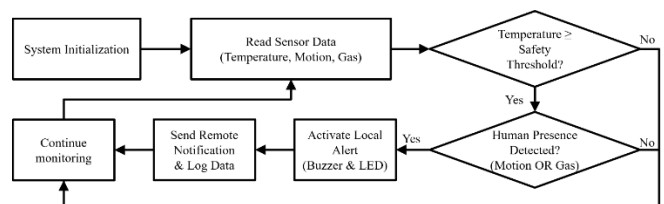


Figure 3. Flowchart of the proposed multi-sensor detection and alert algorithm, illustrating continuous monitoring, environmental threshold evaluation, PIR motion detection, and activation of local and remote alerts.

The DHT22 supplies the temperature measurements, the PIR sensor reports detected movement, and the MQ-2 provides an environmental analog reading. Because the MQ-2 output was acquired through the ESP32 analog input without gas-specific calibration, the recorded values were treated as raw analog readings rather than concentrations expressed in parts per million (ppm). The final design temperature threshold was set at 35 °C, and the programmed MQ-2 threshold was set at 800 raw analog units. During prototype development, selected thresholds were temporarily adjusted so that the complete sensing-to-alert sequence could be safely verified under room conditions without creating a hazardous high-temperature environment.

The final DANGER rule requires PIR-detected motion together with at least one environmental threshold condition: a temperature of 35 °C or above, or an MQ-2 reading at or above the programmed threshold. Motion without either environmental threshold remains SAFE, while an

environmental threshold without PIR-detected motion also remains SAFE under the implemented rule. When the DANGER rule is satisfied, the ESP32 activates the buzzer and LED, sends a Telegram alert when Wi-Fi is available, and uploads the sensor state to Google Sheets. These outputs provide local warning, remote caregiver notification, and a time-stamped development log.

Following alert activation, the system continues to operate in a closed-loop monitoring mode. The alert state is maintained until the hazardous condition is resolved through environmental normalization or the absence of detected occupant motion. Once safe conditions are restored and the alert is acknowledged, the system automatically resets and returns to monitoring loop, thereby enabling continuous operation without program termination.

### B. System Development

The proposed system was physically implemented by integrating the selected sensors, processing unit, and alert components into a compact prototype platform. Figure 4 illustrates the electrical schematic of the system, detailing the interfaces between the ESP32 microcontroller and the peripheral sensors and alert devices. The DHT22 temperature sensor, PIR motion sensor, and MQ-2 gas sensor were connected to the ESP32 through dedicated digital and analog input pins to enable synchronized environmental and occupancy monitoring. Local alert components, including the buzzer and LED, were interfaced through general-purpose input/output (GPIO) pins to support immediate actuation upon detection of unsafe conditions.

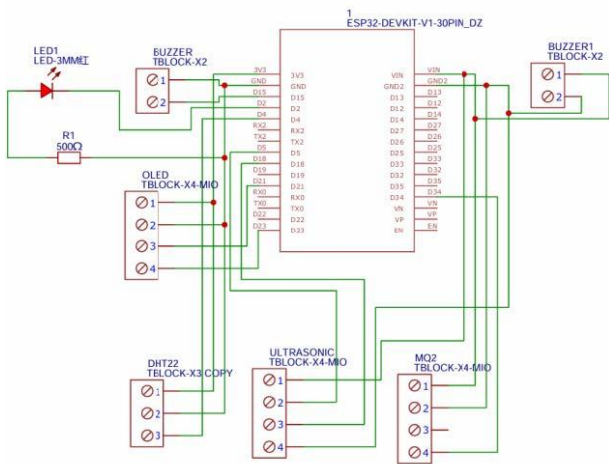


Figure 4. Electrical schematic of the proposed IoT-based child safety system, illustrating the interfacing between the ESP32 microcontroller, environmental and motion sensors, local alert components, and power management circuitry.

To enhance mechanical stability and wiring reliability, all components were assembled on a custom-designed printed circuit board (PCB), as shown in Figure 5. The PCB layout was designed to minimize signal interference, reduce wiring complexity, and support compact packaging suitable for in-vehicle placement.

The firmware was developed in the Arduino IDE to acquire sensor inputs, apply the threshold-based decision rule, update the display, activate the local alarms, and communicate with Telegram and Google Sheets. Selected thresholds were temporarily adjusted during development to verify the response of each functional pathway. The final design

thresholds reported in this study were 35 °C for temperature and 800 raw analog units for the MQ-2 input.

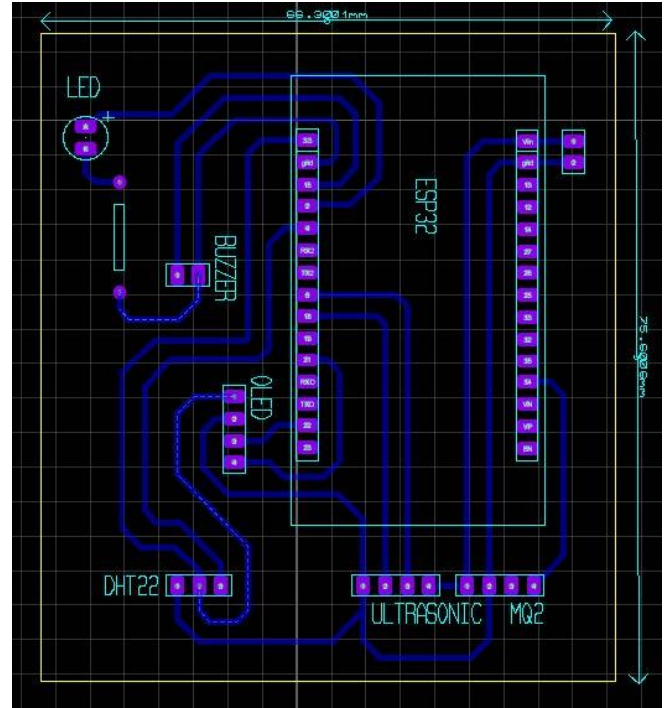


Figure 5. Printed circuit board (PCB) layout of the prototype system, showing component placement and signal routing for the ESP32 processing unit, sensor interfaces, alert devices, and power regulation modules.

### C. Prototype Development

Figure 6 shows the fully assembled prototype of the proposed plug-and-play child safety system housed within a transparent enclosure. The ESP32 microcontroller was mounted on a custom-fabricated printed circuit board (PCB), which provided centralized electrical interfacing for the connected sensors and alert components. The DHT22 temperature sensor, PIR motion sensor, MQ-2 gas sensor, and OLED display were integrated through dedicated connectors, enabling stable signal transmission and modular maintenance. Backup power was supplied by an internal lithium-ion battery and charging module after the vehicle supply was switched off.

The frontal interface of the device was configured to provide suitable sensing for coverage and included a Passive Infrared (PIR) sensor for motion detection and an MQ-2 gas sensor for environmental monitoring. For manual user interaction, a red push button was installed to facilitate system resetting or alert acknowledgments. It was positioned adjacent to a high-decibel buzzer that provided audible emergency warnings. The lateral aspect of the enclosure housed the DHT22 temperature and humidity sensor, which was strategically mounted to ensure accurate sampling of the vehicle's ambient conditions. This compact arrangement minimised the device's footprint, making it suitable for portable automotive applications. The system achieved operational independence through a dedicated power module located at the rear of the assembly. A 3.7 V UltraFire lithium-ion battery provided backup power, regulated through a charging circuit board and boost converter.

Component placement and internal wiring were arranged to reduce mechanical strain and signal interference, thereby supporting stable operation during the prolonged use. The compact enclosure demonstrates the feasibility of deploying

the system as a standalone aftermarket device without requiring modification of the vehicle's electrical system.

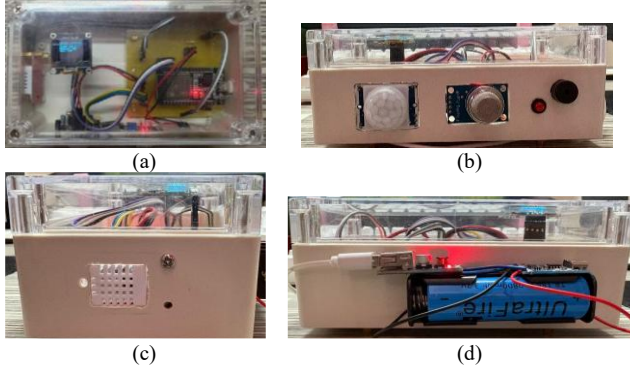


Figure 6. Fully assembled prototype of the proposed plug-and-play child safety system enclosed in a compact casing, (a) top view, (b) front view, (c) side view and (d) back view, highlighting internal hardware integration, sensor connections, power supply components, and the ESP32 control unit.

#### D. Experimental Setup and Validation

Functional demonstration was conducted in a stationary vehicle using simulated sensor inputs under development-stage conditions. The tests were intended to verify the sensing, classification, local alarm, Telegram-notification, and cloud-logging pathways. They were not conducted using a predefined ground-truthed protocol and, therefore, were not used to determine detection accuracy, reliability, false-alarm performance, or operation under real parked-vehicle conditions. Testing was carried out by monitoring in-cabin temperature variation using the DHT22 sensor while observing the system's response and alert-activation behavior. The system was powered by the vehicle supply while the engine was running and switched to the backup battery when the engine was turned off. However, the effects of different vehicle electrical loads and voltage fluctuations were not evaluated. False alarms or missed detections observed during prototype development were used for troubleshooting and resolved before the final functional tests, hence, they were not included in the reported results.

The experiments focused on verifying the system's response to simulated temperature, PIR motion, and MQ-2 environmental inputs. During each test, the system operated continuously for extended periods to observe temperature trends, alert-triggering consistency, and operational stability. Occupant presence was simulated through controlled movement and proximity within the vehicle environment, allowing evaluation of the PIR and MQ-2 sensor responses under practical conditions. Sensor readings and alert events were recorded through the implemented IoT logging mechanism for subsequent analysis.

## IV. RESULTS AND DISCUSSION

The performance of the proposed plug-and-play IoT-based child safety system was evaluated through functional validation under simulated parked-vehicle conditions. The evaluation focused on verifying (i) environmental monitoring behavior, (ii) multi-sensor detection logic and (iii) alert triggering and notification delivery. All results presented in this section are derived from real-time system logs and IoT notifications generated by the implemented prototype.

#### A. Environmental Monitoring and Temperature-Based State Evaluation

Continuous in-cabin temperature monitoring was conducted using the DHT22 sensor, with the readings logged in a cloud-based spreadsheet. Baseline cabin temperatures remained within the range of approximately 29–30 °C under non-hazardous conditions, which is consistent with ambient values reported in Malaysian vehicular heat studies[12]. A safety threshold of 35 °C was adopted with reference to reported pediatric heat-risk criteria, as prolonged exposure above this level significantly increases the risk of heat-related illness [18]. During midday observation periods, the cabin temperature exhibited rapid upward trends consistent with previously reported heat accumulation in parked vehicles [19][20].

Importantly, the proposed system did not rely solely on temperature magnitude to classify hazardous states. The transition from SAFE to DANGER occurred only when elevated temperature readings coincided with confirmed occupancy. For example, temperature readings of 29.6 °C and 30.4 °C were classified as DANGER when PIR motion was detected and the temporarily adjusted development threshold was satisfied. This context-aware logic reflects decision principles employed in rule-based child presence detection frameworks described in ASEAN NCAP evaluation protocols[21].

The hazardous-state decision rule can be expressed as:

$$Danger = M \wedge (T \geq T_{th} \vee G \geq G_{th}) \quad (1)$$

where:  $D$ = DANGER state;

$M$ = Motion detection;

$T$  = Measured cabin temperature;

$T_{th}$  = Temperature safety threshold (35 °C);

$G$  = MQ-2 raw analog reading; and

$G_{th}$  = 800 raw analog units.

As illustrated in Figure 7, the DANGER entries at approximately 29–30 °C were produced using a temporarily reduced development threshold. This adjustment allowed the alert function to be tested safely without creating a hazardous high-temperature environment. The final design threshold remained 35 °C.

|                     |      |     |     |        |
|---------------------|------|-----|-----|--------|
| 15/01/2026 12:05:22 | 29.7 | NO  | 145 | SAFE   |
| 15/01/2026 12:05:52 | 29.7 | NO  | 153 | SAFE   |
| 15/01/2026 12:07:53 | 29.6 | NO  | 167 | SAFE   |
| 15/01/2026 12:08:27 | 29.6 | YES | 800 | DANGER |
| 15/01/2026 12:08:56 | 29.5 | YES | 400 | SAFE   |
| 15/01/2026 12:09:27 | 29.5 | NO  | 195 | SAFE   |
| 15/01/2026 12:09:57 | 29.5 | NO  | 183 | SAFE   |
| 15/01/2026 12:11:30 | 29.4 | NO  | 107 | SAFE   |
| 15/01/2026 12:12:00 | 29.8 | NO  | 105 | SAFE   |
| 15/01/2026 12:12:32 | 30.3 | NO  | 73  | SAFE   |
| 15/01/2026 12:13:05 | 30.4 | YES | 87  | DANGER |
| 15/01/2026 12:13:39 | 29.7 | YES | 64  | SAFE   |
| 15/01/2026 12:15:27 | 29.7 | NO  | 315 | SAFE   |
| 15/01/2026 12:15:57 | 29.7 | YES | 176 | SAFE   |
| 15/01/2026 12:16:30 | 29.7 | YES | 148 | SAFE   |
| 15/01/2026 12:17:00 | 29.7 | NO  | 155 | SAFE   |
| 15/01/2026 12:17:31 | 29.7 | YES | 123 | SAFE   |

Figure 7. Excerpt of cloud-logged sensor data showing time-stamped temperature readings, motion status, MQ-2 raw analog readings, and corresponding SAFE/DANGER classifications.

Repeated functional tests were conducted to validate the consistency and reliability of the programmed system behavior. Figure 7 presents selected time-stamped observations comprising SAFE and DANGER classifications, while additional test records collected at different times are not shown. The DANGER entries at approximately 29-30 °C were recorded using a temporarily reduced threshold to test the alert function safely under room conditions. These observations provide evidence of repeated functional testing but do not constitute a complete performance evaluation of the final 35 °C temperature and 800-unit MQ-2 threshold configuration.

#### B. PIR Motion and MQ-2 Environmental Indicators

The decision logic combines PIR motion detection with temperature and MQ-2 environmental inputs. The PIR sensor continuously monitored physical movement within the vehicle cabin, while the MQ-2 sensor captured variations associated with combustible-gas or smoke-related conditions. As shown in Figure 7, a hazardous state could be triggered when detected motion coincided with an MQ-2 reading at or above its programmed threshold. For instance, an MQ-2 raw analog reading above 800 combined with PIR-detected motion resulted in a DANGER classification, whereas MQ-2 readings below the threshold without detected motion remained SAFE. Compared with single-sensor approaches such as temperature-only or reminder-based systems[9], the multi-sensor strategy provided additional contextual information for the programmed classification rule.

To further illustrate the implemented decision behavior, representative operating scenarios extracted from the experimental logs are summarized in Table 2. The results show that the recorded state transitions were consistent with the defined decision rule. No unintended triggering was observed under motion-only conditions or environmental variations below the programmed threshold without detected motion. These observations demonstrate that the recorded system states followed the programmed decision rule; however, they do not establish detection accuracy or false-alarms performance under real-world conditions.

Table 2  
Experimental Scenarios for Multi-Sensor Decision Validation

| Scenario               | Motion | Temp (°C) | MQ-2 reading | System State |
|------------------------|--------|-----------|--------------|--------------|
| Normal cabin           | NO     | 29.2      | 145          | SAFE         |
| Motion only            | YES    | 28.8      | 164          | SAFE         |
| Gas spike + motion     | YES    | 29.3      | 1241         | DANGER       |
| MQ-2 response + motion | YES    | 30.1      | 802          | DANGER       |
| No motion              | NO     | 30.4      | 200          | SAFE         |

#### C. IoT-Based Alert Notification and User Interaction

The system's IoT communication function was implemented using Telegram notifications. Under normal operating conditions, the platform displayed the current sensor readings and a NORMAL system state when the user submitted the '/status' command, as shown in Figure 8. When a hazardous condition was detected, an alert containing the relevant sensor readings and event description was transmitted. In the examples shown in Figures 9 and 10, the status and alert messages were recorded within the same minute, indicating a notification interval of less than one minute. Similarly, after the user submitted the '/okay'

acknowledgement command, the system deactivated the buzzer and displayed an acknowledgement message within the same or following minute. However, communication delays may occur due to network conditions, which were not systematically evaluated in this experiment.

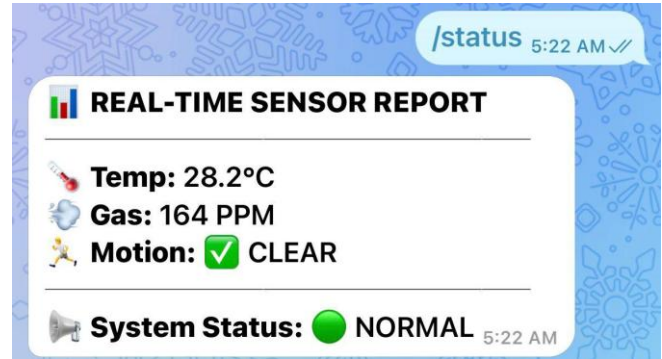


Figure 8. Telegram interface displaying real-time sensor status under normal operating conditions.



Figure 9. Telegram alert generated when the programmed MQ-2 threshold and PIR motion input were simultaneously present.



Figure 10. Telegram alert triggered by elevated temperature combined with motion detection, followed by user acknowledgement.

As discussed in the literature review, radar-based child presence detection systems provide high sensing sensitivity but are commonly associated with higher hardware costs, complex calibration requirements, and dependence on vehicle-level integration [6][7]. Conversely, low-cost IoT-based systems that rely on a single sensing parameter offer

greater affordability and ease of deployment, but may provide limited contextual awareness information [12]. The proposed system combines multiple low-cost inputs, local and remote alerts, cloud-based logging, and backup power within a portable prototype. Compared with GSM-based reminder systems that may suffer from communication delays or require manual intervention, the present design provides automated remote alerting together with local fail-safe mechanisms. Nevertheless, its remote notification and cloud-logging functions remain dependent on Wi-Fi availability.

Rather than substituting for advanced OEM solutions, the proposed system is positioned as a complementary and accessible safety enhancement, particularly for older vehicles and cost-sensitive applications. Although advanced sensing technologies such as radar and thermal imaging provide higher spatial resolution, their cost and energy requirements may limit their use in low-cost aftermarket systems. The present functional demonstration shows the feasibility of implementing these features using a low-cost IoT platform.

## V. CONCLUSION

This study presented the design and functional demonstration of a plug-and-play IoT-based safety prototype for unattended-child risk scenarios. The system integrates an ESP32, PIR motion sensing, DHT22 temperature measurement, an MQ-2 environmental analog input, local buzzer and LED warnings, Telegram notifications, Google Sheets logging, and a hybrid vehicle-and-battery power arrangement. The functional tests demonstrated that the prototype could monitor the selected inputs, execute the programmed decision rule, activate local warnings, transmit remote classifications, and record sensor data in the cloud.

Several limitations should be recognized. The PIR sensor may not detect a stationary or sleeping occupant, and the MQ-2 is an uncalibrated environmental sensor rather than a human-presence or respiration detector. Telegram notifications and cloud logging also depend on Wi-Fi availability. Furthermore, battery's labelled capacity of 9800 mAh, system current consumption, battery operating duration, power-source transition performance, and behavior under automotive electrical loads were not quantitatively evaluated. Future work should include controlled and repeated trials using independent ground-truth measurements, quantitative assessments of notification latency and battery discharge, stationary-occupant scenarios, and testing across different vehicles and environmental conditions.

Within these limitations, the prototype demonstrates the feasibility of integrating low-cost sensing, local and remote alerts, cloud-based logging, and backup power into a portable aftermarket safety concept. However, further performance and automotive-environment validation are required before the system can be considered suitable for safety-critical deployment.

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## CONFLICT OF INTEREST (COMPULSORY)

Authors declare that there is no conflict of interest regarding the publication of the paper.

## AUTHOR CONTRIBUTION (COMPULSORY)

The authors confirm contribution to the paper as follows: study conception and design: Nur Aina Batrisyia Binti Abd Halim, Siti Musliha Ajmal Binti Mokhtar; data collection: Nur Aina Batrisyia Binti Abd Halim; analysis and interpretation of findings: Nur Asfahani Binti Ismail, Shakira Azeehan Binti Azli; draft manuscript preparation: Zahari bin Abu Bakar, Nor Affida binti M. Zin. All authors reviewed the findings and approved of the final manuscript.

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