

A Sustainable IoT Approach to Child Presence Detection in Vehicles Using PIR Sensors and GPRS Communication

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ABSTRACT

Leaving children unattended in a parked vehicle had already become a major concern, especially related to death caused by heatstroke or “Forgotten Baby Syndrome”, including the risk of car theft. Motion Guard is a product designed to increase the efficiency of vehicle safety systems and provide a sense of security to vehicle owners, specifically parents and guardians. Even with a variety of inventions and technologies, there's a need for an effective, low-cost, real-time alert system capable of detecting the presence of children in parked vehicles. This research focuses on fulfilling these needs by presenting a sustainable Internet of Things (IoT) based child presence detection system to monitor and send fast alerts in order to increase car safety. Motion Guard has merged an ESP32 microcontroller with a Passive Infrared (PIR) and GPRS communication module to provide real-time alert notifications while the engines turn off. When motion is detected, the system will automatically send a Telegram notification within 10 seconds. The Telegram application was selected for its low storage requirements and user-friendliness. Moreover, this innovation implemented solar power technology to avoid frequent battery replacements, which would otherwise compromise the product's effectiveness. This study used an online questionnaire via Google Forms, distributed to vehicle owners, to collect data on experiences, awareness, and community needs regarding this new system. Results showed that 67.50% of survey participants rated the invention as a “Very Effective” system, indicating that the system was strongly recognised by users. The outcome has shown that Motion Guard provides a dependable and effective solution to decrease the risk of child death issues in relation to leaving children unattended in parked vehicles and vehicle-related crime, consequently promoting a safer society.

Keywords: Child Presence Detection, ESP32, Forgotten Baby Syndrome, Internet Of Things (IoT), Real-Time Alert System, Vehicle Safety System

INTRODUCTION

These days, cases involving children, especially babies left unattended in parked cars, are rising worldwide (Pluck et al., 2025). Recent events in Gua Musang highlight how serious this problem is, such as a four-year-old girl who died from heatstroke after being left alone in a car. Reports stated that her parents didn't realize their child was inside the vehicle (Kamarudin, 2025). Another incident happened in Kuala Lumpur, where an eight-month-old girl died after being left alone in a car for about 10 hours at the Chancellor Tuanku Muhriz Hospital (HCTM) parking lot in Cheras. The mother, a hospital doctor, reportedly forgot the infant was in the car when she arrived for her shift (Astro Awani, 2023). The term “Forgotten Baby Syndrome” (FBS) refers to a child being unintentionally left in a vehicle. This issue is growing more serious and can have devastating

effects on parents, families, and the community as a whole (Anselmi et al., 2020). Such cases often result in severe outcomes like fatal heatstroke (hyperthermia), mental health problems, and even death due to rising temperatures and trauma (Kaltwang et al., 2024). Additionally, vehicle-related crimes such as theft and carjacking are concerns. These incidents highlight the importance of advanced safety systems, including real-time alerts, to prevent tragedies and improve vehicle security (Mansor et al., 2023).

A wide array of technological solutions, including a motion detection sensor, a PIR sensor, and an IoT-based system, is available. Studies have shown that integrating a real-time notification system with a sensor can effectively and efficiently improve car owners' ability to respond during emergencies, particularly when children are left unattended in parked cars (Mat Juna et al., 2024). Most existing products focus either on a basic alarm or an anti-theft system, while child detection sensors tend to be costly, difficult to install, and have limited features (Abu Bakar et al., 2023). Furthermore, these devices often rely on batteries and have limited data storage capacity, which may affect their reliability and performance.

In addition to this development, a few limitations exist in current systems. Some are inefficient at integrating child and vehicle safety into one solution. Others depend on external storage and need frequent battery charging and replacement, which can affect system consistency. Also, not all systems can send real-time alerts through a user-friendly app, potentially reducing alertness during shocking events. These gaps clearly show the need for more functional, efficient, and user-friendly systems that can solve both child safety and vehicle protection issues.

This research presents Motion Guard, a solar-powered safety system that combines motion sensors with real-time mobile alerts to monitor the interior of parked vehicles. Its primary goal is to prevent pediatric vehicular entrapment by sending immediate notifications to guardians when movement is detected. The study also examines the system's dual role as a security measure against unauthorized vehicle entry. By integrating low-power sensing hardware with widely available communication platforms, Motion Guard offers a reliable, energy-efficient way to reduce preventable deaths and improve overall safety.

LITERATURE REVIEW

Existing Technologies for Child Presence Detection and Safety

Various technologies have been developed to address the serious safety concern of children being left alone in vehicles. One common approach uses pressure-sensitive sensors, often built into car seats. These systems detect a child's weight and trigger alerts if the child remains seated after the driver leaves the vehicle. Although effective for infants and toddlers who regularly use car seats, this method has clear limitations. It cannot identify older children or situations where a child moves away from the seat sensor. Moreover, the accuracy of pressure-based systems depends heavily on proper sensor placement and user cooperation, which can lead to inconsistent performance under real-world conditions (Panagiotopoulos & Karyotis, 2025).

Another set of solutions uses proximity-based systems that use Bluetooth or radio-frequency identification (RFID) to track the location of a connected caregiver device relative to the vehicle. These systems send alerts when the caregiver's phone or key fob moves beyond a set distance. While such technologies can help increase parental awareness, they are inherently reliant on external devices staying charged and within signal range. Fluctuations in Bluetooth signals and battery drainage can cause false alarms or missed warnings, reducing the reliability of these systems (Rosli et al., 2021).

Modern vehicles increasingly include in-vehicle reminder systems, such as rear-seat alerts that use door sensors and ignition status to prompt drivers to check the vehicle interior at the start or end of a trip. While these systems represent a major advancement in automotive safety, they only function during the trip and do not continuously monitor occupant presence after parking. Consequently, critical situations where a child remains inside a parked vehicle—especially during routine changes or due to forgetfulness caused by cognitive overload—are not addressed by these passive alerts (Morsy et al., 2025).

Review of Motion Detection Technologies

Motion-based detection offers an alternative way to sense occupant presence without relying on seat position or caregiver monitoring. Among the options, Passive Infrared (PIR) sensors are popular because they are affordable, low-power, and easy to integrate with embedded microcontrollers. PIR sensors detect changes in infrared radiation emitted by the human body. Previous studies show that PIR sensors effectively monitor human presence indoors, and their use in vehicle safety prototypes has shown potential for detecting occupant movement after parking (Kumar, Singh & Verma, 2020).

However, the performance of PIR sensors in enclosed spaces, such as vehicle cabins, is affected by environmental factors. Ambient heat, sunlight through windows, and temperature changes can reduce sensitivity or cause sporadic triggers if the sensors are not properly calibrated (Swetha et al., 2025). These issues require robust signal processing and filtering to ensure reliable motion detection without excessive false alarms.

Alternatively, image- and video-based systems use camera sensors and computer vision or machine learning algorithms to detect human occupants. These systems provide richer contextual information and higher detection accuracy. For example, studies combining thermal imaging with deep learning have demonstrated reliable human presence detection across varying lighting conditions (Ali & Abidin, 2025). However, camera-based systems raise privacy concerns, require more computational power, and consume more energy. These issues make them less practical for portable, battery-powered applications designed for everyday vehicle use.

Although Passive Infrared (PIR) sensors are popular for their affordability and low power consumption, current research primarily focuses on general security or indoor monitoring applications (Ngamakeur et al., 2022). Similarly, studies on Internet of Things (IoT)-based alert systems often emphasize notification delivery via Wi-Fi and cloud platforms (Fitriyan et al., 2024). Importantly, these studies often treat sensing, communication, and power management as separate issues.

There is a research gap in integrating PIR motion detection, solar power, and Telegram-based real-time alerts to prevent Forgotten Baby Syndrome (FBS) in unattended vehicles. This combination remains underexplored, underscoring the urgent need for a sustainable, portable, and affordable child presence detection system.

Justification for Motion Guard

The main innovation of Motion Guard is its shift from localized, short-range alerts to a GPRS-enabled IoT system. While Bluetooth-based systems stop working once the caregiver moves beyond a 10-30 meter radius, Motion Guard uses the SIM900A module to connect to a wide-area network. The system integrates with the Telegram Bot API to send real-time "push" notifications over mobile data. This ensures the guardian receives an alert no matter how far they are from the vehicle, addressing the "Distance Gap" that renders proximity-based systems ineffective in large parking lots or shopping malls. By combining PIR-based motion detection with global GPRS connectivity, Motion Guard offers a dependable, "always-on" safety layer that doesn't depend on specific seating positions or short-range signals.

METHODOLOGY

Research Design

In this study, we employed a quantitative research design using a survey approach. This design aims to analyze community awareness, past experiences, and perspectives on leaving children unattended in parked vehicles, including the need for a new motion-based alert system. The project focused primarily on parents and guardians who own vehicles, as they are our primary target consumers for Motion Guard. This research design was chosen because our team needed to analyze, evaluate, and organize data to improve the product and determine whether Motion Guard is a suitable solution for child safety.

Data Collection Method

Data for this research were collected through an online questionnaire using Google Forms. This platform was chosen for its efficiency in gathering high-quality data from a diverse group of respondents within a short period. The recruitment process used convenience sampling, targeting vehicle owners, especially parents and guardians. This strategy was selected to gather feedback from the primary stakeholders most affected by "Forgotten Baby Syndrome" and vehicle safety issues.

Participants

This study mainly focuses on parents and guardians who own vehicles and frequently use them to commute with their children. These target audiences were chosen because they have a significant need for the Motion Guard. Participants shared their perspectives on child safety, leaving children unattended in parked vehicles, and vehicle security.

Hardware Design and Components

The Motion Guard system is designed with multiple key hardware components that work together to detect movement inside a parked vehicle and send real-time alerts to caregivers. The main components include an ESP32 microcontroller, a Passive Infrared (PIR) motion sensor, and a SIM900A GSM/GPRS communication module.

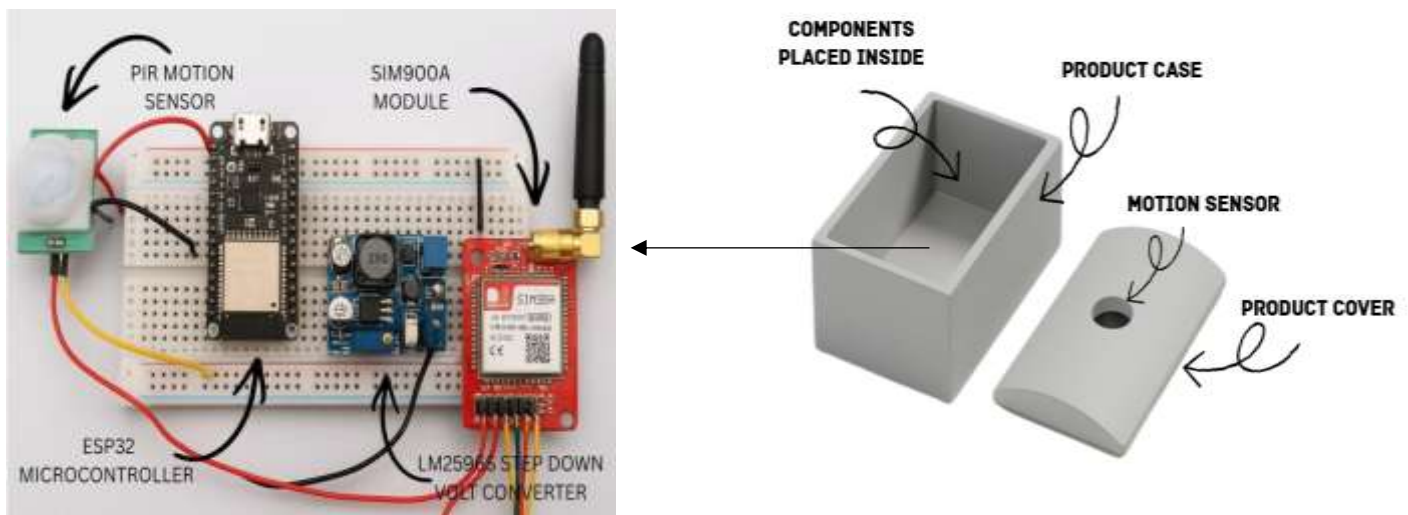


Figure 1. Motion Guard

The PIR sensor was chosen because it can detect human body heat, is inexpensive, and is reliable for motion detection, making it suitable for a portable in-vehicle safety device. However, it is important to note that PIR sensors are governed by the Cosine Law of Incidence, which dictates that detection sensitivity is highest when a heat source crosses the sensor's radial zones laterally (side-to-side) rather than moving directly toward or away from the lens. For motionless or sleeping occupants, the sensor's placement was optimized within the vehicle cabin to capture even minute lateral shifts in a child's position.

Furthermore, the ESP32 was selected because it offers low power consumption, sufficient processing power, and built-in wireless capabilities suitable for embedded safety applications. To counter the risk of a child being "forgotten" if they fall asleep and stop moving after an initial trigger, the ESP32 is programmed with "Latching Alert" logic. Once motion is initially validated, the system "latches" into an alarm state. In this state, the SIM900A module, which allows cellular communication via Telegram even without Wi-Fi, will continue to send periodic alert notifications at fixed intervals regardless of subsequent movement. This ensures that the caregiver is continuously prompted until a manual reset is performed via the Telegram bot interface.

Power is supplied by a rechargeable lithium battery, with an option to add a solar charging module to extend

operating time. During the prototyping phase, all components were assembled on a breadboard, and the final design is intended to be housed in a compact 3D-printed enclosure. Figure 1 shows the overall system architecture, illustrating how motion data from the PIR sensor is processed by the ESP32 and then transmitted via the SIM900A module.

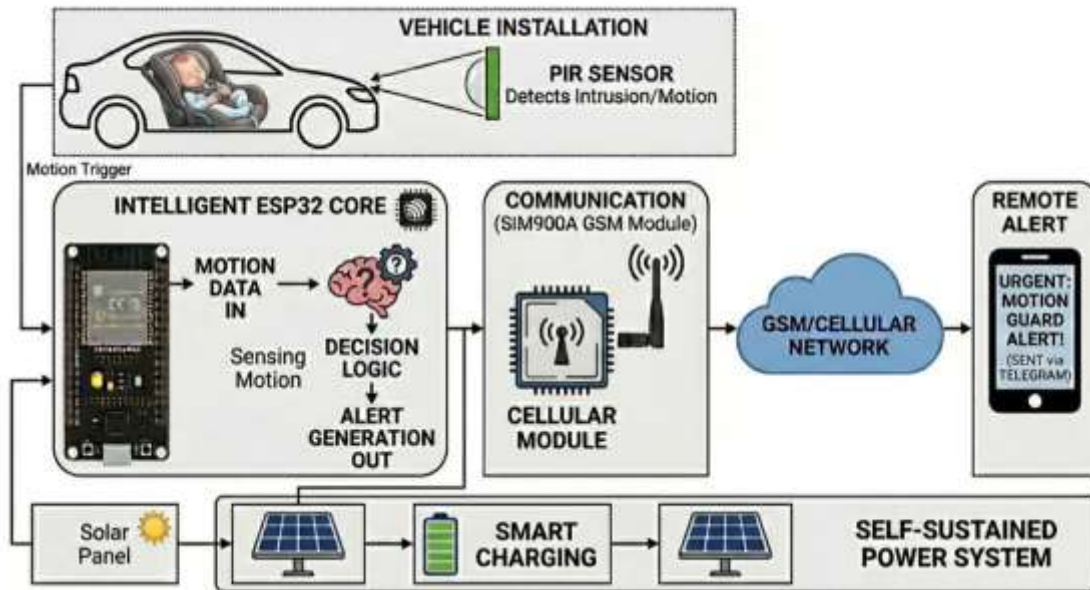


Figure 2. Overall system architecture

Software and Algorithm Design

The software part of the Motion Guard system was created using the Arduino IDE and written in C/C++. The ESP32 microcontroller constantly reads input signals from the Passive Infrared (PIR) motion sensor to track movement inside the vehicle cabin.

To reduce false alerts caused by minor environmental disturbances, such as vibration, airflow, or sudden temperature changes, a time-based validation process was implemented. Motion must be detected consistently within a set time frame for it to be considered valid. This filtering process helps the system distinguish between insignificant disturbances and meaningful movement, such as a child shifting position inside the vehicle. Once a valid motion is detected, the ESP32 starts the alert process by communicating with the SIM900A GSM/GPRS module. Instead of using SMS alerts, the system uses mobile data connectivity to send notifications via the Telegram messaging platform. The SIM900A establishes a GPRS connection, allowing the ESP32 to send HTTP requests to the Telegram Bot API.

A dedicated Telegram bot is created for each user, ensuring that notifications are delivered securely and directly to the caregiver's smartphone. When motion is detected, the system automatically sends a warning message through the Telegram bot, alerting the user to the possible presence of an unattended child inside the vehicle. To improve reliability and ensure user awareness, repeated notifications are sent at fixed intervals if motion continues. This approach guarantees that alerts are not missed and prompts immediate action by the caregiver.

Experimental Setup and Testing

Testing Environment and Subjects

Testing was performed inside a stationary vehicle under controlled conditions. To uphold ethical standards, no actual children were involved. Instead, mannequins and simulated movement patterns were used to mimic the presence of children. The device was positioned in different locations within the vehicle, such as the rear seating area and dashboard, to assess detection coverage and consistency.

Testing Protocol

Scenario 1: Motion Detection Test

This test evaluated the system's ability to detect motion accurately. Various types of movement were simulated at different speeds and locations within the vehicle to assess the PIR sensor's sensitivity and response.

Scenario 2: False Positive Test

To assess the system's resistance to false alarms, various non-human disturbances were introduced. These included vehicle vibrations, airflow from the ventilation system, and temperature changes caused by sunlight. Any alerts caused by these conditions were recorded and analyzed.

Scenario 3: Alert System Latency Test

This test measured how long it took to receive an alert on a smartphone after motion was detected. Multiple trials were conducted to determine the average delay between detection and delivery of notifications via Telegram.

RESULTS AND DISCUSSIONS

Results

The Motion Guard system demonstrated positive results in enhancing awareness and safety inside vehicles. After installation and activation, the system could detect movement inside the car and send alert notifications to the user's smartphone via Telegram. This enabled guardians to be immediately informed when movement was detected within the vehicle.

During testing, the automatic alert system reassured guardians by sending real-time notifications. This helped reduce worry and mental stress, especially during short stops or when guardians might be distracted, a condition often called Forgotten Baby Syndrome. The system served as a dependable reminder, lowering the risk of human forgetfulness.

The survey results confirmed these findings. From the pre-survey, 36 out of 40 participants said they knew about the dangers of leaving children alone in a vehicle, while 4 reported they did not know. This indicates that although awareness is present, additional safety measures are still needed to prevent accidents.

In the post-survey, participants were asked to rate the effectiveness of Motion Guard in detecting movement inside a car. Table 1 showed that 27 participants rated the system as very effective, while 12 participants rated it as effective. Only one participant gave a neutral rating, and none rated the system as ineffective. These findings demonstrate a high level of user confidence in the system's performance.

In addition to user perception, system performance was assessed using a latency metric. The results show that the PIR motion sensor detected movement in about 1-3 seconds. In several trials, the alert was received in roughly 1 second, while most notifications arrived within 2-3 seconds after motion was detected. This variation is expected due to network conditions and system processing time. Overall, the response time was deemed adequate for safety monitoring inside vehicles.

Table 1. Effectiveness of Motion Guard in detecting movement inside vehicles

Effectiveness Rating	Number of Participants	Percentage (%)
Very Effective	27	67.50%
Effective	12	30.00%
Neutral	1	2.50%
Ineffective	0	0.00%
Total	40	100%

Table 2. Detection to alert time

Trial	Detection to alert time (s)
1	1.1
2	1.4
3	2.2
4	2.6
5	2.8

DISCUSSION

The results of the Motion Guard system show that it is an effective way to increase guardian awareness and improve safety inside vehicles. The system detected movement inside the car and sent real-time alert notifications to the guardian's smartphone. This supports Motion Guard's main goal: to serve as a safety reminder rather than replace the guardian's role and responsibility.

The survey results show that most participants were already aware of the dangers of leaving children unattended in vehicles. However, awareness alone is not enough to prevent accidents caused by forgetfulness or distraction. This finding supports previous studies that explain incidents often happen due to routine changes or cognitive overload, even among careful guardians. Motion Guard helps address this issue by providing an active reminder when movement is detected, which reduces reliance on memory alone.

Compared to pressure-sensitive seat systems discussed in the literature, Motion Guard does not rely on a child staying seated in a specific position. Instead, it responds to movement inside the vehicle. This makes it better suited to real-life situations where children might move around, a known limitation of seat-based systems. Although this study did not directly test seat sensors, the consistent detection of movement indicates that Motion Guard can operate without strict seating conditions, since it relies on movement.

Regarding proximity-based systems such as Bluetooth or RFID, the results indicate that Motion Guard effectively sends alerts based on movement detection rather than caregiver distance. This lessens reliance on external devices such as key fobs or phone proximity, which previous studies have reported as causing missed alerts due to signal instability or battery problems. The high effectiveness ratings in the post-survey suggest that users trust Motion Guard's alert system.

Compared to in-vehicle reminder systems that only alert drivers at the beginning or end of a trip, Motion Guard continues operating after the vehicle is parked. The results showed that the system functions automatically once activated, without needing further user interaction. This continuous operation is crucial for preventing dangerous situations in which a child remains inside a parked vehicle, a limitation of passive reminder systems noted in earlier research.

CONCLUSION

In conclusion, this project centered on developing Motion Guard, a system designed to detect movement inside a vehicle when a child is left unattended. The results show that the system can detect motion and send an alert when movement occurs. This can help reduce safety risks by providing early warnings to parents or guardians. Overall, Motion Guard demonstrates potential as an additional safety feature for vehicles to help protect children. Future work may include integrating AI-based thermal imaging to distinguish between pets and infants.

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