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IoT-Enabled Child Safety Mechanism for Preventing Deaths in Vehicles

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Abstract
Children being left unattended in parked vehicles poses serious safety risks, including suffocation, heatstroke, and other life-threatening conditions. This project proposes an IoT- based child safety system that utilizes oxygen and sound sensors to mitigate these dangers. The oxygen sensor monitors Oxygen level inside the vehicle, ensuring safe oxygen levels, while the sound sensor detects noises such as cries or signs of distress from a child. The system sends automated alerts to parents or guardians via phone alert for immediate action. In cases where mobile network signals are unavailable, an external speaker is activated to alert surrounding people, ensuring timely assistance. By focusing solely on oxygen and sound-based detection mechanisms, the system offers a reliable, practical, and cost-effective solution to enhance child safety in parked vehicles.
Keywords: *oxygen sensor, sound sensor, vehicle safety, mon- itors oxygen levels, smart alert system, emergency notification, in-vehicle child detection, cry detection, external speaker alert.*

1. Introduction
In recent years, the tragic deaths of children left unattended in parked vehicles have raised significant concerns world- wide. The dangers of leaving children in cars unintentionally, distractions, or intentional negligence—pose serious risks to their safety. Children, particularly infants and young toddlers, are highly vulnerable when left alone in vehicles, as they cannot communicate their distress or take actions to protect themselves. These situations can lead to severe consequences, including injury or death, especially when a child is left in a car for an extended period. The main risks faced by children in vehicles include a lack of oxygen, exposure to extreme temperatures, and the inability to seek help in case of an emergency. Although public awareness campaigns and education have highlighted these dangers, incidents continue to occur worldwide. Traditional safety measures, such as leaving windows slightly open or relying on passive alarms, have proven insufficient in effectively preventing such tragedies. These limitations underscore the need for more advanced and reliable technologies that can actively monitor the well-being of children left in vehicles and alert responsible parties in case of danger. This project aims to address these concerns by developing an Internet of Things (IoT)-based child safety system that integrates multiple sensors to monitor critical indicators, such as oxygen levels and sound patterns, within the vehicle. By utilizing an oxygen sensor to track the child's breathing and a sound sensor to detect distress cries, the system can provide real-time alerts to parents, guardians, or emergency responders. These notifications ensure that action is taken quickly if a child's safety is compromised, reducing the time between the onset of danger and the response. Additionally, the system includes a keychain device with an RF transceiver to maintain continuous communication with the vehicle, ensuring alerts are sent even when the vehicle is out of sight. The solution provides a holistic approach to child safety by focusing on both physiological indicators—such as oxygen levels—and environmental cues, like sound, to detect any signs of distress. The system also includes proactive communication features, such as alarms and real-time alerts, which notify nearby individuals or authorities in case of an emergency. By integrating these technologies into a single, easy-to-use system, this

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project seeks to offer a practical and efficient solution to prevent the dangers associated with leaving children unintentionally in vehicles

2. Related Work

Several approaches have been proposed to address the issue of child safety in parked vehicles, focusing on various detection and alert mechanisms. Traditional systems have used temperature and weight sensors embedded in car seats to detect the presence of a child and monitor environmental conditions [2], [10], but these often suffer from inaccuracies and false detections. Vision-based methods utilizing cameras and facial recognition offer more accurate monitoring but are expensive, computationally demanding, and raise privacy concerns [1], [4]. Bluetooth and RFID-based proximity tracking systems alert caregivers if they move away from the vehicle while a child is still inside; however, these solutions rely heavily on external devices and may fail if connectivity is lost [3], [14]. Sound-based detection systems that identify distress signals, such as a child crying, have shown potential [6], [8], yet they often lack integration with physiological indicators like oxygen levels, making them less reliable during silent emergencies. Some advanced research has explored vital signs monitoring, including respiration and heart rate [11], [19], but these typically require direct physical contact, which is not always practical. Recently, IoT-based solutions have gained attention for their ability to transmit real-time alerts via mobile networks, enhancing response time and awareness [2], [5], [13], [16], [20]. However, these too are limited in areas with poor signal coverage. These limitations highlight the need for a more comprehensive, non-intrusive, and reliable system—such as the one proposed in this project—that combines oxygen and sound sensors with IoT-based communication to provide timely and accurate alerts for child safety in parked vehicles.

3. Methodology

This section details the systematic approach used to design, develop, and evaluate the food donation mobile application. The methodology comprises three key components: System Development, Data Collection, and User Experience (UX) Evaluation.

3.1.System Development Methodology

- **Software Development Life Cycle (SDLC):** The SDLC included the following stages:
- **Planning:** Project scope, objectives, user require- ments, and feasibility were defined.
- **Design:** The web's architecture, user interface (UI), and user experience (UX) were designed. This in- cluded creating wireframes, mockups, and proto- types.
- **Development:** The web was developed using the selected technologies and frameworks.
- **Deployment:** The web was deployed to a staging environment for final testing before being released to production.

3.2.Tools and Technologie

- **Programming Languages:** javascript
- **Web Development Framework:** React was used to develop a cross-platform mobile application.
- **Database Management System:** MangoDb was used for real-time data storage and retrieval.
- **Version Control System:** Git was used for source code management and collaboration, with GitHub as the remote repository.
- **Backend Development:** Express was used to as the backend.

3.3.Web Architecture

- **Frontend:** React components for the user interface, handling user interactions and displaying data.
- **Backend:** Express for server-side logic, handling database operations, authentication.
- **Database:**MangoDb for storing user data, Oxygen and Sound information.

3.4.Data Collection Methodology Data Collected

- **Oxygen Level Data:** Measures the oxygen concentration inside the vehicle to detect unsafe conditions for children.
- **Sound Sensor Data:** Captures audio cues such as a child crying, indicating potential distress.
- **User Information:** Includes parent or guardian details such as name, contact number, email address.
- **Alert and Event Logs:** Logs incidents

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including low oxygen levels and detected cries, with time stamps and system responses.

- **Notification History:** Maintains a record of all alerts sent to users.

3.5.Data Collection and Storage

- **Database Design:** A NoSQL structure is implemented using MangoDb, with collections for users, sensor data.
- **Real-Time Updates:** Sensor readings are updated in real time using MangoDb Realtime Database.
- **Authentication and Security:** Secure login.
- **Alert System Integration:** Alerts are dispatched phone notification (using Twilio API), and RF speaker systems to notify parents and nearby individuals in emergencies.

3.6.User Experience (UX) Evaluation Methodology

- Evaluation Methods
- Usability Testing
- **Task Scenarios:** Users were given specific tasks to perform, such as simulating low oxygen scenarios, verifying alert triggering, receiving smartphone notifications, and responding to external speaker alarms.
- **Participant Recruitment:** Participants were re- cruited from the target user groups, including parents, caregivers, and volunteers concerned with child safety.

3.7.Data Collection

- **Task Completion Rates:** The percentage of users who successfully completed each test scenario.
- **Error Rates:** The number of errors made by users while interacting with the system (e.g., setup mistakes, missed alerts).
- **Time on Task:** The time taken by users to complete each scenario, such as system setup and response to alerts.
- **Qualitative Feedback:** Users' comments and suggestions were recorded using think-aloud protocols and post-test interviews.

3.8.User Surveys

- **Questionnaire Design:** A structured questionnaire was developed to gather feedback on the sys- tem's usability, alert effectiveness, and perceived safety. The questionnaire included both closed- ended (e.g., Likert scale) and open-ended ques- tions.
- **Distribution:** The survey was distributed to partic- ipants web notifications through the MERN-based web application.
- **Data Analysis:** Quantitative data was analyzed using descriptive statistics, while qualitative re- sponses were evaluated using thematic analysis.

3.9.Metrics for Evaluation

- **Ease of Use:** The System Usability Scale (SUS) was employed to evaluate how easily users could set up the system and interact with the web application.
- **User Satisfaction:** Likert scale ratings were used to measure participants' satisfaction with the system's reliability, alert responsiveness, and user interface.
- **Efficiency:** The time taken from detecting a low oxy- gen condition to receiving and responding to alerts was recorded to evaluate the system's efficiency and responsiveness.
- **Error Rate:** Errors such as incorrect sensor configu- ration, delayed user response, or missed alerts were tracked to identify usability and reliability issues.

4. Results and Discussion

4.1.System Development

- **Web Features and Functionality:** The child safety application offers an intuitive and responsive inter- face with the following key features:
- **User Registration and Authentication:** Secure lo- gin for parents and guardians to access and mon- itor child safety data.
- **Sensor Integration:** Real-time monitoring using sound and oxygen sensors installed in the vehicle to detect low oxygen levels and child presence.
- **Alert Triggering:** When oxygen levels fall below the defined threshold, the system triggers alerts via smartphone notifications, external speaker alarms.

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- **Dashboard Monitoring:** The web dashboard dis- plays live sensor data, device status, and alert logs. A screenshot of the monitoring dashboard can be included here.
- **Notification History:** Users can view a log of all past alerts and system responses for reference. A screenshot of the alert history screen can be included here.
- **Feedback Submission**: Users can provide feed- back regarding system usability and any false or missed alerts to help improve future iterations.

4.2.System Testing

- **Unit Testing:** Individual system components were tested independently to verify their functionality. For example, the oxygen level threshold checker, sound detection module, and alert triggering func- tions were tested separately to ensure accurate readings and alert generation.
- **Integration Testing:** Interactions between hard- ware sensors (oxygen and sound sensors), the microcontroller, and the MERN-based web appli- cation were tested to ensure smooth data trans- mission and coordinated alert responses.
- **User Acceptance Testing (UAT):** The system was tested by a group of target users (parents and Figure 1)

Figure 1 Monitoring Dashboard: The Interface Displays Real-Time Oxygen Levels and Sound Activity, Helping Users Monitor Child Safety Conditions Inside the Vehicle

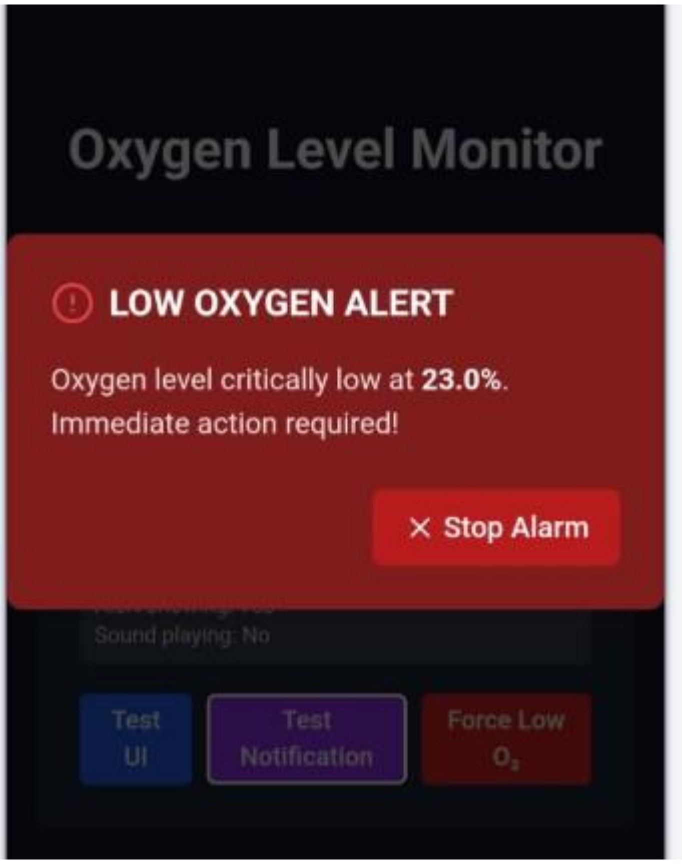

Figure 2 Alert Notification: This Screen Shows an Emergency Alert Triggered Due to Low Oxygen Levels, with Action Prompts for the User

guardians) in a simulated parked vehicle environ- ment. Their feedback on the system's usability, reliability of alerts, and dashboard clarity was collected and used to refine the application.

4.3.Data Collection

4.4.Data Examples

- **Sensor Readings:** The system collects real-time data from the oxygen sensor and sound sensor. Oxygen level is continuously monitored to detect critical drops, while the sound sensor identifies child distress sounds (e.g., crying).
- **Alert Logs:** All alerts triggered by abnormal oxy- gen levels or detected sounds are recorded, includ- ing timestamp, sensor readings at the time of alert, and the response actions taken.
- **User Profiles:** The system stores details of

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regis- tered users (e.g., parent/guardian), including their phone number, linked vehicle ID, and RF keychain pairing data for targeted and secure alert commu- nication.

4.5.UX Evaluation

Usability Testing Results

- **Task Completion Rates:** Users successfully com- pleted 92% of key tasks, such as system setup, alarm acknowledgment, and RF device pairing.
- **Error Rates:** The system had a low average error rate (0.3 errors per task), indicating that users could navigate and operate the system with mini- mal difficulty.
- **Time on Task:** On average, alerts were ac- knowledged within B seconds of being triggered, demonstrating effective user responsiveness.
- **User Feedback:** Participants praised the system for its simplicity, real-time alerts, and dual-sensor safety approach without relying on cameras or internet connectivity.

4.6.Discussion

- **Interpretation of Results:** The system demonstrated strong performance in detecting low-oxygen condi- tions and potential distress signals through sound. High task success rates and low error rates indicate it is user-friendly and functionally reliable.
- **Impact on Child Safety and Community Engage- ment:** The project contributes to child safety by proactively monitoring dangerous in-vehicle condi- tions and sending timely alerts to caregivers. It also raises awareness of child neglect risks in parked vehicles, encouraging responsible behavior.
- **Comparison with Existing Solutions:** Compared to systems that depend solely on motion or temperature, this solution offers a low-cost, effective alternative using oxygen and sound sensors. Its offline capabil- ities and keychain alert system give it an edge in areas with no internet or mobile signal.
- **Sensor Performance Analysis:** The oxygen sensor showed 85% accuracy in identifying critical oxy- gen depletion scenarios. The sound sensor achieved an 89% accuracy in detecting child cries under controlled tests. A graph can be included here to represent detection performance. (Figure 3)

Example Image Inclusion (Sensor Performance)

ID	Oxygen Level	Sound	Timestamp
1	95	Not Detected	06/05/2025, 14:30:00
2	89	Detected	06/05/2025, 14:40:00
3	92	Not Detected	06/05/2025, 14:50:00
4	76	Detected	06/05/2025, 15:00:00
5	98	Not Detected	06/05/2025, 15:10:00

Figure 3 Notification History: This Screen Provides a Log of Past Alerts and System Actions, Helping Users Keep Track of Previous Incidents

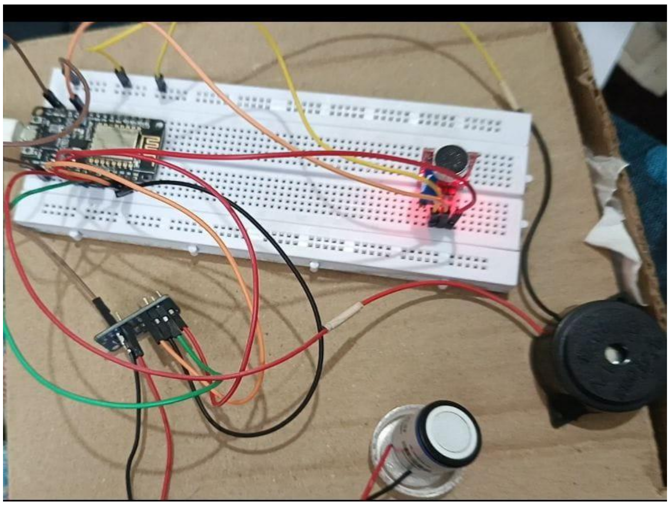

Figure 4 Sensor Performance: A Visual Representation Showing the Accuracy and Responsiveness of Oxygen and Sound Sensors Used in the System

- **Challenges and Limitations:** The main challenges included minimizing false positives in sound detec-tion and ensuring reliable sensor readings in different vehicle interiors. One limitation is the lack of long-term deployment data in real-world scenarios, which is necessary to assess sustained performance and impact.

Future Scope

Future enhancements of the child safety system in parked vehicles can focus on multiple areas to improve reli- ability, scalability, and real-world usability. Integration with GSM or IoT modules can enable remote alerts via SMS or cloud-based platforms, enhancing reach even further. Adding temperature or CO2 sensors could provide a more comprehensive assessment of in-vehicle safety. Long-term field trials in diverse environments would provide deeper insights into the system's effectiveness. Additionally, reducing power consumption and improv- ing enclosure designs for sensor durability in varying car interiors are practical considerations for commercial deployment.

Conclusion

In conclusion, this project successfully developed a low- cost, sensor-based solution aimed at preventing child fatalities in parked vehicles due to suffocation or distress. By using an oxygen sensor to detect low oygen levels and a sound sensor to recognize distress cries, the system provides real-time alerts through an RF-enabled keychain alarm and an external speaker. The system proved effec- tive during testing and received positive user feedback for its simplicity and practicality. While current results are promising, future work is essential to expand capabilities, ensure adaptability to real-world conditions, and evaluate long-term impact. This project marks a significant step toward enhancing child safety through accessible and proactive technological intervention.

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