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Survey Paper on IoT- Enabled Child Safety Mechanism for Preventing Deaths in Vehicles

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ABSTRACT

Child safety in parked vehicles has emerged as a pressing public health concern, with numerous cases of unattended children leading to fatal incidents like hyper- thermia and suffocation. This survey reviews the existing body of research on child presence detection and safety mechanisms aimed at mitigating such risks. It focuses on the role of IoT-based systems, environmental sensors, and alert mecha- nisms in identifying and responding to potential hazards. The paper also examines the challenges faced in the implementation of such systems, including limitations in sensor accuracy, environmental variability, and the occurrence of false alarms. Additionally, the survey explores human factors such as caregiver behavior and public awareness, which significantly influence the effectiveness of safety interven- tions. Findings suggest that while advancements in technology have significantly improved detection capabilities, gaps remain in integrating these solutions seam- lessly into daily life. The survey also highlights the importance of standardizing safety protocols to enhance adoption. Future work should aim at addressing these limitations through interdisciplinary collaboration.

Keywords: child safety, parked vehicles, hyperthermia, suffocation, IoT, environmental sensors, child presence detection, safety mechanisms, alert systems, safety protocols, false alarms, sensor accuracy.

1. Introduction

Child safety in parked vehicles is a critical and often overlooked aspect of vehicular safety, with severe consequences for neglect. Every year, tragic incidents involving chil- dren left unattended in vehicles highlight the pressing need for technological solutions. Parked vehicles can become death traps, especially in warm climates, where the inte- rior temperature can rise to life-threatening levels within minutes. Research shows that even when outside temperatures are as low as 21°C (70°F), a car's interior can exceed 40°C (104°F) within an hour [11, 12]. While existing automotive safety features focus on collision avoidance and passenger restraint systems, they rarely address the unique vulnerabilities of children left in vehicles. This research proposes leveraging Internet of Things (Io T) technologies to develop an innovative solution that ensures real-time monitoring and proactive alerts to protect children from such preventable tragedies.

1.1 Problem Statement

The primary problem is the alarming frequency of child fatalities caused by hyperther- mia or suffocation in parked vehicles. A lack of advanced monitoring systems in most vehicles exacerbates this issue. Between 1998 and 2021, an average of 38 child deaths per year in the United States alone were attributed to vehicular heatstroke [11]. These incidents occur due to various reasons, including caregivers unintentionally leaving children behind, children locking themselves inside vehicles, or a lack of awareness about the dangers of hot cars. Moreover, traditional safety features, such as door lock alarms or seat belt reminders, do not cater to scenarios involving unattended children. Challenges include detecting the presence of children accurately and providing timely notifications to caregivers or authorities. A solution is needed to bridge this gap by addressing not only the detection of children but also the environmental factors that exacerbate the risks. The absence of reliable systems to monitor child presence and alert caregivers in such scenarios leaves a significant void in vehicular safety standards.

1.2 Motivation

The increasing number of child fatalities in parked vehicles serves as a poignant reminder of the inadequacies in current automotive safety measures. Public awareness campaigns, though impactful, have failed to eliminate these incidents, emphasizing the need for technological intervention. Io T technologies provide an unprecedented opportunity to develop intelligent, responsive systems capable of addressing this issue effectively. The motivation behind this research lies in the potential of Io T to trans- form vehicular safety, particularly in safeguarding children. Additionally, the societal impact of

such systems is immense. Beyond preventing tragedies, they can raise aware- ness about the importance of child safety in vehicles and set new benchmarks for automotive safety standards. This research aims to create a solution that not only pro- tects children but also instills a culture of safety and accountability among caregivers. By integrating affordable and accessible technology, this project aspires to make a global impact, particularly in regions where vehicular safety awareness is minimal.

1.3 Critical Challenges

Designing a reliable child safety system for parked vehicles involves addressing several multifaceted challenges:

- **Accurate Detection:** Ensuring precise identification of a child's presence is criti- cal. Advanced sensors must differentiate between humans and objects to minimize false alarms. This requires integrating technologies like mm-wave radar, infrared sensors, and sound analysis [6, 7, 18].
- **Environmental Factors:** The system must perform reliably in varying conditions such as extreme heat, cold, or humidity. For instance, temperature sensors need to provide accurate readings despite fluctuating vehicle conditions [5, 18].
- **Integration and Scalability:** Seamless integration of diverse sensors, wireless modules, and power-efficient systems is essential. A unified framework must ensure real-time processing and adaptability to different vehicle types and sizes [6, 19].
- **User - Friendly Design:** The solution should provide intuitive alerts that are easily understood by caregivers, whether via mobile notifications, audible alarms, or visual indicators.
- **Cost Constraints:** To achieve widespread adoption, the system must be cost- effective without compromising performance, especially in low-income regions where the risk of such incidents is higher [4, 21].

1.4 Objective

The research aims to design and implement a robust IoT-based system to prevent child fatalities in parked vehicles. Key objectives include:

- **Real- T im e Monitoring:** Developing a system capable of continuously monitor- ing the interior of vehicles using sensors such as oxygen, motion, and temperature sensors.
- **Immediate Alerts:** Creating mechanisms to notify caregivers or emergency ser- vices through smartphones, RF transceivers, or external alarms when a potential threat is detected.
- **False A l a r m Reduction:** Employing machine learning algorithms to enhance detection accuracy and minimize false positives.
- **Environmental Adaptation:** Ensuring the system functions optimally under diverse conditions such as high humidity, extreme temperatures, or low lighting.
- **Accessibility and Affordability:** Designing a cost-effective solution that can be implemented in both new and existing vehicles globally.

1.5 Scope of the Research

This research explores the integration of Io T technologies with automotive safety systems to address child safety concerns in parked vehicles. The scope includes:

- **Sensor Integration:** Investigating the use of advanced sensors, including motion detectors, sound sensors, and temperature sensors, to create a comprehensive detection system [6, 7].
    - **I o T Framework:** Developing a scalable Io T architecture that supports real-time data collection, processing, and communication. This involves integrating cloud- based systems for data analysis and remote notifications [4, 19].
    - **Testing and Validation:** Conducting extensive real-world testing to evaluate the system's performance across different vehicle types and environmental conditions [5, 18].
    - **Social Impact:** Addressing societal challenges by making the system affordable and raising awareness through educational campaigns and community engagement [4, 21].

By addressing these elements, this research aims to advance vehicular safety stan- dards and establish a robust framework for preventing child fatalities in parked vehicles. The findings of this study have the potential to inspire future innovations and contribute to global efforts in enhancing child safety and welfare.

2. Related Works

The safety of children in parked vehicles has emerged as a critical issue, leading to numerous studies and systems designed to monitor and mitigate the risks associated with leaving children unattended in vehicles. Several research initiatives have focused on the development of child detection systems and safety monitoring solutions to pre- vent incidents such as heatstroke, suffocation, or entrapment, which have resulted in tragic fatalities. These systems typically integrate multiple sensors, communica- tion protocols, and machine learning algorithms to provide timely alerts to caregivers or emergency services. Despite significant advancements, there are still gaps in the effectiveness and reliability of these systems that need to be addressed.

1. Child Detection Systems Using Io T

The use of IoT-based systems to detect the presence of children in parked vehicles has been widely researched. Wei Li et al. [1] introduced an in-vehicle occupant detection system that utilizes millimeter-wave (mm-Wave) radar for occupant detection. This system can detect not only the presence of people but also their movements within the vehicle, ensuring that even a sleeping child is detected. The radar's ability to operate under various environmental conditions, such as extreme temperatures or heavy rain, makes it a promising candidate for real-time monitoring of vehicle occupants. However, the focus of this research was primarily on occupant detection, with limited attention given to environmental hazards like temperature or air quality that contribute to child safety.

Further advancements in IoT-based child detection systems have been made by Kiran Jyothi Miryala et al. [4], who proposed a system that combines sensors for temperature, humidity, and child detection. Their system is designed to monitor the internal environment of the vehicle and issue an alert if the conditions become haz- ardous, such as in the case of extreme heat. The system utilizes a GSM module to send text messages or calls to parents when unsafe conditions are detected. While this approach offers valuable protection against heat-related accidents, it remains heavily dependent on the caregiver's response, and connectivity issues can hinder the system's effectiveness, especially in rural areas or areas with poor network coverage.

2. Vehicle Heatstroke Alarm Systems

Heatstroke is one of the leading causes of death for children left in parked vehicles. Several researchers have focused on designing heatstroke alarm systems that use tem- perature sensors to detect unsafe conditions inside a vehicle. Mohan and Kumar [2] developed a safety and monitoring system that integrates both GSM and Io T tech- nologies to monitor the temperature inside the vehicle. When the internal temperature exceeds a critical threshold, the system sends an alert to the parent's phone. This early warning system aims to reduce the likelihood of hyperthermia fatalities in children. However, the temperature alone is not always sufficient to determine the presence of danger, as other environmental factors like humidity or oxygen levels can also play a critical role in a child's safety.

In a similar vein, Rachana Bhaskaran Venugopal et al. [3] proposed an advanced heatstroke alarm system utilizing Io T technology. Their system incorporates tempera- ture sensors that monitor the interior of the vehicle in real-time and send notifications to the parent if the temperature becomes dangerous. However, as effective as these temperature-based systems are, they tend to be limited by their inability to detect other potential hazards, such as the buildup of carbon dioxide or a lack of oxygen inside the vehicle. Additionally, such systems may fail if the child is unable to make noise or show signs of distress due to unconsciousness or the severity of the heatstroke.

3. Sensors for Child Safety in Vehicles

The integration of various sensors is another common approach in child safety systems for parked vehicles. Khamil et al. [7] proposed a babycare alert system that uses a combination of motion and temperature sensors to detect the presence of children inside the vehicle. The system is designed to alert parents or guardians when a child is left behind in a parked vehicle, preventing heat-related fatalities. While this approach utilizes motion sensors to detect the presence of a child, it may struggle to detect a child who is not moving, such as an infant who is sleeping. In such cases, the system might fail to activate, leading to a potential safety risk.

Similarly, Hashim et al. [9] developed a child-in-car alarm system that uses mul- tiple sensors, including infrared, temperature, and motion sensors, to detect both the presence of a child and unsafe environmental conditions. This multi-layered approach ensures greater reliability, but it also comes with its challenges, such as sensor cal- ibration and minimizing false positives. The system's reliability can vary depending on the specific sensor type used and its performance under different conditions. For example, infrared sensors may have difficulty detecting a child if the car's interior is heavily tinted, leading to potential inaccuracies in child detection.

4. Integration of Multiple Sensor Systems

The integration of multiple sensor types into a unified system has gained attention in recent research efforts as it offers a more comprehensive solution to child safety.

Sensors measuring temperature, motion, and air quality can work together to create a more accurate and reliable system that can detect a range of potential hazards. Zhang et al. [18] explored the use of Wi-Fi-based sensors to track the breath status of individuals within a vehicle. Their system uses the detection of breath patterns to determine if a person, such as a child, is inside the vehicle. While this system is innovative and capable of detecting changes in breathing patterns, it may not be as effective in real-time situations due to the complexity of detecting breath patterns in a car environment, where air movement is dynamic and sensor placement can vary.

Another example of integrating multiple sensors is the work by Pawar and Trivedi [19], who emphasized the importance of device-to-device (D 2D) communication in cre- ating a more efficient Io T system for child safety. Their research highlights the potential for using inter-device communication to enhance the effectiveness of child detection systems. However, challenges remain in terms of ensuring reliable communication between devices, especially in vehicles where the presence of metal or other materials can interfere with signal transmission. Furthermore, integrating various sensor technologies into a cohesive system requires careful calibration and real-time processing to ensure accuracy and prevent errors.

3. Methodologies

3.1 Sensor-based Detection Methods

A critical component of child safety systems in parked vehicles involves the use of sensors to detect the presence of a child. These sensors can include motion sensors, infrared (IR) sensors, and weight sensors. Motion sensors, typically based on passive infrared (P IR) technology, are used to detect movement inside the vehicle [7]. Infrared sensors detect the temperature difference between a child and the surrounding environ- ment, making it possible to monitor heat patterns within the vehicle [9]. Additionally, weight sensors can be integrated into the seats or the vehicle floor to sense if a child is occupying the seat [31].

3.2 Environmental Monitoring and Analysis

Environmental factors such as temperature, humidity, and oxygen levels are critical in determining whether a child's safety is at risk. High temperatures in a closed vehicle can pose significant dangers, so systems are equipped with temperature sensors to continuously monitor the internal climate of the car. If the temperature rises above a predefined threshold, the system triggers an alert [13]. Similarly, some systems monitor the oxygen levels inside the vehicle. If these levels drop below a safe range, the system can notify the parents or guardians [18].

3.3 Microcontroller-based Data Processing

The sensor data is collected and processed by a microcontroller or embedded system. This system analyzes the data from various sensors in real time. The microcontroller compares the received data against predefined safety thresholds, such as a set tem- perature range or the detection of a child's movement. If any condition breaches the threshold (e.g., high temperature or the detection of a child), the microcontroller ini- tiates an alert response [5]. It may also process the data to control other components such as alarms or communication modules [20].

3.4 Alert Mechanisms and Notifications

Once a potential safety risk is detected, the system triggers an alert. These alerts typically include in-vehicle alarms such as loud sounds or visual indicators to draw attention to the child's presence and the hazardous condition [9]. In addition to in- vehicle alarms, many systems integrate GSM technology to send text messages (SMS) to parents or guardians. These messages contain information about the vehicle's location, as well as the detected safety issue [6].

For more advanced implementations, RF communication modules can be used to activate external alarms, ensuring that people outside the vehicle are also notified of the potential danger. This mechanism helps in ensuring that the alert reaches the nearest individuals, even if the person in charge does not immediately respond to the in-vehicle alerts [7].

4. Literature Survey

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
1	In-Vehicle Occupant Detection System Using mm-Wave Radar	Wei Li, Yang Gao, Zekun Hu, Nanqi Liu, Kexin Wang, Siyi Niu	IEEE, 2022	Used 2D-FFT for radar signal processing, CFAR for object detection	The system uses 77GHz mm-Wave radar with 2D-FFT and CFAR algorithms to detect micro movements, ensuring reliable child detection in vehicles.	The system has limited range, processing complexity, false positives and false negatives.

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
2	Safety and Monitoring of Children Stuck Inside the Car using GSM and IOT Technology	J. Mohan, V. Kishen Ajay Kumar	Internation Journal of Food and Nutritional Sciences, 2022 [2]	aPIIR motion and temperature sensors, integrating GSM for alerts	Warning system detects children in vehicles, sends alerts via GSM, enhancing child safety.	The PIR sensor has a limited detection range and can produce false alarms due to changes in temperature.
3	IoT-Enhanced Vehicle Security and Child Presence Detection in Parking Area	Dr. Kiran Jyothi Miryala, Shaik Aayubpasha, Seelam Naga Durga Sree	Res Militaris Journal, 2021	IoT technologies to create a smartphone notification system using vibration sensors and RF keychain alarms	IoT technologies effectively enhance child safety by providing real-time notifications to parents through smartphones when children are left in parked cars.	Battery life issues for both the safety pad and keychain alarm device.
4	In-Vehicle Passenger Occupancy Detection Using 60-GHz FMCW Radar Sensor	Sohee Lim, Jaehoon Jung, Eunji Lee, Jeongsik Choi, Seong-Cheol Kim	IEEE, Sep 2021	60-GHz FMCW radar sensor	60-GHz FMCW radar sensor detects passenger count and location with 97.68 accuracy.	Did not trigger alarm when the child was left in the car.
5	D2D Communication	Zhang Q., Li W	IEEE, 2021	D2D communication technology for short-range alerts	Effective for short-range communication.	Ineffective when vehicles are out of range or in poor signal areas.

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
6	Implementat of Real-Time Passen-ger Safety Alert System	ioAnaron Krouse, Ahmed Abdelhadi	IEEE, 2020	Combined with various sen-sors to improve safety	The system monitors all seats and alerts the driver if any passenger is not securely seated.	Dependent on driver response to alerts, which may not always be immediate.
7	IoT Based Advanced Heat Stroke Alarm System	Rachana Bhaskaran Venu-gopal, Ravis-hankar Dudhe	IEEE, 2021	Using dual temperature sensors, the sys-tem monitors temperature	Uses dual tempera-ture sensors for early detection of elevated body temperatures in drivers, reducing heat stroke risks.	The PIR sen-sor has a limited detec-tion range and can pro-duce false alarms due to changes in temperature.
8	Babycare Alert System for Pre-vention of Child Left in a Parked Vehicle	K. N. Khamil, S. I. A. Rah-man, M. Gambilok	ARPN Journal of Engi-neering and Applied Sci-ences, 2015	Incorporates a load sensor in the safety pad to detect a child's pres-ence in the car seat and notify parents via smartphone	The system enhances child safety in vehicles by detecting a child's pres-ence with a load sensor and sending smartphone alerts, while a keychain alarm offers additional protection when out of range.	If a heavy load is placed on the sen- sor, it may trigger a false alarm, and if the child is present in another seat, it may not trigger the alarm.
9	Vehicle's Interior Movement Detection and Noti-fication System	Fairuz R. M. Rashidi, Ikhwan H. Muhamad	Safety Lit, 2015	Using a micro-controller, PIR motion detec-tor, and GSM module	The system effectively detects interior move-ments in parked vehi-cles, provides timely SMS alerts to owners.	The PIR sen-sor has a limited detec-tion range and can pro-duce false alarms due to changes in temperature.

S.no	Title	Author(s)	Journal & Year	Methodologies	Key Findings	Gaps
10	Child in Car Alarm System Using Various Sensors	N. M. Z. Hashim, H. H. Basri, A. Jaafar, M. Z. A. Aziz, A. Salleh, A. S. Ja'afar	ARPN Journal of Engineering and Applied Sciences, 2014	Employs a PIC microcontroller to detect sound, and movement in the vehicle, using a GSM	The system effectively detects sound, voice, and movement in vehicles, sending timely SMS alerts via GSM when children are left unattended.	The system includes potential false alarms from environmental noise.

The Table 1 gives an interesting comparison of ten important studies that have focused on enhancing child safety in vehicles using various detection and alert systems. These studies utilize different technologies such as radar, infrared sensors, load sensors, GSM modules, and Io T systems to detect the presence of children left in parked vehicles and send alerts to parents or guardians.

[1] presents a system using a 77 GHz mm-Wave radar, employing 2 D - FFT for signal processing and C F A R for object detection. The system is designed to detect micro-movements in vehicles, ensuring reliable child detection but suffers from a limited range, processing complexity, and false positives. [2] discusses a child safety system that uses P I R motion and temperature sensors integrated with GSM for alerts. This system is effective for detecting children left inside a car but faces challenges such as limited detection range and potential false alarms caused by temperature changes. Similarly, [3] explores IoT-based technologies using vibration sensors and RF keychain alarms, providing real-time notifications to parents, though it highlights issues with battery life and device reliability.

The study by [4] uses a 60 GHz F M C W radar sensor to detect passenger count and location with a high degree of accuracy, although it does not include child-specific alarms. [**?**] examines D 2 D communication for short-range alert systems, with an effective range but a major gap in scenarios where vehicles are out of signal range. [**?**] provides a real-time passenger safety alert system using various sensors to monitor vehicle occupancy but depends heavily on driver responsiveness, which may not always be immediate.

In [**?**], a dual temperature sensor-based system is discussed, aimed at preventing heat strokes in drivers by monitoring body temperature. While effective, it shares the limitation of false alarms from temperature changes. [**?**] proposes a babycare alert system using load sensors in safety pads to detect children, sending smartphone alerts and activating keychain alarms, though issues with sensor accuracy and detection in different seating positions are noted. [**?**] presents a vehicle interior movement detection system using a microcontroller, P I R sensor, and GSM module, though like other PIR-based systems, it suffers from false alarms due to environmental factors.

Finally, [**?**] offers a system for detecting sounds and movements in vehicles using a P I C microcontroller and GS M for alerting parents, although it is prone to false alarms from environmental noise. The findings from these studies provide valuable insights into the advancements and limitations of current child safety systems, highlighting the need for further development in sensor technologies, communication systems, and overall system reliability.

Article multirow longtable

Table 2: Comparative Analysis of Child Safety Systems

System	Technology Used	Detection Method	Accuracy	Limitations
GSM and IoT-based Motion Detection	GSM, IoT	Motion Detection	High	False alarms in low light conditions
Infrared Sensors	Presence Detection	Medium		Limited range
RF Modules and Temperature Sensors	RF Modules	Child Detection	Medium	False positives due to noise
Temperature Sensors	Heat Monitoring	High		Only works in extreme temperatures
Machine Learning and Radar-based Occupancy Detection	Machine Learning, Radar	Occupancy Detection	Very High	Requires complex hardware
Ultrasound	Distance Measurement	Medium		Limited by environmental conditions
GSM and GPS-based Location Tracking	GSM, GPS	Location Tracking	High	Battery dependency, coverage issues
Sound Detection	Alarm Trigger	Medium		Detection inaccuracies in noisy environments

Table 2,summarizes five studies on child saftey system,designed to detect children in parked vehicles, summarizing key attributes such as technology used, detection methods, accuracy, limitations, and relevant references. The GSM and IoT-based Motion Detection system uses GSM and Io T technologies for motion detection, offering high accuracy but fac- ing false alarms in low-light conditions [1, 9]. Infrared sensors are also employed for presence detection, though they have limited range [27, 30]. The RF Modules and Temperature Sensors system combines RF modules for child detection and temperature sensors for heat monitor- ing, with high accuracy in extreme temperatures. However, it struggles with false positives due to noise in the RF module [19, 27, 29, 38]. The Machine Learning and Radar-based Occupancy Detection system provides very high accuracy using advanced technologies like machine learning and radar, though it requires complex hardware and is limited by environ- mental factors such as interference from ultrasound measurements [5, 18, 20, 40]. Lastly, the GSM and GPS- based Location Tracking system offers high accuracy by tracking the vehicle's location using GSM and GPS, though it faces challenges like battery dependency and cover- age issues [6, 25]. Sound detection is used to trigger alarms, but it can be inaccurate in noisy environments [7, 14]. The table provides a clear overview of the strengths and weaknesses of each system, demonstrating how different approaches balance accuracy with environmental or technical limitations.

5. Limitations and Future Directions

The child safety system for parked vehicles presents an innovative solution for preventing the tragic incidents of children being left inside hot cars. However, there are several limitations associated with its current implementation. The primary challenge is the sensor limitations. The sensors used in the system, including oxygen sensors and motion detectors, may have limited sensitivity and range. This can lead to false negatives, particularly if the child is positioned in a way that obstructs the sensor or if the child is in an unusual position [7]. Addi- tionally, environmental factors, such as high temperatures or humidity, can impact sensor performance, causing either false alarms or failure to detect critical conditions [12]. Further- more, the communication delay is another significant limitation. The system uses GSM or RF transceivers for notifications, but communication delays can occur, especially in areas with poor signal coverage. This could hinder the timely transmission of alerts, making the system less effective in urgent situations [9].

Moreover, the system depends on battery-powered sensors and communication modules, which can pose a challenge. In cases where the vehicle remains parked for extended periods, the power supply to these devices may deplete, causing the system to stop functioning. This raises concerns about the reliability of the system over time [14]. Additionally, while the system is effective in detecting the presence of a child, the complexity of real-time monitoring in varying conditions can result in occasional misdetections [8].

Despite these limitations, the system has the potential for improvement and further devel- opment. Future advancements can focus on enhancing sensor accuracy and reliability. One way to improve detection would be to utilize more advanced sensor technology with greater sensitivity and a wider detection range [6]. Machine learning algorithms can also play a key role in distinguishing between a child and other objects, thus reducing false alarms and increasing the overall effectiveness of the system [20].

Another important area for future work is the integration of advanced communication technologies, such as 5G or low-power wide-area networks (LPWAN). These technologies can improve the reliability of communication, ensuring that alerts are sent without delays, even in areas with weak network coverage [10]. Moreover, the introduction of a mobile application could allow parents to receive real-time alerts and monitor the system remotely, providing an added layer of security [25].

Energy management is another challenge that requires attention. The current system's reliance on battery-powered devices could be enhanced by implementing low-power sen- sors or incorporating energy-harvesting techniques, such as solar power, to ensure long-term operation without frequent recharging [29]. Additionally, the introduction of IoT-enabled devices could facilitate easier integration with other smart systems in vehicles, expanding the functionality of the child safety system [24].

In summary, while the current system offers significant advancements in child safety for parked vehicles, there are several opportunities for improvement in sensor accuracy, communication efficiency, energy management, and system integration. Future research and technological advancements could make the system more reliable, efficient, and user-friendly, thereby reducing the risks associated with leaving children unattended in vehicles.

6. Experimental Setup and Results

Various systems have been developed and tested over the years to address the issue of child safety in parked vehicles. These existing systems primarily focus on detecting a child's pres- ence inside a vehicle and triggering an alert to prevent heatstroke, suffocation, or other hazardous conditions. Many of these systems utilize a combination of sensors, communica- tion technologies, and alarm mechanisms to ensure that children are not left unattended in a parked vehicle.

One of the most common approaches in these systems involves the use of *motion sensors* to detect the presence of a child inside the vehicle. These sensors are designed to recognize movement and differentiate between a child and other objects, such as pets or inanimate objects. A notable example is the system developed by Khamil et al., which uses motion sensors combined with other technologies to prevent children from being left in cars by acci- dent [7]. These motion detection systems are often tested for reliability in various conditions, including different seating positions and car interior layouts, to ensure they accurately detect a child's presence [8].

Additionally, oxygen sensors have been integrated into several child safety systems to monitor the air quality inside the vehicle. These sensors measure the oxygen concentration and can trigger an alarm when the oxygen levels drop below a safe threshold. The system by Bhaskaran et al. is a notable example that uses oxygen levels to assess the condition inside the vehicle, ensuring that the environment remains safe for children [3]. Research on oxygen sensor accuracy has shown that environmental factors, such as temperature and humidity, can influence the readings, necessitating periodic calibration to maintain performance [9].

Another important technology used in these systems is the *GSM module*, which enables communication between the vehicle and the parent or guardian. When the system detects a hazardous situation, the GSM module sends a message or makes a call to alert the parents. A study by Mohan and Kumar discusses a system that uses GS M to notify parents if a child is left inside a vehicle for too long, ensuring prompt action can be taken [6]. These GSM-based systems are effective in areas with good network coverage, but they often face challenges in remote areas with weak signals [12].

In addition to GSM, some systems integrate *RF transceivers* or *alarm devices* that notify people nearby about a child left inside a vehicle. The RF keychain alarm system developed by Khamil et al. provides an audio alert to the surrounding people when it detects a child inside the car, helping to raise awareness and prevent accidents [7]. This approach is particularly useful in crowded or public parking areas where the guardian may not be close enough to hear the vehicle's internal alert.

The integration of machine learning algorithms in child safety systems has been explored to improve the accuracy of sensor data and reduce false alarms. For instance, the system developed by Kautz and Beach combines traditional sensor technology with machine learning techniques to distinguish between a child and other objects, improving the reliability of detection [21]. Similarly, AI-based systems have been proposed to enhance the ability of these devices to monitor multiple conditions simultaneously, such as temperature, motion, and oxygen levels, to ensure that the child's environment is safe at all times [32].

In terms of power consumption, many systems are battery-powered, which can be a limitation for long-term usage. The systems rely on low-energy sensors and communication modules to ensure they operate for extended periods without draining the battery too quickly. However, energy efficiency remains an area of concern, as these systems must operate reliably even when the vehicle is parked for hours or days. Research on energy-efficient sensors and battery management has been conducted to optimize power consumption [29].

Overall, existing child safety systems in vehicles use a combination of motion sensors, oxygen sensors, communication modules, and alarms to protect children from being left unattended in vehicles. These systems are effective in many scenarios, but they still face chal- lenges such as environmental influences on sensor accuracy, limited communication range, and energy consumption. Future research and development are needed to address these limitations and improve the overall effectiveness of child safety systems in parked vehicles.

7. Conclusion

The development of child safety systems in parked vehicles has made significant progress over the years, leveraging various technologies such as motion sensors, oxygen sensors, GSM modules, and RF transceivers to ensure the safety of children left inside vehicles. These systems have shown their potential in addressing critical issues such as preventing heatstroke and suffocation by providing timely alerts to parents and surrounding individuals.

However, despite their effectiveness, several challenges remain, including issues related to sensor accuracy under varying environmental conditions, limitations in communication range, and the energy efficiency of battery-powered systems. Furthermore, while existing systems provide useful alerts, their effectiveness depends on factors such as network coverage, sensor placement, and system calibration.

Future advancements in child safety systems could focus on improving the accuracy and reliability of sensors, reducing false alarms, and enhancing communication capabilities to ensure timely responses in any environment. Additionally, integrating machine learning and artificial intelligence could lead to smarter systems that can better adapt to dynamic condi- tions within a vehicle. Overall, the continued development and refinement of these systems are essential for further enhancing child safety and preventing tragic incidents of children being accidentally left in parked vehicles.

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