DESIGN OF A MOTION SENSOR-BASED WARNING SYSTEM TO PREVENT CHILD ABANDONMENT IN BUSES

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Abstract - In recent years, the use of public transportation has significantly increased to accommodate growing travel demands, particularly in urban areas. Consequently, incidents involving children being unintentionally left behind in vehicles have occurred with greater frequency, raising serious safety concerns. This situation underscores the urgent need for the development of a reliable and effective preventive system. The present study proposes the design and implementation of an intelligent warning system that utilizes motion sensors to detect the presence of children inside vehicles. Upon detecting a child after the engine has been turned off, the system activates an audible alarm to alert nearby individuals and simultaneously transmits warning messages to the driver's and parents' mobile devices. The proposed system is developed based on key criteria including ease of installation and use, cost-effectiveness, and potential for large-scale deployment.

Key words - Anti-abandonment system; motion sensor; child safety; Blynk; Iot; GSM alert

1. Introduction

In recent years, numerous incidents have been documented in which children were inadvertently left in vehicles, particularly on school buses, due to negligence [1]. These situations pose a severe threat to child safety, as children are highly susceptible to heat-related complications. Their body temperature increases three to five times faster than that of adults, and they lack the physiological capacity to regulate heat effectively, especially in enclosed environments [2]. Additionally, their vulnerability to dehydration further accelerates the risk of fatal outcomes [3].

Existing reliance on manual inspection procedures has proven inadequate, as such methods are prone to human error and inconsistencies [4]. To effectively mitigate these risks, there is a pressing need to implement automated safety systems in child transportation vehicles that ensure timely detection and response [5].

A typical child-presence detection system comprises two fundamental components: a sensor mechanism to identify occupancy - often through pressure, optical, or motion-based technologies - and an alert system that can be activated either automatically or manually. While several countries have adopted such technologies, their application remains limited in Vietnam. Though the incidence rate is relatively low, most reported cases involve delayed detection and result in fatalities, particularly among preschool children. This underscores the urgent necessity for research into cost-effective, practical, and scalable solutions that can be widely adopted to prevent such tragedies.

2. Overview, purpose and scope of research

Globally, children being left on buses has led to many tragic incidents, prompting countries and organizations to develop technological solutions to prevent this situation.

2.1. Overview

In 2022, Thailand's Digital Economy Development Agency (DEPA) introduced the "Smart School Bus" system, incorporating motion sensors and artificial intelligence (AI) to monitor student presence. The system provides parents with real-time updates via a mobile application, thereby enhancing child safety during transit [6]. In the United States, several states - such as California - require buses to be equipped with rear-mounted alarms that must be manually deactivated after engine shutdown, compelling drivers to inspect the vehicle before exiting [7].

In Vietnam, although formal regulations remain limited, increased awareness has led to grassroots innovations. For example, students from iSchool Quy Nhon developed a sensor-based alert device for detecting children left on school buses, currently under pilot implementation. Similarly, students from Bai Chay High School designed a system that transmits SMS and call notifications upon detecting a child left behind, contributing to public awareness and safety enhancement.

These initiatives reflect a broader international movement toward technology-assisted child safety systems in transportation. Compared to manual protocols, IoT- and AI-enabled solutions demonstrate superior accuracy, reliability, and response speed. Furthermore, recent advancements have leveraged infrared imaging and motion classification to achieve detection accuracies exceeding 94%, even under low-visibility conditions [8]. Integration with GPS and GSM modules supports real-time alerting and location tracking [9], while edge computing helps reduce latency in data processing for time-sensitive applications [10].

In resource-constrained environments, low-cost infrared and GSM-based systems remain viable, though they may be affected by temperature extremes or signal interference [11]. To address the limitations of motion-only detection - particularly for stationary or hidden children - vision-based AI systems have been introduced, enhancing robustness and adaptability in complex operational contexts [12]. These technological trends provide a strong foundation for future enhancements of the proposed system.

2.2. Purpose and scope of research

The aim of the research is to develop an intelligent warning system that detects and prevents children from being left behind on buses, raising awareness and responsibility of drivers, schools and parents in protecting children.

The main objectives of the project include:

● Research and design an alarm device that can detect the presence of children based on heat, motion, or AI sensors.

● Integrate the system with a mobile application/phone SIM to send timely warning notifications.

● Test the effectiveness and accuracy of the device in real-world environments.

The scope of the research includes studying existing technologies in the field of warning devices, thereby proposing optimal solutions to prevent children from being left behind on school buses. Based on theoretical research, the author develops a prototype of the device and conducts tests on a bus model to evaluate its performance under simulated real-life conditions. This process helps to test the effectiveness, feasibility and applicability of the system, thereby making necessary adjustments and improvements before actual implementation.

3. Basic literature and designing tool

3.1. Design motivation

One widely adopted solution in this field is the Ecall SCC-34, a child-leaving prevention device comprising a central unit and an alarm stop button positioned at the rear of the vehicle. Its primary function is to prompt the driver to inspect the bus before exiting; failure to do so triggers an audible alarm. The system is compact, easy to install and maintain, and integrates well with bus interiors. However, as it relies entirely on manual confirmation, the risk of human error remains - potentially resulting in children being inadvertently left behind.

Figure 1. *Ecall SCC-34*

To address the limitations of manual systems like the SCC-34, this research proposes an autonomous solution using motion sensors strategically placed throughout the vehicle to detect the presence of children. Upon detection, the system activates a buzzer and simultaneously sends alerts to the driver's and parents' mobile devices, enabling timely intervention. While this approach introduces greater system complexity and cost compared to the SCC-34, it significantly reduces the risk of human error.

The proposed system offers notable improvements in automation, reliability, and ease of deployment. Unlike the SCC-34, which depends entirely on the driver's inspection, this system operates independently, enhancing safety through continuous monitoring. Compared to Thailand's DEPA Smart Bus - which employs AI and mobile tracking but requires expensive infrastructure - this design achieves a practical balance between functionality and affordability. It is particularly well-suited for implementation in resource-limited contexts, given its use of low-cost components, simple installation, and minimal reliance on proprietary technologies.

To clearly demonstrate its advantages, Table 1 compares the proposed system with the SCC-34 and DEPA Smart Bus across key performance dimensions, including automation, detection accuracy, alert mechanisms, and deployment feasibility.

Table 1. *Comparison of Child Safety Alert Systems*

Feature	Ecall SCC-34	DEPA Smart Bus	Proposed system
Detection Method	Manual (driver-based)	AI-based cameras + IoT	PIR motion sensors
Automation Level	Low	High	High
Real-time Mobile Alerts	No	Yes	Yes
Response Time	Dependent on driver	1–2 sec (AI trigger)	2–3 sec (avg. measured)
Accuracy (Detection Rate)	Unavailable	~95%	~90% (tested in simulation)
False Alarm Rate	Unknown	~3%	~8%
Cost	Low	High	Moderate
Installation Complexity	Low	High	Low
Internet Dependency	No	Yes	No (uses GSM/Blynk)

As shown, the proposed system provides a favorable balance between functionality, affordability, and ease of implementation. While it may not yet reach the AI-level accuracy of the DEPA Smart Bus, it significantly improves upon SCC-34 by eliminating the reliance on human action and introducing automatic detection with real-time alerts. Furthermore, it can be installed at lower cost and complexity, making it suitable for schools or bus operators with limited resources.

3.2. Design tools

A key consideration in developing the proposed system is the careful selection of hardware and programming platforms to ensure reliability, scalability, and ease of implementation.

The ESP8266 Wi-Fi module serves as the system's core, offering high processing power, compact size, and compatibility with various programming environments such as Arduino IDE, MicroPython, and Lua. Its support for communication protocols like TCP/IP, MQTT, and HTTP makes it highly suitable for IoT applications. However, it requires a stable 3.3V power supply and careful current management during startup.

For motion detection, the system utilizes the HC-SR501 PIR sensor, which identifies changes in infrared radiation caused by human movement. With a range of 3–7 meters and a 120-degree field of view, it is effective for monitoring enclosed vehicle spaces. While the sensor may struggle with detecting stationary individuals or those behind obstructions, deploying multiple units can enhance coverage.

To transmit alerts, the SIM800L GSM module is integrated, enabling SMS notifications and call functions. Its wide frequency compatibility and UART communication simplify integration with the ESP8266, although stable power and good signal strength are essential for optimal operation.

The ESP8266 is programmed using Arduino IDE, a widely adopted and beginner-friendly platform. This environment enables rapid implementation of sensor data acquisition, processing, and communication features, accelerating development.

Additionally, the system incorporates Blynk - a cloud-based IoT platform that allows real-time monitoring through customizable mobile dashboards. Its intuitive interface and seamless integration with the ESP8266 enhance usability for non-technical users such as parents or school staff, further improving the system's practicality and accessibility.

4. Project architecture

4.1. Anti-abadonment system structure

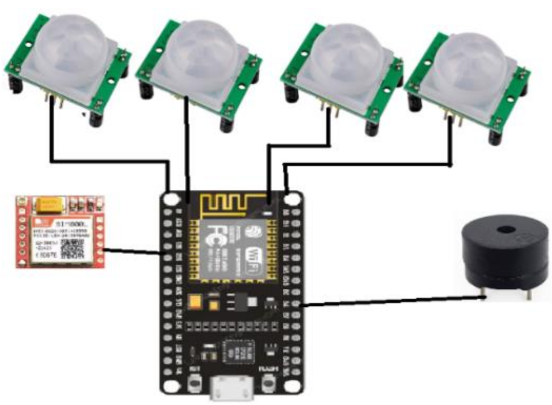

Figure 2. *System structure*

The system will be built basically according to the above structure. All four HC-SR501 sensors, buzzer, SIM800L module are connected to ESP 8266 through an intermediate circuit board to be able to supply the correct rated voltage for each type of device as well as make the system compact.

For the four HC-SR510 sensors, the sensors operate independently, meaning that if only one of the four sensors detects movement, the system will turn on the buzzer to notify that there are students on the bus.

4.2. Algorithm structure diagram

The device's operation is described in the diagram below. When powering the device to operate, to enable the system's functions, the vehicle must be turned off. After the vehicle is turned off, the control circuit begins to read signals from the motion sensors. When motion is detected, the control circuit processes the information and controls the alarm and sends a signal to the SIM module to send a notification to the SIM of the connected devices. At this time, when the sensor continues to detect motion, the alarm will continue to sound until there is no more motion. In addition, the system has a safety button, allowing the alarm system to be activated proactively when the button is pressed by human. When the vehicle restarts, the system will turn off the alarm functions.

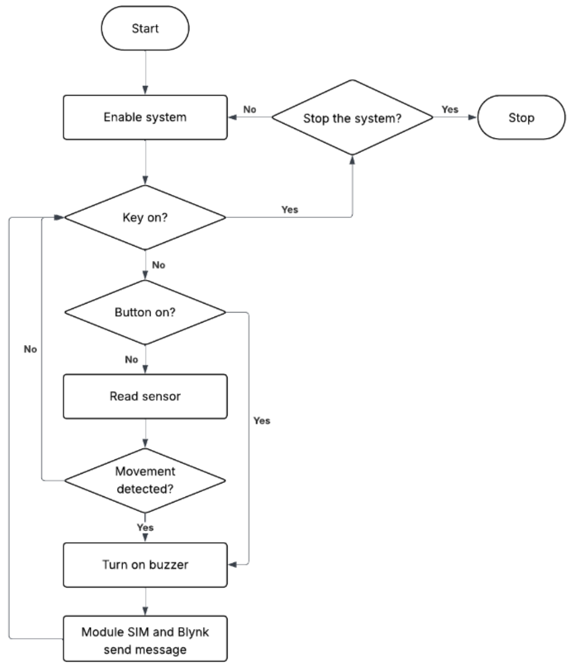

Figure 3. *system structure diagram*

4.3. Step-by-step to build the system

The project follows a structured development process to ensure functionality and reliability. Initially, all component specifications and system requirements are analyzed to ensure compatibility with design objectives. This includes reviewing available hardware, technical documentation, and relevant datasheets to determine appropriate configurations.

Subsequently, the ESP8266 is programmed to control the system's components. This stage involves designing the circuit layout with proper voltage considerations and implementing code based on a predefined algorithm. Key programming elements include library imports, pin and variable declarations, and input/output control logic. Sensor sensitivity is calibrated during this phase to optimize performance.

Once functionality is verified in software, the physical circuit is assembled to achieve a compact and safe layout. Components are soldered onto the board, and the system is re-tested to ensure stability. Multiple test scenarios are conducted to validate consistent operation under varying conditions, confirming the system's readiness for deployment.

5. Task performed

5.1. Circuit diagram

Creating circuit diagrams in Proteus is a crucial stage in system development, providing a foundation for simulation and validation before hardware implementation. The software allows engineers to visualize circuit behavior, detect design issues, and test functionality under diverse conditions - all without physical components. This approach streamlines development, reduces errors, and minimizes the risk of failure during assembly.

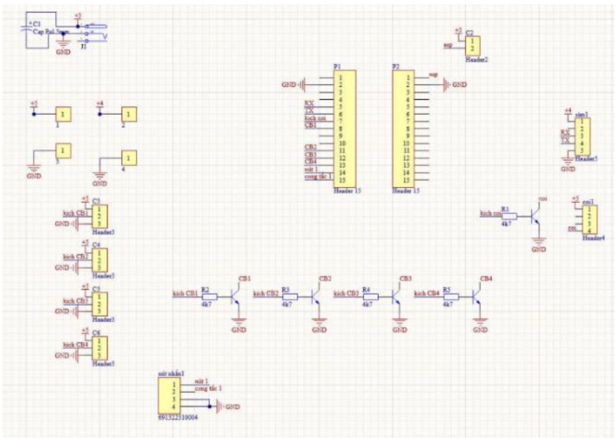

Figure 4. *Circuit diagram on Proteus software*

The schematic diagram created in Proteus demonstrates the integration of core components, including the ESP8266 microcontroller, PIR sensors, a buzzer, and the SIM800L GSM module. The PIR sensors are connected to the ESP8266 via bipolar junction transistors (BJTs), which function as amplifiers and switches to ensure stable signal transmission. Upon motion detection, the system activates the buzzer and sends warning messages through the SIM800L to predefined mobile numbers.

To support stable operation, the circuit includes voltage regulators and capacitors that filter noise and maintain consistent power - critical for the ESP8266 and SIM800L, which are sensitive to fluctuations. Components are arranged logically to reduce interference, save space, and simplify wiring, thereby enhancing reliability and facilitating easier soldering and maintenance.

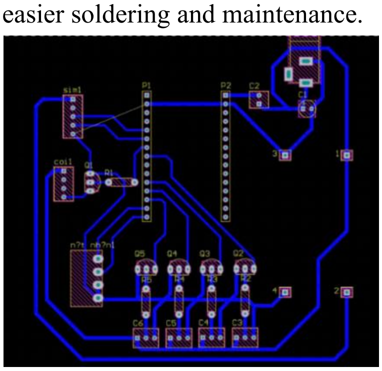

Figure 5. *PCB design*

After successful simulation in Proteus, the circuit is transitioned to PCB design. This involves routing signal paths, adjusting trace widths, and assigning ground/power planes to ensure electrical integrity. A well-structured PCB is essential for converting the virtual schematic into a durable, compact hardware system suitable for real-world transportation environments.

The PCB design for the system is optimized to accommodate key components, including the ESP8266, SIM800L module, PIR sensors, and buzzer.

Signal and power traces are clearly routed, with components such as transistors, capacitors, and resistors arranged to minimize noise and facilitate soldering. The organized layout enhances signal stability and simplifies both testing and maintenance. Once the PCB was fabricated and all components soldered in place, the hardware assembly of the system was completed and ready for final integration.

5.2. Programing

The programing is Arduino-based that is easy to understand and flexible to alter in different cases. Below will be some important program:

```
void loop() {
  Blynk.run();
  Serial.println((String)digitalRead(nut_canh_bao) + "   " + (String)digitalRead(chia_kho
          + "   " + (String)digitalRead(CB_CD_3) + "   " + (String)status_chia_kho
```

Figure 6. *Set up loop program*

In the loop() function, the system maintains a connection with the Blynk platform through the Blynk.run() command, ensuring uninterrupted real-time data communication. The Serial.println() command is used to output the status of the signal pins, making it more convenient to monitor and test the hardware.

```
if (digitalRead(chia_khoa) == 0 && status_chia_khoa == 0) {
    Blynk.virtualWrite(V1, 1);
    status_chia_khoa = 1;
    tg = millis();
  }
```

Figure 7. *Key-status check program*

Then, the program performs a key status check by reading the value from the chia_khoa pin. If the lock is detected to be off and the system status has not been updated, the program sends a signal to Blynk (via V1), and saves the current time using the millis() function to determine the delay time for subsequent actions.

```
else if (digitalRead(chia_khoa) == 1 && status_chia_khoa != 0) {
    status_chia_khoa = 0;
    canh_bao = false;
    digitalWrite(coi, LOW);
    Blynk.virtualWrite(V1, 0);
    Blynk.virtualWrite(V2, 0);
    Blynk.virtualWrite(V3, 0);
  }
```

Figure 8. *Sensor status check program*

When the lock is detected to be turned back on (i.e. digitalRead(share_key) == 1), the program resets the status_share_key to 0 and silences the alarm by interrupting the buzzer (digitalWrite(coi, LOW)) and updates the status on the Blynk interface by assigning 0 values to virtual pins V1, V2, and V3. This update synchronizes the actual state of the device with the remote monitoring system and ensures that the system returns to a ready state for the new test cycle.

```
if (status_chia_khoa == 1 && millis() - tg > tg_canh_bao) {
  status_chia_khoa = 2;
  digitalWrite(coi, HIGH);
  delay(500);
  digitalWrite(coi, LOW);
  Blynk.virtualWrite(V2, 1);
}
```

Figure 9. *Active alarm program*

When the system detects that the vehicle has been turned off for a period longer than the defined tg_canh_bao threshold, it activates the alarm condition. The buzzer is triggered by setting the control pin to high for 500 milliseconds, producing a short audible alert. Simultaneously, a signal is sent to the Blynk platform via virtual pin V2 to inform remote users, and the system status is updated accordingly.

In parallel, when the status_chia_khoa variable reaches 2, the program checks the state of the manual alarm button. If the button is pressed (logic low), the canh_bao flag is set to true, prompting the buzzer to sound and transmitting an additional alert through Blynk using virtual pin V3. This ensures that both local and remote users are promptly notified of the emergency condition.

The system then utilizes the SIM module to send an SMS alert to a predefined phone number. This is executed using the AT+CMGS command to specify the recipient, followed by the warning message "WARNING DETECTED PEOPLE ON THE VEHICLE". A brief delay ensures stable transmission, after which the sim.write(26) command finalizes and sends the message. Once completed, the status_chia_khoa variable is set to 3, indicating that the alert has been processed and preventing redundant notifications in subsequent program cycles.

```
if (status_chia_khoa == 2) {
    if (digitalRead(nut_canh_bao) == 0) {
      canh_bao = true;
    }

    if (canh_bao == true) {
      digitalWrite(coi, HIGH);
      Blynk.virtualWrite(V3, 1);

      sim.println("AT+CMGS=\"+84375443119\"");
      delay(500);
      sim.print("CANH BAO PHAT HIEN CO NGUOI TREN XE");
      delay(500);
      sim.write(26);

      status_chia_khoa = 3;
    }
  }
```

Figure 10. *Detecting and signal sending program*

5.3. Blynk Interface

The Blynk application features a minimalist and user-friendly interface, enabling users to monitor and interact with the system without requiring technical expertise. Key functions such as "Key", "Status", and "Child On Bus?" are clearly labeled and intuitively arranged, allowing quick access to system status via smartphone.

As a cross-platform solution, Blynk is easily downloadable from major app stores and can be installed and used on demand. Real-time notifications from the system ensure that parents or supervisors are promptly informed in case of emergencies. Its clean layout and responsive design enhance usability, offering a reliable and accessible experience for end users.

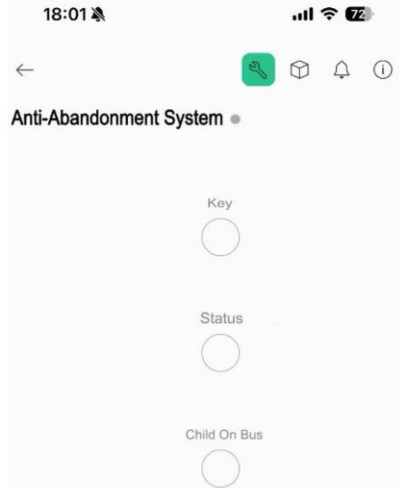

Figure 11. *Blynk Interface*

5.4. Testing

The system was tested to assess its stability, sensitivity, and overall performance under various simulated conditions. Test scenarios included different levels of movement, such as a child sitting still, slight motion, and an empty environment. These conditions were used to evaluate the motion sensor's responsiveness and the system's alert delay upon detection.

To evaluate the system's performance in the absence of access to a real school bus, testing was conducted in a controlled indoor environment using a standard classroom to simulate the enclosed space of a bus cabin. The room was configured to match key conditions such as limited airflow, enclosed layout, and variable lighting. Test scenarios included: (1) a person moving actively within the space, (2) a person sitting still in a corner, (3) multiple people moving simultaneously, and (4) an empty room.

The system demonstrated promising quantitative performance during simulation-based testing conducted in a classroom environment. It achieved an estimated detection accuracy of approximately 90%, with reliable identification of human presence under various conditions. The false positive rate was around 8%, primarily triggered by non-human movements such as oscillating fans or shifting curtains. In contrast, the false negative rate remained low at approximately 2%, typically occurring when the subject remained completely motionless or was partially obstructed. The average response time - from the simulated "engine off" signal to alarm activation - was measured at 2.5 seconds, while SMS alerts were generally delivered within 4 to 6 seconds, depending on the strength of the GSM signal inside the room.

Although the testing did not take place in an actual vehicle, the classroom environment provided a sufficiently constrained space to simulate real-world conditions. Future testing will be needed on actual school buses is planned to further validate system robustness under dynamic conditions such as vehicle vibration, ambient noise, and shifting lighting.

6. Conclusion and further development

6.1. Achieved result

The completed system has successfully met its initial objectives, including detecting the presence of children left in a vehicle, triggering timely alarms, and sending warning messages to designated phones. The Blynk-based control interface proved stable, user-friendly, and capable of clearly displaying system status. Testing results confirm the system's fast response and high potential for real-world application.

6.2. Further development

Although the prototype performs well under simulated conditions, further refinement is required for deployment in actual vehicles. Different bus models vary in interior layout and dimensions, necessitating adjustments in sensor quantity and placement to ensure full coverage. The wiring, power supply, and circuit enclosure must also be re-engineered to meet safety and durability standards suitable for transportation environments.

Transitioning to a production-ready version will require collaboration with vehicle manufacturers or installers and adherence to regulations on electrical safety, fire protection, and transport standards. These steps are critical to ensuring practical implementation and wide-scale adoption.

While the current system meets basic functional requirements, improvements are needed to enhance accuracy and reliability. PIR sensors may not detect stationary or obscured children, highlighting the need for additional sensing technologies such as thermal imaging or AI-based vision modules. Similarly, the GSM-based alert system can experience delays in low-signal areas; therefore, integrating alternative communication methods like Wi-Fi, LoRa, or MQTT would improve performance stability. User interface enhancements - such as push notifications, GPS integration, and alarm history logging - can also elevate system usability.

In future iterations, incorporating deep learning techniques such as convolutional neural networks (CNNs) will allow for more accurate recognition of human presence, posture, or thermal signatures. These capabilities will enable the system to detect children even when immobile or partially obstructed, reducing false negatives and aligning the system with current advancements in intelligent transportation and smart safety technologies. Such improvements will not only increase real-world robustness but also enhance the system's academic and practical value for broader deployment and scientific dissemination.

6.3. Conclusion

In conclusion, the developed anti-abandonment system demonstrates strong application potential through its ability to detect movement, trigger timely alarms, and notify supervisors via mobile alerts. By integrating sensors, a microcontroller, and the Blynk platform, the system offers a user-friendly and effective solution for enhancing child safety in public transport. Although currently at the prototype stage, initial results provide a solid basis for further refinement and real-world deployment.

Future work will need to be focused on improving detection accuracy and communication stability. To overcome the limitations of PIR sensors in identifying stationary or obstructed children, thermal sensors and AI-based vision modules will be explored. Moreover, communication protocols such as Wi-Fi, LoRa, or MQTT may be integrated to enhance alert reliability in areas with weak GSM coverage. These advancements aim to improve the system's overall robustness and readiness for large-scale implementation.

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