Vehicle Child Seat Alert System

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*Abstract*—Every year, an average of 37 children die in the United States after being left in hot vehicles [1]. Each death is a tragedy that could have been averted with a simple and affordable engineering solution.

Keywords—automobile, vehicle, child, driver, hot car, software engineering, embedded system

Contents

[I. Introduction 1](#_Toc25797959)

[II. Related Work and State of the Industry 2](#_Toc25797960)

[III. Software Engineering 2](#_Toc25797961)

[A. Requirements 2](#_Toc25797962)

[B. Design Methodology 2](#_Toc25797963)

[1) Requirements Phase 2](#_Toc25797964)

[2) Design, Implementation, and Subsystem Testing 2](#_Toc25797965)

[3) Integration and System Testing 3](#_Toc25797966)

[C. Design 3](#_Toc25797967)

[1) Firmware Design 3](#_Toc25797968)

[2) Software Design 3](#_Toc25797969)

[IV. Hardware Selection 4](#_Toc25797970)

[A. Microprocessor 4](#_Toc25797971)

[B. Sensors 4](#_Toc25797972)

[C. Other Hardware 4](#_Toc25797973)

[V. Implementation Details 4](#_Toc25797974)

[A. Hardware Implementation 4](#_Toc25797975)

[B. Firmware Implementation 4](#_Toc25797976)

[C. Software Implementation 5](#_Toc25797977)

[VI. Functionality and Testing 5](#_Toc25797978)

[A. Unit Testing 5](#_Toc25797979)

[B. Functional Requirements Testing 5](#_Toc25797980)

[C. Performance Requirements Testing 5](#_Toc25797981)

[VII. User Manual and Maintenance 5](#_Toc25797982)

[A. User Manual 5](#_Toc25797983)

[1) Hardware 5](#_Toc25797984)

[2) Firmware 5](#_Toc25797985)

[3) Software 6](#_Toc25797986)

[VIII. Bill of Materials 6](#_Toc25797987)

[IX. Future Work 6](#_Toc25797988)

[A. Temperature sensor 6](#_Toc25797989)

[B. Adjustable Alert Intervals 6](#_Toc25797990)

[C. Additional Sensors 6](#_Toc25797991)

[X. Problems and Difficulties 6](#_Toc25797992)

[XI. Conclusion 6](#_Toc25797993)

[XII. Appendix I: Firmware Code 7](#_Toc25797994)

[XIII. Appendix II: Backend Software Code 7](#_Toc25797995)

# Introduction

Modern vehicles are engineering wonders, containing more than 50 pounds of copper wire [2], increasingly sophisticated microprocessors, and safety systems that were unimaginable just ten years ago. The vehicles’ advanced sensors and controls allow vehicles to alert drivers to the presence of other vehicles, perform emergency braking for the driver, and even park and drive themselves. However, car manufacturers have been very slow to include systems that monitor the vehicle for children left alone. These systems are just beginning to be sold in the 2019 and 2020 model year vehicles [3] in many GM vehicles with several other manufacturers following suit. But what about parents that own older vehicles? Options exist, but many of them are video based, adding a device that could become a projectile in an accident. This paper describes a different alert system prototype that can be constructed using a simple microprocessor, simple sensors, and an internet connection that can monitor the vehicle for both a driver and a child that can be retrofitted to any vehicle.

# Related Work and State of the Industry

# Software Engineering

## Requirements

1. System Requirements
   * [SYSFUNCT001] The system shall consist of hardware and software components that have the capability of monitoring a vehicle for the presence of a driver and child as well as the capability of alerting a user via text or email.
   * [SYSFUNCT002] The system shall have a user-configurable delay for signaling an emergency event.
   * [SYSPERF001] The system shall alert a user within 30 seconds (1-sigma) of an emergency event.
2. Embedded System Requirements
   * [ESFUNCT001] The hardware shall consist of an embedded system with one or more microprocessors, one or more sensors, and the hardware to support a wireless communication method (WI-FI or Bluetooth preferred).
   * [ESPERF001] The hardware shall transmit an alert to the backend system within 15 seconds (1-sigma) of an emergency event.
3. Backend Requirements
   * [BEFUNCT001] The software shall receive notifications wirelessly (using WI-FI or Bluetooth) from the hardware and transmit a notification to the user via text message or email.
   * [BEFUNCT002] The software shall be written in a high-level programming language such as C++, Java, or a similar language.
   * [BEPERF001] The software shall transmit an alert to the user within 15 seconds (1-sigma) of an alert received from the hardware.

## Design Methodology

The design method chosen for this project is the Agile system. The project was divided into three parts, each comprising several weeks. These parts are: requirements phase, design and implementation phase, and system integration and testing. The requirements phase was focused on identifying the system and subsystem requirements. This process involves identifying the needs of the system as well as the amount of available time, and creating requirements for the system that are both reasonable to accomplish and together create a functional system. The design and implementation phase involved the system-level design, including block diagrams and flow charts, as well as selecting the hardware that would be used for the project. The final phase involved combining the two parts of the systems and testing them for functionality and requirement validation. Short weekly meetings were used to collaborate between team members to make major design decisions as well as to re

### Requirements Phase

The initial phase of the design revolved around defining the system that would be developed, including requirements definition (see Requirements) for the functionality and performance of the system. The system was divided into two main parts: the embedded system containing the sensors and microprocessor, and the backend software that runs on a PC and the AWS Internet of Things (IoT), which would be used to send a text message to users. The system was laid out using a block diagram to define the parts of the hardware and the major software modules of the system (see Figure 1).



Figure 1: System Block Diagram

Once the entire system was defined, the next step was to decide upon the various parts. The hardware selection process (detailed in Section IV) analyzed various components and their pros and cons before making a selection. Python was decided upon for the programming language for the backend software and Amazon Web Services (AWS) portion of the design.

### Design, Implementation, and Subsystem Testing

The second phase began with designing the Entity Relationship Diagram (ERD) for the system. This defines the relationship between the various parts of the system. Figure 2 shows the ERD for the system. The embedded system portion consists of a single microprocessor that monitors a minimum of two or more sensors. These sensors are wired for monitoring the child or the driver. There can only be one sensor for the driver, but there could be multiple sensors for monitoring multiple children. The child and driver may not be present at all times, so this part alone has a modality of zero. The backend of the system, consisting of the PC software and AWS software, is required for the system to operate (modality of one) and functions on a single instance. The embedded system must communicate with the backend to transmit alerts to the user via text. The driver must also interface with the backend to configure the system with one or more phone numbers to notify during an alert.

Child

Driver

Embedded System

Backend

Sensors

Monitor

Monitor

Communicates with

Alerts

Figure 2: ERD for the System

Once the ERD was completed, the logical flow of the code was designed using flow diagrams (see Section C). The actual design of the code had to take into consideration the programming language in use. This was not important for the Python code, but it was very important for the Arduino code design because of the way code works on these devices. The setup() function is only run at startup, so any one-time configurations needed to be performed here, while any continuous functions needed to be performed in the loop() function that runs continuously. Using the flow charts in Section C, the code was written for the separate parts of the system. The hardware and parts of the code were then tested separately (see Section VI) for functionality using the test plans detailed Section VI.A.

### Integration and System Testing

The final phase of the project was focused on integrating the various parts of the system and testing them together. Due to the highly separated functions of the system, there was only a single point of connection between the two pieces consisting of a TCP connection between the firmware and server used for sending alerts. Once the parts were integrated, the system was tested using the requirements specified in phase one.

## Design

### Firmware Design

The firmware monitors the sensors for the presence of a child and, in the case of a child being left alone, sends an alert to the backend software that will then relay the alert to the user. Thus, the firmware must first monitor for the presence of a child. If no child is present, it is not required to operate at all and must periodically monitor if that status has changed. If a child is present, the system must monitor both the child and driver. The design also requires a timer before sending an alert to prevent false alarms if the driver is filling the car with fuel, loading or unloading the car, or getting out of the car to remove the child, which can take several minutes. The flow chart in Figure 3 shows the flow of the design.

No

Yes

Reset timer

Check Child

Check Driver

Yes

No

Send Alert

Timer

Yes

No

1. Check for child
2. Check for adult
3. If child present and driver is not, set a timer
4. Keep checking for driver or if child was removed
5. If child still alone at end of timer, send alarm

Figure 3: Firmware Flow Chart

### Software Design

The software runs on a PC between the embedded system and the AWS IoT. As a result, most of what the software does is monitor incoming messages and relay them as necessary. The software must establish connections to the various components then begin the monitoring process. The software design was based on the flow chart in Figure 4. The software checks for a connection, receives a message from the embedded system, and then examines the message, then either sends an alert, or sleeps for a time before repeating the process.

No

Yes

Wait & Retry

Send Alert

Heartbeat

Alert?

No

Yes

Figure 4: Backend Software Flow Chart

# Hardware Selection

## Microprocessor

During hardware selection several types of microprocessors were examined, including PIC processors, a Raspberry Pi, and Arduino. Ultimately an Arduino Nano 33 IoT was selected for several reasons. First, it is significantly easier to work with than the PIC, especially due to the fact that a WiFi connection was a requirement. The Arduino Nano IoT contains a WiFi and Bluetooth module on the board as well as included libraries, making this process much easier. The Arduino was also affordable, small, and had more than enough processing power to complete the required tasks.

## Sensors

Identify applicable funding agency here. If none, delete this text box.

The purpose of the sensors is to provide the Arduino with data about the presence of a driver and/or child in the vehicle. Strain gauges were selected to perform this task. A strain gauge is a piece of material (usually metal) that has a flexible backing attached [4]. When this material is bent even slightly, it alters the resistance of the device, producing a minor, but measurable, difference in the voltage across the device.

## Other Hardware

Identify applicable funding agency here. If none, delete this text box.

Due to the extremely small voltage change generated by applying force to a strain gauge, the Arduino requires some assistance. This comes in the form of a microchip called an HX711. This chip combines one or more strain gauges into a Wheatstone bridge [5] that amplifies the signal. In addition, the HX711 has a 24-bit ADC [6] for digitizing the signal with greater sensitivity than the Arduino’s 12-bit ADC.

# Implementation Details

The Vehicle Child Alert System consists of several distinct parts that have been divided into multiple parts. This includes the hardware design, consisting of the strain gauges, HX711 microprocessors, wires, and Arduino, the Firmware design, which consists of the code that runs on the Arduino to monitor the gauges and relay alerts to the backend, and the backend, which alerts the user in case of an emergency.

## Hardware Implementation

The hardware implementation connects the various pieces of the hardware physically. Figure 5 shows the wiring diagram for the system. In order for two 3-wire strain gauges to work properly, one white and one black wire from each gauge must be connected together and run to the HX711. The remaining white and black wires are similarly connected together. These wires are then attached to E+ or E- connection on the HX711 board. The red wires from the strain gauges are connected to the A+ and A- connections on the HX711 board, completing the circuit. The HX711 combines these connections to form the Wheatstone bridge internally. The HX711 is then connected to the Arduino with 4 wires. Power and Ground are connected to pins 2 and 14, respectively. The SCK (clock) and DT (Data Out) pins from the HX711 are then connected to two digital pins on the Arduino board. The Arduino board, in turn, is powered from a USB connection.

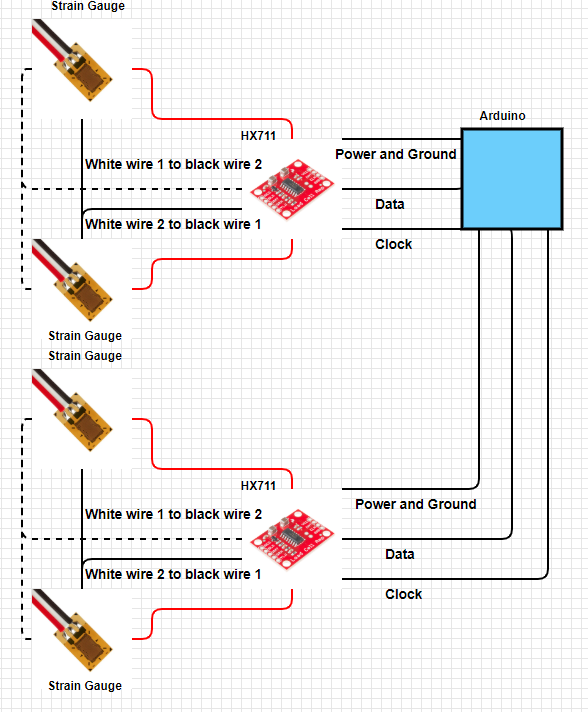


Figure 5: Hardware Wiring Diagram [drawn using 6]

## Firmware Implementation

#### Major Functions

The code is organized very simply, as most Arduino code is. There is a setup() function that performs all of the one-time operations. This includes opening the serial interface between the PC and the Arduino (when developing and debugging), setting up the HX711’s pin configurations, and connecting to the internet (in this case, WiFi).

The other major function is the loop() function. This is the typical continuous loop found in most embedded systems that contains most of the functional code. This section calls several other functions that monitor the sensors, check the WiFi status, and send an alert if necessary.

#### Minor Functions

The connectWifi() function performs the initial connection to the WiFi network, or can be called if a connection is lost at any time. This uses the configured networks SSID and password to connect to a WPA2 encrypted WiFi network and blink the LED when it connects.

The dispWifiStatus() function displays the status of the WiFi connection to the serial monitor, including the network SSID and the Arduino’s assigned IP address.

The checkWifi() function checks that the Arduino is still connected to the network and tries to reestablish its connection if it has been lost using the connectWifi() function.

The checkDriver() and checkChild() functions check the values from the sensors to determine if the driver or child is currently in the vehicle, returning a simple Boolean answer.

The checkSensors(int delayTime) function is the most important function of the code. This is the section where the logic that monitors the driver and child is located. See Figure 3 for the flow chart. This code consists of a while() loop that breaks when the logic determines that an alert should or should not be sent. It first checks for the presence of a child. If there is no child, it breaks the loop and returns to the loop() without sending an alert. If there is a child, it then checks for a driver. If a driver is present, then it breaks the while loop and returns to loop() without sending an alert. Otherwise, if there is a child and no driver, it delays for the specified delayTime before performing the checks again. If the driver has returned to their seat of the child has been removed from theirs, it breaks the while loop and returns to loop() with no alert being sent. Otherwise it returns a true for alert and an alert will be sent to the driver when it returns to loop().

## Software Implementation

The software for this project was written in Python, so the body of code is the \_\_main\_\_ function. This code connects the firmware to the AWS IoT using a protocol called MQ Telemetry Transport (MQTT) to perform this connection. The “MQ” represents an IBM product line called “MQSeries”[9]. The code then opens a Secure Sockets Layer (SSL) connection to the AWS IoT using the ssl\_alpn() function. ALPN stands for Application Layer Protocol Negotiation. This requires a public and private key configuration to encrypt the connection between the local PC and the AWS IoT. Once this connection has been made, the programs starts a monitoring loop for the MQTT connection to receive messages from the system. Once this has been started, a while loop continually monitors the received messages. These messages consist of a single number that relays whether there is an alert situation (2) or not (anything other number). If an alert message is received, the software sends a message to AWS IoT to send an alert message.

# Functionality and Testing

## Unit Testing

An alert system can be built using simple sensors, a microprocessor, and an internet connection that monitors the vehicle for the presence of a driver and a child or children. When a child is left alone in the car for a period of time, an alert is sent to the parent or guardian

## Functional Requirements Testing

* [SYSFUNCT001] -
* [SYSFUNCT002] -
* [ESFUNCT001] -
* [BEFUNCT001] -

## Performance Requirements Testing

* [SYSPERF001] -

# User Manual and Maintenance

## User Manual

### Hardware

The hardware for this system consists of the strain gauges, HX711 boards, an Arduino board, and wires and connectors. To begin setting up the correct configuration, the strain gauges must be connected properly. Each seat is monitored by a pair of strain gauges in a half-Wheatstone bridge. This is performed by the HX711 chip, but it requires the user to correctly wire the strain gauges together. In this configuration, only four (4) of the six (6) connectors are used. To simplify the explanation, the gauges will be referred to as strain gauge 1 and strain gauge 2. The black wire from strain gauge 1 should be wired to the white wire of strain gauge 2. These wires can then be connected to A+ or A-. However, the red wire from strain gauge 1 (with the black wire) MUST be connected to the same polarity (E+/E-) as its black wire. Strain gauge 2 is wired similarly and connected to the remaining strain gauge, keeping the red wire with the same polarity as the black wire. The HX711 board must then be wired to power and ground. The ground connector must go to either pin 14 or 19 while power must be routed to pin 2 on the Arduino board (3.3 Volt output). The connectors for DT and SCK are then wired to pins 2 and 3, respectively, for the child sensor and pins 4 and 5, respectively, for the driver’s sensor. The power for the Arduino can come from a USB connector, DC power supply, or a battery, but it should be noted that the Arduino Nano 33IoT runs on 3.3 volts NOT the standard Arduino voltage of 5 volts, so be wary if using anything other than a USB connector.

### Firmware

The firmware component consists of the Arduino board’s code that monitors the sensors and transmits an alert to the backend software. To configure the board, the Arduino IDE [8] must be installed on a PC. The WifiNINA and HX711 libraries must be installed from inside the IDE by going to Tools -> Manage Libraries, then entering “wifinina” and installing the library, and then doing the same for the HX711 library. The driver for the Arduino must be installed in a similar manner by going to Tools -> Board -> Board Manager and searching for “nano”, then selecting “Arduino SAMDBoards” and installing it making sure that Arduino Nano is listed in the description. Once this has been done, the board should be visible by the computer and have all the correct libraries installed.

Once the libraries are installed and the Arduino has been connected to the PC, the code can be loaded to the board via USB. The file “alertproject.ino” contains code for the Arduino board. To configure the Arduino to connect to a WiFi network, the SSID and password for a WPA2 network must be input into the networkSsid and networkPass variables. The next configuration change is the delay time for detecting if a driver has left the child in the car alone. The variable is in milliseconds and the default is 30,000 ms (30 seconds). In practice this would likely be much longer to allow a driver to pump gas, remove the child from the seat, unload the car, etc.

The final configuration that the user must make is to configure the strain gauges. The variances in manufacturing require that this be done for each strain gauge pair

### Software

An alert system can be built using simple sensors, a microprocessor, and an internet connection that monitors the vehicle for the presence of a driver and a child or children. When a child is left alone in the car for a period of time, an alert is sent to the parent or guardian

# Bill of Materials

|  |  |
| --- | --- |
| Item | Quantity |
| Arduino Nano 33 IoT | 1 |
| 50 kg strain gauge | 4 |
| HX711 ADC | 2 |

# Future Work

## Temperature sensor

A temperature sensor connected to the Arduino would be a possible source for future work. This number could then be reported along with the alert message.

## Adjustable Alert Intervals

An adjustable alert interval is another future improvement that could be made. Ideally this would use the temperature sensor from the previous section to adjust the alert interval based upon the temperature inside the vehicle. This would provide an earlier alert when the temperature reaches more dangerous levels.

## Additional Sensors

Additional (preferably plug-and-play) sensors would improve the system, as they would allow for the monitoring of multiple children or even multiple adults. For instance, if an adult is in the passenger seat but the driver is not present (if the vehicle were getting refueled, for example), then there would be no need to send an alert. This would likely require code in the firmware to measure the amount of weight on the sensors and some threshold weight level that determines if the person is a child or an adult.

# Problems and Difficulties

During the implementation of the child alert monitoring system, many difficulties were encountered, especially in regards to hardware integration. One of the most common causes of problems was due to poor documentation of hardware components, including the strain gauges and Arduino. While the solutions to these problems were generally extremely simple, the process of finding hardware problems was very time-consuming.

The initial difficulty with the hardware was with deprecated software. The Arduino WiFi library had changed fairly recently, adding a wrapper layer called wifiNina around the previous wifi library. This change was not particularly well-documented, requiring fairly extensive research and debugging to find the problem, which was fixed by adding a single library and include file, then slightly altering a function call.

The strain gauges used for this project had little to no documentation available, while the HX711 chip had a small datasheet that was somewhat lacking in detail. The strain gauge had to be connected in a very specific manner to function properly. Initially, the connection between the white and black wires and the HX711 was reversed, causing incorrect readings from the sensors. This was corrected by close examination of the wiring diagram for the Wheatstone bridge and the HX711 datasheet and moving the wires to different pins as necessary.

# Conclusion

An alert system can be built using simple sensors, a microprocessor, and an internet connection that monitors the vehicle for the presence of a driver and a child or children. When a child is left alone in the car for a period of time, an alert is sent to the parent or guardian

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# Appendix I: Firmware Code

# Appendix II: Backend Software Code

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