CARS

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***Abstract*— Every year, a number of people forget their children and pets in their hot cars; leaving them defenseless in a fight for their life against heat stroke. The solution for these individuals is the Child Alert and Rescue System. CARS seeks to provide relief and save lives in the event that a pet or child is forgotten in a hot car. Our system has been designed to integrate with most existing vehicles with little effort.**

I. Introduction

People all over the world forget their children in cars when going about their day. These individuals often face charges on top of losing a loved one from an avoidable mistake. On average, 37 children and hundreds of pets die per year in a hot vehicle in the United States [1].

The lethal temperature for these pets and children occur just above 95 degrees fahrenheit [1]. Once the air temperature within the car has reached this threshold, babies and pets quickly start to overheat and can die within minutes[1]. During warm days cars act like a greenhouse and can easily trap the sun's heat. As shown in figure 1, it only takes about 15 minutes for the inside air temperature to reach 95 degrees on a 70 degree day. When the outside air temperature is 90 degrees it takes just 2 minutes to reach dangerous conditions for your child or pet. This is why with such a limited amount of time it is crucial not only to send an alert to the owner, but to have a system that can take action in saving your child immediately.

In order to better understand the environment we were dealing with, we conducted an experiment to see how hot our vehicle would get. We placed a remote thermometer inside the vehicle and measured the temperature from outside the car over time. The thermometer was suspended from the ceiling in order to get the temperature of the ambient air inside the vehicle. We conducted this test on 2 different days to see the difference between a 90 and 70 degree day.

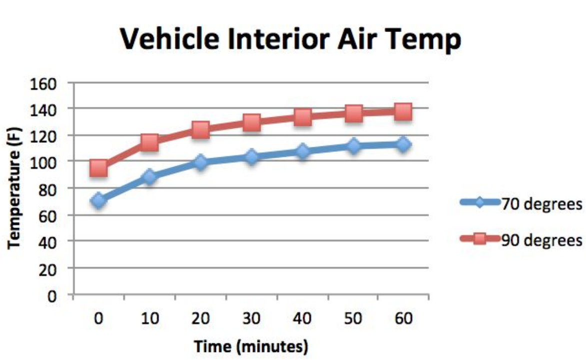

Figure 1:Temperature inside closed car over time

There are rudimentary solutions to this problem. We define these systems as rudimentary because while they do remedy the problem to some degree, they often have deficiencies and do not fully resolve the problem. One of these systems is *Sense a Life.* This system is a pressure pad installed in the child's car seat along with a thermometer. When the temperature is high and there is pressure on the pad, the user and 2 contacts are alerted via text message [2]. Another system, *ChildMinder*, consists of the same sensors but comes with a keyring buzzer that beeps when the alert is triggered [3]. While both of these systems do help, there are some holes in the systems like if you place a bag of groceries in the child seat or the user's phone is dead. Also, these systems do not detect anyone sitting in other parts of the back seat and do not detect pets. When making a system to save a life, you want to have a wide range of sensing and a high level of accuracy because it is a life and death situation.

CARS employs a wider detection range by using multiple sensors to increase life detection accuracy . Then after alerting the user, we are able to take the situation into our own hands by cooling down the car with the existing car system. The goal is to keep the car at a safe temperature until help arrives. Our system is a low power sensing system that is active for one hour and then it enters a sleep mode, consuming on the order of milliwatts as to not drain the car battery. This system has the potential to enter mass market due to its ease to enter the manufacturing assembly line as cars become more computerized.

Our specifications for this project stem from the demands of our goal. In order to know that the child or pet is in danger, we need to be able to measure the temperature in the vehicle. We know what the dangerous temperature range is, so we can set the trigger temperature to be somewhere right below this range so the system has time to react and cool the vehicle. We set this at 95°F. There is no need for alarm if there is no one in the back seat, so that is why we need to be able to detect a child in the backseat. The goal is to react in order to save the life, so our specification is to keep the car below 95°F when cooling. We want to alert the user that they have forgotten someone, so a cell phone alert would the fastest and most consistent way. We do not want our system to drain the life of the car battery because users would be upset to come back to a car that does not start. Our target vehicle is sedans because they are very abundant and common. Finally, we want the installation to be simple so it is easy for us, and anyone else with basic car electrical knowledge.

TABLE I

SPECIFICATIONS
1. Measure temperature in a car
2. Detect if child is in the car
3. Integrate alert system with cell phone
4. System should be compatible with most sedans (target manufacturer level)
5. Easy installation for a mechanic / auto electronics expert
6. Must take action to cool car at or below 95°F
7. Keep car under 95°F
8. Do not deplete power of battery beyond ignition start

II. Design

A. Overview

Our team has solved this problem through the utilization of DC electronics, a microcontroller, an array of sensors, and exploitation of proprietary systems that already exist in most modern cars. The choice for using these technologies is simple; the electronics we plan to exploit in the car are all 12 volt DC circuits, namely the windows, thus we use DC power and signals throughout the design of our system. The sensors we have chosen are as follows: passive infrared (PIR) motion, thermal imaging, temperature, camera for facial detection, and a pressure pad. These sensors were chosen to serve as the best combination for the detection of life. Any child or pet in the backseat of a car can be detected using a combination of the above sensors.

The microcontroller we decided to use in our system is the Particle Electron [8]. We chose this microcontroller because it has an onboard 3G modem, low power sleep mode, and a variety of I/O options required for our system (e.g. I^2C, UART, several ADC inputs). The Particle Electron has a large community and a rich development ecosystem that makes it ideal for fast prototyping. The hardware is open source, and the board is FCC, IC, and CE pre-certified, making it even easier to go from prototype to production.

Our system also uses a Raspberry Pi Zero W for the purpose of running the facial detection algorithm. We chose this particular model for its small form-factor, low power, and computing power. This model is 65mm by 30 mm, allowing it to easily fit within the roof-mounted box [10]. Additionally, the Raspberry Pi Zero W has a single-core 1 GHz CPU, allowing it to execute the facial detection algorithm at a reasonable speed [10]. The Raspberry Pi Zero W is also fairly low-power at an average 120 mA idle current consumption, allowing us to integrate it into our system without worrying about draining the car battery [10].

There are four main subsystems to CARS (Figure 2):

Power: The car battery is more than sufficient for supplying power to our entire system along with driving the motors to roll up and down the car windows. The 12 volts from the battery is stepped down to 5 volts which is all that is needed for powering our sensors, Raspberry Pi Zero and Particle Electron.

Sensors: The sensors communicate directly with our microcontroller through analog inputs, digital inputs, and I^2C bus. These sensors are continuously providing data to the microcontroller while the car is off.

Microcontroller: Once the car has been turned off our microcontroller reads in the data from our sensors. This data is then processed by our life detection algorithm which is designed to accurately detect a child or pet. If our algorithm decides there is in fact a human present, the microcontroller signals the relay to roll down the car windows as well as send a text message alerting the owner.

Car Interface: For the purpose of our project the car interface just consists of the windows. The user can manually roll up or down the windows by pressing on the switch once the car has been turned on. However if our system triggers, we can bypass these switches and supply power to the windows even after the car has been shut off.

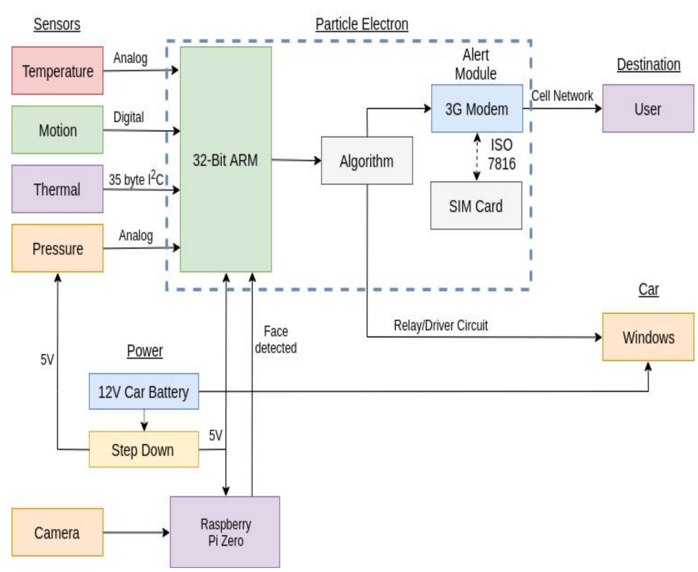

Figure 2:Block diagram

B. Sensors

There are 5 main sensors we are using in CARS to detect life. The first is the TMP36 temperature sensor. This sensor has a temperature range of -40 to +125℃ with a 2℃ accuracy; well above our trigger temperature of 35℃ (95°F). The output is a voltage on the output pin that changes with temperature. It is useful for its 10 mV/℃ scaling, as that makes it easier to process once the voltage has been read in through the microcontroller ADC [4]. The TMP36 is very small, and does not put size restraints on the sensor box.

The second sensor we are using is a passive infrared (PIR) motion sensor [5]. This sensor detects motion by taking in infrared (IR) into 2 slots. When there is no motion, both slots see the same amount of IR and so there is no voltage difference in the sensor. When there is a moving infrared source such as an animal, one slot receives more IR than the other so there is a positive voltage difference in the circuit. As this source moves by the other slot, there is a negative voltage difference created which drives the MOSFET circuit in the sensor to send an output voltage. This particular sensor has a adjustable detection range up to 20 feet and a reset delay of 2.5 to 250 seconds [5]. These settings allow us to create the optimal detection range in the back seat as to not detect motion outside the windows of the vehicle. The reset delay allows us to check for motion frequently. When positioned correctly, this sensor will provide sufficient evidence at trigger that there is a child or animal in the back seat because of the sensor functionality explained above.

The third sensor we are using is the Omron D6T thermal camera [6]. This camera detects the temperature of an area from 5 to 50℃. The sensor consists of a silicon lens that collects radiated heat, the radiated heat produces an electromotive force on the MEMS thermopile sensor, this force is measured and the temperature is calculated, and the measured temperature is output on the I^2C bus. The model we are using, D6T-44L, captures the average temperature of a 16 block square (Figure 3). The thermal camera has a FOV of 44.2° by 45.7° and is placed on the roof overlooking the back seat [6]. This sensor enables us to detect life in the back seat, even if the heat source is stationary (e.g. a child or dog passed out or asleep). This sensor is being used as a backup to the PIR motion sensor. If a child is asleep or unconscious, they will not be moving and therefore not trigger the PIR motion sensor. However, the thermal map from the Omron will show an area hotter than the environment. For this reason, this sensor is integral to the success of life detection. The PIR motion sensor output is just a high voltage when triggered while the Omron's output is a 4x4 pixel picture where each pixel has the average temperature of that area. Figure 3 is a visualization of this output with the temperature printed in the pixel and a corresponding color based on temperature.

The way we are using this for detection is a 2-part algorithm. The first, is a 2x2 square comparison. This compares the average temperature of 2x2 pixels to the surrounding pixels. If the average temperature of the box is different from the surrounding environment, then we can be confident that there is someone there. This is for detecting the head of a child and is done for each possible grouping of pixels. The second part is a 2x4 box comparison with the surrounding boxes. This is similar to the other method, but takes body heat more into account if that is more evident in the thermal camera.

Figure 3: 4x4 pixel output of the thermal camera

The fourth sensor is a force sensitive resistor. This sensor is a 1.75x1.5" square that varies its resistance depending on the force exerted on the sensing surface. This sensor is capable of detecting forces anywhere in the range of 100g to 10kg [7]. This range is adjustable, allowing us to set a threshold for the minimum weight that would trigger detection. This sensor is integrated in the form of a pressure pad, an optional feature that the end-user can insert within their child's car seat to increase the performance of life detection. For this purpose, the pressure pad has a plug built-in, allowing the user to easily take out or move the car seat if needed.

The fifth and final sensor we use is a raspberry pi camera. The camera is connected to our raspberry pi zero running a facial detection algorithm. This algorithm is from the OpenCV library and uses Haar classifiers to detect a face. This classifier was generated using machine learning and feature detection with an advertised accuracy of 95%. To find a feature, it compares different groupings of pixels to others in order to find edge features, line features, or four-rectangle features. For example, the bridge of the nose is often brighter than the eyes because it is more protruded. Comparing the pixels of the nose to both sides around the eyes is often going to be brighter and thus a positive line feature. The learning algorithm would find the most important common features in positive images (images with faces in them that were detected) by using the ones with the smallest error rate. As they are tested more, the weights of each feature change in order to achieve the best detection [11]. When the classifier confirms a face, we send a signal to the particle to relay that we have found a face.

We ran 10 separate trials for each one of our sensors. For each trial we experimented with the range of our sensors along with how well they were able to detect a human being. We sat in different areas of the back seat of the car and observed each sensor's output. There were only a few cases that our sensors gave a false reading (shown as x's in Table 1 below). We noticed that the facial detection camera had the lowest accuracy due to its limited field of view. Overall, our sensors had an average 87 percent success identifying someone sitting in the back seat.

Table 1: Sensor accuracy for detecting life

C. Microcontroller

This subsystem is responsible for implementing all of the backend logic of CARS. This includes reading of sensors (temperature, pressure, motion, thermal camera), processing sensor data for the purpose of detecting life, interfacing with the Raspberry Pi Zero, interfacing with the relays to roll down the windows, and sending out alert messages to the owner of the vehicle.

For this sub-system, we use the Particle Electron 3G cellular development kit. This development board provides a 120MHz STM32F05 ARM Cortex M3 microcontroller with 1MB of flash and 128KB RAM and a U-Blox SARA U260 3G cellular modem that provides a 3G cellular connection to the system.

For the purpose of reading sensor data, this is fairly straightforward. We utilize the built-in I/O capabilities of the microcontroller for this purpose. The temperature and pressure sensors are analog inputs. The motion sensor gives a digital input, and the thermal camera transmits its data using I^2C.

For the purpose of detecting life, we are following a truth table based upon the reliability of our sensors as discussed in part *B* and any false positives that could occur. For example, our pressure sensor could be set off due to a bag of groceries that is left behind in the back seat. As a result, we do not take any action (shown in Figure 4, row 5 of the truth table). Also, if we are not certain someone is there due to some inaccuracy of our sensors based on the testing we did, we only send a text message to the user. For instance, as shown in Figure 4, if the motion sensor goes high while all the other sensors stay low, we will not roll the windows and simply send a text. This is because from our testing we found that our motion can sometimes give a false positive when there is a large increase in air temperature within the car. So for this case we would not want to roll the windows down. For the cases we are confident that someone is in the back seat, we will roll down the windows as well as send an alert to the owner.

Figure 4: Truth table of life detection algorithm

We use the Particle Electron's on-board 3G cellular modem for the purpose of sending alert messages to the car owner. Alerts are in the form of SMS messages for a simplified, reliable, and universal alert system; the end-user does not need to install any 3rd party applications on their phone and we need not consider the mobile device's OS. To send SMS messages, CARS uses Twilio, a pay-as-you-go service for programmable SMS and programmable voice. Twilio charges $0.0075 per outgoing SMS. Given the rarity of our system sending these messages, this gives us plenty of breathing room in terms of cost.

D. Access to Proprietary Systems

This part of the system is an external component to the project. It is something that is variable depending on the make and model of the car. The specific car we are using, the Mazda 3 2006 s Grand Touring, has existing window controls that are fortunately easy to access and manipulate. For the basis of this project, the only parts of the car that need to be accessed are the driver's switch control, and the battery. To reach the driver's control switch wiring, the only work that is required is to take off the plastic coverings, which consists only of two philips head screws and the popping-off of a few plastic clips. Once this is done, a large 10-pin connector can easily be seen entering the driver controls. On this connector, 4 of the pins control the "down" signal. Simply, all that needs to be done is to cut these wires and splice them into their own relays. The diagram below shows this in detail.

Figure 5: Wiring diagram of Mazda 3 windows system

As shown in Figure 5, at rest, the relay acts simply as nothing has changed. However, when the car is off and CARS detects life, the controller sends a signal to switch the relay and connect 12V from the battery to the window motor and roll the window down. After a timed delay, the controller sends a signal to switch the relay again and connect it back to the existing car system.

The secondary task required is to access the battery and create our own power feed to supply power to all of our sensors, microcontroller, and window motors. Fortunately, again, the design of this particular car makes it easy to install your own power feed from the battery into the interior of the car. Since it is an automatic transmission car, there is a plastic cover next to the brake pedal, where the clutch pedal would normally be in a manual transmission model. Drilling a hole through this plastic cover and feeding cables through it directly to the battery terminals allows us to have a nice 30A power feed into the interior of the car.

E. Power Distribution

With the 30A feed, we are basically covered for the extent of our power needs. Our system, while in an active scanning mode, was measured as drawing 0.45A. In sleep mode, it was measured to draw 0.03A. The window motors then each pull approximately 3A each, adding up to a combined 12A for our motors. The sum gives us a total required current of 12.45A for when the system is active. So as previously stated, our custom installed 30A power feed is more than enough for everything to be powered nominally.

As for power consumption, we look to the average car battery power rating, which is 70Ah[9]. Since we know that in the active mode the system pulls 12.45 A, the car can provide 70Ah/12.45 A = approximately 5 hours and 45 minutes of runtime in the active mode. But, since the motors will only be active and pulling 3A for about 5 seconds(time for the window to roll down), the real active mode current draw can be approximated to just 0.45 A. So the time we really get is 70Ah/0.45A = 155.56 hours = 6.5 days. However, since the system is only in the active mode for only 1 hour at a time, this implies it will be in sleep mode most of the time, so the uptime for our sleep mode is then 70 Ah/0.03A = 2333.33 hours = 97.2 days in sleep mode. This calculation also factors in the automatic turn-off of the sensors with a relay that turns the system on and off based on the ignition state of the car. Most of the power is dissipated via the window motors, which is something we have no control over. These simple calculations also clearly show us that our system is not really depleting much power in the active mode, let alone the sleep mode. If the operator takes regular care of their car, meaning replacing the battery every 4-5 years as needed, and all charging electronics in the car work, our system should never be depleting the battery below ignition capabilities.

III. Project Management

Our team was able to complete the project by combining individual abilities and skills into a finished product. Each team member brought their best effort, and dedicated their time to developing a robust system that works exceptionally well.

Table 3: Gantt Chart of team's schedule

Shown in Table 3 above, our group stuck to the schedule indicated by the Gantt chart. Each task was completed in a timely and efficient manner, ensuring that CDR and FPR deadlines would be met, and our team could deliver on promises.

Each team member was selected for their respective task because their expertise best fits that problem. Kevin optimized and created the best algorithm with our sensors to detect life in the backseat of the car. This was important as it is a pinnacle point of our system. We needed the system to be able to correctly detect a person in the back seat of the car, and be certain that the chance for false positives was minimized. With Kevin's expertise in his work with microcontrollers, he was able to create an efficient and effective algorithm for our system.

Amer was assigned to the task of integrating the system into the car, as well as trying to solve the problem of ignition detection. Ignition detection was an important part of the project as our system should not be operating when the car is in use, to avoid false positives and having the windows roll down while the driver is operating the car. This also became a method to conserve more of the car battery energy. Integration into the car was clearly important as well, as the system is supposed to operate in the car hands-free. Amer's expertise with cars proved to be helpful in full integration and making use of proprietary systems.

Sean was assigned to assist Amer with the integration of the system into the car, as well as the fabrication of the PCB. This was an important aspect of the project as the PCB makes our system compact, marketable, and easier to integrate into the car. Sean was the best for this task because he was a strong student in electronics and circuit design. He was also the only one on the team that took an advanced course in analog circuit design. He knew the best design techniques to make our system compact and effective.

George was assigned with assisting Kevin in the optimization of our system algorithm, as well as the creation of the website. George was the best choice for this task because he is the most creative of the group and is a strong "outside of the box" thinker. This skill is important as most people tend to get wrapped up in small details, while George looks at what is most important, the big picture. This, along with his strong coding skills, made George the best selection for these tasks.

Our team was cohesive and strong in communication, as well as cooperation throughout the entire project. We were open with our ideas at all times, and were also each open to constructive criticism. This proved to be an important team dynamic as it helped us get through difficult design challenges. We as a team collectively knocked down every obstacle in our path through good communication and effort. We met twice every week and discussed each new development in the project, along with looking forward 2-3 weeks ahead and assigning tasks and pacing accordingly. This is then extended into the meetings with our project advisor, Professor Ciesielski. He added to our previous conversation and simplified some of our problems, as well as offered help and insight into future tasks. This dynamic allowed us to meet all deadlines without any worry, and to create a great project.

IV. Conclusion

At the Senior Design Project demo days, our group successfully demonstrated the completed prototype. We were able to interface with all of the sensors that we implemented (temperature, motion, pressure, thermal camera, facial detection) in the final design. We also clearly demonstrated that the system can be embedded into a real car.

Our demonstration consisted of the system being tested on a simulated child inside the car. We did ample testing of our sensors on people, but did not want anyone to be uncomfortable in the car for the entire 4 hour demo days. The temperature sensor was set to a lower threshold of 70F due to the temperature that day. Our simulated child (referred to as Jimmy) was a large teddy bear with hand warmers attached to its body and hands. This was to create a heat signature for the thermal camera to pick up. His hands were tied to strings which led outside the car so that people could tug on and move his hands in order to set off the motion sensor. He was placed on top of the pressure pad to keep the pressure sensor high, and he had a picture of a child's face taped onto his head for the purpose of demonstrating facial detection. All of the sensors were able to detect the fake child, and the system was easily demonstrated with its intended action.

V. Appendix

Table 4: 4x4 Cost of CARS

VI. Acknowledgment

We would like to thank our advisor, Professor Ciesielski, as well as our reviewers, Professors Anderson and Irwin for their thoughtful feedback. Additionally, we would like to thank Zbylut Motor Works of Amherst, MA for their generosity in providing to us wiring diagrams and schematics for the car we installed our system into.

VII. References

[1] Willingham, AJ. "More than 36 kids die in hot cars every year and there's no clear solution." CNN, Cable News Network, 7 Aug. 2017, www.cnn.com/2016/08/05/health/hot-car-deaths-charts-trnd/index.html.

[2] "HOW SENSE A LIFE WORKS." Sense A Life, www.sensealife.com/how-it-works.

[3] Coxworth, Ben. "ChildMinder reminds drivers not to leave their baby in the car." New Atlas - New Technology & Science News, New Atlas, 3 July 2012, newatlas.com/childminder-pad-baby-car-alarm/23174/.

[4] Analog Devices, "Low Voltage Temperature Sensors" TMP35/TMP36/TMP37 datasheet, 1996-2008.

[5] Adafruit Learning Systems, "PIR Motion Sensor", https://www.adafruit.com/product/189

[6] Omron, "D6T MEMS Thermal Sensors" D6T-44L-06 datasheet, 2013.

[7] Interlink Electronics, "Force Sensing Resistor Integration Guide and Evaluation Parts Catalog".

[8] Particle. "Particle Datasheets Documentation | Electron Datasheet", https://docs.particle.io/datasheets/electron-(cellular)/electron-datasheet/

[9] LATEST. (n.d.). Retrieved December 17, 2017, from https://www.allaboutcircuits.com/textbook/direct-current/chpt-11/battery-ratings/

[10] Raspberry Pi, https://www.raspberrypi.org/products/raspberry-pi-zero-w/

[11] "Face Detection Using Haar Cascades." *Basic Operations on Images - OpenCV-PythonTutorials1Documentation*,

opencv-python-tutroals.readthedocs.io/en/latest/py_tutorials/py_objdetect/py_face_detection/py_face_detection.html#face-detection.