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ThermSafe: Child Heat Injury Prevention in Heated Locked Cars

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1 Introduction

The number of unnecessary deaths to toddlers caused by careless car owners has been increasing year after year. This uptrend, together with inadequate market solutions in preventing such tragedies from happening, is indeed worrying. Our project thus aims to develop a reliable system, targeting car owners who are caretakers, to reduce such avoidable deaths to innocent children. This report will firstly provide a detailed analysis on the current problem we are facing, followed by a strength and weakness analysis on the various existing solutions available in the market. Because of the ineffectiveness of these solutions, we will propose our own product which uses various sensing technologies to establish vital signs and the environment of the subject, with an effective response system to notify car owners or the relevant authorities when the child is in danger. The choices of the sensors, components, processors and response systems will be evaluated, and the system performance will also be presented with a rough cost estimate. This report will then finally conclude with a summary of what we have presented and any future actions required.

2 Problem Review

2.1 Background

During the summer season, the temperature in a sealed car rises quickly to about 60 degree Celsius within 15 minutes of locking the vehicle[1]. When a child is accidentally left behind unattended in a hot car for a prolonged period of time, they risk dying from heat stroke due to the excessive absorption of heat. Since 1998, 556 children have died in the United States of America (USA) from such a cause in a locked car[2]. Of all non-traffic fatalities for children under 15 years of age between 2006 and 2010, heat stroke constitutes nearly 15%[3]. It is of increasing concern to the USA authorities to attempt to put a stop to such unnecessary fatalities[4].

2.2 How Do Children Get Locked In

From the reported cases of child vehicular heat strokes, there are three common ways whereby children get locked in. In 17% of the cases, child-minders knowingly leave their children in the car without knowing the possible consequences of their action[2]. As of 2011, it is not illegal to leave a child unattended in a stationary vehicle in 31 states in the USA[2]. In another 30% of the cases, children climb into unlocked and unattended cars, and then lock themselves in[2]. The main reason for which children were locked in was that the caretakers forget their child in the locked car. This accounted for 52% of the cases[2].

2.3 Main Causes of Deaths While Locked In

A car behaves like a greenhouse as it is surrounded by windows which allow sunlight in but do not let infrared radiation out. This causes the temperature within the enclosed environment of a locked car to rise quickly. The rise in temperature is significant even if the outside temperature is low. For instance, a stationary car can get as hot as 50 degrees Celsius in an hour while the outside temperature is just 26 degrees Celsius[5]. The heat within the car is unable to dissipate quick enough to lower the temperature even if the windows are lowered slightly.

When one is present within a hot car, his body temperature rises rapidly alongside the ambient temperature. He will be in danger of hyperthermia if his body temperature increases above 40 degree Celsius and may further develop heat stroke if no thermo-regulating measures are taken[1]. Without immediate treatment, these conditions are fatal. Children are more prone since they cannot sweat as effectively as adults, they also absorb heat at a faster rate as they have a higher ratio of surface area to body mass and cannot call for help if they are too young[6]. Such cases are also more prominent in the summer due to the warmer weather and hence higher temperature increase in a locked car.

2.4 Key Takeaways

From the reasons for child fatalities in locked cars, we found two key points that we have to address. Firstly, while majority of the cases stem from the absentmindedness of caretakers, we cannot ignore that a significant proportion arises without the knowledge of caretakers. Hence, we have to provide a system that recognises the presence of the child and provides an alert to the caretaker with little dependence on the cause of the lock up.

Secondly, we noted that immediate response is required once the child is placed in danger of heat stroke. In the event that the caretaker is unable to respond to the alert in time, an alternative should be provided to call for relief to the child. This would mean that we have to first establish that the child is in danger.

Physical signs of heat stroke include a body temperature of greater than 40.6 degree Celsius, rapid heartbeat, high respiration rate and even seizures in very young children[7]. The body is unable to cool itself back down and blood pressure reduces[8]. In severe cases, organ failure and death may result. Measurements of these symptoms and comparing them to a chart of normal body function rates may help to establish if the child is of immediate danger within the car. Once confirmed, the system can be designed to provide relief or to call for help on behalf of the caretaker.

3 Review of Existing Solutions

3.1 Overview

Existing products in the market targeting the issue of child fatalities in heated vehicles generally fall under three different categories: attachment to seat, attachment to buckle or expert installation into the car. Most of the products aim to warn parents if they have accidentally left a child behind in the car using alert signals from a key ring, a phone or an alarm installed within the car. The alert normally sounds when the installed device senses that the key ring is of a certain distance away from the car, indicating that the car owner has moved away from the vehicle with the child still within the car. However, research from the National Highway Traffic Safety Administration (NHTSA) reports that the available devices in the market are unreliable in prevention[9]. We evaluate the products in this section to find out the problems that render most of them ineffective systems.

3.2 Products Available on Market

3.2.1 Attachments to Seats

Products that can be attached to the base of car seats or baby seats make use of pressure sensors to determine if a child is sitting on the seat. It is accompanied with an alarm system that can be hooked onto a key chain or installed on a phone. The alarm device is connected to the sensors on the seat via radio frequency (RF) signals[9]. If the sensor detects that the seat is occupied, the alarm system is activated. It will sound off to remind the caretaker of the child left behind in the car if the distance between the alarm system and the sensor is further than the threshold value.

The problems with the pressure sensing products were that the sensors were not very accurate in determining whether a child was present. This depended highly on the both the positioning of the child and the sensor on the child seat. In addition, the distance between the car and the person before the alert goes off varied depending on the situation or environment. The distance reduced if one walked behind walls as the signal became attenuated. Furthermore in the case of phone alarms, it was shown that the alarm didn't always work if a phone call was being made or if the radio was on[9].The products also faced syncing problems as the sensors frequently disconnected from the alarm device. Products that use pressure sensing include the *ChildMinder Smart Pad System* ($69.95), *Deluxe Padded Safety Seat Alarm System* ($69.95), *safeBABI* which requires programming, *HALO Baby Seat System* ($149.99) [9], and the *Car Seat Monitor* that uses an iPhone application as the alarm.

3.2.2 Attachments to Buckle

Products which are made to be attached to the buckle of the car seat belt determines if a child is present in the car by sensing if the seat belt tongue is connected to the buckle. It assumes with numerous states' Child Passenger Safety Laws that children in a car will have to be secured in their seats with a seat belt and hence a locked buckle indicates that the child has not been removed from the seat[10]. Again, an alarm system sounds off if the product system detects that the child-minder has accidentally left a child behind.

Problems with these kinds of products were similar to those using pressure sensing as a method with regards to the alarm system. In addition, the buckle system works only if the child is buckled up on the seat. It neglects the occasions where the child is left in the car intentionally or when the child locks himself in by accident. Products that have to be attached to seat belt buckles include the *ChildMinder Smart Clip System* ($69.95) [9] and the *Small Ones Safety*.

3.2.3 Expert Installation in Car

These products require professional assistance to install within the car as they need to be fitted accordingly to the car models. The methods used to determine and warn of the presence of a child within the car vary from product to product but they have a similar key disadvantage. The installation aid needed makes the product more costly. Furthermore, the product is limited to the particular car it is installed in. Reinstallations require additional fees, thus making the product unfriendly for families who leave their children to minders or for those who regularly change cars (car rentals etc.). Examples of such products include the *Backseat Minder* ($249.99 with installation)[9], and the *CAREseat Car Seat Systems*.

3.3 Summary of Review

Most of the currently marketed products are limited technically and hence are not fault proof. In addition, they only work on particular circumstances and do not consider cases which fail to meet their assumptions. This is especially the case for devices with only one sensor to detect the presence of the child, suggesting that a more all rounded system comprising of more sensors or sensors which detect human life more accurately is needed. Not only so, the products provide an alert to the caretakers but fail to take into account if the caretaker fails to respond to it, hence placing the child in a precarious state if the conditions within the car are undesirable. This reemphasises the need for a response system in addition to the alert system existent in the marketed products today.

4 Product Design Specifications

4.1 Design Overview

In this section, we plan to outline how we would address the problem with our product. Based on the discussion in Sections 2 and 3, we gathered the following aims which would steer our product design:

- To sense accurately the presence of human life within a locked car
- To respond to the presence of a child left within a locked car
- To determine if the environment is of danger to a child
- To respond to the danger the child faces if established

The system macro-model below shows how the product can be constructed to fulfil our desired aims.

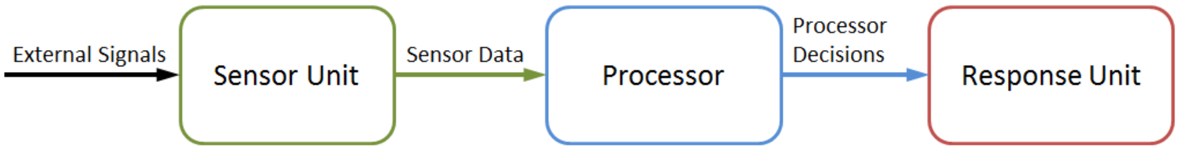

Fig. 1: Macro-model of system showing separate block modules

The sensor unit detects external signals that could represent human life or danger and translates them into analogue current or voltage waveforms. This information is passed to the processor that actively measures the collected signals against a benchmark table to determine if life and/or danger are present. The decision is then relayed to the response unit which will convey the processor decisions to the relevant authorities or carry out practical commands to the car body (e.g. lower the window fully). We discuss the choice of components to form these units below in detail.

4.2 Choice of Components

4.2.1 Sensors

Vital signs indicate life and are possible means to determine if a child is present within the car. As such, we can calibrate sensors to detect and measure these vital signs. The following is a list of possible vital signs we can use:

- Movement
- Weight
- Body Temperature
- Heart Beat
- Breathing/ Respiration Rate
- Voice

To check if the child is in danger, we have to compare the measured information of the above list against a benchmark.

Vital Sign	Infant	Child	Pre-Teen/Teen
	0 to 12 months	1 to 11 years	12 and up
Heart Rate	100 to 160 beats per minute (bpm)	70 to 120 bpm	60 to 100 bpm
Respiration (breaths)	0 to 6 months 30 to 60 breaths per minute (bpm) 6 to 12 months 24 to 30 bpm	1 to 5 years 20 to 30 (bpm) 6 to 11 years 12 to 20 bpm	12 to 18 bpm
Temperature	All ages 98.6 F (normal range is 97.4 F to 99.6 F)	All ages 98.6 F (normal range is 97.4 F to 99.6 F)	All ages 98.6 F (normal range is 97.4 F to 99.6 F)

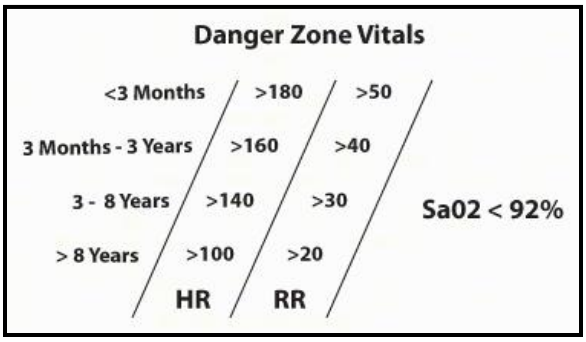

Fig. 2: Normal Readings of Vital Signs[11] (left) and Danger Readings of Vital Signs[12] (right)

4.2.1.1 Tactile Sensors

There are a few different methods of measuring pressure on a surface. Some of them are described below:

- **Mechanical** – A simple mechanical switch can be used to produce a binary touch sensor which is activated when a force greater than its actuating force is applied[13].
- **Capacitive -** Using the capacitive effect of a metal, ceramic or silicon diaphragm the pressure applied to the diaphragm can be measured as changes in the capacitance[13].
- **Electromagnetic** – Same as the capacitive however this time changes in the electric field in diaphragm is used such as inductance and Hall Effect[13].
- **Piezoelectric** – Uses the piezoelectric effect (a voltage is produced when the material is deformed) to measure the pressure on the material. Cannot be used to measure a constant force[14].
- **Piezoresistive** – Uses the piezoresistive effect (a change in resistance when the material is put under stress) to measure the pressure on the material. Force Sensing Resistors use this[15].
- **Optical** – This uses optical fibres and usually a Fibre Bragg Grating which reflects certain wavelengths. When the fibre is put under pressure the shape of the grating changes and hence it reflects a different wavelength[16].

If we are to use pressure sensing as a way to determine the presence of a child we need to use more than a single sensor. What can be used is a pressure sensor array with many sensors connected together inside a material. This sort of array can be used to get a get a very detailed image of the pressure being applied over the material[13]. In fact it can be accurate enough to identify individual people much in the same way as a finger print[13].

4.2.1.2 Doppler Radar

Detecting motion and establishing whether there is anyone locked in a vehicle can be achieved by using a Doppler sensor. The Doppler radar works by emitting microwave frequency signals in its specified range and processing the returned reflected signal, in order to detect an object's movement[17]. Some Doppler radar modules have a built in processor that can process the returned signal and indicate whether any motion was detected. Upon further research we found out that apart from their ability to sense motion, they could be used to detect the heartbeats of people in a certain range, even if they are behind obstacles[19].

4.2.1.3 Carbon Dioxide Sensor

Although the main cause of death for a child stuck in a car is hyperthermia and not the lack of Oxygen, the presence of a child can still be determined by the measuring the amount of Carbon Dioxide in the car. The two main sensor types used to measure CO_2 are non-dispersive infrared (NDIR) sensors and electrochemical gas sensors. NDIR sensors work by sending infrared beams through the gas to a detector[21]. As the CO_2 molecules absorb a certain wavelength of infrared, the detector can tell how much of that wavelength has been absorbed and thus determine the amount of CO_2 in the sample of gas[21]. Electrochemical sensors on the other hand measure the concentration of the gas by oxidizing the gas at an electrode which creates a current in the circuit[22]. The magnitude of the current is dependent on the amount of the gas that is oxidised[22]. The gas is fed into the sensor via diffusion which means that the higher the concentration of the gas in the air the more of it there will be in the sensor. Hence the concentration of the gas can be measured[22].

4.2.1.4 Temperature Sensor

Temperature sensors can be used to measure the ambient temperature in an enclosed car to determine if the child present is in danger. Examples of such sensors include the thermocouple, resistance temperature detector (RTD) or the thermistor. The thermocouple measures temperature differences between two points whereas the RTD and the thermistor measure absolute temperatures of a particular point.

The RTD does this by using a wire made of a pure metal like copper or platinum which is coiled around a ceramic or glass core[24]. The pure metals have a predictable change in resistance when the temperature rises which can be used to measure the temperature[24]. The thermistor is like an RTD however instead of pure metals, a polymer or ceramic is used. This leads to the thermistor having better precision in shorter temperature ranges (-100°C to 500°C) while the RTD's are more precise over larger temperature ranges (-240°C to 649°C). However, the range of ambient temperature in an enclosed car relevant to us falls in the middle of both ranges. Thus, we chose the thermistor as a better solution due to its lower cost.

In addition to measuring the ambient temperature, we could also measure the body temperature of the child using an infrared (IR) thermal sensor. An IR sensor works by measuring the infrared light emitted or reflected by objects in its field of view and converting this to a temperature. However, the accuracy of this method is compromised if the field of view of the sensor expands beyond the child's skin. Elsewise, the sensor will obtain the average temperature of the child and his surroundings. This makes the IR sensor impractical since the sensor must be installed at close approximation to the child who can be located anywhere in the car.

4.2.1.5 Sound Detection

We can detect the presence of a child in a car by detecting the sound he makes or words he speaks. This can be done through the use of a microphone. The microphone processes sound signals into voltage and current waveforms for analysis. For these waveforms, information can be obtained to detect the voice of a child. The frequency of the sound signals, typically between 1 to 5 kHz, could be measured to determine a crying baby. For older children, a voice/speech recognition processor could be used after the sound signal is recorded with a microphone.

4.2.1.6 Facial Recognition

Facial recognition works by identifying features through algorithms and comparing them with a facial database. Using such technology, we could possibly identify a child in the car using a camera or a video recorder and actively compare images taken. To prevent false positives, the images taken can be sent alongside the alert to the caretaker or even the police.

In recent cases, this form of technology has improved where it is now possible to measure heart rate using a camera. The heart rate of the subject is determined by the amount of light reflecting off his face. As the heart beats, the volume of blood pumped to the face increases, hence causing the face to absorb more light[25]. By measuring the light reflection off the face, the program is able to infer the heart rate. This allows for the possibility to also measure the heart rate of the child to identify him.

4.2.1.7 Final Choice of Sensors

Sensor Types	Pros	Cons
Tactile Sensors	➢ Accurate enough to identify individuals in the same way as fingerprints[13]	➢ Requires large sensor density for accuracy ➢ High cost due to large sensor density ➢ High processing power needed to power large sensor density ➢ Needs connection to processor and response unit o Wired connections are cumbersome o Wireless connections can be unstable and increases power usage ➢ Cannot determine if child is in danger
Doppler	➢ Cheap and small	➢ Multiple sensors required at different locations to

Radar	➢ Low power consumption (operates at 5V[18])
	➢ Free from external interference (e.g. temperature, humidity, noise and dust)
	➢ Emitted waves harmless to human body (output power of 5mW[18])
	➢ Long range (longer than 20m[18])
	➢ Can detect heartbeat within a fixed range even behind obstacles[20]
	➢ Tracking heart rate allows us to determine if child is in danger
		cover all areas in the car
		➢ Measuring heart rate requires vigorous post processing on returned signal
		  o High computing power needed
		  o High power consumption
		➢ Doppler radar as a heartbeat detector is a new technology and may require high cost to investigate usefulness

CO_2 Sensor	➢ Commercial method of determining presence of life (used by the UK Border Agency[23]) ➢ Reliable in air-conditioned systems[23]	➢ Effectiveness may be compromised when car is not enclosed i.e. in situations where the window is slightly ajar ➢ May not detect single child accurately since sensor may have a low level of sensitivity and thus cannot detect low levels of CO_2 (sensors generally used to detect multiple adults) ➢ Cannot determine if child is in danger
Temp. Sensor	➢ Measuring ambient temperature allows us to determine if the level of heat in the car is too high ➢ Certain options of temperature sensors (e.g. thermistors) are cheap ➢ Temperature range of sensors are sufficient to measure ambient temperature	➢ Measuring skin temperature of child to determine presence or danger is infeasible
Sound Detection	➢ Microphones are low in cost and small in size ➢ Baby cries can be detected accurately by measuring frequency of sound detected	➢ External noise may interfere since the car is not soundproof ➢ Voice recognition requires pre-recording which is troublesome and non-extensive[28] ➢ Voice recognition is highly unreliable
Facial Recognition	➢ Prevents false positives through manual checking by caretaker or police ➢ May be able to measure heart rate	➢ Dependent on angle of face (most systems can only detect up to 20 degrees of rotation[26]) ➢ Dependent on lighting (poor lighting reduces accuracy[27]) ➢ High processing power required o Use of more powerful microprocessors (e.g. Raspberry Pi) or transmitting to an external server increases cost

Table 1: Pros and Cons Table for Varying Sensors

We chose to use the Doppler radar to sense movement for presence and the thermistor to sense ambient temperature for danger since these were the two cheaper and more reliable options compared to the rest.

4.2.2 Processors

There are a multitude of microcontrollers on the market; however for our purposes we will be considering simpler microcontrollers to meet our demands such as the PIC, Atmel AVR and ARM architectures. The PIC and AVR are very similar to one another in many aspects. They cost roughly the same price and they can both be programmed in Assembly, BASIC and C[29]. They both come with free compilers for C although the AVR compiler is a bit better as the PIC compiler has some features like high level code optimisation which only comes with the paid version[29]. Furthermore both come with the usual features such as ADC, comparator, timers etc. However one area in which they differ is the performance, an AVR can fetch the next function while executing the current one which means it can feasibly execute one instruction per clock cycle[30]. On the other hand the PIC needs 4 clock cycles to execute an instruction[30]. In addition the AVR can be used with the incredibly popular Arduino development board which has built a large community online which offer tutorials and help. These features mean that the AVR is a better option than the PIC.

The ARM chips are different from AVR and PIC, they are much more powerful but also more complex. The reason they are appealing is because they allow us to do processes which require a lot of processing power. These include using the Doppler radar to detect heart rate, using the camera for face detection or for measuring heart rate.

4.2.3 Response System

After detecting that a child is in danger, our system has to respond to the situation in some form to prevent the child from being harmed. There are a few response methods including

- **Independent communication network** – Such as a Radio Frequency(RF) connection as used in existing products
- **Cellular Network** – Already established networks as used in mobile phones (GSM, GPRS, 3G)
- **Wi-Fi –** Connecting to the internet via available hotspots
- **Direct Response -** Doing things such as opening windows, setting off the alarm or possibly turning on the fans

From our research into the current solutions, we found that using radio communication between the alarm and the system was not very reliable as they had a limited/non-constant range and tended to disconnect from each other haphazardly. On the other hand using a cellular network gets rid of these problems. Incorporating a mobile connection to our system can be quite inexpensive as mobile manufacturers are selling phones for as cheap as £10[31]. Furthermore it is a much more robust form of alarm then a RF connection as we can send messages, data or make calls to multiple people. Additionally there is the possibility of using 3G and now even 4G networks to connect our system to the internet and send pictures or videos via an app or by other means to the user. However using a cellular network has its own problems, the main one being network availability. This is continually improving, and is only a problem in very rural areas[32]. The option of including a Wi-Fi was considered briefly due to steadily increasing availability of hotspots however currently the coverage is not extensive enough to be of any benefit.

Apart from the alarm systems mentioned above we also considered ways to reduce the temperature via a direct response. The common problem between these methods was that, to carry out these actions the system would need to have access to the car’s internal system which would complicate installation and also increase costs.

4.3 Prototype

We constructed a simplified prototype as a proof of concept, using an Arduino ATmega328 microcontroller, an Ethernet shield, a thermistor and a Doppler radar. Due to a budget restriction, we used an Ethernet shield instead of a Cellular shield, accomplishing the same task in theory. Likewise we were restricted to only two sensors; the Doppler radar to establish the presence of motion in a monitored area; the thermistor, which resistance is a function of temperature, to reflect the danger of the surroundings. The Arduino concurrently monitors the voltages across the thermistor and the Doppler radar, sending an alert through the Ethernet shield when motion is detected and the threshold temperature is violated. Alerts are sent using a free service called ‘pushingbox’ as it provides the necessary infrastructure required. It also allows us to customize the type of alerts such as sending emails, SMS or push notifications (which require an app).

This concept is easily implementable and illustrates our project’s concept effectively. This model can be built upon to include multiple sensors and different alerts.

4.4 Estimated Cost

Components	**Estimated Cost (£)**	**Comments**
Doppler Radar	6.00	HB100 Microwave sensor
Thermistor, NTC SMD	1.00	Vishay BC- 2322 615 13153
GSM component in Cellular shield	10.00	Excluding the shield
Arduino	4.00	Excluding development board
PCB fabrication	20.00	Average price quoted after enquiry
Car adapter for Power supply	4.25	24V car to 5V DC powering Arduino system
Others	20.00	Any supporting hardware required
Total	65.25	-

Table 2: Table of estimated cost of all components required

A very rough estimate of our product cost based on the chosen components works out to be less than 70 pounds, which is about similar cost as a baby car seat, a reasonable amount car owner will be willing to spend we believe. A detailed survey is required to determine the maximum amount our targeted customers are willing to spend, and more detailed evaluation of components is required to make it more cost effective and reliable.

5 Conclusion

In summary, this report gave a clear analysis of the current problem we face today; the increasing trend of unnecessary deaths to toddlers caused by car owners, despite prevailing market solutions. The inadequacies of such solutions were also distinctly highlighted. This gave rise to our motivation for this feasibility study, and after thorough evaluation of sensors, processors and response systems, a viable product is proposed. Though only a simple prototype was built, it clearly demonstrated our concept and there is tremendous potential to the product, in terms of integrating more sensors and further investigating the system performances. Nevertheless, we believe this report will provide a springboard in tackling such issue, and hopefully ameliorate such tragedies in near future, where no child has to suffer because of careless car owners.

6 References

1) Catherine McLaren, J. N. (2005). *Heat Stress From Enclosed Vehicles: Moderate Ambient Temperatures Cause Significant Temperature Rise in Enclosed Vehicles*. Pediatrics, 109-112. Retrieved January 4, 2013, from http://pediatrics.aappublications.org/content/116/1/e109.full.pdf+html

2) Null, J. (2012, November 5). *Hyperthermia Deaths of Children in Vehicles*. Retrieved January 4, 2013, from Department of Geosciences, San Francisco State University: http://www.ggweather.com/heat/

3) Kids And Cars. (2011, September 22). *U.S. Child Fatalities by Type (2006 - 2010)*. Retrieved January 4, 2013, from www.kidsandcars.org: http://www.kidsandcars.org/userfiles/dangers/shared/fatalities-pie-chart.pdf

4) NHTSA. (2012, July 18). *NHTSA Joins Raleigh Safety Advocates to Highlight Dangers of Child Heatstroke in Hot Cars*. Retrieved January 4, 2013, from National Highway Traffic Safety Administration: http://www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA+Joins+Raleigh+Safety+Advocates+to+Highlight+Dangers+of+Child+Heatstroke+in+Hot+Cars

5) National Weather Service. (2012, November 28). *Heat: A Major Killer*. Retrieved January 4, 2013, from www.noaa.gov: http://www.nws.noaa.gov/os/heat/index.shtml

6) Tsuzuki-Hayakawa, K. Tochihara, Y. *Thermoregulation during heat exposure of young children compared to their mothers*. Retrieved January 6, 2013, from: European Journal of Applied Physiology and Occupational Physiology [1995;72:12–17]

7) Rampulla, J. (2004). Hyperthermia & Heat Stroke: Heat-Related Conditions. In: *The health care of homeless persons: a manual of communicable diseases & common problems in shelters & on the streets.* Boston Health Care for the Homeless Program with the National Health Care for the Homeless Council, pp. 199-204

8) Stöppler, M. C. Shiel JR, W.C. (2012, July 18). *Heat Stroke*. Retrieved January 6, 2013, from www.MedicineNet.com: http://www.medicinenet.com/heat_stroke/article.htm

9) Arbogast, K. B., Belwadi, A., Allison, M. (2012, July). *Reducing the Potential for Heat Stroke to Children in Parked Motor Vehicles: Evaluation of Reminder Technology.* Retrieved January 6, 2013, from www.nhtsa.gov: www.nhtsa.gov/DOT/NHTSA/NVS/811632.pdf

10) Governors Highway Safety Association. (2013). *Child Passenger Safety Laws.* Retrieved January 10, 2013, from http://www.ghsa.org: http://www.ghsa.org/html/stateinfo/laws/childsafety_laws.html

11) Pamela Dugle. Triage. Retrieved January 20, 2013, from http://www.ceufast.com/courses/viewcourse.asp?id=249

12) Healthwise Staff (2012) *Vital Signs in Children*. Retrieved January 20, 2013, from http://www.uwhealth.org/health/topic/special/vital-signs-in-children/abo2987.html

13) Crowder, R. M. (January 1998). *Automation and Robotics: Tactile Sensing*. Retrieved January 10, 2013 from Southampton University: http://www.southampton.ac.uk/~rmc1/robotics/artactile.htm

14) PCB Piezotronics. (no date). *Introduction to Piezoelectric Pressure Sensors*. Retrieved January 10, 2013 from http://www.pcb.com/: http://www.pcb.com/TechSupport/Tech_Pres.aspx

15) Krause, P. Michels, H. Varma, G (2011, May 25). *Trends of Piezoresistive Sensor Technology*. Retrieved January 11, 2013 from www.leibniz-institut.de: http://natesan.net/images/includes/66.pdf

16) O. Hill, K. Meltz, G. (1997, August). *Fiber Bragg Grating Technology Fundamentals and Overview*. Retrieved January 15, 2013 from: Journal of Lightwave Technology, VOL. 15, NO. 8

17) Zhou, Q. Liu, J. Høst-Madsen, A. Boric-Lubecke, O. Lubecke, V. (2006, May 14-19). *Detection of Multiple Heartbeats Using Doppler Radar*. Retrieved January 15, 2013 from IEEE Xplore: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1660554

18) AgilSense. (no date). *HB100 Microwave Sensor Module*. Retrieved 16January, 2013 from: http://www.agilsense.com/: http://static.openimpulse.com/blog/wp-content/uploads/wpsc/downloadables/HB100_Microwave_Sensor_Module_Datasheet.pdf

19) Obeid1, D. Sadek, S. Zaharia, G. El Zein, G. (2011, November 24-26). *Doppler Radar for Heartbeat Rate and Heart Rate Variability Extraction*. Retrieved January 20, 2013 from IEEE Xplore: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6150419

20) J. Høst-Madsen, A. Boric-Lubecke, O. Lubecke, V. M. Fathy, A. E. (2007, June 3-8). *Through-the-Wall Radar Life Detection and Monitoring*. Retrieved January 20, 2013 from IEEE Xplore: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4263932

21) CO2 Meter. (2012, May 1). *How Does an NDIR CO2 Sensor Work?* Retrieved 20 January, 2013 from www.co2meter.com: http://www.co2meter.com/blogs/news/6010192-how-does-an-ndir-co2-sensor-work

22) International Sensor Technology. (no date). *Electochemical Sensor*. Retrieved 20 January, 2013 from www.intlsensor.com: http://www.intlsensor.com/pdf/electrochemical.pdf

23) UK Border Agency. (no date). *Methods we use to detect clandestine entrants*. Retrieved 21 January, 2013 from www.ukba.homeoffice.gov.uk: http://www.ukba.homeoffice.gov.uk/business-sponsors/transportindustry/vehicleoperators/detectionmethods/

24) Innovative Sensor Technology. (2010, December 24). *Resistance Temperature Detector (RTD) - Principle of Operation, Materials, Configuration and Benefits*. Retrieved 21January, 2013 from www.azom.com: http://www.azom.com/article.aspx?ArticleID=5573

25) Poh, M.-Z., McDuff, D. J. and Picard, R. W. (2010). *Non-contact, Automated Cardiac Pulse Measurements Using Video Imaging and Blind Source Separation*. Optics Express, vol. 18, no. 10, 10762--10774.

26) Thorat, S.B. Nayak, S.K. Dandale, J.P. (2010). *Facial Recognition Technology: An analysis with scope in India*. Retrieved 31 January, 2013 from: International Journal of Computer Science and Information Security,Vol. 8, No. 1, 2010

27) Bonsor, K. and Johnson, R. (no date). *How Facial Recognition Systems Work*. Retrieved 31 January, 2013 from www.howstuffworks.com: http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/facial-recognition.htm

28) NSK Electronics. (no date). *Voice Recognition Kit - Speech Recognition System*. Retrieved 31 January, 2013 from www.nskelectronics.in: http://www.nskelectronics.in/voice_recognition_kit.html

29) Fried, L. (2012, Apirl 17). PIC vs. AVR. Retrieved 31 January, 2013 from www.ladyada.net: http://www.ladyada.net/library/picvsavr.html

30) Figueiredo de Sá, D. (2011, September 8). *Comparison between Microchip PIC and Atmel AVR microcontrollers*. Retrieved 31 January, 2013 from: http://my.opera.com/CrazyTerabyte/blog/2011/09/08/comparison-between-microchip-pic-and-atmel-avr-microcontrollers

31) Argos. (no date).*Cellphone price*. Retrieved January 21, 2013, from http://www.argos.co.uk/static/Product/partNumber/5189043.htm?CMPID=GS001&_$ja=tsid:11527|cc:|prd:5189043|cat:technology+%2F+mobile+phones+and+accessories+%2F+mobile+phones

32) ITU Telecom World.(2011).*ICT Facts and Figures 2011*. Retrieved January 21, 2013, from http://www.itu.int/ITU-D/ict/facts/2011/material/ICTFactsFigures2011.pdf