Development of an Automatic Vehicular Heatstroke Detection System

To cite this article: S N David Chua et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 429 012056

View the article online for updates and enhancements.
Development of an Automatic Vehicular Heatstroke Detection System

'S N David Chua¹, W J Goh¹, S F Lim¹, A Joseph¹, Oon Y B² and C V Sia³

¹Faculty of Engineering, Universiti Malaysia Sarawak, 94300, Sarawak, Malaysia
²Faculty of Cognitive Sciences and Human Development, University Malaysia Sarawak, 94300, Sarawak, Malaysia
³University of Technology (Sarawak Campus), 93350, Kuching, Sarawak, Malaysia

*csndavid@unimas.my; davidchua2@mail.dcu.ie

Abstract. The cases of children being left in a car and died of heatstroke are on the rise every year. Car manufacturers have not implemented any sort of alert system that could prevent these unfortunate events from happening. There are many baby car seat alert systems available in the market, however, they are mostly inconsistent and unreliable. There is a need for more effective and efficient alert system to remind the users of their forgotten child. This paper aims to provide solutions to caretakers through application of multiple sensors for integration of a child detection system and also to discover the best placement of the sensors for a more effective system. The selection method is based on experimental setup with a test subject which is a human being. A prototype for the detection system is fabricated and results show a combination of ultrasonic and motion sensors produces the best results. The best position to place the ultrasonic and motion sensor is determined to be above the child seat and in the middle of the car respectively. The prototype of the detection and alert system is validated via a set of assessments to determine its accuracy, adaptability and reliability.

1. Introduction

Heatstroke is a condition where body overheats to a certain degree from a prolonged exposure in high temperature surroundings which might ultimately lead to permanent damage and even death. The hot weather in countries like Malaysia makes it even easier to get a heatstroke or also called hyperthermia. There have been many cases over the years where a baby or a child left in the car under the scorching heat has died of heatstroke. Based on a fact sheet by a non-profit organisation, there were 793 children that died in vehicles due to heatstroke since 1998 in the U.S. [1]. From a research done to a total of 171 fatalities in the U.S. of heat related deaths to young children in parked cars from 1995-2002, 73% (125) were children who were left unattended by adults [2]. One of the reasons that children are left unattended is because of the carelessness of parents who forget or unaware of the present of their child in the car. The parents fail to realise how hot a car would become if it is exposed to direct sunlight for a period of time. A normal human being body temperature is around 37 Celsius. Heatstroke would occur when the body temperature reaches around 40.5 Celsius. It could take as little as fifteen minutes being stuck in an overheated car for a child to suffer heatstroke [3]. There is no guarantee it can be prevented from just opening the car windows by a small gap. Children die of heatstroke in cars when parents get distracted from their daily routines and does not realise that they left their child unattended. The busy schedule of parents combined with the tendency to seat their sleeping child in the rear seat is one of the major reasons why these unwanted cases are happening. Moreover, tinting of car windows prevents the child to be noticed by passers-by.
2. Related work and products
There are a few studies and research done on the development of a device to alert the parents of an unattended child left in a car in recent years. However, all the inventions are yet to provide an effective and comprehensive warning and feedback system for the unattended child in the car [4]. There are also some products being sold in the market that parents can buy to prevent such a death-defying situation from occurring, but they are mostly unreliable and inconsistent [5]. Types of products that are currently available in the market can be divided into three categories i.e. seat based reminder system, buckle based reminder system, and reminder system installed in car.

The first kind of heatstroke detection system is through attaching the device to the car seat. The device is placed at the base of the seat which usually makes use of pressure sensor to determine the presence of a child. It comes with an alarm system that can be hooked as a keychain or installed on a phone. The alarm device is connected to the sensor on the seat via a communication medium such as radio frequency, Wi-Fi or Bluetooth. The alarm device alerts the driver when the device is set apart and a weight is detected on the seat. A study that reported the problem with pressure sensing products was due to positioning of the pressure sensors [6].

There are also products that are attached to a baby seatbelt buckle to determine the presence of the child. It uses a sensor to sense if the seatbelt tongue is connected to the buckle. The alarm system functions similarly to the pressure type detection system where the alarm system will go off if the child is left buckled to the seat and the parents has gone off to a certain distance away from the car. There are also some problems with this type of system as it works with the condition that the child is buckled up to the seat. The weakness of this type of detection system is that if the child is unbuckled or the child unbuckles by himself from the seat, it will fail to trigger.

There is also a type of heatstroke detection system that is installed within the car. This kind of device usually uses a human presence sensor to determine if a child is being left unattended in the car. The examples of sensors that can sense the presence of a human being are thermal sensor, carbon dioxide sensor, motion sensor, facial recognition, radar and sound sensor. This kind of system can be installed during the manufacturing process of the car but the downside is that it is dearer compared to seat based type and buckle type.

2.1. Types of sensors for heatstroke detection system
A human presence sensor is required for the system to detect a child that is left unattended in a car. The sensor must accurately determine if there is a child left in the car and able to differentiate between a non-living object and a child that is unattended in the car. The presence of a human being can be detected using thermal, motion, carbon dioxide and distance. Table 1 shows the comparisons between the human presence sensors available in the market.

2.1.1. Thermal human presence sensor. A thermal sensor captures the heat condition in the monitored area and determines the range of the surrounding temperature. Then, a dynamic threshold is obtained to constantly update the range of the surrounding temperature. The presence of a human can be detected if there is a temperature higher than the threshold value. It only takes less than two seconds for the system integrated with the thermal sensor to sense a human being [7]. A research was done using heat based human sensing method to determine the location of the user for an intelligent fan [8]. Thermal and visual information integration was introduced to detect and identify a human [9]. The proposed system has main modules that works with visual images and thermal images. Thermopile sensors can also be used to detect human presence in a supervised environment [10]. Thermopile sensor was chosen because of its low cost and intrusive qualities. The sensor reacts to the level of infrared signals generated by the temperature of human subject.

2.1.2. Carbon dioxide sensor. There are two types of carbon dioxide (CO2) sensor. The first one uses a chemical reaction to determine the level of CO2 in the area. The second simpler CO2 sensor is the Non-dispersive Infrared (NDIR) sensor. This sensor uses infrared light and a detector to analyse the drop in light through space. Carbon dioxide sensors needs design algorithms
for estimating the presence of a human being. There are models to determine occupancy using a carbon dioxide sensor [11].

2.1.3. Motion sensor. A typical motion sensor to detect human presence is Passive Infrared (PIR) sensor. It uses the change in infrared light reflected onto it from objects to determine if there is motion in its field of view. Based on a research on PIR sensor to monitor occupancy patterns, it is found that if the sensor is placed in a room smaller than the sensor’s maximum detection range, it is even possible to discriminate between different movements and provide a rough estimate of energy expenditure [12]. The disadvantage of PIR sensor is if there is no movement, it results in a false negative as the occupant may not be moving [13]. In order to address this problem, researchers came up with a solution which utilises particle filtering method [14]. Particle filtering method which moves particles and eliminates incorrect state transition particles.

2.1.4. Ultrasonic sensor. Ultrasonic array sensor transmits short bursts of sinusoidal pulses periodically. Human presence is determined processing the received echoes at the receiver array. A combination of ultrasonic array sensor and tracking algorithm was proposed for the detection of a human in a confined space as it can detect minor motion that are usually missed by another detecting device [15]. An ultrasonic sensor can even detect muscle activity by designing a complex algorithm that estimates joint torque of knee [16].

2.1.5. Pressure sensor. A pressure sensor is used to measure the changes in applied pressure or force and converting them into electric charge. When place in the car seat, it can be used to detect the presence of a human being by arranging sensor logic to differentiate between a person, child or belonging. A research proposed to have four pressure pads on each seat of the car to distinguish between person, child and luggage [17]. Based on a study, it is found that by using a movement detection algorithm, the pressure sensor can detect small movements such as breathing [18].

### Table 1. Overview of human presence sensors.

| Sensor       | Advantages                                                                 | Disadvantages                                                                 |
|--------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Thermal      | Able to detect human being and animals. Simple algorithm.                   | Detection of temperature depends on the proximity of the object.              |
|              | Non-contact temperature measurement.                                       | High cost.                                                                   |
|              | Able to determine the position of an object. High sensitivity. Low noise.   |                                                                              |
| Carbon dioxide| Able to detect multiple people at a time.                                  | Inaccurate if car windows are opened. Calibration drift.                      |
|              |                                                                             | Sophisticated method required to estimate occupancy. Low sensitivity if CO$_2$ level is too low. Preheated is required. |
| Motion       | Fast response time. Can detect small movement. Low power consumption. Low cost. | Unable to detect stationary human being. False detection if range is not set properly. |
| Ultrasonic   | Free from external interference (e.g. temperature, humidity, noise and dust). Emitted waves are harmless to human body. | Requires complex algorithm to detect human being.                             |
| Pressure     | Can differentiate between an object, adult and child with the use of multiple sensors. Simple mechanism. Low cost. | Troublesome to install. Difficult to maintain or replace.                     |
3. Materials and methodology

3.1. Main system
Figure 1 shows the system block diagram of the product constructed to fulfil the aims of the product design. Power is supplied to the whole system and the sensor unit detects signals that represent a child is being left unattended and in danger. This information is transferred to the processor that determines if the child is left unattended and in danger. The processor will then relay the decision to the response unit which will convey the processor decision to users.

![Figure 1. Main system block diagram.](image)

3.2. Components
Basically, the detection system consists of sensors, processors, response system, transmitter and receiver. Vital signs to indicate life are the means to determine if a child is present within the car. Amongst sensors selected for experiment are Passive Infrared (PIR) motion sensor, HC-SR04 Ultrasonic Sensor, Analog Infrared CO₂ sensor, and Melexis MLX90614 Infrared Temperature sensor. Arduino UNO is used for constructing and programming electronic devices and it is based on ATmega329P as its brain. The nRF24L01 is used to transfer simple data from one Arduino UNO to Arduino Pro mini in the keychain device. When an unattended child is detected in the hot car, the Arduino Uno sends a signal via the transmitter to the keychain device. The receiver receives the signal and alerts the user of the unattended child in the car.

3.3. Experimental setup

3.3.1. Sensor selection criteria. The selection of the sensors to detect the presence of life in the car is based on the four selection criteria which are range, response time, false alarm and cost. The range of the sensor must be at least more than two meters so that the location of the sensor is not limited, and the number of required sensors can be reduced. The experiment is done with a sensor placed in line of sight of a human being, then the distance that is able to stimulate the sensor is recorded. Response time is the most critical criteria in the selection of the sensors as users must be alerted as soon as the unattended child is detected. The experiment starts with a test subject (human being) sitting in the car. The time taken to detect the test subject is recorded from the time the system is turn on. False alarm is the largest factor that causes unreliability of existing vehicular heatstroke detection systems. Therefore, sensors are tested if it reacts to surrounding movements and movements of the car itself. Cost is a huge determining factor in the overall justification of the system which might influence its marketability. The cost of the sensors is justified through market survey and benchmarking with the existing available products.

3.3.2. Receiver device selection. A receiver device using an Arduino Nano with a radio frequency transmitter is used for this research. The receiver device is assessed based on its range and accuracy through obstacles. The range is tested by having a test subject (human being) walking in line of sight from the vehicle holding the receiver device with the transmitter inside the vehicle. For the accuracy through obstacles, the test subject with the receiver device stands behind a wall between the vehicle and the receiver device. The distance of the
user from the vehicle is measured to determine the range of the device. The experiment is repeated for 5 times.

3.3.3. Placement locations. The selected sensors are subjected to finding the best placement locations once they are finalised. The selection criteria for the best placement locations is determined by the reaction time to detect life and range coverage of the sensors. The sensors are placed on the front, middle and back ceiling, above the front and rear seats of the vehicle. The test object is placed on the front and rear seats in separate experiments to determine the most suitable sensors placement.

3.4. Validation of detection system
The validation of the whole device which consists of the Arduino UNO integrated with the sensors chosen are done based on three criteria which are accuracy, resistance and reliability. The device must be able to accurately determine the presence of an unattended child. The assessment covers the detection of stationary human and non-living objects. Moving human beings and a moving object must be differentiated accurately by the sensor. The device must be able to resist and adapt to extreme conditions such as hot weather. The device is placed under hot sun for an hour and systems functionality is tested after subjected to the harsh conditions. The reliability of the system is for the system to operate and response to many different situations. Situations such as a child moving around in the car, a sleeping motionless child, the range of connection and obstacles between systems are tested to prove its reliability.

4. Results and discussion
Table 2 shows the outcomes of the testing results based on the selection criteria mentioned. Both the ultrasonic sensor and motion sensor met the minimum requirement of two meters range (sufficient to cover the entire vehicle) despite less than three meters of detection. The Melexis temperature sensor provided the fastest response time but the range of detection were very limited. In terms of the false alarm testing, all the four types of sensor responded without giving false alarm. The CO2 sensor provided the best range, but its response time was extremely slow as it needed preheating time and the cost of the sensor was high when compared to others. The non-contact temperature sensor had very small range of detection and it was more expensive than the ultrasonic and motion sensors.

Table 2. Summary result of sensors evaluation.

| Criteria          | PIR  | Ultrasonic | CO2  | Melexis |
|-------------------|------|------------|------|---------|
| Range             | > 2 m| > 2 m      | > 3 m| < 0.1 m |
| Average response time | 5.0 s| 2.9 s      | > 5 min | 1.8 s  |
| False alarm       | No   | No         | No   | No      |
| Cost              | RM5.30| RM25       | RM285| RM137.50|

Table 3 shows the scores for each type of sensors based on its weightage. Obviously, the total scores for ultrasonic and motion sensors stood out from the evaluations. The ultrasonic sensor and motion sensor were the most suitable sensors for developing the detection system based on the criteria chosen. A detection system based on the ultrasonic sensor and motion sensor was therefore developed for this research.

Table 3. Decision matrix.

| Criteria        | Weightage | PIR | Ultrasonic | CO2 | Melexis |
|-----------------|-----------|-----|------------|-----|---------|
| Range           | 3         | 4   | 4          | 5   | 1       |
| Average reaction time | 5     | 4   | 4          | 1   | 5       |
| False alarm     | 4         | 4   | 5          | 1   | 2       |
| Cost            | 4         | 5   | 5          | 3   | 4       |
The receiver device was validated based on its range and its capability transmitting the signal through obstacles. The device could receive the signal between 3 and 4 meters around the vehicle and this value diminished when there was a wall in between the receiver device and the vehicle.

The best placement locations of the sensors were carried out for the ultrasonic sensor and motion sensor since it was chosen as the most suitable sensors for integration of the child detection system. The best placement of the ultrasonic sensor to detect the child was determined to be above the child seat as it used distance to detect the child in a straight line and gave the best result. The best placement for the motion sensor was on the ceiling in the middle of the vehicle. The sensor was able to pick-up movements anywhere in the vehicle at that position.

Figure 2 and 3 showed the prototyping of the detection system. The whole device was validated based on the assessment criteria mentioned. The validation showed the detection system passed the accuracy test, high resistance and reliable. The device was able to detect a stationary or motionless sleeping child and differentiate between a living and non-living object. The device also could withstand the harsh conditions as in the hot vehicle and function as required. The device was able to pick-up the movements and alert the user of the unattended child when the child got out of the baby seat and moved around in the vehicle.

Figure 2. Main device (Prototype).
Figure 3. Receiver device (Prototype)

5. Conclusions
The aim to develop an automatic vehicular heatstroke detection system to reduce the unfortunate cases of a child death due to heatstroke after being left unattended in the car was achieved. The most suitable sensors which were the ultrasonic and motion sensor were selected for integration of the detection system. The sensors were used for fabricating the prototype in this research. The best placement locations of the sensors were determined. The detection system was also validated based on criteria set which were accuracy, resistance and reliability. The prototype was able to achieve the results required to function as an automatic vehicular heatstroke detection system without false alarms.

6. References
[1] Kidsandcars.org U.S. Child Vehicular Heatstroke Deaths Fact Sheet 2017
[2] Guard A and Gallagher S S 2005 Heat related deaths to young children in parked cars: an analysis of 171 fatalities in the United States. 1995-2002 Inj. Prev. 11 1 p 33–37
[3] Grundstein A, Duzinski S and Null J 2017 Impact of dangerous microclimate conditions within enclosed vehicle on pediatric thermoregulation Theor. Appl. Climatol. 127 1–2 p 103–110
[4] Sulaiman N, Ghazali K H, Jadin M S, Hadi A A, Najib M S, Zain M S M, Halim F A, Daud S M, Zahed N and Abdullah A A 2017 Development of comprehensive unattended child warning and feedback system in vehicle MATEC Web Conf. 90 vol 01008 p 1–9
[5] Rudd R, Prasad A, Weston D and Wietholter K 2015 Functional assessment of unattended child
reminder systems Report No. DOT HS 812187 (Washington DC: National Highway Traffic Safety Administration) p 76

[6] Karaman A, Augustine S Z T, Bofeng L, Lawrence G H T, Ruo X Y, Sheng Q and Yao Y 2013 ThermSafe: Child Heat Injury Prevention in Heated Locked Cars Imperial College London p 1–9

[7] Tan T F, Teoh S S, Fow J E and Yen K S 2016 Embedded Human Detection System Based on Thermal and Infrared Sensors for Anti-Poaching Application. IEEE Conference on System, Process and Control (Melaka: Malaysia) p 37–42

[8] Parmin S and Rahman M M 2016 Human Location Detection System Using MicroElectromechanical Sensor for Intelligent Fan International Conference on Mechanical, Automotive and Aerospace Engineering vol 184 012042 p 1–8

[9] Correa M, Hermosilla G, Verschae R and Ruiz-del-Solar J 2012 Human Detection and Identification by Robots Using Thermal and Visual Information in Domestic Environments Journal of Intelligent & Robotic Systems 66 1–2 p 223–243

[10] Guettari T, Boudy J, Benkelfat B, Chollet G, Baldinger J, Dore P and Istrate D 2014 Thermal Signal Analysis in Smart Home Environment for Detecting a Human Presence 1st International Conference on Advanced Technologies, (Sousse: Tunisia) p 334–339

[11] Wang S, Burnett J and Chong H 1999 Experimental Validation of CO2-Based Occupancy Detection for Demand-Controlled Ventilation Indoor and Built Environment 8 6 p 377–391

[12] Kaushik A R and Celler B G 2006 Characterization of passive infrared sensors for monitoring occupancy pattern Annual International Conference of the IEEE Engineering in Medicine and Biology – Proceedings (New York City: USA) p 5257–5260

[13] Luppe C and Shabani A 2017 Towards Reliable Intelligent Occupancy Detection for Smart Building Applications IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE) p 1120–1123

[14] Yokoishi T, Mitsugi J, Nakamura O and Murai J 2012 Room occupancy determination with particle filtering of networked pyroelectric infrared (PIR) sensor data Proceedings of IEEE Sensors p 3–6

[15] Caicedo D and Pandharipande A 2012 Ultrasonic Array Sensor for Indoor Presence Detection In 20th European Signal Processing Conference (EUSIPCO 2012) p 175–179

[16] Koyama T, Tanaka T, Kaneko S, Moromugi S and Feng M Q 2005 Integral ultrasonic muscle activity sensor for detecting human motion IEEE International Conference on Systems, Man and Cybernetics vol 2 (Waikoloa: USA) p 1–6

[17] Garethiya S, Agrawal H, Gite S, Suresh V, Kudale A, Wable G and Yendargaye G R 2015 Affordable system for alerting, monitoring and controlling heat stroke inside vehicles International Conference on Industrial Instrumentation and Control (ICIC) p 1506–1511

[18] Holtzman M, Townsend D, Goubran R and Knoefel F 2011 Breathing sensor selection during movement Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS) p 381–384

Acknowledgments
Authors wishing to acknowledge assistance from colleagues especially for providing the physical vehicle for experimental tests in this research. This research was also funded by the UNIMAS Research Grant Scheme SGS Grant: F02/SGS/1600/2017.