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Development of User-Centered Smart Child Seat for NCAP Requirements Via IoT Platform

Abstract. *Recently, the 'forgotten baby syndrome' term has become a regular headline in the newspaper. The syndrome is referred to a scenario of a child dying from a heat stroke after being accidentally left in a car. Herein, the Smart Child Seat (SCS) has been designed with a real-time monitoring-based system that consists of temperature, humidity, heart rate, sound, ultrasonic and a carbon monoxide sensor to monitor and measure the condition of the child left inside the car. The system's requirement is designed based on the market survey to provide direction for the optimized SCS system. The system will send the notification via the Blynk IoT application to the parents if there is an abnormal reading from the sensors.*

Streszczenie. *Ostatnio termin „syndrom zapomnianego dziecka" stał się stałym nagłówkiem w gazecie. Zespół odnosi się do scenariusza, w którym dziecko umiera na udar cieplny po przypadkowym pozostawieniu go w samochodzie. W tym przypadku inteligentny fotelik dziecięcy (SCS) został zaprojektowany z systemem monitorowania w czasie rzeczywistym, który składa się z temperatury, wilgotności, tętna, dźwięku, ultradźwięków i czujnika tlenku węgla, aby monitorować i mierzyć stan dziecka pozostawionego w środku samochód. Wymagania systemu są projektowane na podstawie badania rynku, aby wskazać kierunek dla zoptymalizowanego systemu SCS. System wyśle powiadomienie za pośrednictwem aplikacji Blynk IoT do rodziców, jeśli nastąpi nieprawidłowy odczyt z czujników.* (***Projekt inteligentnego fotelika dziecięcego zorientowanego na użytkownika dla wymagań NCAP za pośrednictwem platformy IoT***)

Keywords: forgotten baby syndrome, dying child, heatstroke, IoT, sensors, NCAP, child monitoring, child seat.
Słowa kluczowe: samochodowy fotelik dziecięcy, Internet Rzeczy IoT.

Introduction

A car-related injury and the death of a child that accidentally being left in the car is one of the crucial issues in a global society. The situation includes cases where children have been forgotten left inside vehicles, who accidentally lock themselves inside the vehicle. A safety organization Kids and Cars reported that every year, an average of 37 children dies due to the entrapment in vehicles. The situation includes cases where children have been forgotten left inside vehicles, who accidentally lock themselves inside the vehicle [1]. The heatstroke occurs when the body is not capable of dissipating and absorbing the heat it produces, for instance, when it is left unattended by the body in an adjoining vehicle even if only for a few minutes. Vehicular hyperthermia in young children is an uncommon, but the heatstroke can be one of the causes of the baby's death in the car. Heatstroke is characterized by when a body is at rest, the temperature exceeds 40°C. Brain death would occur when the body temperature reaches 41°C and at 45°C which can lead to a critical injury [2]. The leakage of carbon monoxide (CO) gases inside the car also contributed to the sudden death of a child being left in the car. Typically, CO is used in the compressor of an air-condition and refrigerators. The blood system in the body will be blocked by CO and will affect the oxygenation in the body and leads to severe damage to the brain and heart [3]. Towards increasing consumer awareness, and enhance a market for safer vehicles, New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP) launched the new roadmap for 2021-2030, which includes a child presence detection assessment to ensure that manufacturers take responsibility for the children travelling in their vehicles [4]. The assessment contributes to 20% to the overall rating, additional point will be given if the system accomplishes to remind the driver to check the back seat at the end of each journey.

Thus, this project aims to design a user-centered smart child seat embedded with multi-sensors to support the ASEAN NCAP requirements. A variety of the system to detect the unattended child within a vehicle was explored recently. Charles J. Cole proposed a system that detects the presence of the child in a vehicle using pressure and motion sensors [5]. As the child is detected, the system will disable the vehicle's door locks. The system also can measure the temperature inside the vehicle. However, there is no real-time monitoring device incorporated into the system. Victor H. et al proposed the system that detected the presence of a child and the driver inside the vehicle [6]. A wireless baby monitoring system attached to the baby's crib and embedded with the temperature sensor, motion and audio sensor was designed and introduced in [7] to prevent accidental choking and in-bed suffocation. The smartphone is used as a monitoring tool to alert the parents by text messaging their smartphone. Patil S. P. invented a smart baby monitor system based on the Global System for Mobile Communication (GSM) which aims to provide children with better care [8]. The collected data of temperature, humidity, pulse rate and infant movement will be sent to the parents through a GSM network. Although the data were sent to the mobile phone, parents cannot analyse the data as it is not transferrable to the other application. A recent Internet of Things (IoT) developments has led to renewed attention in the child safety division. By incorporating the IoT technology into the child safety division, K. N. Khamil proposed a research on the baby care alert system for prevention of child left in a parked vehicle [9]. This system provided a notification through a smartphone and cooperated with a load sensor to sense the child's presence inside the child's car seat. A keychain alarm device also was added and worked as a security feature in case of an emergency when the smartphone's battery is dying. Nevertheless, the employment of RF transceivers limits the coverage for data transmission. The system also did not provide the real-time monitoring system of the child. A warning alarm will be activated on the device as soon as parents walk outside the RF signal range.

Nowadays, the IoT is like a giant network connecting things and people [10]. Implementing the IoT technology welcomes us to a world where we can use the internet to connect, interact, and command any device. While current child safety systems mostly focus on detecting the presence of the baby, real-time monitoring via the IoT has not yet been explored in depth. The whole concept behind the development of the Smart Child Seat (SCS) is to enable parents to check up on their infants and monitor their activities from afar. The IoT-based SCS includes the real-time monitoring system on a cry detecting mechanism and the other sensors to check the combustion gas leakage, humidity, and temperature inside the vehicle. The data generated by the sensors is stored in the cloud and can be analysed for future product enhancement and development. Hence, the SCS developed in this study which is embedded with multi-sensors is aimed to detect and measure the presence of the baby, baby's sound and heart rate, surrounding's humidity and temperature and detect a combustion gas leakage inside the vehicle using an IoT system via the Blynk- IoT platform.

Methodology

The Design Survey

The user-centered design (UCD) is one of the methods in interaction design which will determine whether the designed SCS with an IoT integration is a good or bad design, interactive or not, or whether it has the essence of user experience (UX) throughout the prototype design process [11]. The advantages of using this method are we are able to gather the designs' understanding and task requirements from users and implement the design iteration and assessment, which is the main contribution to product usefulness and usability [12]. Hence, at the beginning of the study, the design survey was carried out to collect feedback from them and gather their expectations and requirements for the development of our SCS.

The first section of the survey is demographic data. It has two questions that are age and gender. Section two focus more on users' requirements, needs and preferences of the system. Part A in Section two are to examine whether: i) The baby car seat can prevent the unnecessary incident? ii) Does introduce a monitoring system for baby car seats will give a good impact? iii) Does implement IoT into the baby car seat will improve the child monitoring system? iv) Does the IoT system will make the child monitoring system user-friendly? Does the car seat need a temperature, heart rate, CO sensor inside the car?. Part B is regarding the respondent's preference by introducing the real-time monitoring system to the child seat.

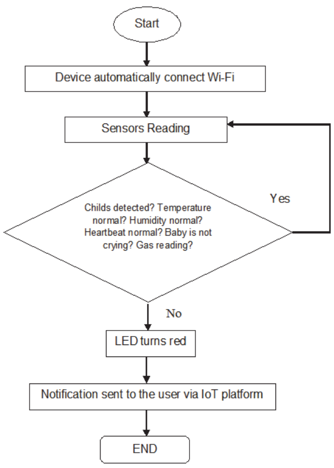

Fig.1. Flowchart of the system

Hardware Development

The SCS proposes a solution that comprises hardware, software, and communication integrated into a solution that aims to optimize the SCS design through an IoT implementation. For the hardware part, the system comprises the Arduino UNO as a microcontroller that integrated with a multi-sensor to measure and monitor the baby's condition being left inside the car Fig. 1 shows the flow chart of the system.

Once the device is activated, it will connect to the internet through a Wi-Fi module. Next, the sensors reading are as follows. First, the presence of a child in the seat will be detected using the HC-SR04 infrared sensors. If no baby is presence on the child seat, the system will jump to the end-stage, thus send the warning notification to the parents. Next, the DHT11 temperature sensor will measure the temperature and the humidity, the leaking of the combustion gas will detect by the MQ-9 gas sensor module, the Hw-827 pulse sensor checks the heart rate of a child and lastly, the KY-038 sound sensor detects whether the child is crying or not. A Wi-Fi shield module is used to make the connection through IoT. For each sensor stage, if an abnormal condition is present, the parents will get the warning notification through the smartphone via the IoT platform. The system also provides a real-time monitoring system via a smartphone in the Blynk application and the light indicators using the LED at the prototype. All of the embedded sensors follow the criteria of child presence detection in the NCAP standard [13].

As for the initial state, when all the condition in the normal state, the standard reading for temperature, humidity, heart rate, sound, ultrasonic and CO gas level is 27 to 33 [°C], 40-80 [%] Relative Humidity ([RH]), 55 to120 [beats per minute] ([BPM]), 550 [Hz], 10 [cm] and 10 [Rs/Ro], respectively.

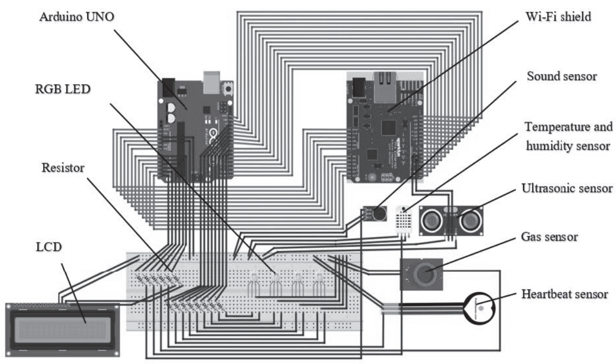

Fig. 2 Element in hardware and software

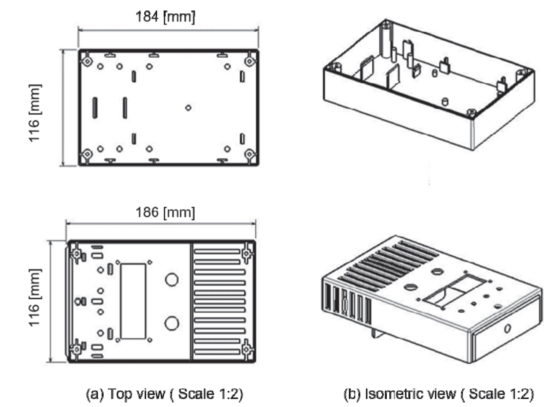

Fig.3. Dimension of prototype casing

Creating a 3D Printed Case for the Electronics Components

All the sensors and the electronic components were stored in the 3D printed casing as in Fig. 3. Fig. 3(a) and 3(b) show the top and isometric views of the casing, respectively. The casing will be placed near the baby's car seat in the car. The digital sketch is made in CATIA software, while the sketch is print using the Ender-3 Pro. All the dimension and measurement of the casing is calculated to make the prototype miniature in size.

Software Development

The software application that is used to develop in this project is Arduino IDE software and Blynk Applications. Arduino supports the programming languages C and C++ by employing special code structuring rules [14]. The software is used as a platform to write and upload programs to Arduino compatible boards. Blynk is an iOS and Android app that allows users to create interfaces for controlling and monitoring hardware projects quickly [15]. By using the widgets, the user can control the output from sensors. Blynk supports most Arduino boards, Raspberry Pi models, the ESP8266, Particle Core, and a few other popular microcontrollers.

Results And Discussion

Survey results

The demographic survey of gender and the age of the respondents shows 60% of them are male, and the rest are female (35 respondents in total). Meanwhile, the distribution age of the respondent is 61.8% is 20-25 years old, 32.4% is 26-30 years old, and the rest is around 30-35 years old. The collected data show that the questionnaire is balanced distributed to the respondent. No bias would occur in the next section.

As for Part A in Section two, the results distributions of user's requirements are as in Fig. 4. The majority of the respondents agreed 97.10 % to 100% with the statement asked in the questionnaires. Only 25.70% did not agree with the statement of there is a need for a heart rate sensor in the system. Fig.5. shows the distribution results for the survey of Section two in Part B. In this set of questions, the participants are asked to rate the following statements. 1) Current baby car seat is user friendly, 2) The current system for car seat baby monitoring is able to provide the user interface to monitor baby's condition, 3) The current baby car seat can prevent heat stroke if the baby is left inside the car, 4) The SCS are easy to monitor the baby's condition by using the temperature and humidity sensor, heartbeat sensor, and carbon monoxide sensor, 5) If a proper IoT is implemented, I believe that baby monitoring would be made easier, and 6) This product is unique and can be commercialized. The Likert scale is anchored from a score of 1 to 5. The lowest score (1) indicates strong disagreement while the highest score (5) indicates strong agreement. Therefore, the higher the score the better, in our case.

Table 1.

Label	Questionnaire
R 1	Does baby car seat can prevent the unnecessary incident?
R 2	Does introducing a monitoring system for baby car seat will give a good impact?
R 3	Does implementing IoT into the baby car seat will improve the child monitoring system?
R 4	Does IoT system will make the child monitoring system user-friendly?
R 5	Does car seat need a temperature sensor to measure temperature inside the car?
R 6	Does car seat need a heartbeat sensor to measure the heart rate of the baby inside the car?
R 7	Does car seat need a carbon monoxide sensor to detect harmful gas leak inside the car?

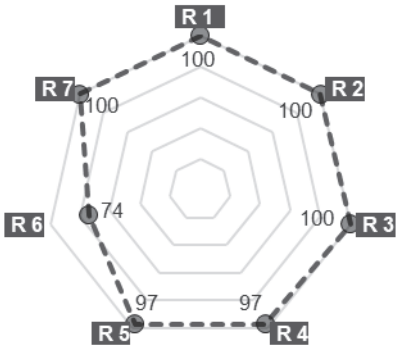

Fig.4. The agreement of the SCS requirements by users

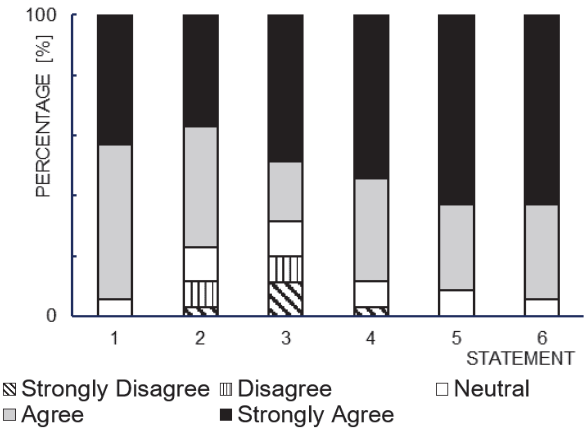

Fig.5 Distribution results for the agreement statements from users.

The results show for statement 1), more than 50.0% agreed that the currently available car seat is not user-friendly and a majority of 62.9% of respondents strongly agreed with statements 5) and 6). Hence, the design prototype of our SCS will follow the user's agreement and requirement from the survey.

Digital Sketch vs 3D Printed Prototype

Fig.6.(a) shows the top and bottom casing of the digital sketch and Fig.6.(b) is the 3D printing results, respectively. The printing process is done by laying down successive layers of material until the object is complete. The printed object is using the PLA material with a wall thickness of 2[mm]. As a result, the casing is tough enough to hold all the components inside.

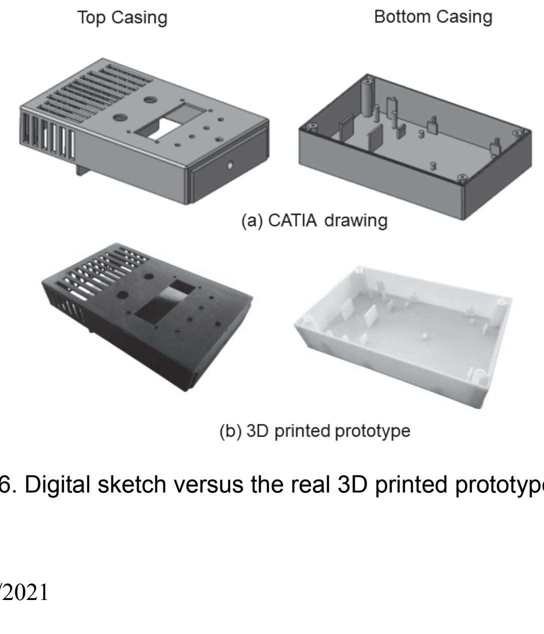

Fig.6. Digital sketch versus the real 3D printed prototype

Serial monitor testing

The sensor first was tested using the serial monitor and the initial measurement was recorded. As for the measurement of heart rate, 83 [BPM] was obtained. The humidity of air is 66% [RH]. As for the sound sensor, the frequency of 389 [Hz] was measured inside the car. The temperature is 32°C, and the gas ratio level is 7.52. All of the readings show that the baby is normal.

On-Board Testing

Fig. 6 shows the result of on-board testing. Fig. 6(a) shows all the LEDs are green in colour indicates the sensor's reading is in the normal range and the initial condition. The LED will turn red if the sensor's reading reaches the threshold value. LED 1 represents the detection of the baby inside the child seat as in Fig.6(b). and it will turn red as there is no presence of the baby detected. LED 2 and LED 3 in Fig.6(c) and (d) represent the temperature and humidity status inside the vehicle, respectively. The LED turned red when abnormal reading is measured. LED 4 represents the gas level status inside the vehicle. The combustion gas is measured using the ratio particle per minute of CO. The ratio of clean air is around 4 to 12, and when the sensor's reading is out from these ranges, LED 4 will turn red as in Fig.6(e).

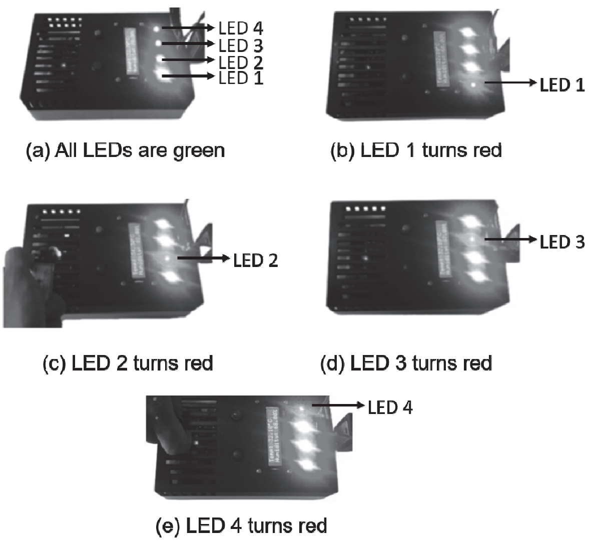

Fig.6. On- board testing

Blynk Application Testing

Fig. 7 shows the user interface in the Blynk mobile application. The four parameters displayed in a meter form represents the heart rate, gas level, temperature, and humidity reading.

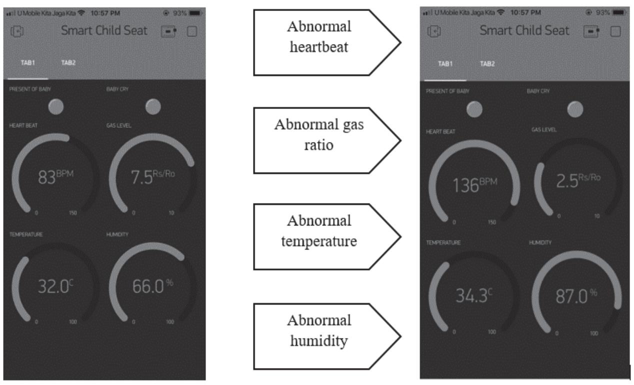

Fig.7. Blynk application testing

For the heart rate measurement, the meter range is from 0 to 150 [BPM] and the normal reading is around 55 to 120 [BPM]. Next, the meter for the gas ratio is from 0 to 10, and the clean air is defined as the ratio higher than 4. For temperature sensing, the meter range is set from 0 to 100 [°C]. Therefore, the normal reading for temperature should be 25 [°C] to 34 [°C]. Finally, the humidity meter sensor is programmed from 0 to 100 % [RH] with the normal range is around 40 to % [RH]. The concept is simple where there is an abnormal reading by the sensor, the green meter will turn red. In Fig.7, the left figure is the Blynk interface in green when all the sensors' readings are in normal condition and the right figure with the red indicator in the Blynk is when the abnormal condition is detected.

Experimental Results from Blynk

The observational study was obtained to measure the temperature and humidity inside the car, the baby's heart rate and the CO level in real-time. The graph in Fig.8 is the screenshot of the Blynk interface in the mobile phone. Because of the Corona circumstances and we did not want to increase contamination risk, the observational study was made without the real baby inside the SCS. As a result, the gathered data for all the sensors were almost the same as in the initial data, such as heart rate reading stays around 70 [BPM], gas ratio level stays around 80, the temperature is approximately at 30°C with 75% [RH] of humidity. We also noticed that, because the reading has only been measured for short time, so we cannot see so much difference in the reading. However, the SCS able to capture the data as user's preferred timeframes for example 15 minutes, 30 minutes, 1 hour, 1 day, 1 week, and 1 month as shown in the bottom left of the interface.

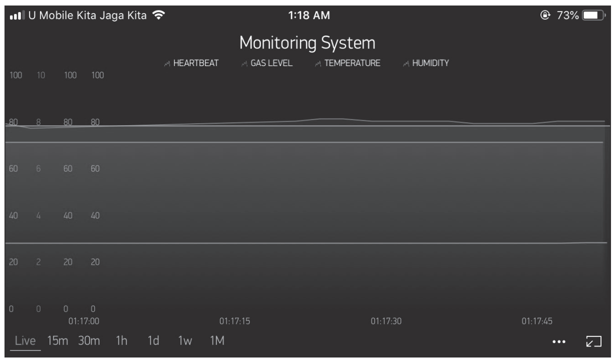

Fig. 8. Monitoring system from the Blynk interface

Analysis of the Measured Data

For further analysis, the data from the Blynk can be export to Microsoft Excel. Fig.9. shows the collected data in 20 minutes duration. The data was collected during the hot day (not rainy) with the air conditioner in the car was ON and the combustion gas was applied.

Fig.9. depicts the graph of the temperature (orange line with diamond marker) and the humidity readings (grey line with triangle marker), respectively. In 20 minutes, the temperature was increasing from the initial value of 30 [°C] to 34 [°C]. Although the air conditioning was in an ON state, the temperature inside the car is still increasing on a hot day. As for the humidity, the reading was fluctuated with the lowest and approximately at 60% [RH] and highest at 82% [RH]. The reading is in the normal range, meaning that it will not affect the baby if the baby is in the car seat at the pre-set condition.

Fig.10 shows the measurement of the heart rate is in BPM. It was fluctuated between 60 to 80 [BPM], but still in the normal range, thus telling the user their child is safe. One of the situations given for the experiment is the combustion gas is applied. At the minute of the sixth, the gas ratio almost reaches zero, meaning a high amount of combustion gas is detected, and from minutes seventh and onwards, there were in the increasing pattern, meaning that the amount of combustion gas slowly decreases with time.

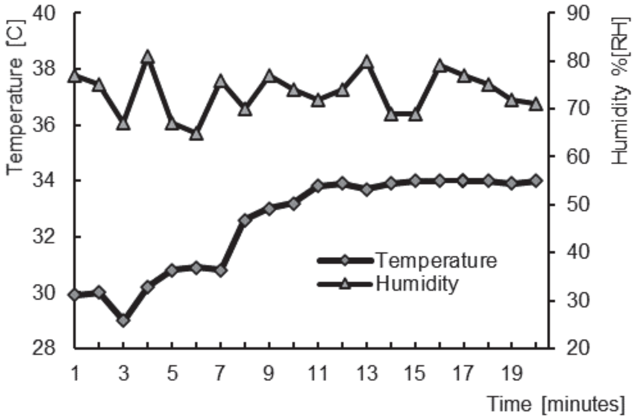

Fig.9. Temperature and humidity VS time

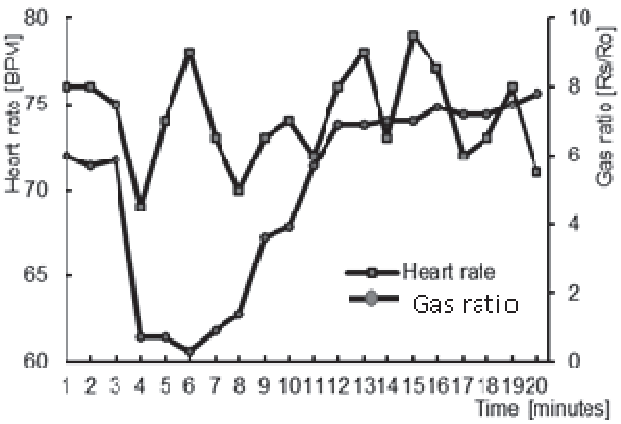

Fig.10. Heart rate and gas ratio VS time

Conclusion

From the first stage of the SCS development process, most respondents showed a positive agreement on questions concerning child safety. Therefore, it can be shown that a child's presence and detection system are crucial to be implemented in the automotive field. As the car-related death keeps increasing each year, referring to a child's situation that being left inside the car, the survey showed that the awareness among the parents of their child being left in the car is at a satisfying level.

In conclusion, the study's primary goal is to develop a prototype of SCS that can measure the presence of the baby, baby's sound, baby's heartbeat, surrounding's humidity, surrounding's temperature, and combustion gas leakage inside the vehicle using an IoT system was achieved. By applying technical knowledge in this field and conducting several tests, this project receives the desired results. First, the most suitable sensor was embedded in the system. Second, the best placement locations of the sensors were determined, and the interactive design concept is applied to increase the usability of the product. We realize that the interactive design method should be a focus in this study's research cycles as it will determine whether the design of the SCS with an IoT implementation is good or bad, interactive design or not, or whether it has the essence of user experience.

Finally, the design of SCS holds the promise of a constant real-time monitoring system for the infant and prompt notification through the visual and mobile application of an emergency scenario. The system also succeeded to notify the user when the baby is exposed to the risk of vehicular heatstroke.

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REFERENCES

[1] Kids and Cars, "Heatstroke," 2020. https://www.kidsandcars.org/.
[2] S. R. Mehta and D. S. Jaswal, "Heat stroke," *Med. J. Armed Forces India*, vol. 59, no. 2, pp. 140–143, 2003, doi: 10.1016/S0377-1237(03)80062-X.
[3] V. W. Rees and G. N. Connolly, "Measuring air quality to protect children from secondhand smoke in cars," *Am. J. Prev. Med.*, vol. 31, no. 5, pp. 363–368, 2006.
[4] K. A. Abu Kassim, "ASEAN NCAP Roadmap 2021--2030." ASEAN NCAP, Kajang, Malaysia, 2018.
[5] C. J. Cole, "System to detect the presence of an unattended child in a vehicle." Google Patents, 2007.
[6] V. H. Rams Jr, "Child occupancy detection system." Google Patents, 2008.
[7] J. Annouri, T. Moyo, H. Wang, D. Zuber, Z. Soriano, and D. Soriano, "Knight's Wireless Baby Monitor," 2014.
[8] S. P. Patil and M. R. Mhetre, "Intelligent baby monitoring system," *ITSI Trans. Electr. Electron. Eng.*, vol. 2, no. 1, pp. 11–16, 2014.
[9] K. N. Khamil, S. I. A. Rahman, and M. Gambilok, "Babycare alert system for prevention of child left in a parked vehicle," 2006.
[10] H. U. Rehman, M. Asif, and M. Ahmad, "Future applications and research challenges of IOT," in *2017 International conference on information and communication technologies (ICICT)*, 2017, pp. 68–74.
[11] N. F. Azmi, "Designing Colour Changing Actuation for Realistic Cyanosis in a Baby Manikin," 2021.
[12] J.-Y. Mao, K. Vredenburg, P. W. Smith, and T. Carey, "The state of user-centered design practice," *Commun. ACM*, vol. 48, no. 3, pp. 105–109, 2005.
[13] N. ASEAN, "ASSESSMENT PROTOCOL – CHILD OCCUPANT PROTECTION," 2019. [Online]. Available: http://www.aseancap.org/v2/wp-content/uploads/2020/01/5.-ASEAN-NCAP-Asessment-Protocol-Child-Occupant-Protection-2.0_2019_FINAL_15-NOV-2019.pdf.
[14] Y. A. Badamasi, "The working principle of an Arduino," in *2014 11th international conference on electronics, computer and computation (ICECCO)*, 2014, pp. 1–4.
[15] M. Todica, "Controlling Arduino board with smartphone and Blynk via internet." November, 2016.