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RIVER VALLEY TECHNOLOGIES

An innovative complete solution for health safety of children unintentionally forgotten in a car: a smart Arduino-based system with user app for remote control

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Abstract: This paper describes an innovative complete car control system against children abandonment in unattended vehicles. Even if systems of this kind are already available in automotive market, other solutions are currently object of intense researches by several important R&D centres or under patent procedure. In this paper, it is provided a description of the technologies already adopted in the currently used car control systems and in those that are in research and testing phase too. Then, it will be introduced the proposed control system, which enables to improve all described systems by providing innovative technologies and functionalities. The proposed system implements a microwave motion sensor, two infrared sensors, a carbon dioxide sensor, a temperature/humidity sensor, a vocal detector and a micro-camera. These acquisition devices are connected to a microcontroller board that is able to combine all acquired data for detecting the alarm scenario and consequently acting some warning procedures: alarm SMS transmission with vehicle GPS position, vehicle's horn activation and/or car windows lowering. Thanks to such wide set of sensors, the system can correlate the acquired information in order to ensure a good detection capability in every condition in which it can operate.

1. Introduction

Nowadays, the human society is constantly at the center of a frenetic technological evolution. The achievements of science and engineering have produced electronic systems and devices that can improve people's lives, establishing a real human-machine interaction, in order to help, to assist and to protect people during their daily activities. People's everyday life is pervaded by a galaxy of intelligent systems that autonomously acquire data from surrounding environment, process them, exchange data with each other through communication networks and perform real actions based on the results of their analysis. All these systems daily interact with us, through graphical interfaces, communication platforms, sound or light feedbacks and physical actions. Hence, expressions like M2M (Machine to Machine), D2D (Device to Device) or IoT (Internet of Things) are almost part of common language, describing a new scenario in which electronic devices cooperate with each other and with the user in a network logic [1]. In this paper, it is evaluated how the current technological solutions can be employed in order to mitigate a problem, which has recently acquired worrying dimensions.

As shown in Fig. 1, in last years an increasing number of events related to children forgotten in the car from their parents have occurred in USA. Unfortunately, similar statistics can be obtained for countries where people have high stressed lifestyle. Typically, during these events, the cockpit internal temperature can reach particularly high or low values, leading to child hyperthermia, hypothermia and other serious consequences that could also cause child's death. In USA about 37 children on average die each year for heat stroke or hyperthermia in the car, and about the 87% of them is aged between 1 and 3 years. These events have increased the need to develop and install innovative systems able to detect the presence of a child into an unattended vehicle through proper sensors and to alert the driver or other possible contacts with different types of alarm.

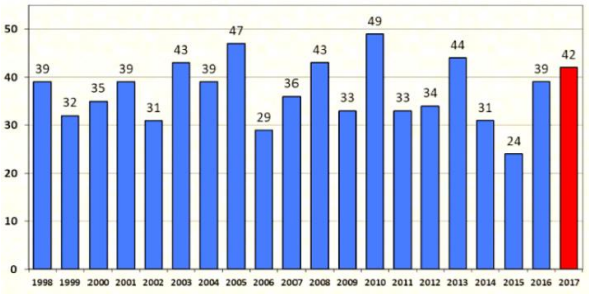


Fig. 1. *Child deaths in USA for heat stroke in cars from 1998 to 2017(www.noheatstroke.org).*

The automotive sector has undergone profound changes during the last two decades. In detail, electronic technology, less present respect to the mechanical component in the past, nowadays has reached and perhaps exceeded the latter in vehicles design and construction. The modern cars have many complex electronic systems, which manage most of the vehicle's functionalities, from the simplest (lights, wipers, air-conditioning etc.) to the most complex (engine, stability, traction, security, consumption etc.). The number of control systems that assist the driver in managing the vehicle, increases with car's complexity level. For instance, competition cars need an high control level for all functional parameters, thus they continuously send wireless information to the control station, which allow to tune car in real time for optimizing their performances. This functionality is called telemetry. Scientific research is very active in this field [2], since, in the future, common cars will probably be more and more network connected and the use of telemetry will be applied to them.

Technological research applied to automotive sector has given more and more attention to the problem studied in this paper. In scientific literature, there are different contributions that describe innovative systems for detecting child's presence in unattended vehicles. Moreover, some important automotive companies (e.g., *Hyundai*, *Nissan*, *General Motors*) and other companies that manufacture electronic systems for automotive sector have developed and installed, on vehicles currently in production, several technological solutions for preventing and reducing these critical and dangerous eventualities.

This manuscript aims to analyze all these solutions and compare them with the proposed detection system (provided with an RF microwave movement sensor, two PIR sensors, a carbon dioxide sensor, a temperature/humidity sensor, a vocal detector and a micro-camera) for detecting the presence of a child into a turned off car with blocked doors. The designed system allows to warn the driver, the rescue teams and other secondary contacts by sending alarm messages (the text of the SMS include the GPS position of the vehicle), by activating horn sound and by lowering car windows (if the internal temperature overcomes a certain threshold value). Thanks to the several sensors / devices distributed inside the car's furnishing, the system can reduce significantly the false alarm probability compared to similar system already reported in literature, as below described. In fact, the electronic control unit correlates the information acquired by sensors through a suitable firmware logic, ensuring the detection capabilities in every condition in which the system could operate; in particular, the system integrates a smart camera implementing a face recognition algorithm and a sound recognition board to detect an infant even in the conditions in which it is asleep or is covered with a blanket. From the vehicle point of view, the proposed system doesn't alter the other functionality of the car and could be installed regardless its model, given the generality of the connections required with the car control unit. Furthermore, the signals involved by the system don't interfere with other apparatus equipping the car (navigation system, Bluetooth, etc.). Summarizing, the developed system, by combining different recognizing and detecting technologies, represents a secure, low cost and more effective solution, for detecting child unintentionally left in a car compared to other solutions reported in the scientific literature or available on the market.

2. Detection systems currently available on the market

Several vehicles currently on the market are equipped with monitoring systems for detecting the presence of a child inadvertently abandoned into a car. For instance, a commercial detection system currently, based on motions detection, is the "*Rear Occupant Alert*", conceived by Hyundai that equips its vehicles from 2019. The system employs ultrasound sensors for detecting the movements over the entire rear seat, if the car is off and the car doors are closed [3].

A second example, based on the same principle, is the system proposed by a team of designers/parents [4] that employs infrared technology (PIR movement sensor) rather than ultrasounds technology for movement's detection.

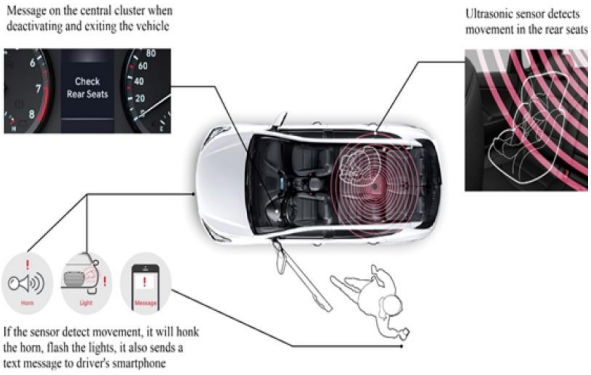


Fig. 2. *Rear Occupant Alert system [3] developed from Hyundai (image provided by Hyunday®).*

Nissan and *General Motors (GM)* have developed two systems based on the opening sequence of car rear doors. The Nissan system, called "*Rear Door Alert*", stores the rear doors opening sequence, warning the driver if, after engine's shutdown, the stored sequence is not performed (Fig. 3).

The GM system, called "*Rear Seat Reminder*", alerts the driver at vehicle's shutdown if, before vehicle's ignition, a rear door was opened and then closed. In this case, the system shows a warning message on the graphical interface of the on-board computer.



Fig. 3. *Rear Door Alert system interface [4]:* Activation message at vehicle's turning-on, after rear door opening and closing (a); warning message for rear seats control, at vehicle's shutdown (b); system settings interface (c); access interface to system settings (d). (*images provided by Nissan®*)

The IEE Company has developed the *VitaSense* system that uses RF technology in the ISM frequencies (*Industrial, Scientific and Medical*) at 24 GHz, for detecting the presence of child based on its movements [5]. The system detection unit generates RF signals that are reflected from objects and vehicle occupants and are processed through a specific algorithm, able to detect all minimal movements, including those caused from child breathing during sleep. The algorithm exploits two classification methods for evaluating the observed movement level. The first one, called *Global Motion Recognition*, is used to detect the significant movements performed by the child on rear seats. The second one, called Sleeping Child Recognition, is used to detect all minimal movements, including those caused from child breathing during sleep on rear seats. In Fig. 4 are shown some details of transceiver device of the *VitaSense* system.

Moreover, other systems for the detection of child presence are integrated in the child safety seat. Some of them have been designed and developed in Italy and use a weight sensor installed in baby's chair. The "*Remmy*" system, developed by two designers which have founded a company for marketing this system; the "*BebèCare*" system, developed in cooperation with *Samsung* and *Chicco*; the "*Remember me*" system, designed from the students of an High School in Bibbiena (Arezzo, Italy).

Other detection systems based on a weight sensor are: the "*Sense A Life*" system, developed in Florida by a local start-up and the "*InfantSOS*" system, developed by a team of engineers of *Rice University*.

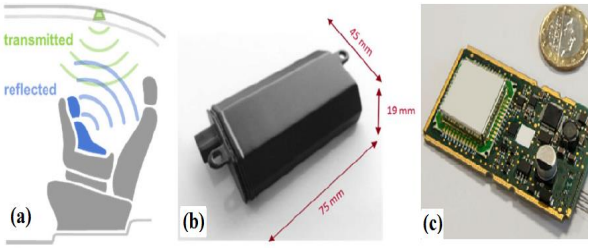


Fig. 4. *VitaSense system:* RF sensor position related to rear seat (a); RF sensor case with dimensions (b); Electronic Control Unit (c) *(images provided by VitaSense systems®)*.

Two similar systems have been patented in USA. The first one employs a weight sensor to detect the driver presence and a sensor on safety belt of baby's chair to detect child presence [6]. The second one uses the RFID technology, exploiting an RFID tag installed on baby's chair and an RFID reader placed into the car, in order to detect child presence on safety seat [7]. In Table 1 is shown a summary of technical features and main functionalities of the described systems. For each of them, the table shows the detection method, the involved sensors, the alarm conditions and the type of implemented alarms.

From Table 1, it can be observed that "*VitaSense*" system is a very effective system for the detection of unattended child. It can detect also the smallest child's movement such as the one relative to the breathing of a newborn asleep on the seat. Furthermore, it should be noted that systems in the table that try to detect child's movements through an ultrasound or infrared sensors, in some situations might fail. For example, in case of a sleeping child, an ultrasound sensor would not be able to detect its presence because of the very small movements related to child's breathing. At the same time, a PIR sensor may not work properly if cockpit internal temperature reaches high values.

Moreover, note that all systems integrated into baby's chair works by a weight sensor or a switch under the seat that reveal the presence of a child. This detection method in some cases may limit the systems efficiency, because weight sensors may not work properly. Some of these systems have implemented improving solutions that make detection more reliable. The "*Remmy*" system provides three sound signals if, after engine starts, the child moves from the correct position and the weight sensor does not detect its presence anymore. The "*Sense A Life*" system is provided with a weight sensor, that requires only 1kg pressure for correctly detecting child presence on the seat. Finally, the "*InfantSOS*" system uses an additional foil switch on the safety belt of baby's chair.

From the point of view of implemented alarm typologies, it can be observed that the more efficient and safe systems are those that allow the transmission of alert messages to mobile phone of the driver or of other secondary contacts.

Table 1: Characteristics of the described systems

Name	Detection method	Alarm condition	Alarm types
Rear Occupant Alert	Ultrasound movement sensor	Vehicle off, doors locked	flashing lights, horn sound, phone message
Car Passengers Detector	PIR movement sensor	Vehicle off	Acoustic and bright alarms, windows lowering
Rear Door Alert (Nissan)	Rear doors opening before vehicle start	No rear doors opening after vehicle off	Message on instr. panel, horn sound
Rear Seats Reminder (GM)	Rear doors opening before vehicle start	Vehicle turning off	Message on instr. panel, acoustic alarm
Vita Sense	RF movement sensor	Vehicle off	Not provided
Remmy	Weight sensor in baby's seat	Vehicle off	Acoustic alarm
Bebè Care	Weight sensor in baby's seat	Phone-sensor Bluetooth connection	Phone messages
Sense A Life	Weight sensor in baby's seat and optical sensor	Driver door opening	Acoustic alarm, phone messages
Infant SOS	Weight and safety belt sensors, accelerometer	Parked vehicle	Acoustic and bright alarms, SMS, heat absorption materials

3. Systems Under Development: Scientific Literature, Patents And Researches

In addition to the systems already present on the market, several research projects and scientific publications aim to improve functionalities and performances of the current detection systems.

The system reported in [8] has been conceived in order to detect the movement of a child forgotten into a vehicle and to warn the driver through an SMS message. The system must be set for enabling the infrared sensor, installed into car roof, only when the vehicle is parked. This scenario can be discerned by means of two different conditions: doors blocked and turned off engine or, eventually, parking mode "P" for car automatic transmission (if available). As schematized in Fig. 5, when a movement into car cockpit is detected from PIR sensor, a microcontroller sends a serial command to a GSM module through the RS232 interface; thus, GSM module sends a warning SMS to the driver. The algorithm implemented on the microcontroller has been designed to ensure simplicity and fluidity, avoiding complex instructions. As previously introduced, the detection system will be enabled only if parking conditions are verified.

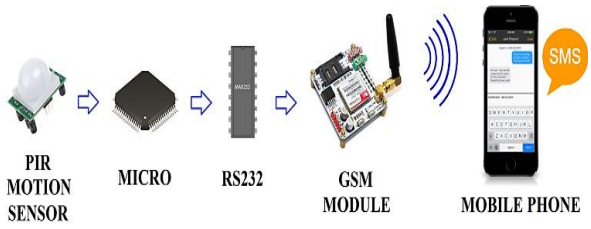


Fig. 5. *Functional scheme of the system reported in [8].*

In [9], a similar system uses a PIR sensor, a PIC16F877A microcontroller and a GSM module for detecting the presence of child in a parked vehicle and to alert the driver with an SMS transmission. The additional feature is a condenser microphone, which can detect the voice of a particular child and to discern it from external disturbs. In addition, this system is switched on only when car is in parking status, on the base of the previous described conditions. These systems typology, based only on presence sensors, can lack of detectability in conditions in which the child/infant is asleep or is covered with a blanket; for these reasons, the proposed system integrates, not only presence sensors, but also a smart camera and a voice detection device to overcome these shortcomings.

The system reported in [10] uses a weight sensor for detecting the child presence on the baby's seat, eventually sending a notification to driver's smartphone and enabling an acoustic alarm on the electronic keychain device. Two units compose it: a safety mat, to be installed in baby's chair, and an electronic keychain device. The main components of the mat are the TEM01052B weight sensor, the Arduino Uno platform with motherboard role, the *1Sheel*d module and the NRF24L01 RF transceiver. The weight sensor, used for detecting the presence of child on the seat, has a 50 kg capacity and generates an output voltage proportional to the pressure exerted on the sensor, so enabling the system operation. The Arduino platform continuously controls the child presence and, until the weight sensor detects it, a periodic message is sent to driver's smartphone with a time interval of few minutes. The RF transceiver integrated in the mat receives signals from electronic keychain until it is into transmission range. When the driver reaches the destination point and moves away from the vehicle without withdrawing the child, the weight sensor detects its presence and so continues to send periodic messages to driver's phone. If the driver exits from transmission range of RF signal, the keychain device loses communication with the transceiver in the mat and so enables its acoustic alarm. In Fig. 6 is shown a block scheme of the described safety system. The proposed system, described below, isn't based on a weight sensor, because this can't ensure enough reliability in the detection; for this reason, a combination of different detection mechanisms (presence sensors, gas sensor, face and voice recognition) was employed for ensuring a good detection probability.

The system referred in [11] can detect presence and movements of a child forgotten into a vehicle and to alert the driver by sending to the smartphone a warning message (SMS) and a video of the child in the rear part of car cockpit.

The main system components are a capacitive sensor installed into child safety seat, a PIR sensor, an LM35 temperature sensor, a PIC16F877A microcontroller, an USB camera, a GSM module, an acoustic alarm and a fan integrated into the vehicle.

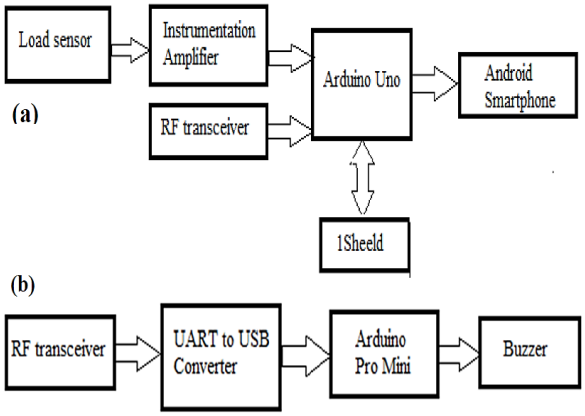


Fig. 6. *Block diagram of the system reported in [10]:* safety mat (a) and electronic keychain device (b).

The capacitive sensor installed into child safety seat detects the electrical capacity between the first armature of a capacitor and the child's body, which represents the second armature, allowing to detect child's presence until a distance of 30cm. The system is enabled when car engine turns off or doors are blocked. If capacitive and PIR sensors detects the child presence on safety seat, the microcontroller enables an acoustic alarm and sends the proper commands to GSM module for transmitting an alarm message (SMS) and the video of the child in the rear part of car cockpit to driver's smartphone. Moreover, in order to delay child's hypertermia, if temperature sensor detects a internal temperature greater than a certain threshold value, the microcontroller enables the fan and lowers car windows by a few centimeters.

Fig. 7 shows the prototype version and the block diagram of the system referred in [12]. It is designed for detecting the child presence into a vehicle on the base of different parameters as movement, temperature, voice and odor, eventually sending a message to the driver, activating horn sound and lowering car windows.

The system is provided with a temperature sensor, a PIR sensor, a vocal detector and an odor detector, able to recognize child's scent. It is enabled after vehicle is parked and a vocal message notifies to the driver this activation. Then, temperature sensor, PIR sensor and vocal detector are enabled according to the following sequence. If temperature sensor detects a cockpit internal temperature greater than 40 °C or the PIR sensor detects movement or the vocal detector catches child's voice, then the microcontroller sends an alarm message to the driver through the GSM module. If the child is not withdrawn from car within a certain time interval, the microcontroller also enables horn sound and car windows' lowering. In addition to these features, immediately after vehicle's parking, before the activation of all other sensors, the odor detector is enabled, that can immediately detect child's presence through its odor profile and eventually alert the driver in previously described cases, using the same alarm procedures. This additional feature speeds up the reaction time of the system. Compared to the apparatus previously described, the designed system includes also a smart camera assisted by an algorithm for facial recognition (conceived by P. Viola and

M. Jones [13]), for taking over the face of the unattended child, thus allowing to reduce the false alarms probability due to event external of car or for a child who is motionless because he is asleep.

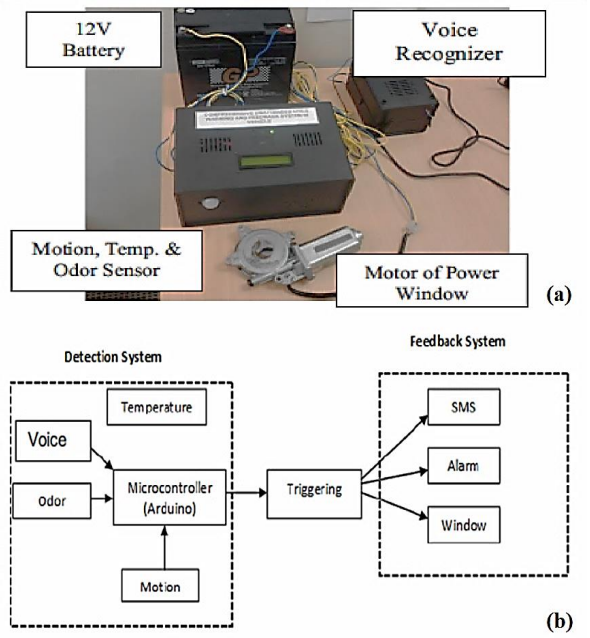


Fig. 7. Prototype (a) and block diagram (b) of the system in [12].

The "*Hot Car Baby Detec*tor" system reported in [14] allows to detect the presence of child in a car through its movement, its voice and its breath, also in conditions of high cockpit temperature. The system uses the following sensors for monitoring the vehicle's cockpit: a temperature sensor, an ultrasounds movement sensor, a vocal detector and a carbon dioxide sensor, used to detect child's breathing. The system waits in suspended mode until the car internal temperature is lower than a certain threshold. If the threshold level is reached, the temperature sensor enables the microcontroller and the other sensors, putting the system out of the suspended mode. In this case, if a movement, a sound or a growth of carbon dioxide levels are detected, the system enables an acoustic alarm. Before alarm activation, an acoustic signal is generated for 10 seconds, for allowing to the driver to disable the system for 10 minutes, whether the alarm has been activated from the driver. The sleep switch (see the system block diagram of Fig. 8), realized with a bounce switch in order to remove spurious pulses, allows to disable the alarm. Similarly, also the proposed system employs a CO_2 gas sensor to monitor the gas concentration variations induced by breathing and, by correlating these last with the information acquired from other sensors, to detect the child presence.

The system is powered by the battery and is provided with several voltage regulators in order to satisfy the power supply requirements of the different components. When the battery is about to run out, a warning message is shown to the driver.

Finally, the last system described in this Section is the "*Vehicle Occupancy Detection System*", referred in [15]. Its two main features are the recognition of children inadvertently abandoned in the car through infrared technology and the monitoring of temperature and humidity into car cockpit. Whether the system detects a child in the cockpit and, simultaneously, dangerous values for temperature and humidity parameters, the system transmits a warning message towards the car owner and it enables an acoustic signal to attract the attention of passers-by.

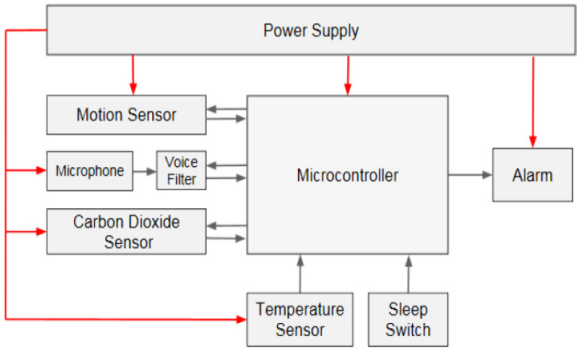


Fig. 8. *Block diagram of the system reported in [14].*

The system consists of a main unit and a secondary unit, an acoustic alarm and a GSM module for SMS sending to the driver. As it can be observed from the system block diagram shown in Figure 9, the main unit is composed by the *ATmega328P* microcontroller, by the *BlueSMiRF* Silver Bluetooth module and by the *Adafruit HTU21D-F* module, that integrates a capacitive humidity sensor and a thermistor. The secondary unit is composed by another *ATmega328P* microntroller, by a *HC-06* bluetooth module and by a PIR sensor.

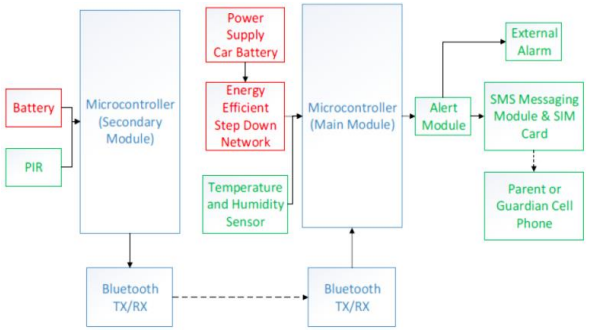


Fig. 9. *Block diagram of the "Vehicle Occupancy Detection System" referred in [15].*

The secondary unit, provided with PIR sensor in order to detect movements into car cockpit, communicates with the main unit through the bluetooth modules installed on both of them. The main unit receives and processes temperature and humidity measurements and consequently determines the internal climatic conditions of the car. The range of measurable temperature goes from -40 °C to 125 °C, as well as the operating interval for relative humidity is about 5-95%. When the PIR sensor detects the movement of an abandoned passenger into the car, the microcontroller of the secondary unit sends a bluetooth message to the main unit microcontroller. The latter processes the information and enables the temperature/humidity module, for controlling cockpit climatic conditions. If the obtained heat index is dangerous

for child's health, the system sends a warning GSM message to the driver. If the child isn't picked up, the microcontroller also enables an external acoustic alarm. This alarm strategy based on SMS was also employed by the proposed system, because more robust and available in every condition in which the car can be.

Furthermore, in [16] is presented a simple and efficient capacitive sensing system, suitable for detecting presence of a child inside the car; the prototype is based on a capacitive sensor system for detecting the child occupancy. In particular, the developed capacitive sensor is applied to infant seat; a suitable conditioning and control section, based on a sigma-delta capacitance to digital converter, generates warning signal as function of sensor data along with engine status; once the car's engine is turned off, the control system enables the capacitance-to-digital converter to compute the sensor capacitance. The system integrates an alerting section for warning the parents and the rescue teams if a child is found to be left alone in a car. In particular, if the cockpit temperature increases upon a fixed threshold, the warning system automatically sends, by means an integrated GSM module, a notification to parents or driver to help the child and automatically turns on the air conditioning system; in fact, the notification is suddenly transmitted to the child parents phone by means a mobile application. In addition, the car owner can remotely control in every time the air conditioning system status through the application afore discussed. The system includes also a CO_2 for monitoring the oxygen content inside the car cockpit; if acquired values indicate an anomalous CO_2 concentration, an alarm notification is automatically sends and the door windows will be slightly opened until the optimal oxygen level will be reestablished. Similarly, also the proposed system employs a CO_2 sensor, as below described, but to monitor the CO_2 variations in order to detect, along with the other sensors, the presence of child in the vehicle.

In [17], the authors reports some preliminary experiments aimed to develop an safety alert system to detect the presence of a child abandoned into an unattended car. The underdevelopment system is constituted by three main components; a vibration sensor is used for detecting if the car engine is still running, presumably because the car is still in motion or the driver is still inside the car. The system includes a temperature sensor for measuring if the temperature of the car interior exceeds 40°C, thus allowing to detect eventual critical situations for an unattended child; finally, a PIR motion sensor is used for detecting if a child is left inside a car. The coordinating unit of system is based on the ATMega328p microcontroller. The monitoring unit consists of a piezo-vibration sensor, a temperature sensor, a PIR sensor, a reed switch and a SKM53 GPS module, as well as the real-time output unit is constituted by a LCD display, status LEDs and a GPRS shield V3.0. If the temperature of car cockpit exceeds 40°C, the system checks the engine status by means the vibration sensor; if the car is turned off, the system looks for any movements inside the car. If any movements are detected, at first the system sends to car owner an alert message and, then, if no intervention is taken within 5 minutes, the system sends another alert message with the GPS location of car to the car owner and the car alarm is turned on. Compared to the prototype apparatus afore described, the proposed system acquires the information related to both engine status and doors status, by interfacing the system control board with the car electronic control unit, after an OBD II (On Boar Diagnostic) to UART signals conversion; in this way, more reliable information on car status are obtained compared to with obtained with a vibration sensor.

Another similar system for detecting unattended child left into a car is reported in [18]; it employs an environmental LM35 temperature sensor, to measure the temperature of the car interior and a sound detector, based on electret microphone and an LM393-based comparator, for detecting sounds inside a car cockpit when the car doors are closed. An on-board potentiometer can used to set sensitivity of the module; thus, if the sounds overcomes the set threshold, the on board digital output have a logic transition. This last is detected by a microcontroller board (Arduino Uno), that starts an alarm procedures; hence, the system looks for child movements by means of a PIR sensor. If any movements are detected, the systems sends an alert message, in form of SMS or e-mail, to the car owner, by means a GSM/GPRS module (based on SIM900 chip) interfaced with the Arduino board, through a UART communication. Compared to proposed system, the afore described system employs a simple sounds detector, that detects any sound with a level over a set threshold, with no distinction if the sound is internal or external the car; conversely, the proposed system employs a sounds recognition board for univocally detect some key words/phrases of child, discerning them from extraneous sounds.

In [19], the authors propose a simple and cost effective solution to alert vehicle owners of the presence of a child inadvertently left inside a vehicle and, thus avoid dramatic consequences. The proposed system uses a simple and compact capacitive sensor system applied to the infant seat to detect the child occupancy. Besides the capacitive sensor and other sensing devices (temperature and presence sensors), the monitoring unit includes a control system, that will take, based on acquired data, the corrective measures to overcome such critical situations. Furthermore, the developed platform is supported by a coordinator unit for sending the collected data to a remote server through web-services, in order to make them available for the law enforcing agencies and authenticated end-users. The monitoring system includes a warning unit that, once the car is turned-off and a child is found to be left alone in the car (in an infant seat), at first generates an audio alarm and, then, through a Wi-Fi or GPRS module, sends detailed information about the car position (GPS location) to the remote server. The controller acts as client of such safety system for communicating with a remote server. This last is implemented using node.js based web-services and it uses MongoDB database to store the data. Controller is equipped with a GPRS / Wi-Fi module to connect it with network; the data will be in form of JSON object. The controller calls web-service of remote server whenever the child presence is detected and temperature reaches the set threshold; specifically, the controller carries out the proper operations (lower the doors windows and sends alarm messages) if the temperature is above 104°F and the child presence is detected. Also the described system includes both a GSM/GPRS (SIM900) and a GPS modules (NEO6MV2), used to send warning SMS with the car's GPS location and real-time pictures from the car cockpit to a mobile app,

whether an unattended child is detected inside the car or on request from the car owner.

4. Strengths and weaknesses of described systems and possible improvements

Based on afore provided descriptions, some final considerations can be drawn on the sensors and methods used to detect the presence of a child inside the vehicle.

Referring to systems on the market, systems that use only the weight sensor installed into safety seat or into rear seat do not completely satisfy the desired reliability requirements, because the adopted sensors may not always work properly, despite its correct positioning. For example, it may generate false alarms due to objects placed on the seats. In the same way, systems based on motion detection using infrared sensor (PIR) may not always be effective: when the car internal temperature is very high or when the sensor is directly hit by the sun's rays, its accuracy decreases. An ultrasonic motion sensor could be more useful than infrared technology, because it is not affected by temperature conditions or sunlight exposure, but it could generate false alarms due to the sensitivity of ultrasounds to drafts and vibrations.

The systems provided with a vocal detector may enhance these detection systems for minimizing the probability of false alarms. The carbon dioxide sensor technology improves the performances of the movement sensors, because it allows detecting child presence also when it is stationary or asleep. At the same time, a temperature sensor makes the system safer, as it allows controlling car internal temperature in order to prevent harmful consequences for child's health.

We can now discuss on the properties and features of the systems under development as described on scientific literature. The first two systems, respectively reported in [8] and [9], appear simple to be installed into the vehicle. The second one, moreover, ensure a greater detection effectiveness using a vocal detector besides to the PIR movement sensor. In order to improve these systems, they may be installed connected to the vehicle security alarm system, exploiting its alarm types, besides to the warning message to the driver.

The system reported in [10] may be improved for ensuring a greater effectiveness. For instance, other detection technology, based on child movement, could be added in order to decrease the probability of detection failure of the weight sensor installed into safety seat. It may be modified also the condition for sending warning message to driver's phone, enabling it only when the vehicle is turned off and the doors are blocked.

The system reported in [11] appears simple and easy to install into any vehicle, because it is realized with cheap components and the control unit has small size. Moreover, it ensures safety and effectiveness from both points of view of child detection method (weight and movement) and of the implemented alarms and countermeasures (acoustic alarm, warning SMS, video, fan and windows lowering).

The system reported in [12] allows to reduce the false alarms probability, because the detection is based on several parameters: movement, voice, odor and temperature. The main feature of this system is the *e-Nose* (electronic Nose) technology, able to recognize child's scent into the vehicle. The system may be improved reducing its size, in order to allow a better integration into the vehicle.

The "*Hot Car Baby Detector*" project, referred in [14], provides a complete detection method, minimizing the number of false alarms and of detection lacks, thanks to the use of different kinds of sensors. The main system features are the controlled activation of the temperature sensor and the child presence detection through a carbon dioxide sensor into the car cockpit. The latter allows to detect child presence even when it is asleep and movement and voice sensors result ineffective. Another important feature is the long battery life, ensured by the suspended mode, enabled when the temperature is lower than a certain threshold or when no presence is detected into the vehicle for 30 minutes. A drawback of this system may be the possible generation of false alarms by vocal detector, due to external disturbs. An improvement can be obtained by including an additional enabling condition for temperature sensor (useful when temperature value goes down a minimal threshold), the integration of other alarms and countermeasures kinds, as warning messages to the driver and windows lowering for child's health safety.

Finally, the "*Vehicle Occupancy Detection System*" project, reported in [15], may be improved by adding other sensor kinds in order to minimize false alarms and situations of detection lack. Indeed, the PIR sensor cannot detect small movements as the one generated by child's breathing during sleep and, in other cases, it may also generate false alarms. In order to provide further improvement, a low battery warning or a switch for system disabling could be introduced with the aim to reduce energy consumption when the driver deems it appropriate.

5. Features and functionalities of the proposed solution

The proposed system employs an Arduino Uno platform, provided with the ATmega328P microcontroller, as main section; the board is connected to a SIM900 GPRS/GSM module (AZDelivery) and to NEO6MV2 GPS module (U-blox). The environmental parameters are acquired by an HB100 Doppler motion sensor (ST), two HC-SR501 PIR sensors, an MG-811 CO_2 sensor (Sandbox Electronics), a DHT22 digital humidity / temperature sensor (Homotix), an EasyVR Shield 3.0 vocal recognition system (Robotech) and a PixyCam camera (Charmed Labs). The block diagram of the whole system is shown in Fig. 10.

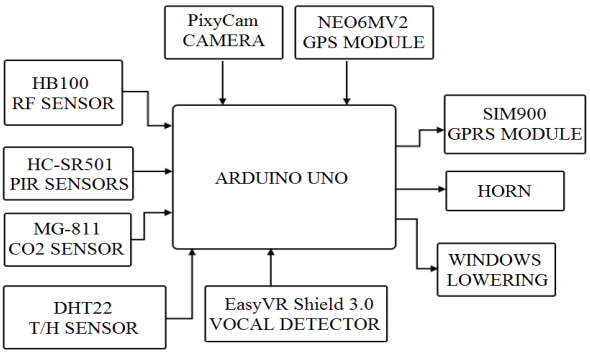


Fig. 10. *Block diagram of the proposed detection system.*

Aforementioned devices and sensors are all connected to Arduino board, employed to process the acquired data, to detect when the engine turns off and to monitor the doors status, to discern alarm conditions and, consequently, to enable the horn and the windows lowering.

An Arduino board was used as motherboard only for simplicity of implementation; however, the proposed solution could be implemented with several microcontroller models, because all used sensors and devices employ standard communication interfaces.

In Figure 11 it is shown a diagram of all physical connections between motherboard and the several peripherals, where the connections between the different sensors / devices with the Arduino board are indicated with numeric labels. The PixyCam camera communicates with Arduino board by means of the SPI interface (ICSP connector). The MG-811 CO_2 sensor is interfaced with an analog channel of the motherboard (A0 pin), for acquiring and converting the analog voltage provided by the sensor as function of CO_2 detected levels. The EasyVR Shield 3.0 voice recognition device is interfaced with the Arduino board through TX/RX pins of the serial communication bus (1 and 0 pins), as well as the DHT22 humidity / temperature sensor communicates by a single digital pin (2 pin). The HB100 Doppler motion sensor provides on the IF pin an analog output signal, that is conditioned by low frequency and high gain amplification stage and acquired by analog channel of the Arduino board (A1 pin). The two PIR motion sensors are connected to the Arduino board by means of two different digital inputs (5 and 6 pins, respectively).

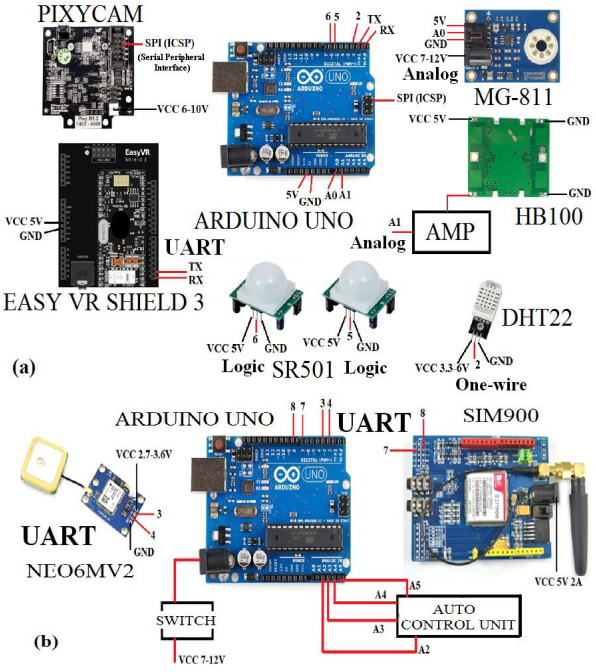


Fig. 11. *Diagram of the physical connections between motherboard and each block of the proposed system:* the connections between the different sensors / devices with the Arduino board are indicated by numeric labels placed near each pin.

Both SIM900 GSM/GPRS board and NEO6MV2 GPS module are interfaced to the control unit by means of two different UART interfaces, enabling the data exchange with the motherboard (7, 8 and 3, 4 pins-serial software). Furthermore, four different pins have been employed to interface the Arduino board with car control unit, for acquiring information related to the vehicle, as doors and engine status, and to manage horn activation and windows lowering (A2, A3, A4 and A5 pins); this signals are provided by a codec board, that interfaces with the car control unit, door lock control units and car startup circuit, respectively. Figure 12 shows the system's modules arrangement inside the car cockpit. From car's top view, it can be observed the positioning of the different modules: the car control unit interfaced with the Arduino motherboard, the voice recognition board, the RF and PIR motion sensors, the temperature sensor, the PixyCam smart camera and the GSM / GPS modules, which represent, along with the Arduino board, the processing unit of the system. From car's side view, it can be noticed the placement of the smart camera and of the carbon dioxide sensor inside the rear door furnishing, on the same side of child's safety seat location, as well as the vocal recognizing module, the temperature sensor, the motion detectors and the smart camera will be placed inside the vehicle's roof. Similarly, RF microstrip antennas and the optical group of smart camera have to be pointed toward rear car seat, for getting an optimal view. Inside the car boot, the processing unit will be located, as well as near driver's seat, the deactivation switch will be placed.

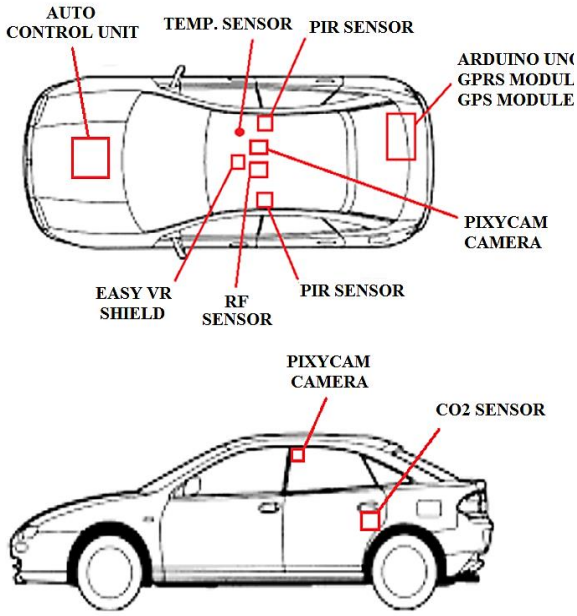


Fig. 12. *System's device positioning into the vehicle.*

The power supply of the whole system is obtained by the 12 VDC of the car battery; specifically, a step down voltage regulator D24V25F5 (produced by *Polou*) was used for obtaining a steady 5 VDC in output and ensuring the relatively high current level when the GSM/GPRS module transmits the data. Moreover, another LDO(low-dropout) voltage regulator was employed (LM317) for obtaining a steady voltage of 7 VDC, for powering supply the PixyCam smart camera and the MG-811 carbon dioxide sensor. The

estimated power consumption of the whole system is nearly 250 mW when the GSM/GPRS module is in sleep mode, whereas reaches transient peaks values of 9.5W when the system transmits the data; however, the time duration of the transmission phase is very short(~ 230 ms) with a low duty cycly (0.1%), then it has little effect on the average consumption of the system.

Now a detailed description of system's control logic is given. The motherboard, including ATmega328P microcontroller, checks the occurrence of two contemporary conditions: the engine is off and the doors are blocked. If these conditions are verified, the system waits five minutes to allow the car owner to come back to the vehicle; whether passengers are inside the car, the driver can easily turn off the control board. If after five minutes, the doors aren't blocked, the system verifies the status of engine.

Otherwise, if after this time interval the car doors have not been unlocked, the system enables the control sequence for child's presence detection. At first, the control board acquires the initial CO_2 level inside the cockpit and, then, the system initializes a counter of detection events and activates the face recognition module. If the face recognition module recognizes the child's presence, the counter is increased and the voice detector is enabled. Instead, if the camera does not detect child's face, the system directly enables the vocal detector without increasing events counter. Thus, if the voice detection module picks up the voice or a sound produced by the child, the events counter is increased and then checked. If the counter overcomes 1, both Pixycam module and voice recognition system have detected the presence of child, thus the system starts the alarms activation sequence, as below described. Otherwise, if events counter is lower or equal than 1 or voice recognition module doesn't detect any sound inside the car cockpit, the system verifies the CO_2 level variation respect starting levels with a defined threshold. Therefore, if this variation overcomes the set threshold, the system increases and then verifies the events counter. If the counter is greater than 1, the system alarms activation sequence is enabled. This mechanism allows to detect an infants abandoned in the car also in the condition in which he is asleep and it is covered with a blanket, because due to his respiration activity the CO_2 level inside the car changes equally. However, if the counter doesn't overcome 1, or if the measured CO_2 level variation is lower or equal than set threshold, the system sequentially activates the Doppler motion sensor, the PIR1 sensor and the PIR2 sensor. Even if only one of these sensors detects movements into car cockpit, the detection counter is increased. If the counter value overcomes 2, it indicates that at least three sensors have detected child's presence, thus alarms activation sequence is enabled; conversely, the system will restart the verification cycle described above, resetting the events counter. The two PIR presence sensors and a Doppler effect presence sensor were employed in order to ensure a detection zone covering the whole rear seat of the car, hence, they are able to detect any movements on the rear seat.

According the aforementioned operation logic the overall detection probability can be expressed as following reported in (1):

$$P_{DET} = P_{face}P_{voice} + P_{face}P_{CO2}(1 - P_{voice}) + (1 - P_{face})P_{voice}P_{CO2} + (P_{PIR1}P_{PIR2} + P_{PIR1}P_{MW} + P_{PIR2}P_{MW} + P_{PIR1}P_{PIR2}P_{MW}) \quad (1)$$

Where P_{DET} is the detection probability of the system. P_{face} and P_{voice} are the detection probabilities of the face and voice recognition systems, respectively. P_{CO2} is the detection probability of CO_2 detection system; whereas, the P_{PIR1}, P_{PIR2} and P_{MW} are the detection probabilities of the two PIR presence sensors and of the microwave movement sensor. However, the single detection probability is function of installation position, sensitivity settings and devices training.

The afore described logic, implemented by control unit, takes decisions by correlating the information acquired by multiple sensors / devices distributed inside the car's furnishing; in this way, we believe that a reliable detection mechanism is ensured, allowing to reduce the risk of positive and negative false alarm. In particular, the combination of different detection systems, as the face recognition, the voice recognition and the movements detection, according a gradual and crossed logic can allow to detect an unattended child in every condition in which it could be found, also whether it is asleep or covered by a blanket; in this way, by equipping the system with multiple recognition systems (voice and face), apparently redundant, a reliable detection of a child abandoned inside the car cockpit, regardless his position on the rear seat and in every operative scenario is ensured.

The alarms activation sequence starts by measuring the cockpit internal temperature, in order to compare it with a set threshold value. If the internal temperature is greater than the threshold, the system activates the horn, lowers car windows by few centimeters and sends both alarm messages (with vehicle's GPS position) and pre-recorded phone calls to the configured contacts. As an alternative, if internal temperature is lower than threshold value, the system only sends alarm messages (with vehicle's GPS position) and pre-recorded phone calls. After this sequence, a delay of five minutes is introduced for allowing the car's owner to come back to car. Furthermore, if the system takes over a doors opening or opening and closing, it concludes cockpit monitoring; therefore, if the driver left the car for a short time period, the system avoids to warn the relatives and the rescue teams. Otherwise, the system sends a recorded phone call and alarm messages to the driver (with vehicle's GPS position), to alternative contacts and to the rescue teams. These alarm messages are in form of SMS directed to the car owner reporting the car's GPS location, but also in form HTTP (hypertext transfer protocol) response / request toward the remote database (DB); the remote database was realized using MongoDB. This last is periodically polled by the specially designed mobile application for detecting the status of monitored car. In fact, besides the developed firmware and hardware solutions, a custom IT platform was realized to support the operation of system. Specifically, the IT platform includes a remote database (DB) and a mobile application communicating with hardware section of vehicle by means of an internet connection. Through this application, the car owner can checks the system status, checks the car location, remotely requires pictures of the internal of car

cockpit and, mainly, receives alert messages whether a unattended child is detected inside the car. In addition, this application enables to remotely control numerous car functions, as the horn activation, the lights flashing, the windows lowering, the doors locking and unlocking. In fact, the data exchange with remote DB is bidirectional, namely the vehicle transmits on DB its status data and queries the DB for any incoming commands from application; simultaneously, the application can query the DB for acquiring the information related to the system's operating status and insert on DB the requests for commands to be executed by the vehicle system.

6. Technologies and devices involved in the proposed detection system

In this section, it is provided a detailed description of all devices involved in the realization of the proposed system, from the control unit, which processes all system's operations, to all peripherals used in acquisition and actuation phases.

The Arduino Uno platform represents the system control unit. It processes the proper signals in order to discern if engine is in on or off status and if doors are locked or unlocked, it manages data acquisition from sensors, processes extracted information and activates the proper alarm procedures. The core of this board is an *ATmega328P* microcontroller (*Atmel*), provided with 14 GPIO pins (*General Purpose Input/Output*), 6 of which configurable as PWM output (*Pulse-Width Modulation*), 6 analog input pins, a 16 MHz oscillator, an ICSP header (*In Circuit Serial Programming*) and a reset button. The ICSP header allows to program the microcontroller while the platform is installed in a global system (without removing it).

The *PixyCam* module, shown in Fig. 13, is an image sensor used in this system to recognize child's face. The device is able to recognize, by means of a color filtering algorithm based on hue and saturation processing of each RGB pixel, some objects previously stored in memory. The *PixyCam* module is composed by an LPC4330 dual core microcontroller (NXP) and by an OV9715 sensor (*Omnivision*) with M12 standard lens, 75° horizontal angle and 47° vertical angle. The microcontroller is based on a 32 bit ARM Cortex-M4 core (Harvard) with an ARM Cortex-M0 coprocessor. Its operation frequency can reach 204 MHz and its core has low power consumption and high integration level.

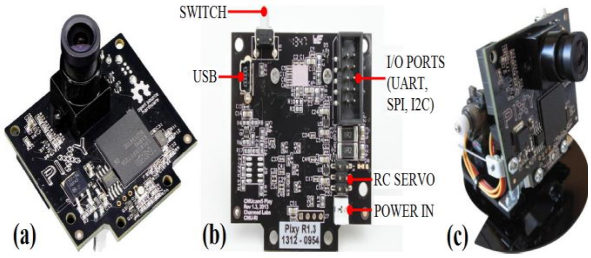


Fig. 13. *PixyCam module:* top view (a), bottom view (b) and Pixy Linker Kit mounting support (c).

The OV9715 sensor has an HD 720p video resolution at 30/50 fps with high sensitivity technology; it includes advanced functionalities related to image processing, exposure control, white balancing, defective lenses, pixels corrections and it can operate from -30°C to +85°C. The module can be integrate with additional tools, as the *Pixy Linker Kit* (Fig. 13c) and the *IR-LOCK starter kit*. The *Pixy Linker Kit* is a mounting support with a biaxial servomotor, interfaced through RC servo output shown in Fig. 13b. The application of the embedded control logic to a motorized actuator allows to correct camera orientation in order to always obtain the optimal framing for the monitored space. The electronic management of mechanical engines is widespread in several application fields, because it allows the devices' movement or rotation according to real time data processing. In photovoltaic sector, electronically controlled motors are employed in order to orient the PV (Photo Voltaic) panels with the angle of greater solar radiation, that 8hanges during the day [20]. Moreover, in literature there are many contributions related to the study of methods for driving and controlling different kinds of electric motors [21]. The *IR-LOCK starter kit* includes a filter and infrared lenses to be installed on camera in order to also enable the night vision. In addition, this smart camera can be used to acquire pictures from the internal of car cockpit, if the child presence is detected or the user requires this operation. After the acquisition, the pictures are sent by means of the GSM/GPRS module to the remote server, where the user can download them through the mobile application.

The *MG-811* (Sandbox Electronics) CO_2 detection module (Fig. 14), is composed by a conditioning circuit, that amplifies the output signal and by a heating circuit, that leads sensor to the proper work temperature. It has high sensitivity and selectivity towards CO_2, low humidity, and its output voltage signal is inversely proportional to the CO_2 concentration. The sensor consists of a cell that provides an output voltage in the 100-600 mV interval for CO_2 level detection from 400 to 10000 ppm. The output voltage during clean air conditions (typically 400 ppm of CO_2 concentration) is about 200-600 mV, that represents the base voltage.



Fig 14. *Sandbox Electronics MG-811 CO_2 detection module.*

The conditioning circuit is necessary, because the cell output signal has a low amplitude and an high impedance. The MG8-11 sensor detects carbon dioxide levels through a solid electrolyte; when the gas (CO_2) diffuses on the sensor, the chemical state of the electrolyte material placed between two electrodes changes by chemical reaction and consequently also the current between the electrodes. There are other methods for detecting gas or suspended particles concentration, such as spectrophotometry, which measures the absorption of light radiation from a gas subjected to a light source. A significant reference of an electronic system that employs this gas detection method is reported in [22].

The *DHT22* (Homotix) sensor module allows measures with long term reliability and stability; it includes a capacitive humidity sensor and an high precision temperature detection device. The module works with a power supply from 3.3V to 6V and absorbs a current of 1.5 mA during measure and of 50 µA during idle state. Its temperature detectable interval goes from -40 °C to 80 °C with a 0.5 °C step, while its humidity detectable interval goes from 0 to 100% with a 2% step. The sensor switches from low power mode to working mode only when Arduino platform sends the start signal. After this triggering signal, the sensor sends a 40 bit response signal, which contains temperature and humidity measures.

The HB100 RF microwave sensor (ST Electronics) is a transceiver module based on Doppler effect for movement detection. It emits microwaves at a defined frequency. If an object is into its detection range, it reflects the emitted signal. Therefore, if the object is stationary, the reflected signal will have the same frequency of the emitted one, otherwise the frequencies will be different. The HB100 sensor, shown in Fig. 15b, is obtained by a couple of microstrip antennas, by a dielectric resonator oscillator, and by a microwave mixer. It emits X band RF signals at 10.525 GHz through microstrip antenna and receives the reflected signal. After mixer processing, the sensor provides an analog output voltage in µV order, with amplitude proportional to the energy of reflected signal and frequency proportional to object's speed. Fig. 15a shows a block diagram of the described sensor. The module has to be installed with microstrips faced to detecting zone, in order to obtain the best coverage.

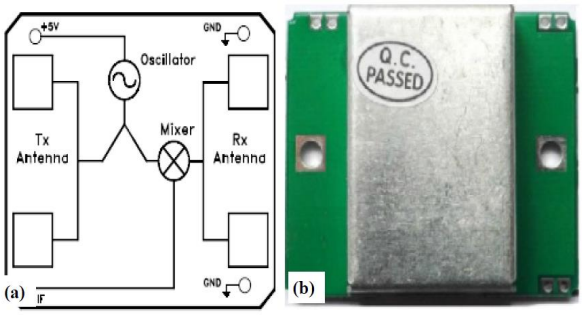


Fig. 15. *HB100 microwave movement sensor*: block diagram (a), top view of considered sensor (b). *(images provided by ST ELECTRONICS®)*

The sensor module is powered by 5V voltage and presents a low power consumption and a large detection range, with a 40° vertical angle (radiation diagram in Fig. 16a) and a 80° horizontal angle (radiation diagram in Fig. 16 b). It works in both 'Continuous Wave' (CW) or 'pulse' modes, but in the second case it needs a sample&hold circuit on output pin.

This system uses two *HC-SR501I* PIR sensor modules, that consists of a passive pyroelectric sensor, a *BISS0001* integrated circuit, a 3.3V voltage regulator and a diode for polarity inversion protection.

It is able to detect target up to 7 meters away, with a 110° angle. The sensor has an operating temperature that goes from -15 °C to 70 °C and provides a digital output signal (high = detection, low = silence). The module is provided with a trimmer for sensitivity regulation and another one for output maintenance time regulation (from 3 to 300 sec).

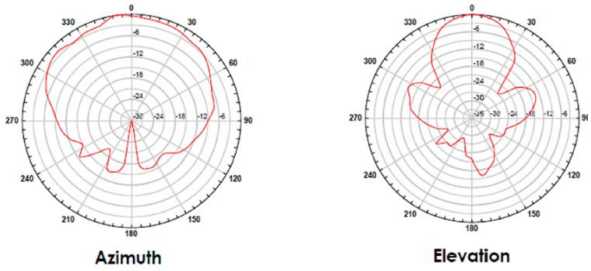


Fig. 16. *Radiation diagrams of HB100 microwave sensor:* vertical (a) and horizontal (b) view *(images provided by ST ELECTRONICS®)*

The *EasyVR Shield 3.0* module (Robotech), reported in Fig. 17, is a support board for *EasyVR 3* vocal detector and allows its simple interfacing with Arduino platform. It is provided with additional connectors for microphones, speakers, headphones and GPIO headers. The module supports 32 vocal commands, belonging to different categories: speaker dependent (SD), trigger SD and speaker verification (SV). Speaker dependent and speaker verification commands are completely user-definable and they works only with the voice used during configuration. SD commands recognize the pre-recorded words, while SV commands recognize the used voice. The module also allows to set vocal passwords in order to deny the access to unrecognized voices. Moreover, it provides a selection of some already set speaker independent commands, that can be used without a previous configuration.



Fig. 17. *EasyVR Shield 3.0 vocal detection module.*

The detection of child's presence through vocal recognition gives a greater reliability to the proposed system. The acoustic–phonetic analysis of speech and the voice recognition are very current topics in technological research and in literature there are several contributions related to the study of the most reliable methods for the implementation of devices able to recognize sounds, voice and language [23].

The *SIM900 GPRS/GSM* module (*AZDelivery*), compatible with Arduino platforms, is based on SIM900 quad band module (*SIMCOM*). The module integrates a TCP/IP stack and is provided with 12 GPIO pins, 2 PWM outputs and a built-in ADC.

It is managed through AT commands on UART interface and so it allows to receive and send SMS messages, phone calls and to access Internet by means of GPRS mobile

network. In the proposed system, this module is used to alert driver and other secondary contacts during alarm procedure. The module includes a SIM card holder and a 3V CR1220 battery holder are installed on the bottom side of the module. The battery provides continuous power supply to RTC (Real Time Clock). The device is also provided with an external power supply connection, two jacks for microphone and speaker, two LEDs for power and network states.

Finally, the NEO6MV2 GPS module (U-blox), provided with an high performances six positioning engine, has a time-to-first-fix (TTFF) lower than a second and it is able to mitigate multipath effects, ensuring high performances. The module is equipped with a ceramic antenna and an EEPROM memory, in order to maintain configuration data during power supply absence.

The command/response exchange with the module is performed on TX and RX pins of its UART peripheral, with TTL logic (0-3.3V) and a default baud-rate of about 9600 bps.

7. Experimental Results and Discussion

In this section, the experimental results concerning the testing of above described unattended child detection system are reported; in such way, its effective performances in terms of detection capability were assessed, when the system is applied to a pseudo-real testing environment, as below described. Particularly, the most difficult conditions in terms of detection capability were reproduced in order to highlight the correct functioning even in the worst operating conditions.

For testing the system, a prototypal setup was realized for reproducing the car cockpit; inside, this environment, the different sensors and devices are installed according the arrangement previously reported (Figure 12). Afterwards, a training phase of both Pixycam module and of the EasyVR module, by setting frames of the target and voice samples, was performed. Moreover, by means to a motorized mannequin, the child presence was simulated, whereas by means a sound recorder, the child voice was reproduced. Furthermore, by putting in the environment a controlled flow of CO_2 (8 cm^3 / min), the respiration activity of child was simulated. Through this setup, four different conditions were considered for testing the system; in particular, the considered conditions are the following: 1) the infant is covered by a blanket but he moves and cries; 2) the infant is motionless and not covered but he cries; 3) the infant is mute and not covered but he moves; 4) the infant isn't covered and he is motionless and mute. These test cases are chosen in order to testing every components of system, beside to reproduce the scenarios and situations in which the system can operate.

After preliminary tests with obtained high detection percentages related to the first three scenarios described above, an upgrade of the system was carried out by installing a further CO_2 gas sensor inside the upper portion of the rear sit, near to the position where the classic isofix connectors are located. In this way, the more localized measure of CO_2 concentration combined, by a weighted average, with data provided by other gas sensor, installed inside the car's door furnishing, allowed to improve the detection capability (up to 82%) in the more critical scenario (identified with number 4 in the following Table 2), respect to the unsatisfactory detection capability (only 50%) previously obtained before the realized technical update.

Moreover, successive optimizations were performed in firmware implementation and sensors arrangements, for improving the child's detection probability; in particular, a dynamic thresholds' adaptation for the gas and microwave movement sensors was adopted in the firmware, in the case of the face recognition system or voice detector don't detect any child. More in detail, this adaptation mechanism progressively reduces the threshold value (respect to the initial one) by 1% every minute up to 20% during the time interval in which no face or voice is detected; if in this time interval a recognition event is detected, the threshold values are restored to their initial ones.

By using the upgraded experimental setup, several measurement campaigns were carried out for testing the proposed system under different operating conditions. In particular, fifty different tests, for each of the four operative conditions previously described, were carried out; the obtained results of aforementioned tests are reported in the following table (Table 2).

Table. 2: Table with reported tests' results performed by using the upgraded system under different operating conditions.

	Scenario	Detected	Not detected	Detection percentage
1	Infant covered, but he moves and cries	44	6	88%
2	Infant motionless and not covered, but he cries	43	7	86%
3	Infant mute and not covered, but he moves	45	5	90%
4	Infant not covered, and motionless and mute	41	9	82%

As evident from results reported in Table 2, the designed system ensures a good detection capability in all considered scenarios. In particular, when the child isn't covered but is motionless and mute, a detection percentage of 82% was obtained, result surely satisfactory given the critical scenario in which the system has to operate, taking into account that in similar conditions other competitor systems can't ensure comparable performances.

Summarizing, thanks to the wide set of used sensors and detectors, the developed unattended child detection system guarantees a mean detection probability higher than 86% relatively to the critical scenarios described in Table 2,

a satisfactory result considering the unusual and worst conditions in which the system was tested. Specifically, a 90% maximum detection percentage was obtained when the child is mute but he is moving and not covered, detection mostly ascribable to the face recognition detector and to movement sensors; instead a 82% minimum detection percentage was determined with the experimental tests when the child isn't covered but he is motionless and mute, detection attributable to the face recognition module and CO_2 sensors.

Finally, a table that summarizes the used devices, system technical features and functionalities is below reported (Table 3).

Table. 3: Table with reported the used devices, technical features and functionalities of developed detection system.

Used devices	System technical features	System functionalities
Arduino UNO board	Power supply voltage: 12V	Warning SMS with GPS coordinates to parents and rescue team
PixyCam face recognition module with IR LOCK	Peak power absorption: 9.5W	Smartphone app to receive warning messages and control system functionalities
2 x MG-811 CO_2 sensors	Mean power absorption: 250mW	Pre-recorded calls to parents
HB100 RF microwave motion sensor	Mean detection capability: 86%	Automatic car windows lowering
2 x HC-SR501I PIR sensors		Horn activation
EasyVR Shield voice recognition module		Flashing alert light
DHT22 temperature and humidity sensor		
SIM900 GPRS/GSM module		
NEO6MV2 GPS module		

8. Conclusions

The manuscript proposes an innovative system for detecting the child's presence inside an unattended vehicle; it has several innovative features compared to the other systems, because it employs several detection technologies that work together, for reducing the false alarms probability. Some of these technologies, as the *PixyCam* image sensor or the RF microwave sensor based on Doppler effect, represent an innovative features. The proposed system is complete and effective from the point of view of alarm types and procedures, because it provides all possible solutions related to alarm communication: automatic phone calls to car owner, SMS message with the GPS coordinate of vehicle to the driver, to alternative contacts and to rescue teams.

The integration of proposed system with an efficient anti-theft system for performing detections outside the vehicle can be considered a future development. For instance, shock/vibrations sensors could be integrated to the system for detecting vibrations to which the vehicle undergoes, or further smart cameras, faced outwards, could be used for controlling whether unknown individuals are approaching to the vehicle, and, consequently warning the car owner.

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