Arduino-Based Solution for In-Car-Abandoned Infants' Controlling Remotely Managed by Smartphone Application

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Original scientific paper

***Abstract*—This manuscript deals with V2V/V2I (Vehicle-to-Vehicle and Vehicle-to-Infrastructure) communication systems developed for smart city applications, with the aim to provide new services and tools for making driving safer and improving the human lifestyle. The considered systems can be supported by suitable software applications for making the services more accessible. In this context, research groups and automotive companies are currently developing systems against children abandonment in unattended vehicles and are installing them on new car models. In this paper, an innovative Arduino-based control system against children abandonment in cars is described. It introduces new functionalities respect to systems reported in literature or already on the market, in order to improve safety and reliability. The proposed system integrates a mobile app, which gives the possibilities of receiving alert or status messages, along with images directly acquired from car cockpit. In addition, the app allows to remotely control several car functionalities, such as horn activation, windows lowering and doors locking/unlocking. The wide set of employed sensors allows to solve some shortcomings of detectability presented by similar detection systems, thanks to a proper cross-checking of the acquired information.**

***Index Terms*—smart city, VANET, microcontroller, wireless communication, safety application, infants health safety.**

I. Introduction

Nowadays, the technology is deeply pervading all human activities, literally revolutionizing our lifestyles and allowing to solve or prevent issues irresolvable up few years ago. Recent advances in electronic and telecommunication fields allowed the development of new communication standards able to support the interaction between vehicles (V2V) and between vehicles and infrastructures (V2I).

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These communication standards are enabling the development of smart city paradigms, featured by new services and control systems, facing towards the sustainability, ecological measures and optimized solutions for mobility and security. Based on these considerations, in 2000 the VANET (vehicular ad-hoc network) concept was introduced [1]. These new networks are constituted by proper designed mobile nodes, interacting with fixed infrastructure by means of complex exchange of data packets. Given the continuous variability of this scenario, proper designed communication protocols and routing algorithms were introduced for ensuring the reliability of new proposed services. Furthermore, the development of 5G communication technologies can ensure high throughput and low latency data transmissions, essential for applications where real-time data exchange is required.

In the smart city scenario, the VANETs can have potential applications in several fields of human activities, leading significant advantages in terms of safety and efficiency of transport, better usage of parking spaces and enhanced infotainment services. In particular, the main application field is related to traffic safety systems, for assisting the drivers in their drive experience, allowing to prevent road accidents and to enhance traffic efficiency. Further applications regard infotainment and wireless payment services, enabling the driver to perform economic transactions, to access information and services directly from his vehicle. In most cases, these services are supported by a properly designed mobile application, that allows a complete remote control via a common smartphone or tablet. Therefore, the car companies are developing, jointly to their innovative services, also mobile apps for making these services remotely accessible in user-friendly manner. Hence, applications for monitoring fuel consumptions and traveled distances, but also to remotely control the engine starting/stopping, the windows lowering or to assist the driver during parking place searching are already present on market, as further described below in this paper.

In this context, vehicular sensors networks can be effectively applied for solving a serious problem, that is children abandoned inside cars. It is a deplorable problem, because it involves defenseless individuals that in many cases are not able to talk. Every year, thousands of this events lead in some cases to dramatic consequences, as heatstroke or hypothermia, up to death in extreme situations. In fact, in 2018 the total number of U.S. pediatric vehicular heatstroke deaths is increased respect to previous year, leading car companies and research groups to search for not very invasive and remotely controllable solutions. All the proposed systems, supported by different sets of sensors, can detect the presence of child forgotten in the car, by acquiring some meaningful quantities, such as motion, sound and CO_2 concentration. Most of these systems are installed in car cockpit, integrated inside its furnishings or into the child seat.

This manuscript describes the development of an innovative control system based on a Arduino Uno microcontroller board, for detecting infants forgotten inside a vehicle. The system allows to enhance its reliability by a proper combination and cross-checking of acquired information by the wide set of employed sensors; in this way, it permits to reduce the probability of false alarms in the detection of infants, under any conditions in which it could operate. Further novelty of the developed system is the availability of a software platform, that allows automatic alerting and remote monitoring functions, whose functionalities will be described in detail later in the manuscript. The Arduino Uno acquires information from a wide set of sensors placed in strategic positions of car cockpit and combines these data according to the designed firmware logic for supporting the decision-making process. Successively, it sends proper warnings for alerting the child parents and the police of the immediate danger. Specifically, the system integrates a smart camera equipped with a face recognition firmware and a sounds recognition board for detecting the face and the voice of forgotten children. Moreover, motion sensors (microwave-based and infrared-based) and a CO_2 sensor are placed in proper positions for detecting eventual human presence inside car. Beside the proposed hardware and firmware solutions, a suitable IT platform is designed for supporting the system operation. In particular, the platform is constituted by a mobile application and a remote database (DB) interfaced with vehicle's hardware section by internet. The platform allows driver to receive alert messages and images from car cockpit, when a child presence is detected within a parked car. Furthermore, it allows the remote control of several car functionalities, as the horn activation, the windows lowering, the lights flashing, the doors locking and unlocking.

The remainder of manuscript is structured as follows. The second paragraph reports an overview about the usage of V2V/V2I communication on a smart city scenario. The third paragraph presents an overview on control systems (manageable by mobile applications) applied to remotely interfaced vehicles. In the fourth paragraph, at first the description of developed Arduino-based control system for detecting infants abandoned in car is reported, successively mobile app functionalities for supporting the operation of hardware and firmware sections are reported. Finally, last section is dedicated to conclusions and future developments.

II. State of Art about Applications of V2V/V2I Communication in the Smart Cities Scenario

The advances in both hardware and software technologies have provided the opportunity of connecting vehicles with each other, giving origin to the commonly defined V2V (vehicle to vehicle) interaction. In this context, the mobile networking is the main technology for implementing an ad-hoc network, in which the vehicles represent its nodes. Furthermore, the interaction between nodes are usually based on a wireless mobile network, in which all mobile nodes interact with an access point, constituting the fixed core network. A vehicular ad-hoc network (VANET) is constituted by several mobile nodes, dynamically arranged as network, that exchange information with each other, not supported by a preexisting static network. For this application, three communication standards typologies were considered suitable for vehicular networks, namely the IEEE 802.11p (WAVE) standard, IEEE 1609 standards family and, finally, the SAE (*Society of Automotive Engineering*) J2735 standard. In 2015, the so-called *IEEE Connected Vehicles Initiative* was proposed by *IEEE Vehicular Technology Society* (VTS), leading to identify three main areas of interest of VTS, namely automotive, electronics, mobile radio and transportation systems; this initiative intends to promote the technical activities, the networking, the publications, the standards and the access to technical information in connected vehicles.

Considering a VANET, the routing of data packets between mobile nodes is a critical issue, because the mobile routers and their reciprocal connectivity can change frequently. In addition, also mobile nodes vary continuously their connection point towards the fixed infrastructure, thus a dynamic routing protocol is required for efficiently supporting the communication [1]. Hence, taking into account that the routing infrastructure is itself mobile, the data packets forwarding must be dynamic, resulting in a temporary address assignments to mobile nodes. Consequently, most of routing algorithms and networking suites must be adapted for an efficient operating in the mobile scenario.

Furthermore, the introduction of 5G networks will open new perspectives of applications in smart cities scenario. In fact, low communication latency, featuring this communication technology, enables an ensemble of new smart city applications, including smart urban agriculture, real-time detection of crime, intelligent traffic management and, of course, self-driving cars [2].

Several applications, services and technologies regard the connection of a vehicle to another vehicle or to an infrastructure or to its surrounding, enabling the vehicle's connection to external devices, networks, applications, and services. In particular, the applications of V2V/V2I communication are mostly related to improve traffic safety and efficiency and to provide information or entertainment to the driver [3], as well as other services, such as parking assistance, roadside assistance, remote diagnostics and telematics for autonomous self-driving vehicles and global positioning systems (GPS). Regarding to the traffic safety applications, the following several benefits can be achieved:

- Warnings before entering an intersection or a departing highways;
- Warnings about presence of obstacles or accidents on the road (Fig. 1);
- Alerts on a sudden stop condition (e.g., related to car collisions) or pre-crash warning;
- Lane change/keeping warnings/assistance;
- Privileging ambulances, fire trucks, and police cars.

All these safety applications are designed to increase the danger awareness and to reduce the accidents, by means of Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I) communication. For instance, in ref. [4] a warning message forwarding scheme, designed to improve the message delivery efficacy in vehicular environments, is proposed. The developed algorithm broadcasts the emergency warnings using duplicates as implicit acknowledgements and adopting an adaptable contention windows size, ensuring a reduced end-to-end delay. In fact, since the vehicle does not wait for acknowledgment, the warning message can be forwarded after only 50ms, allowing a rapid reception. In ref. [5], the authors propose a prediction scheme, based on a ICU (intelligent control unit), for estimating the collision probability at highway intersections, through the use of vehicle-to-vehicle communication. The ICU constantly monitors and records the vehicles positions in its range and, as a result of this information, calculates the collision probability of the vehicle. Therefore, on the base of future vehicle's path, the ICU evaluates the situation dangerously, alerting, by warning messages, the interested vehicles. Furthermore, ref. [6] proposes a predictive framework for collision warning based on connected vehicles, in order to warn the driver if the time-to- collision is within a preset threshold. The proposed framework estimates the vehicle trajectory by a Kalman filter algorithm, for predicting the vehicle collision event. However, the prediction results demonstrate an efficacy lack of algorithm in vehicle latitude estimates.

Fig. 1. Hazardous location warning (source: http://car-to-car.org).

The V2V/V2I communication found application, also, in traffic efficiency optimization, thus improving the efficacy of the transportation network. This aim is obtained providing useful information to the transport network managers, as well as to the vehicle drivers. For instance, this technology can reduce the traffic congestion through the transmission of useful information towards a central hub, giving to the transportation agencies true real-time traffic data, enabling them to manage their facilities, to maximize efficiency and to minimize congestions. In ref. [7] a novel architecture for effectively estimating the traffic density on a specific road is reported. The developed approach is based on the information collected by sensor nodes (represented by vehicles and road side units (RSUs)) and on the road map topology, in order to precisely estimate the instantaneous density of vehicles. Specifically, two estimation functions (i.e. V2V and V2I- based function) are needed for estimating this quantity, because different typologies of services require different information.

The V2V/V2I systems could also enable vehicles to cooperate, allowing them to travel much closer each other on the freeway and platooning. As a result, roads gain more capacity by fitting more vehicles into the same amount of space. In addition, systems for supporting the drivers into the driving experience belong to this scenario, providing them useful information about the road, related to speed limits, information on precedence, inhibitions, and so on. In this context, the *DS Extended Traffic Sign Recognition* system (developed by Citroën) is able to read speed limits and road signs, displaying them on instrumentation panel. The system is based on a smart camera placed on the top of the windscreen and by means of a visual recognizing algorithm, elaborates the acquired frames for detecting the different road sign typologies and, thus, providing feedback directly on car dashboard (Fig. 2).

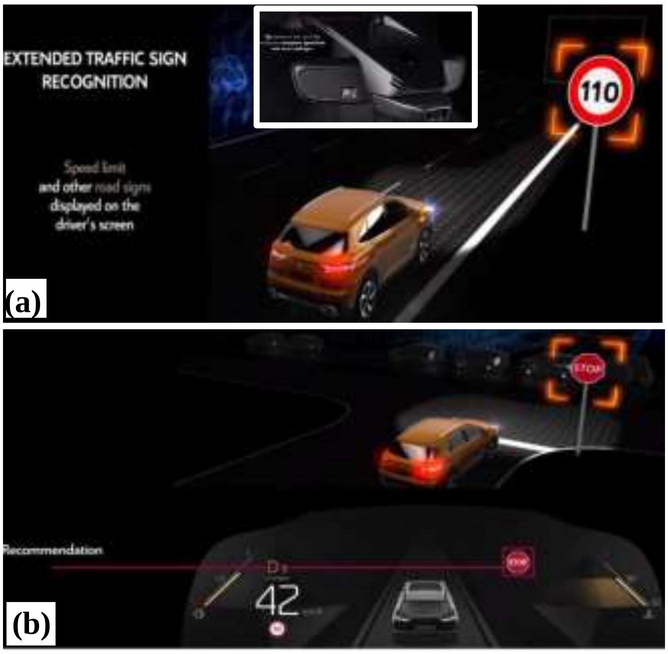

Fig. 2. *DS Extended Traffic Sign Recognition* system: speed limit sign recognition (a), stop road sign detection (between 20m and 40m away) (b).

Another application, where V2V/V2I communication could be employed, is the smart parking field. These systems can optimize the parking space usage for improving the traffic flow. In ref. [8], the authors propose a model by which the users can rapidly find a parking slot, by means of a smart combination of V2I (vehicle-to-infrastructure) communication and DGP (distance geometry problem), in order to obtain accurate and reliable information about the location of most appropriate parking slot, as function of user needs and objectives. A V2I communication system (Fig 3) requires the information transmission from the infrastructure to a vehicle, by means of a roadside equipment (RSE) that includes a DSRC apparatus (dedicated short-range communication). Some examples of application regarding this technology are related to cooperative intersection collision avoidance, to road departure warning, to danger zone alert, to speed limit communication, as well as to weather-based hazard.

Fig. 3. General structure of a V2I (vehicle-to-infrastructure) communication system.

Further application fields of V2V and V2I communication are the comfort services related to infotainment and payments. In this context, the vehicle directly interacts with the driver, providing periodic entertainment or information (weather, traffic and navigation information), as well as all the functionalities employed to minimize the driver distractions (Bluetooth and voice recognition commands). Since three years ago, Audi rolled out its *Audi Connect wireless parking-payment* program, which connects cars and parking services. This technology not only provides to driver the location lists of parking areas, but also allows parking barriers to be raised and to automatically pay for spaces. Furthermore, in 2017 Cadillac has started to equip its vehicles with a new version of the brand’s *CUE* (Cadillac User Experience) *infotainment*; this system provides access to new media and navigation services, but mainly marks the debut of vehicle-to-vehicle (V2V) communication technology on commercial vehicles. *Cadillac’s CTS* model will be the first car on market to get this new communication technology, under development for more than a decade. The V2V communication system in the *CTS* is based on dedicated short-range communication (DSRC) technology, which is a variant of the common Wi-Fi. This communication technology combined with a new augmented radar, additional cameras and a LIDAR (*Laser Imaging Detection and Ranging*) scanner, allows to extend the situational awareness hundreds of yards down the road or around corners, in order to make control systems aware of other vehicles approaching to a blind intersection. Furthermore, the placing of DSRC radios to infrastructures and smartphones can extend that awareness to traffic signals, pedestrians and more. The V2V/V2I communication systems can be also integrated in driver assistance systems, for aiding drivers in some complex operations such as parking pilot functions or adaptive cruise control, up to autonomous vehicles. For instance, the CACC (*cooperative adaptive cruise control*) is the most promising technology for obtaining autonomous vehicles driven in cooperative manner, thus introducing system-wide benefits [9]. Generally, a CACC system is based on information sharing between single vehicles in a network (VANET) by V2V communication, realized in autonomous manner without a central management. Through the information sharing of speed, acceleration and position, the autonomous vehicles can cooperate inside a certain range for obtaining these objectives:

- Reduce time/distance headway between vehicles;
- Improve the traffic throughput;
- Reduce the aerodynamic drag of vehicles, thus reducing the fuel consumption and pollutants emissions;
- Smoother flow and greater traffic stability.

Several CACC architectures are both reported in scientific literature and already installed on commercial vehicles. Most of these architectures are also equipped with various sensors typologies such as such as odometers, radars and/or LIDAR scanners. A fundamental phase of the CACC system implementation is the planning phase, that includes several algorithms for driving the systems in their decisions (e.g., as longitudinal and lateral position control algorithms) [10]. Specifically, the longitudinal controller is responsible for regulating the vehicle's cruise velocity, while the lateral controller steers the vehicle's wheels for path tracking. Both algorithms base their decisions on a high number of vehicle parameters, such as position, pedal angle, expected velocity, acceleration and so forth (Fig. 4). The several controls, given by the high-level planning phase, are provided in input to another low-level controller in order to implement the actuator phase, for converting the input commands into throttle and brake actions. Another main phase of the autonomous vehicle implementation is the information phase, defining the manner vehicle obtains information from surrounding vehicles. Several typologies of information flow are possible: predecessor-following, predecessor-leader following, two predecessor-following, two predecessor-leader following and bidirectional types.

The V2V/V2I communication find application also in policing and surveillance field, for supporting the activities of police and security bodies. Thus, police vehicles could use the V2V communication in several ways, especially for controlling infractions and crimes situations, such as:

- Surveillance application (e.g. finding stolen vehicles);
- Detect any speed excess;
- Crossings with red light;
- Entry into restricted traffic areas.

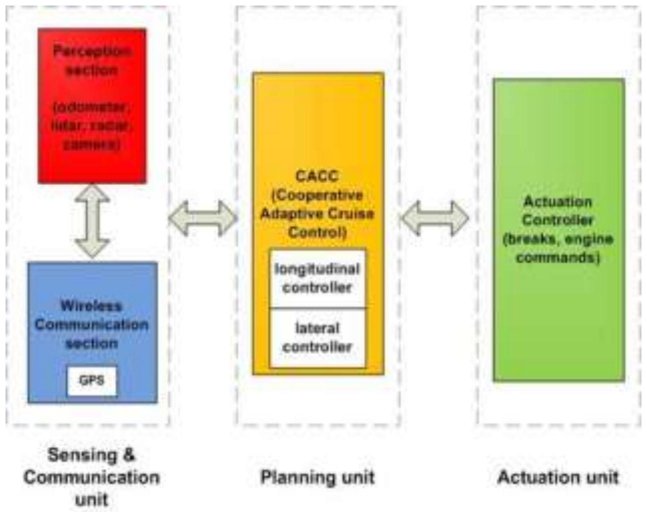

Fig. 4. System architecture of CACC (*cooperative assisted cruise control*) assisted vehicle.

III. Vehicle Control Systems Managed by Mobile Apps

In last years, technological innovations in electronic, IT and communication fields have radically changed people's life and habits. Just think about how many daily operations are carried out with the help of complex automated systems to understand the indissoluble link between modern society and technology. The progresses in communication, internet and mobile networks has certainly represented a key moment of technological development, giving to electronic devices the ability to interact, to convey information, to remotely communicate with the user. In particular, the widespread diffusion of smartphones, able to provide internet connectivity to everyone in every place and time, has made possible the design and development of many electronic systems remotely manageable by the user, through common applications installed on mobile phones. Today, mobile applications allow to carry out many operations, from the simplest to the most complex, from every part of the globe: purchases, mobile banking, domotics, video surveillance, industrial automation, remote controlling, environmental monitoring are only some examples [11].

The modern automation and control systems also find several applications in automotive field: the latest generation vehicles are assisted by electronic systems in most of their operations, managed by control units comparable to computers for performance and complexity. Scientific research has focused its attention on the development of electronic systems able to monitor all vehicle's functional parameters, to remotely control specific information and functions [12] or to locate vehicle from everywhere [13]. Several already marketed systems can monitor the vehicle's status, manage specific functions, check the car's geographical position, and receive notifications on particular events and much more.

Fig. 5. *Hyundai Blue Link* System connected with relative smartphone app (for further inform. see https://www.hyundaiusa.com/bluelink/index.aspx).

Naturally, vehicles equipped with remote management systems must be provided with internet connection, in most cases achieved by means of a modem device equipped with a mobile SIM card.

In USA, Hyundai Motor Company has developed a remote car control system named *Blue Link*, able to communicate with the vehicle through a Bluetooth link or remotely through a internet connection. Thanks to a mobile application installed on the phone, shown in the right side of Fig. 5, the user is able to monitor car conditions through diagnostic information, to check and change the status of the doors, to locate the car, to activate the horn or lights, to start and stop the engine and to manage the air conditioning system.

Ford Motor Company has developed *Ford Pass* system, similar to the previous one, but more focused on vehicle diagnostics and on some trip assistance services. The mobile application exploits internet and Bluetooth connections to allow the user to check diagnostic information and fuel level at any time, to start and stop the engine, to open and close the doors. Moreover, *Ford Pass* allows to quickly contact the roadside assistance, to find parking, to get useful information on service and refueling stations, during the trip. Fig. 6 shows some screens of Ford Pass application: vehicle's status monitoring (a), parking search (b), door opening/closing and engine ignition/shutdown (c).

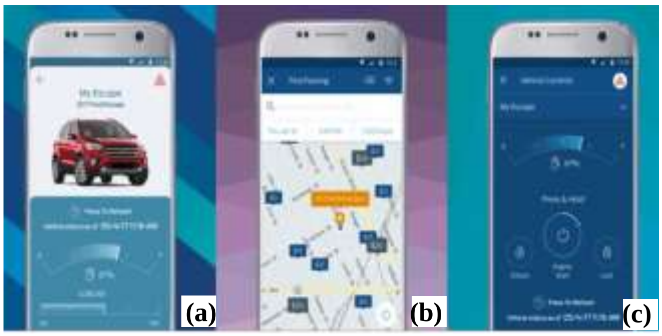

Fig. 6. Different dashboards related to *Ford Pass System*: main dashboard (a), *Find parking* dashboard (b), *Vehicle Control* dashboard (c) (for further information see https://www.ford.it/assistenza/ford-service/fordpass).

Several independent companies in the automotive sector have also developed and marketed remote controlled devices that can be installed on any branded vehicles and that have the same functionalities of *Hyundai* and *Ford* systems. These electronic devices have small size, must be installed in the car and have to be connected to its control unit. This systems are provided with a specific Android application, in order to allow the remote management. Some examples of these universal aftermarket systems are: *V-Auto* system (Vodafone, IT), *Smart-Start* system (Viper, CA), *Smart-Start* system (Clifford, UK) and *Mycar* system (WarmCarNow, NY). All these systems employ a small electronic device installed on the OBD (*off-board diagnostics*) connector of car control unit, which has an internal SIM card and is able to communicate with mobile phones through both bluetooth and remote mobile connection.

Modern vehicles are becoming adjusted to the current scenario of "smart cities", featured by increasingly connected cities, managed by intelligent control systems able to interact with the real environment and with people, for making everyday operations much simpler and faster. User safety is certainly the main target of electronic control systems related to automotive sector. The systems above described, for example, beside to car status monitoring and actions managing, allow to locate the vehicle, to alert the rescuers in case of accident or illness, to provide assistance in the event of a breakdown or to prevent a not still happened breakdown.

Other types of electronic systems applied to vehicles have been dedicated to the solution of specific problems related to safety, as the fight against theft and damage or the passengers" health protection [14]. These systems are often equipped with different types of sensors, that are able to acquire the greatest information amount from surrounding environment and to adopt the appropriate countermeasures in case of dangerous situations detection.

The anti-theft systems sector is certainly one of the most successful in terms of market demand. Modern anti-theft systems, properly connected to vehicle's control unit, are able to control many car parameters, to precisely track its position, to remotely communicate with smartphone applications for alerting driver in case of suspicious movements, vibrations or ignition attempts. An example of this kind of system is *Carlock*, shown in Fig. 7, that is composed by three parts: an electronic device to be connected on OBD connector of car control unit, able to communicate through both bluetooth and remote connection, an application installed on driver's smartphone and a remote database system.

Fig. 7. Schematic representation of *Carlock system* (for further information see https://www.carlock.co/).

The system periodically controls the car for detecting some specific actions (movement, steering movements, engine ignition, etc..) and sends data on the cloud, from where notifications are sent to driver's phone. The device is equipped with an own GPS system, that allows vehicle tracking from everywhere. In case of suspicious events or manumissions, the system immediately sends alarm notifications to the application, with the possibility to warn police.

Another increasing problem linked to automotive sector is related to the involuntary abandonment of infants in the car by parents. In these cases, the consequences for child's health can also be very serious. For this reason many automotive companies have developed different control systems able to detect the presence of the child forgotten in the vehicle, to monitor the environmental parameters, to perform some first intervention actions (such as windows lowering) and to send the alarm to driver's smartphone, along with other auxiliary information relating to environmental conditions or child state, up to audio and video acquired via microphones and cameras. On the basis of implemented functionalities, these systems can use different communication channels or provide a smartphone application for managing vehicle's operations.

A first example of this kind of detection system, based on child movement, is the "*Rear Occupant Alert"* system, developed and installed by *Hyundai* on its cars since 2019 (Fig. 8). This system uses ultrasound sensors for detecting child's movements from rear seat, when the car is turned off and the driver has closed the vehicle and has moved away. When the system recognizes a passenger left in the unattended car, it activates car lights, horn sound and it exploits the SMS communication channel for sending an alarm message to the driver. In this case, no application is needed on phone side.

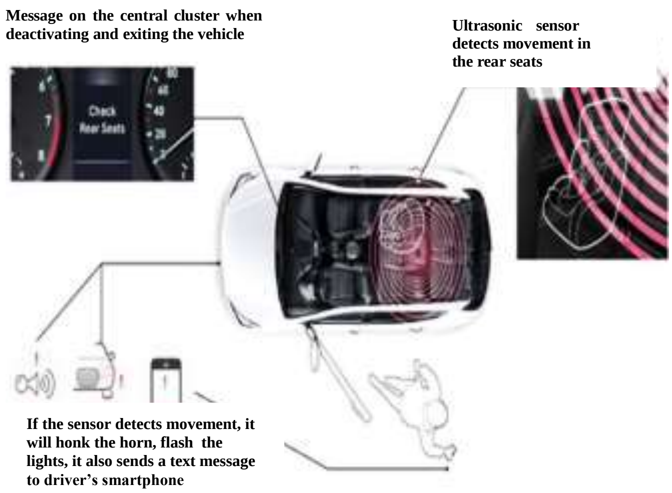

Fig. 8. Rear Occupant Alert system developed from *Hyundai* (for further information see https://www.multivu.com/players/English/75060517-hyundai-rear-occupant-alert/).

An example of child presence detection system into the vehicle, managed by a smartphone application, is the "eClip" system, realized by *Elepho* company thanks to *Kickstarter* community support (Fig. 9). This system bases its functionalities on Bluetooth Low Energy (BLE) link between the electronic device (*eClip*) (shown in the left side of Fig. 9) installed on the safety belt of child's seat, and the supplied application for driver's smartphone (shown in the right side of

Fig. 9). When the parent puts the child on the seat, it hooks the *eClip* on child's safety belt, activates it and establishes the Bluetooth connection with its smartphone through the app. If the parent moves away from its vehicle without the infant, the app stops receiving Bluetooth signal and performs some alarm messages and sounds.

Fig. 9. *eClip* system developed by *Elepho* (a) and relative smartphone app (b) (for further information see https://elepho.com/product/eclip-baby-reminder-for-your-car/).

The described system does not allow any remote control, but control, but aims to avoid that parents forget children in car by means of proximity detection. Several systems typologies have been developed in this sector, each with different complexity and features. As below described, the aim of this paper is to propose a system for child's presence detection into an unattended vehicle, provided with many different detection technologies and remotely connected with driver's phone. The proposed system is able to offer innovative features and to minimize detection failures or false alarms.

The advances of cellular communication networks that in last twenty years have rapidly evolved from 3G to the current 5G, today allow data exchange over mobile network at very high speeds, giving incredible potentialities to remote systems in view of increasingly smart cities and world scenario.

IV. The Proposed Smart System for Abandoned Child Detection into Unattended Vehicles

In this section, it will be described the proposed prototype system for infants' presence detection into an unattended vehicle. As previously introduced, this system exploits the mobile data network in order to be always connected with an application installed on user phone, by which the user can remotely control all systems" functionalities [11]. The core of the proposed system is composed by the Arduino Uno microcontroller board, equipped with the ATmega328P microcontroller and connected to SIM900 GPRS/GSM module (AZDelivery) and to NEO6MV2 GPS module (U- blox). The environmental parameters are detected by the following sensors set: an HB100 microwave movement sensor (ST), two HC-SR501 passive infrared (PIR) sensors, an MG- 811 carbon dioxide sensor (Sandbox Electronics), a DHT22 temperature/humidity sensor (Homotix), an EasyVR Shield 3.0 vocal detector (Robotech) and a PixyCam camera (Charmed Labs). The block diagram of the developed system is shown in Fig. 10. The described modules and sensors are connected to Arduino board [15], that elaborates the useful signals for detecting the engine shutdown and controlling the doors status. Based on this information, the microcontroller is able to discern alarm conditions and consequently to activate the horn sound and the windows lowering. A diagram of all physical connections between motherboard and the several peripherals is shown in Fig. 11.

The EasyVR shield 3.0 is a multi - purpose speech recognition module, designed to easily add a versatile, robust and cost effective speech recognition capabilities to almost any application. In particular, the device allows to store a sound table and custom recognition grammars, that can be processed by a proper managing/programming software (*EasyVR Commander*) and loaded on the module. Hence, the module during the detection phase calculates the correlation between data acquired by the integrated microphone and the pre-recorded samples with the aim of recognize voices or sounds. Therefore, during the roll-out phases of system, a programming phase for recording the voice and the characteristic sounds of the child is needed.

The PixyCam smart camera is connected to Arduino board by means of SPI (serial peripheral interface) bus. The MG-811 carbon dioxide sensor is connected to an analog input pin of the motherboard, for acquiring and converting the analog voltage value provided by the sensor as function of the CO_2 environmental concentration. The EasyVR Shield 3.0 vocal detection module is connected to UART (Universal Asynchronous Receiver Transmitter) communication bus of Arduino board, whereas the DHT22 temperature/humidity sensor is connected to a common digital input. The IF analog output of HB100 microwave movement sensor is connected to a low frequency and high gain amplification stage, before the analog input pin of Arduino board. The logic outputs of the two PIR movement sensors are connected to two digital inputs of the Arduino board. The PixyCam is equipped with a vision sensor, which along with a proper elaboration algorithm allows to detect any kind of object; specifically, the PixyCam pairs a powerful dedicated processor (OV6620 produced by *Omnivision*) with an image sensor; the processor elaborates the images acquired from the image sensor and sends only the useful information to the system motherboard. In particular, the smart camera was equipped with a C++ version of Viola-Jones face recognition detector, that is a lightweight face recognition algorithm based on the well-known algorithm conceived by P. Viola and M. Jones in 2004 [16].

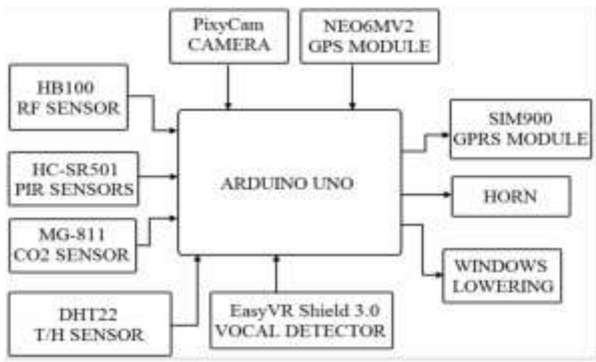

Fig 10. Block diagram of the proposed detection system.

This last introduces a novel technique to detect faces in real-time and with very high detection rate; it is essentially a feature-based approach, in which a classifier is trained for *Haar-like* rectangular features selected by the *Adaboost* algorithm.

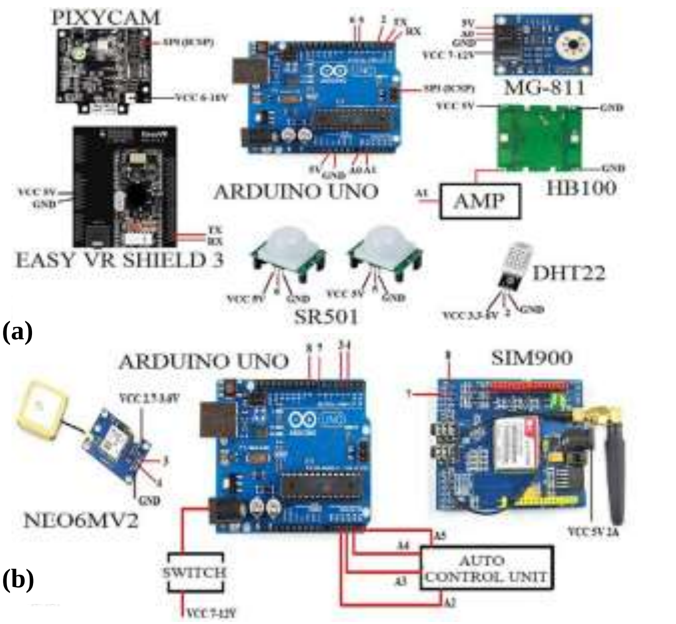

Fig. 11. Diagram of the physical connections between motherboard and each block of the proposed system.

The SIM900 GSM/GPRS module and NEO6MV2 GPS module are connected to the motherboard through UART interfaces, in order to allow data exchange towards main microcontroller. Four pins of Arduino Uno unit have been dedicated to car control unit interfacing, for acquiring information about vehicle doors and engine status and managing horn activation and windows lowering.

In Fig. 12 the system's modules positioning into the vehicle is represented. The car's top view shows the position of the following devices: the car control unit to which the system will be connected, the microwave and PIR movement sensors, the temperature sensor, the vocal detection unit, the PixyCam camera and the GPS and GSM modules, which constitute, together with Arduino board, the system's processing unit. The interaction between the designed system and the car's electronic control unit is implemented by transducing the information, provided by the control unit and coded according to the OBD-II (on-board diagnostic) standard (CAN protocol), into UART signals that are acquired by a software serial interface on Atmega 328P created by the *Software-Serial* library. Therefore, an OBD-II to UART converter, based on ELM327 IC (manufactured ELM Electronics), was connected to the standard diagnostic connector (DLC) of the vehicle and by means of a proper device library, several information regarding the car status can be extracted, including the status of the malfunction indicator light (MIL), diagnostic trouble codes (DTCs), inspection and maintenance (I/M) information, freeze frames, hundreds of real-time parameters and more.

The car's side view shows the positions of the PixyCam camera and CO_2 sensor, placed near car's rear door, on the same side of child's safety seat, whereas, the temperature sensor, the vocal detector, the movement sensors and the camera will be placed into vehicle's roof. The micro-strip antennas of RF sensor and camera lens must be turned toward rear seat, for ensuring an adequate coverage. The system processing unit will be placed into car boot and the switch for system's deactivation will be installed near the driver's seat.

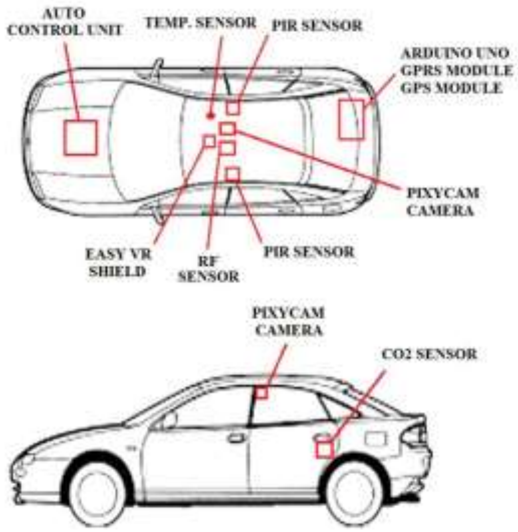

Fig. 12. System"s device positioning into the vehicle.

By means of GPRS module, the system is always connected with a remote server through mobile data network This feature allows the system to push its operative status and information on a remote data base, from which the mobile application periodically reads data and consequently performs the proper operation for interacting with user. The communication with remote database is performed on both sides: the vehicle system sends on DB its operating information and reads from DB eventual incoming commands from application; at the same time, the application reads from DB system's operating status for vehicle's monitoring and writes on DB the requests for commands to be executed by the vehicle system. In next section the remote application functionalities will be described more in detail. Fig. 13 shows the block diagram of the described remote communication between car system and driver's mobile phone, organized into three functional levels.

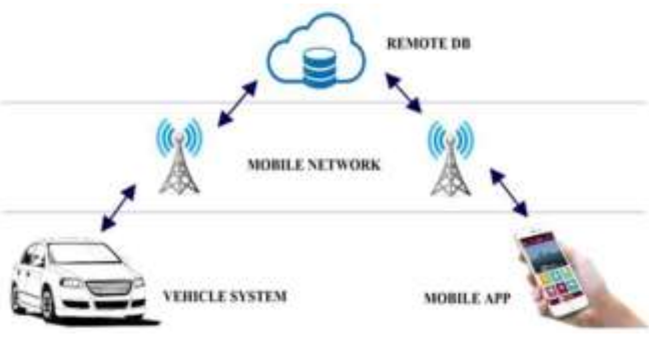

Fig. 13. Block diagram of the proposed detection system.

This periodic polling mechanism between mobile devices and remote server is implemented in this prototyping phase by means of HTTP (*hypertext transfer protocol*) requests / responses towards the server. Surely, more proper protocols could be employed for these application typologies, such as push notifications; in fact, in push notifications the publisher can send pop-up messages at any time and doesn't require the user to keep the application open all the time, fundamental requirements given the delicacy of the application. Therefore, as future development of the designed system, the employment of more efficient and functional communication protocols has to be provided.

In addition, the designed system could communicate with other near vehicles equipped with the same system, for alerting the near users of the danger and providing to it the GPS position of the car with the abandoned child. This additional function can be obtained equipping the system with an additional mid-range communication module supporting, for instance, 802.11p (WAVE) or 802.11a/b/g/n standard, for enabling this further alerting functionality and giving to the overall system a V2V character; such functionality could permit a more rapid intervention, issue very critical for this application. For instance, a *WaveCombo*™ (*ReadPine*® *Signals*) could be suitable for this scope; it is a multi-protocol wireless solution for connected car applications (V2X), supporting 802.11p, 802.11a/b/g/n, Classic Bluetooth, BLE and 802.15.1554/ZigBee standards in a single module.

The system's firmware, for managing in real time the vehicle's status [17], [18], is following described. The main microcontroller, placed on the motherboard, checks the occurrence of two contemporary conditions: engine shutdown & doors closed. In positive case, it enables a five minutes delay to allow the driver to return to the vehicle after parking. In the case of passengers on board, the driver can easily disable the system. If, after such time interval, the doors aren't locked, the microcontroller returns to check the engine status. Else, if doors are still locked, the control sequence for child's presence detection is enabled. Then, the system initializes the child detection counter, starts to detect CO_2 concentration into the car cockpit and enables the PixyCam camera. If the camera detects child's presence through its facial recognition or CO_2 level is greater than a fixed threshold, the system increases the counter and enables the vocal detector. Instead, if the camera doesn't detect the child's face, the system directly enables the vocal detector without increasing the detection counter. Hence, if the vocal detector picks up the preset voice or a recorded sound produced by the child, the detection counter is still increased. If its value is two or more, namely camera and/or vocal detector have assessed child's presence, thus the system enables the alarms activation sequence, as described below. Else, if counter's value is not greater than 1, namely vocal detector and camera don't detect any sound or face, the system continues to check the CO_2 level and compares the difference between current and starting levels with a defined threshold. Therefore, if this difference is greater than threshold, the system increases the detection counter, enabling the alarm sequence if it is greater than 1. If the counter isn't greater than 1, namely difference between the CO_2 levels isn't greater than threshold, the system sequentially enables the microwave movement sensor, the PIR1 and PIR2 sensors. If one of these sensors detects movement into the car cockpit, the detection counter is increased. If its value is greater than 2, it means that at least three sensing devices have detected child's presence, thus the system enables the alarms activation sequence, otherwise the system will restart from CO_2 level detection, resetting the detection counter. Therefore, the following Figure 14 shows the flowchart that summarizes the operation of the designed system, as previously described.

The alarms activation sequence starts with the measure of the cockpit internal temperature, comparing it with a preset threshold value. If the temperature exceeds the threshold, the system enables the horn sound, lowers car windows and writes the alarm command on remote DB, in order to start the alarm procedure on the phone application. The phone periodically controls the remote database for monitoring the vehicle status. When the alarm is found, the application activates warning sounds, phone's vibrations and shows alarm messages on phone display. After this alarm procedure, the system waits five minutes in order to allow the driver to return to the vehicle. If the system detects doors opening or opening and closing, it ends the cockpit monitoring. Else, the system sends a pre-recorded phone call to the driver, to other secondary contacts and to the police. The mobile application also allows the driver to perform some remote actions, i.e. the checking of wireless remote connection and system status, vehicle's position, car cockpit parameters and so on. All these features will be described in the next section.

In this prototyping phase, we set the cockpit temperature threshold to the value of 40 °C; given that the child's body overheats 3-5 times faster than an adult body, an exposition to such temperature for also a short period could led to a hyperthermia status [19]. For the CO_2 difference threshold, an empirical value of 1000 ppm was chosen for detection application (really the CO_2 difference threshold has to be chosen as function of the car cockpit volume and child age).

V. Mobile Application Functionalities for System Remote Control

As described during previous sections, the proposed smart system for child presence detection into unattended vehicles is provided with an Android application, that allows user to remotely control all system functionalities through its phone. This application has been developed by means of Java language, exploiting Eclipse SDK and Android Development Tools (ADT) software platforms. A description of main functionalities of the application will be provided in this section, in order to show the implemented remote control possibilities.

The system installed on vehicle (client role), periodically performs (each ten seconds) several HTTP posts towards a database placed on a remote server, for sending its acquired data (temperature, humidity, CO_2 levels, cockpit images), its GPS position, its presence detection and to control if any command has been set from user through phone application.

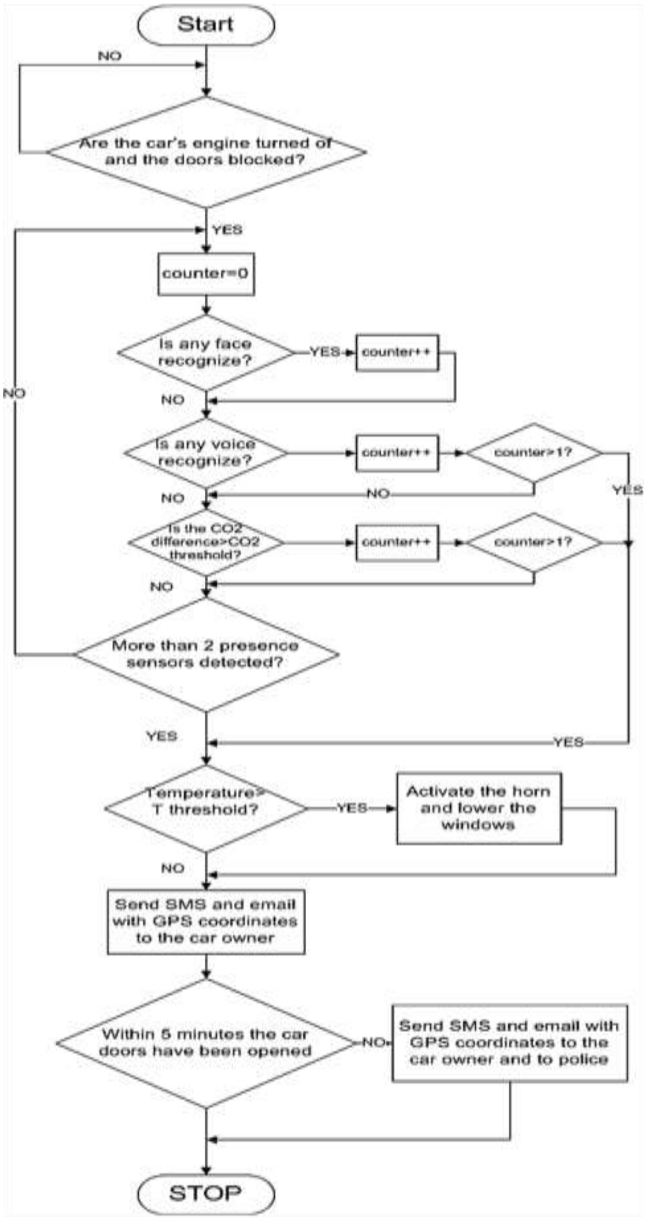

Fig. 14. Flowchart related to the operation of the proposed system.

At the same time, the mobile application (client role) periodically controls (each ten seconds) on remote DB the information posted from the system, for updating its status and controlling if the alarm procedure must be triggered. On server side, the corresponding PHP web services have been developed in order to serve clients invocations and consequently perform the requested actions (Fig. 13).

The mobile application allows up to three password-protected accounts, so it can be installed on three different phones. After the correct login procedure, the application shows the main screen reported in Fig. 15a.

In the upper box, the user can control the connection status of its vehicle: if the control system is correctly performing its periodical posts on the remote server through its GPRS module, the connection-status LED is green and the label „*CONNECTED*" appears under car's plate number. Otherwise, the connection-status LED is red and the label „*NOT CONNECTED'* appears. In the bottom box, the application shows the updated date and time information. The central box encloses the most important app's functionalities: the red LED (top left) always indicates if child's presence has been detected (LED on) or not detected (LED off) into the vehicle; the "*tracking"* button (top right) opens vehicle's tracking page; the "parameters" button (bottom left) opens a consultation page for data acquired from sensors installed into the vehicle; the "*action"* button opens a page through which the user can perform some remote interventions.

Fig. 15. Application's main dashboard (a) and alarm dashboard (b).

Fig. 15b reports the alert screen of the application when the system detects the child presence in the unattended vehicle and consequently writes an alarm condition on remote server. The phone vibrates and emits warning sounds until the user doesn't press one of the two buttons enclosed in the bottom box of Fig. 15b: the "home" button reports the application in the main screen (with red LED in ON state), instead the "*action"* button directly opens the action page allowing user to perform some operations, while he returns to the vehicle.

The "*action"* page, reported in Fig. 16a, allows user to perform the following actions by pressing one of the six icons shown in the phone's screen: windows lowering of few centimeters, doors opening/closing, emergency lights flashing, horn activating, sending pre-recorded phone calls to emergency contacts and to police, watching cockpit pictures acquired through internal camera. These manual actions were included inside the application for allowing an immediate intervention by car owner in condition of extreme emergency before the arrival of the police or when the call to police fails. Furthermore, the manual activation of the "watch camera" functionality can allow the user a visual remote check, in any time, of the car cockpit.

Fig. 16b shows an example of what appears on phone screen when the user presses the camera button (bottom right in Fig. 16a): the mobile application extracts from database the last image acquired and posted from system PixyCam and displays it. The image has a maximum delay time of few seconds respect to real time, because the system updates it each ten seconds in standard case and each five seconds in alarm case. At the same manner, if the user presses one of the other five action buttons shown in Fig. 16a, the application opens the corresponding action management page in order to allow user to control all other functionalities.

Fig. 16. Application's action dashboard (a) and camera image dashboard (b).

The bottom left and the bottom right buttons shown in the central box of main screen (Fig. 15a) allow user to check the value of vehicle's internal parameters as temperature, humidity and CO_2 concentration and to localize the vehicle position. Fig. 17a shows the application screen that appears when user presses "*parameters*" button on the main screen: the graphical interface shows three real time graphs, that report on X-axis the 24 hours of the current day and on Y-axis the acquired values of temperature (°C), humidity (%) and CO_2 concentration (ppm), updated to the current time.

Fig. 17. Application's parameters screen (a) and tracking screen (b).

Fig. 17b shows the application screen that appears when the user presses "*tracking*" button on main screen: the graphical interface shows the local road map, placing a red marker at the point identified by the GPS coordinates sent from vehicle's control system. If the user deems it appropriate, he can activate phone GPS system and press the "*go*" button on the map (blue button in bottom right of central enclosure) in order to start the navigation mode from user position to vehicle's position. Finally, the user can exit from all application screens by pressing the "*back*" button on the mobile phone.

VI. Conclusions

The development of an innovative control system for detecting infants forgotten inside an unattended car is reported in the present manuscript. The proposed system is based on a Arduino Uno microcontroller board, for acquiring information from a wide set of sensors and the car control unit, elaborating the acquired data to support the decision-making process and finally providing the actuating signals and alerts messages for signaling the presence of infants inside the car cockpit. The designed control system is equipped with a *PixyCam* smart camera with face recognition functionality and an *Easy VR* vocal detection module, for recognizing infant preset voice or pre-recorded sounds inside the car cockpit. In addition, the system includes a RF motion sensor based on Doppler effect and two PIR sensors for detecting movements inside the car and a CO_2 sensor (*MG-811*) for detecting minimal CO_2 variation related to the infant's breathing. When an alarm condition is detected, the alarm command with vehicle's GPS position is written on the remote DB in order to start the alarm sequence on phone application of the car owner, of other secondary contacts and to police alerting service. Thus, the system has a GPS receiver and a SIM900 GSM/GPRS Arduino-compatible expansion board for equipping the system with the needed connectivity to implement the aforementioned functionalities. Furthermore, a proper IT platform has been designed to support the system operation, enabling the user to remotely receive some warning messages and pictures from the car cockpit and also to control the main car functionalities (as lowering windows, activating horn and emergency lights).

Possible future developments of the designed system regard its integration with anti-theft system equipping car and for performing different kinds of detection outside the vehicle. For instance, the vibration sensors could be integrated for detecting the vibrations level to which the vehicle is subjected. Other image sensors, faced outwards, could be used to control if an unrecognized face is approaching to the unattended vehicle, alerting the car owner.

References

[1] T. Jeyaprakash, R. Mukesh, "An Optimized Node Selection Routing Protocol for Vehicular Ad-hoc Networks – A Hybrid Model", *J. Commun. Softw. Syst.*, vol. 11, no. 2, pp. 80–85, Jun. 2015, DOI.10.24138/jcomss.v11i2.106.

[2] K. Cengiz, M. Aydemir, "Next-Generation Infrastructure and Technology Issues in 5G Systems", *J. Commun. Softw. Syst.*, vol. 14, no. 1,pp. 33-39, Jan 2018, DOI.10.24138/jcomss.v14i1.422.

[3] Paul, N. Chilamkurti, A. Daniel, S. Rho, *Intelligent Vehicular Networks and Communications: Fundamentals, Architectures and Solutions*, 1st ed, NL, Amsterdam: Elsevier, 2016, pp. 43-75.

[4] F. Hoque, S. Kwon, "An Emergency Packet Forwarding Scheme for V2V Communication Networks", *Sci. World J.*, vol. 2014, no. 1, pp. 1–7, March 2014, DOI. 10.1155/2014/480435.

[5] S.B. Raut, P.R.P. Bajaj, L. G. Malik, "Prediction of Vehicle Collision Probability at Intersection using V2V Communication",*Int. J. Sci. Eng. Res.*, vol. 6, no. 5, pp.295-300, May 2015.

[6] R. Zhang, L. Cao, S. Bao, and J. Tan, "A method for connected vehicle trajectory prediction and collision warning algorithm based on V2V communication", *Int. J. Crashworthiness*, vol. 22, no. 1, pp. 15–25, Jan. 2017, DOI.10.1080/13588265.2016.1215584.

[7] J. A. Sanguesa *et al.*, " Sensing Traffic Density Combining V2V and V2I Wireless Communications ", *Sensors* , vol. 15, no. 12, pp. 31794 –31810, Dec. 2015, DOI.10.3390/s151229889.

[8] W. Balzano, F. Vitale, "DiG-Park: A Smart Parking Availability Searching Method Using V2V/V2I and DGP-Class Problem," in *2017 31st Int. Conf. on Adv. Inf. Netw. and Applic. Workshops (WAINA)*, Taipei, Taiwan,2017, pp. 698–703, DOI. 10.1109/WAINA.2017.104.

[9] Z. Wang, G. Wu, M. Barth, "A Review on Cooperative Adaptive Cruise Control (CACC) Systems: Architectures, Controls, and Applications" in 2018 IEEE 21st Int. Conf. on Intel. Transp. Syst. (ITSC),Maui, Hawaii, USA, 2018, pp. 2884-289, DOI.10.1109/ITSC.2018.8569947.

[10] A. Raffin, M. Taragna, M. Giorelli, "Adaptive longitudinal control of an autonomous vehicle with an approximate knowledge of its parameters", in *2017 11th International Workshop on Robot Motion and Control (RoMoCo)*, 2017, pp. 1–6, DOI. 10.1109/RoMoCo.2017.8003885.

[11] P. Visconti, P. Primiceri, G. Cavalera, "Wireless Monitoring System of Household Electrical Consumption with DALY-based Control Unit of Lighting Facilities Remotely Controlled by Internet", *J. Commun. Softw. Syst.*, vol. 12, no. 1, pp. 1–15, Mar. 2016, DOI.10.24138/jcomss.v12i1.86.

[12] U. Shafi, A. Safi, A. R. Shahid, S. Ziauddin, and M. Q. Saleem, "Vehicle Remote Health Monitoring and Prognostic Maintenance System",*J. Adv. Transp.*, vol. 2018, pp. 1–10, Aug 2018, DOI.10.1155/2018/8061514.

[13] D. S. Rani and K. R. Reddy, "Raspberry Pi Based Vehicle Tracking and Security System for Real Time Applications", *Int. J. Comput. Sci. Mob. Comput.*, vol. 5, no. 7, pp. 387 – 393, Jul 2016.

[14] M. Jyothikiran, S. Raviteja, "Vehicle Health Monitoring System", *IJERA*, vol. 2, no. 5, pp. 1162–1167, Sep. 2012.

[15] F. Gaetani, P. Primiceri, G. A. Zappatore and P.Visconti, "Design of an Arduino-based platform interfaced by Bluetooth Low Energy with MYO armband for controlling an under-actuated transradial prosthesis", Proc. of IEEE 2018 Int. Conf. on IC Design & Technology, Otranto, Italy, 2018, pp. 185–188, DOI. 10.1109/ICICDT.2018.8399787.

[16] P. Viola, M. J. Jones, "Robust Real-Time Face Detection,"*Int. J. Comput. Vis.*, vol. 57, pp. 137–154, May 2004, DOI.10.1023/B:VISI.0000013087.49260.fb.

[17] P. Visconti, B. Sbarro, P. Primiceri, "A ST X-Nucleo-based telemetry unit for detection and WiFi transmission of competition car sensors data: firmware development, sensors testing and real-time data analysis", Int. Journal on Smart Sensing and Intell. Systems, vol. 10, no 4,pp. 793-828, 2017, DOI. 10.21307/ijssis-2018-019.

[18] Patrizio Primiceri, Paolo Visconti, A. Melpignano G. Colleoni, A. Vilei, "Hardware and software solution developed in arm MBED environment for driving and controlling DC brushless motors based on ST X-Nucleo development boards," *Int. J. Smart Sens. Intell. Syst.*, vol. 9, no. 3, pp. 1534–1562, Sep. 2016, DOI: 10.21307/ijssis-2017-929.

[19] "Heatstroke - Symptoms and causes - Mayo Clinic." [Online]. Available: https://www.mayoclinic.org/diseases-conditions/heat-stroke/symptoms-causes/syc-20353581. [Accessed: 19-Mar-2019].

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