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Procedia Manufacturing 35 (2019) 27–34

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Materials Processing and Manufacturing,

(SMPM 2019)

Internet of things architecture for a smart passenger-car robotic first aid system

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Abstract

Health emergencies occur in passenger cars where victims do not have immediate access to either layperson or professional, proper medical services, resulting in deterioration of their health or death. Installation of a robotic first aid system for passenger car occupants has been proposed. This research is part of a larger work of designing the system and identifies the existing hardware and software automotive infrastructure that the robotic first aid system can functionally use. These resources are reviewed in categories of sensing, connectivity, data analysis and information exchange, which form the internet of things. Consequently, the system's design for internet of things mechanical requirements are identified in sensing. Finally, a preliminary framework for the system's internet of things infrastructure is established to facilitate the development of a smart robot.

Peer-review under responsibility of the organizing committee of SMPM 2019.

Keywords: Architectural Framework; Health Monitoring; Internet of Things Infrastructure; Robotic First Aid; Smart System

1. Introduction

We live in an invisible jungle of communication where millions of devices interact with each other at any one time, their signals travelling at colossal speed through land, air and even water – all because of the internet. As

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2351-9789
Peer-review under responsibility of the organizing committee of SMPM 2019.
10.1016/j.promfg.2019.05.006

envisioned by its pioneers, the internet today connects computers in automobiles, homes, industrial and business spaces, and wearable devices, forming the Internet of Things (IoT). The past decade has seen rapid development of IoT systems because gadgets operate more efficiently, effectively and at lower costs towards a common goal when connected to share information and facilities, both hardware and software [1], [2]. One of the most significant research areas in the field of IoT is human healthcare.

Vehicle safety is a top priority for automakers, consumers, governments and other parties concerned with road transport safety [3]–[5]. Despite their efforts, several studies report that morbidity and mortality rates resulting from road-traffic accidents (RTAs) are on the rise in some regions of the world, particularly low- and middle-income countries (LICs and MICs), and road traffic injuries are a leading cause of preventable death [6]–[9]. Additionally, vehicle occupants are susceptible to non-traumatic medical emergencies including cardiovascular and respiratory complications [10]–[12]. It is well documented that quick and correct medical assistance is the key to survival of any major medical emergency, such as an injury, a stroke or a heart attack [13], [14]. First aid given to victims of RTAs is known to preserve life, prevent further harm y and at lower costs towards a common goal when connected to share information and facilities, both hardware and software [1], [2]. One of the most significant research areas in the field of IoT is human healthcare. and promote recovery in most cases [15]–[18]. Unfortunately, a number of studies have found that there are high chances of victims not getting proper help for reasons including unavailability of bystanders, responders fearful of worsening the condition and entrapment of victims in the wreckage, thus inaccessible [16], [19]–[25]. Evidence suggests that professional emergency medical service (EMS) post-crash response also influences the recovery of patients [26], [27], and the underlying assumption is that EMS response times should be reduced continuously. A more recent report confirms that if trauma care systems for severely injured RTA victims in LICs and MICs countries were improved to match those in high-income countries (HICs), half a million lives could be saved each year [28]. However, it has been shown that even for areas with effective EMSs, the greatest delays in responding to emergencies come not from EMS response time but from the reaction of patients and bystanders [29]. For such scenarios, it has been suggested that policy concentrates on public first aid education – the same public with a low response rate as mentioned earlier!

It is against this background that the authors of this paper are confident in an on-board robotic first aid (RFA) system in all passenger-cars; to be by the victim's side when the emergency occurs and give immediate assistance without any reservations. Robotic first aid is still in its infancy in terms of development and implementation, and to the best of the authors' knowledge, there is no such research exclusive to passenger-car on board systems yet. However, the few researches carried out so far suggests quicker and better quality first aid through human-robot integration [30]–[33] . In the context of passenger cars, which are getting more connected [34], it is necessary to ascertain possible areas of integration for the RFA system and incorporate the requirements in the mechanical design. For optimum functionality of the RFA system, this paper delves into key issues including sensing, connectivity, data analysis and data sharing pertaining to automobiles and human healthcare. The study specifically seeks to answer the following fundamental questions:

1. What are the existing hardware and software that the RFA system can functionally use?
2. What considerations should be made in the RFA system's mechanical design for IoT?

Answers to these questions will be instrumental in the physical development of an optimized RFA system.

2. Automobile Internet of Things

Despite the excitement around the IoT at global level, there is no single and universally accepted definition for the term [35]. However, the European Research Cluster on IoT gives the common definition as "A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network." [36]. This definition best explains IoT in this research.

Autodesk suggests that IoT is creating a future with a compendium of smart, connected products, which can leverage data and operate with increased productivity and efficiency by communicating with each other [37]. This is the relationship that the authors of this paper envision for the RFA smart system and all devices it can partner with. Smart products use various senses to collect data about their environments and perform computations on the big data through software, and connect to other things thereby allowing them to exchange data and commands. These characteristics are elaborated in the following paragraphs in the context of automobile IoT and health monitoring systems.

2.1. Sensing

Health monitoring systems have been trickling into passenger cars in recent years as either standard, optional or aftermarket equipment, although most are still experimental. Harman has developed a system that can detect if a driver is distracted or if one could potentially drive dangerously by measuring one's cognitive load [38]. The technology tracks fluctuations in pupil diameter to measure brain memory usage. The sensor is designed for location behind the steering wheel in front of the instrument panel. Although the concept eliminates the need for complex sensors built into the car's upholstery, it will need to carefully filter-out false positives such as pupil dilation due to unharmful stimuli. As per the recommendations from a precursor study to this paper [39], this technology would be active in non-traumatic health emergencies where there is no vehicle damage. However, it would be limited to conditions that can be diagnosed by miosis or mydriasis alone. Moreover, the technology would not be reliable in RTA situations where there may be damage to itself or other devices upon which it depends, for example, the battery. In this case, data collected by the system may be useful to patient treatment if stored prior to the incident. Research continues to support the enduring value of high-quality patient history in diagnostics [40]–[42].

BMW in collaboration with researchers from the Technical University of Munich are developing a sensor system integrated into the steering wheel, designed to give the driver health-checks [43]. Heartrate and oxygen level data are collected unobtrusively when the driver's hands are on the steering wheel. Similarly, Toyota and Nihon Medical University has been experimenting with cardiovascular-function monitoring system, acting though the steering wheel [44]. It is uncertain whether a driver's hands would be on the steering wheel in a health emergency, therefore the concept would only be of use in providing patient history.

Ford Motor Company is developing concepts that could help drivers with non-communicable diseases [45]. One is of the built-in type, comprising an electrocardiography (ECG) reader which, as the type implies, is built-into the driver's seat. Heartrate is sensed through the seat-occupant's clothes. The car seat incorporates six capacitive plates that record the signal transmitted from the sensors by registering an electric charge between the plates and the driver's body, which changes with every heartbeat. Similar to the system developed by Harman, the ECG reader could be used in non-traumatic emergencies to monitor a patient. In the same breath, the technology would not be dependable in RTAs, given that the vehicle seats' proximity to the vehicles sides could result in considerable damage. Furthermore, the system is limited to heartrate monitoring yet there is a myriad of vital signs that should be considered in medical emergencies. Moreover, developers admit that the sensors may not work with thick clothing including winter jackets or leather coats.

Ford is also developing a beamed-in health monitoring system that is connected to the internet and other devices [45]. Some concepts by the automaker include body temperature measurement by infrared cameras or in-seat sensors. Low-intensity radar is also noted as a sensor for heartrate and respiration. There is also potential for the automaker to collaborate with Philips to produce the company's vital signs camera specifically for automobiles. Although the technologies are still in development, they have the potential to perform a full checkup for the driver. Once again, they will be limited to instances where there is no vehicle damage, otherwise they would not work, let alone record accurate information.

It is evident from the literature that the existing accounts of in-car human monitoring systems are restricted to controlled environments. Therefore, there is a need to develop a fully equipped RFA system as far as sensors are concerned, especially for unknown environments.

2.2. Connectivity

The buzzword in the automotive industry today is the "connected car". Connected cars are those that have access to the internet and various sensors, and thus the ability to send and receive signals, sense their surroundings and interact with other vehicles and entities [46]. Recent studies predict that there will be 250 million street-legal connected cars globally by 2020 [47]. The RFA system would be an addition to the devices within the vehicle and would network with the vehicles smart gadgets as well as external devices. The interactions made possible by car connectivity have been categorized by researchers as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) [48], [49]. If the RFA system is considered an integral part of the vehicle, then it would

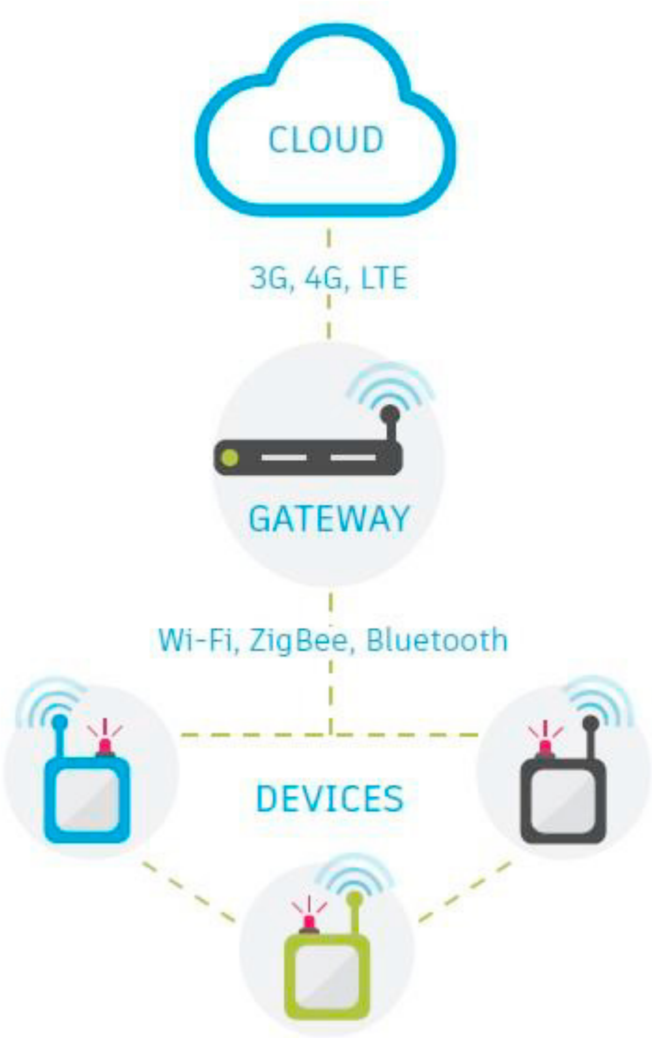

Fig. 1. Typical internet connectivity configuration between devices and the cloud.

be connected to the vehicles' health monitoring systems, personal devices such as smartphones and wearable devices, and emergency medical service providers.

There is a consensus among IoT specialists about transmission of data from the device (RFA system) to the cloud and back. Following collection of data by the sensors, it is conveyed to the cloud via communication protocols. Common protocols include Bluetooth, Wi-Fi and cellular connections configured as shown in Fig. 1. Even as the automation in automobiles increases and fifth generation wireless systems (5G) technology replace the fourth generation as the medium through which car connections are made, this architecture will suffice in all communications the RFA system will need to perform its functions [50], [51]. 5G has been demonstrated successfully in connected cars [52]. However, the gateway module should be in an accident damage-free zone of the vehicle [39]. The gateway bridges the RFA's microcontroller and the Internet that will normalize raw data into a standard format and support communication to the Internet.

It is clear that a large and growing body of literature has investigated connectivity in IoT and standards that the RFA system can follow have already been established.

2.3. Data Analytics

There is a growing interest in the use of cloud computing for automobiles to facilitate data intensive tasks and computation. The data generated by the RFA system itself and supporting smart devices will be transmitted to the cloud, which is the storage and computing facet of the entire system. Data is stored, processed and analyzed in the cloud, which operates remotely and has virtually unlimited storage capacity [37], [53]. Several cloud computing tools have been designed for applications such as the RFA system. Bosch has developed the Automotive Cloud Suite targeted at automakers and mobility service providers [54]. Software updates from the cloud are already available for smartphones and in the same manner, the Automotive Cloud Suite provides solutions for implementing software updates on individual software modules.

2.4. External Information

Also informing the cloud will be external sources, including business systems and internet resources. This additional data will be processed in the cloud together with data from sensors, all of which will reveal further insights into the patient’s condition. The topic of health monitoring is one of the most active areas in IoT and several devices have already been developed and produced with IoT capabilities [55], [56]. Therefore, there are no additional requirements in the mechanical design of the RFA system regarding IoT.

3. IoT Requirements for Robotic First Aid System

Consequent to the literature above, the following requirements have been identified in line with a precursor study on RFA functions [57]. Inclusion or exclusion of some entities will impact the space required by the robot and its weight.

3.1. Navigation and Mapping

The RFA system should be equipped with sensors that allow it to simultaneously localize, map an unknown environment and navigate its work envelop, with no human intervention.

3.2. Human Detection, Tracking and Triage

An unpredictable environment such as that of the vehicle interior following an RTA calls for a sensor system that can distinguish human beings from the other objects. Furthermore, it should be able to identify human body parts and deploy its various first aid tools accordingly. With further development, the system should have the ability to assign degrees of urgency to illness or wounds to decide the order of treatment of the vehicle occupants.

3.3. First Aid

Preliminary functions of the robot have been outlined in a precursor study as calling for help, checking victims for injuries, looking for signs of breathing, performing CPR, dealing with open wounds, scanning for fractured bones, giving bystanders information on the correct procedure and giving emergency medical service personnel information on the victim's condition [57]. The robot should be equipped with sensors and actuators that allow it to identify these conditions and react appropriately. It may be noted that these functions address RTA situations and more requirements will emanate from non-traumatic emergency medical conditions.

4. Robotic First Aid System IoT Architecture

Having addressed the issues relating to making the RFA system smart, its IoT architecture can be established. This architecture is a framework for specification of the IoT’s physical components and their functional organization.

Sensors on the RFA system collect relevant data from the work envelop. The data is transmitted between devices and to the cloud through communication protocols. The literature recommends use of the 5G protocol, which is already being developed for the automotive industry. In the cloud, the RFA system software monitors and controls its functions by converting unorganized data into actionable information in real time. The big data engine analyses incoming data and reveals product insights. Information from external sources from wearable health monitors and healthcare providers to the weather, traffic and maps is processed along with data from the RFA system. Access to data via visualization platforms including smartphones and vehicle infotainment systems enables users, particularly bystanders and EMS personnel, to ascertain the patient's health status and the appropriate course of action. Cloud computing is already being implemented by several automakers, cloud computing and IoT specialist firms.

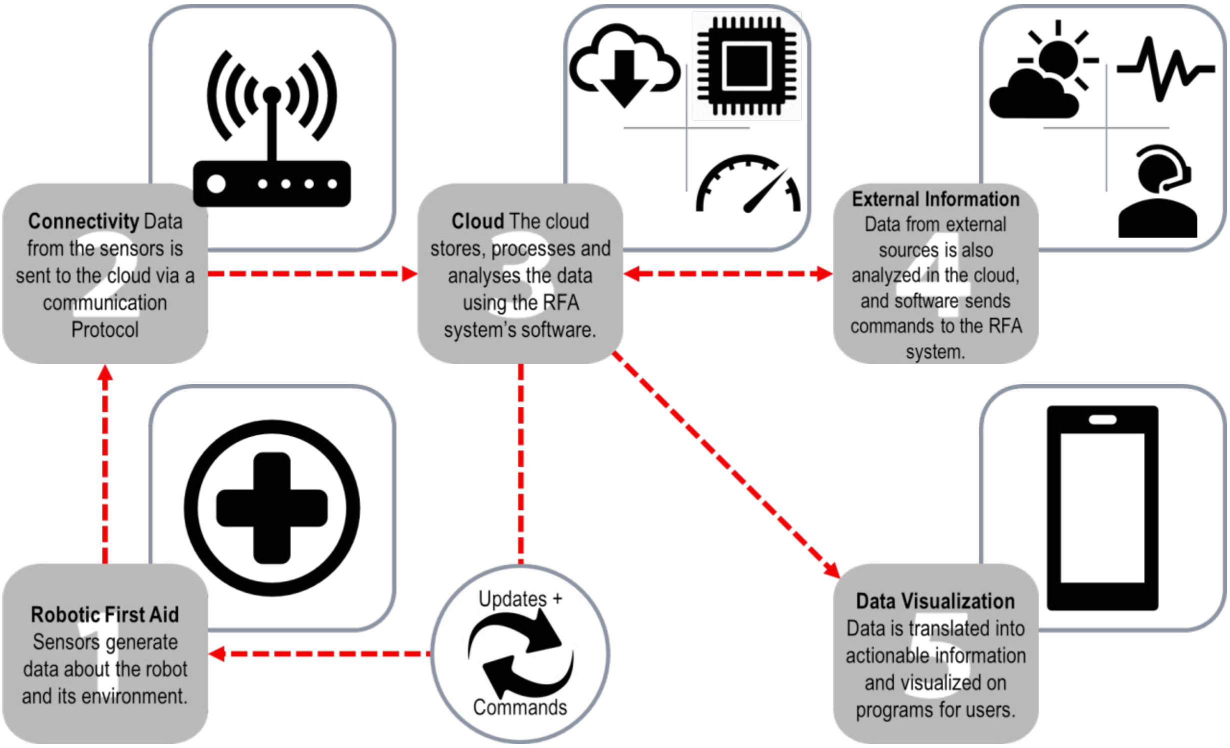

Fig. 2. Preliminary architecture of the RFA system's IoT network.

5. Conclusion

This paper set out to determine existing hardware and software that the RFA system can functionally use, and come up with considerations to be made in the RFA system's mechanical design for IoT. Although there are health monitoring technologies that can provide patient history, findings suggest that these cannot support the robot's functions in real time, implying that the RFA system should be fully equipped in this regard. It was also shown that connectivity, data analysis and data exchange facilities are readily available for use by the RFA system. An IoT architecture linking the RFA system to other devices via the internet was drafted and it will serve as a base for future studies and be used to articulate the organization of physical components in the RFA's IoT.

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