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Internet of Things in Emergency Medical Care and Services

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Abstract

Emergency care is a critical area of medicine whose outcomes are influenced by the time, availability, and accuracy of contextual information. In addition, the success of emergency care depends on the quality and accuracy of the information received during the emergency call and data collected during the emergency transportation. The success of a follow medical treatment at an emergency care unit depends too on data collected during the two phases: emergency call and transport. However, most information received during an emergency-call is inaccurate and the process of information collection, storage, processing, and retrieval, during an emergency-transportation, is remaining manual and time-consuming. Emergency doctors mostly lack patient's health records and base the medical treatment on a set of collected information including information provided by the patient or his relatives. Hence, the emergency care delivery is more patient-centered than patient-centric information. Wireless body area network and Internet of Technology (IoT) enable accurate collection of data and are increasingly used in medical applications. This chapter discusses the challenges facing the emergency medical care services delivery, especially in the developing countries. It presents and discusses an IoT platform for a patient-centric-information-based emergency care services delivery. The study is focused on a case of road traffic injury. Results of conducted experiments are discussed.

Keywords: emergency medical care, Internet of Health Things, road congestion, pervasive/ubiquitous computing, road traffic injury

1. Introduction

Road traffic injuries are, according to the WHO report on the topic, the leading causes of death worldwide. Over 1.2 million of individuals died each year on the road [1]. "Road

traffic injuries (RTI) are on increasing in developing countries. Healthcare facilities are poorly equipped to provide the needed services.” [2]. Efforts are made over the past years to improve the emergency care services delivery in the developing countries. Emergency services policies and training programs for emergency providers have been implemented, though, these programs are still facing challenges in the training [3]. The developing countries are facing further challenges beyond the weak training. However, developing countries lack medical transport system. In 2002, Razzak and Kellermann carried out a study [4] and found out that the lack of medical transport is a common issue facing the most of healthcare systems in the developing world; the authors, further, state that “The provision of timely treatment during life-threatening emergencies is not a priority for many health systems in developing countries.”

Previous works conducted in 2016 and 2017 in the sub-Saharan African countries have revealed that most healthcare systems have partially improved the medical transport issues by acquiring a few numbers of ambulances. However, this fact does not completely meet the issues facing the emergency transportation. The roads are in bad state and though lead to massive time-wasting, with the high risk of medical complication or death.

In [5–7], the authors have found out that electronic medical records (EMR) have the potential to “improve the delivery of healthcare services” [5] and especially “to improve emergency care in low- and middle-income countries” [7]. However, the global healthcare system is keeping used analog (paper-based) medical records, especially that this is the order in the majority of healthcare systems of low- and middle-income countries [6–8], while the healthcare systems in the high-income countries are slowly adopting the digital medical record systems [5, 6].

According to the “The Free Dictionary,” emergency medical care (EMC) is defined as *providing life-saving measures in life-threatening situations*. Schneider et al. had defined the emergency medical care as “Emergency Medicine is the medical specialty with the principal mission of evaluating, managing, treating and preventing unexpected illness and injury” [9]. Riner, a medical doctor (MD)/emergency physician (EP) defined in 2011 in a post the emergency medical care as “the sudden onset of a medical condition manifesting itself by acute symptoms of sufficient severity (including severe pain) such that the absence of immediate medical attention could reasonably be expected to result in: placing the patient’s health in serious jeopardy, serious impairment to bodily functions, or serious dysfunction of any bodily organ or part.” [10]. According to Riner, life-saving care must timely be provided. Time is then an important factor in the emergency medical care.

The common generic scenario in MEC is to transport an injured person from an accident place to the emergency services (commonly called emergency room) at a hospital, where he will be intensively treated. The emergency doctor in charge to transport the injured person to the close emergency care center is requested to stabilize him in providing life-saving first treatment during the transport. The emergency doctor (ED) needs patient-centric information for the primary care during the transport and has to timely provide the emergency center with the collected data and information about provided treatment and his diagnostics. Diagnostics made remotely based on patient-centered information provided through the emergency call

need to be confirmed or revised once the injured person reaches the emergency center or the ED arrives at the accident place. As Schneider et al. stated in [9], a patient at an emergency room gets screened to confirm or revise the first diagnostics:

“...The first contact with nursing staff and the EP during the screening examination in the ED confirms or modifies this initial determination. EPs are specifically trained in the rapid assessment and triage of all patient presentations regardless of patient age or gender. The EP’s role is to organize and manage the emergency care system based in the ED.” [9].

Beyond this, the EP is considered as the manager with the mission to evaluate the life-threatening situation that the patient is facing. These operations request accurate data that are in the best case patient-centric and patient-centered. Accessing these data can be time-consuming; therefore, the EP and whole nursing staff need to be assisted by modern technologies to gain time and quickly efficiently provide the first life-saving care to the patient within the golden hour. The golden time, critical where one can lose the injured, is the first hour between the accident occurs and the time the injured receives the first aid. In certain cases, the golden hour is less than 60 min. In this golden time, the emergency has to prevent the injured from any life-threatening medical issues.

Modern information and communication and data security technologies can contribute to collect, process, and store important data and quickly retrieve these data in the case of emergency as well as assure data security. Wireless sensor networks (WSNs) especially the wireless body area network (WBAN) are technologies that can help to collect and ensure data.

The chapter presents a concept for improving emergency medical care process and services delivery in the developing countries. It further pursues the objectives to connect the unconnected health things to enable patient-centric emergency medical care delivery using the Internet of Things paradigm. Data security, communication protocols, and technologies are out of the scope of this chapter. There are various previous works such as [11] that have already covered the EHR access control.

The remainder of this chapter is structured as follows: (i) Section 2 presents the state of the art (literature review) regarding the usage of the Internet of Things in medical application and especially in the emergency medical care. The research objectives and context are presented in Section 3. The technical background is briefly presented in Section 4. The concept and architecture are described in Section 5. The proof of concept (experiment) is presented in Section 6. The test results are discussed in Section 7. Section 8 concludes the chapter.

2. Related works

This section provides a short but comprehensive literature review on the use of the Internet of Things in medical applications like remote medical monitoring using various modern technologies such the wireless technology. It further investigates the state of the art on the use of the Internet of Things in delivering emergency medical care and the patient-centric medical care delivery.

2.1. Wireless sensor network in medical applications

The wireless sensor networks (WSNs) are being used by the healthcare industries to measure patient's vital parameter through medical sensors that are attached to his body. Bio-signals like body temperature, blood pressure, pulse oximetry, ECG, and breathing activity are, thus, sensed. Further, remote medical centers use end-point devices like video and audio devices to perform advance patient's monitoring [12].

In a multi-tier WSN, tasks are assigned to different nodes, where certain nodes (e.g., sensors) are assigned to simple tasks with low energy consumption. Low energy consuming nodes last for a long time and best fit for sensing data in healthcare applications. Multi-tier architectures have been used in similar applications like SensEye [13] and IrisNet [14] and have proven to be efficient. Moghadam et al. develop in [15] "an energy efficient data transmission technique for communication between a single-antenna medical sensor/microrobot inside the body to multi-antenna receiver on the body surface though non-homogeneous propagation environment."

Sensing data from the human body and transmitting over multiple spatial and temporal scales remain the first critical challenges in advanced health informatics [16]. In [17, 18] a noninvasive in vivo glucose sensors for measuring the blood glucose level was developed. In [19], the authors proposed a platform that combines IoT end-point devices (e. g. wearable sensors) with in-home healthcare services to improve user experience and service efficiency.

M. Mazhar Rathore et al. have discussed the presence of the Internet of Things in the medical sector and the amount of data these systems produce [20]. The wireless body area network (WBAN), a subset of the wireless sensor networks (WSNs), is using in the healthcare's applications to monitor the patient bio-signal [21].

In a previous article, the author presents a wireless sensor network system used at a cardiologic intensive care unit (CICU) to monitor the cardiologic in-patient and the ambient air in the hospital rooms. The patients are attached to a WSN that collect in real time the patients' vital parameters [22]. The experiment described in [22] has demonstrated that the WSN systems show a promise in collecting and retrieving medical data.

2.2. Internet of Things in the emergency medical care

The Internet of Things (IoT) especially the Internet of Health Things (IoHT) presents various potentialities for enhancing the emergency medical care from the beginning of the process till to the admission of the patient at the emergency room.

The emergency operation begins with the first call at the emergency coordination station. At this stage, the call center personal collects under time pressure important information on the occurrence. Most callers are, however, not able to correctly report the event and give information about the exact place of the event. In [23] the contributors proposed an IoT-based smart technology that can overcome the challenges facing the emergency call by automatically provide additional data. The data could be embedded the patient data in the emergency call. Such a system will enhance the emergency response and save time as well as reduce the

death rate. In [24], the authors present a comprehensive survey on the usage of IoT in the medical field. Systems to handle the emergency medical care regarding the use of semantics and ontologies in sharing a large amount of medical data as well as data analysis have been described. The survey also presents the so-called indirect emergency health care that aims to assure data availability. Data availability requires data collection at a previous stage. This can happen through the medical record. The survey further discusses a medical record system that enables remote medical advice. It recommends reading the given paper to get more insight into the state of the art on the use of IoT in the health care.

The IoT is facing various challenges such as interoperability, security, authenticity, etc., because of the diversity of objects that can be involved in an IoT system as well as the size of the network that can issue security challenges. In [24], the authors present in an experiment a concept to meet the interoperability challenges in IoT systems. Interoperability can represent a barrier and especially an important issue in the emergency care. IoT system for emergency cases in China is presented in [25]. The authors describe an IoT-based system to monitor blood donation. This system can also help to set personal medical files. A remote monitoring and management platform of healthcare information, similar to that described in [22], is described in [26]. This system shows the potential of using the WSNs (IoT) in the health care. Various advantages of using IoT in the health care are described in [27]. The authors present an interesting aspect "The Anti-counterfeit of Medical Equipment and Medication."

As discussed earlier, the emergency response phase is an important phase of the whole process. Errors occurred at this phase can be hardly corrected. It is, therefore, important to avoid errors at this phase. In [28], the authors pose two research hypotheses as follows: (i) *H1: IoT technology fits the identified information requirements* and (ii) *H2: IoT technology provides added value to emergency response operations in terms of obtaining efficient cooperation, accurate situational awareness, and complete visibility of resources.*

Their findings fit the hypotheses and thus show that using IoT at emergency calling and response processing can enhance the emergency care.

2.3. Patient-centric and patient-centered emergency care delivery

2.3.1. Brief definition

Patient centrality: Patient-centric information is the information that emanates from the patient himself added to the data that are mined from the (electronic) medical and/or health records, which in turn must include genomic information, which enables to detect any disease predisposition [29].

Patient-centered care: Patient-centered care is a visit-based care, which means that patient-centered information is the information the patient and/or his parents provide the physician with [30].

2.3.2. Patient-centric versus patient-centered information

The patient-centered information originates from the patient and is mostly concerning the patient's needs and preferences regarding his healthcare concerns. It relies on the communication

and a good relationship between the patient, patient's relatives, and the treating personnel. Starfield points out in [30] that patient-centered information or care rests on core elements such as communication or interaction and adherence to the recommendation concerning the care. It is determined by the interaction between patient and medical doctors [31].

The patient-centric information is directly produced by the patient himself added to the data that are mined from the (electronic) medical and/or health records, which in turn must include genomic information, which enables to figure out any disease predisposition.

The modern wireless technologies are used to collect the patient vital parameters as well as to filter clinical document to gain patient-centric data. The use of patient-centric information including genomic data in the emergency care is still not in order. Medical records do not include genomic information yet [32], and only few healthcare professionals are using electronic medical and/or health records [6].

2.3.3. Usage of patient-centric information in medical care

The use of electronic health records (EHR) in the medical care delivery impacts positively the treatment outcomes [31, 32]. In [33] the authors have shown that context-aware data and patient-centric decision-making are vital for personalized healthcare delivery. They discuss the challenges facing these new paradigms in wirelessly collecting physiological data and consequently proposed patient-centric care delivery for ubiquitous health care. The study found out that the proposed patient-centric information "will significantly improve the response time, quality, and relevance of data- and compute-intensive medical applications."

To our best knowledge, patient-centric-based emergency care delivery is still at an embryonic stage. The comprehensive literature review has shown that only few research works have been done regarding the topic. However, the terms are often mixed up or confused. Earlier articles written on the topic have confused patient-centric with patient-centered information. In [34] one can note this regarding the definition the authors made. This can be the reason why only a few articles handle the topic.

3. Objectives, context, and ethical approval

The main objective pursued in this study is to enhance the emergency medical care process from the response operation till to the hospital admission, especially in the developing countries, using IoT to autonomously and automatically provide in real time the emergency healthcare professionals and the emergency care centers with accurate and appropriate patient-centric information and, thus, substantially reduce the death rate.

This study aims at enhancing the data provision and exchange for a data-driven, patient-centric, and patient-centered emergency care.

At the present stage, the study focuses on the improvement of the emergency process in the case of a road accident in the developing countries. The developing countries and the road

traffic injury represent therefore the research context of the study. The main reason for this choice is (i) the several healthcare access issues people are facing, (ii) the challenges the emergency transportation is facing, (iii) the lack of information and communications technology infrastructure, and the information paucity in the medical sector. The developed countries will also be considered. For evaluation purposes, cohorts of participants were built to simulate, test, and evaluate the different systems proposed. In collaboration with involved clinics and hospitals, we recruit patients using snowball approach. Each involved individual gives his consent so that their data can be collected, processed, and stored. The data were anonymously collected, processed, and stored. We also apply for ethical approval at the involved hospitals and clinics as well as at local municipal authorities.

4. Technical background

4.1. Internet of Health Things (IoHT)

Internet of Health Things (IoHT) integrates health objects with network connectivity from the digital and physical world. Furthermore, it combines personal health technologies and IoT and takes full advantages of IoT in expanding abilities to exchange useful data and enable improvements in context awareness and the ability to initiate actions based on data that are collected and analyzed [35].

4.2. Device-to-device (D2D) communication

Device-to-device (D2D) communication enables devices to communicate directly without interaction of base stations or access point. It is intended to exchange data utilizing various technologies such as ultrawideband (UWB), near-field communications (NFC), Zigbee, Bluetooth, Wi-Fi Direct, or LTE Direct. The distance between the devices is relatively short and defined by the using protocol. The communication is technology dependent [36].

4.3. Machine-to-machine (M2M) communication

M2M is an autonomous communication, based on a cellular network such as GSM, LTE, etc., where the communication passes through core networks via base stations or access points and M2M Server (application server). Compared with D2D, the communication is not direct and does not matter if the devices are approximate to one other. The distance between the devices is unlimited. Furthermore, the M2M communication is application oriented and technology independent (interoperability) [36].

4.4. Wireless sensor network (WSN)

WSN refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location. Sensors, within the network, sense and process data and communicate with

each other [7]. WSNs are intended for efficient and cost-effective medical monitoring/surveillance for deployment at emergency medical care centers so that health professionals can easily monitor their in-patients irrespective of location and time and thus collect important bio-signals and environmental data for an effective treatment.

4.5. Crowdsensing

Crowdsensing is a critical component of the Internet of Things [37]. Crowdsourced data can be collected using participatory or opportunistic crowdsensing paradigms, where participants' smartphone sensors are used to collect information/data. Smartphone sensors or sensor systems are increasingly used for measuring the quality of ambient air [38] and temperature and particularly sensing bio-signals within an in- or outdoor crowd.

4.5.1. Participatory versus opportunistic sensing

Crowdsensing systems are either participatory or opportunistic. Participatory crowdsensing requires participants' active involvement: participants perform computations and generate data as inputs for the systems, while in opportunistic crowdsensing requires fewer participants' involvement: sensing is more autonomous, data are automatically generated without user involvement, and computations are also automatically performed using participants' devices or available sensors [39].

5. IoT-enabled emergency medical care services delivery

This section describes the proposed IoT-based patient-centric information processing system for improving the global emergency medical care services delivery and especially equipping the developing countries' emergency medical care systems with an adapted and context-sensitive emergency medical care system.

A distributed and federated medical record that includes information like genomic information as designed and implemented in [6] is the central piece of the proposed patient-centric information system that uses the IoT paradigm to collect, store, and process data. The EMR is accessible to any emergency doctor during an emergency transportation. The EMR features components like emergency cases relating to information, medical case files, and genomic files including disease predisposition information.

Additionally, a crowdsensing-based road traffic congestion detection unit is featured and contributes to early detect road traffic congestion and consequently compute an alternative route to quickly attend the emergency center closer to the accident place.

The emergency calling disposes an IoT-based calling system capable to embed the injured person's emergency data, data of place of the occurrence, geographical data, and personal data of the caller in emergency response that will be forwarded to emergency doctor and emergency transportation unit.

Wireless sensor network technology is used to collect patient-centric data and timely update the EMR. Furthermore, the proposed should enable to autonomously, automatically, and contactlessly exchange data with the information desk at the emergency care hospital and any computer networking wireless devices that can ad hoc be registered and connected to the ambulatory emergency care information system for providing or collecting data.

The communication between the proposed system and the information desk as well as any wireless (mobile) devices will follow the D2D and/or M2M communication paradigms. The communication within the system is based on M2M communication paradigm to prevent the interoperability issues and to enable the machines (physical or logical) to use different communication technologies and protocols to easily communicate with each other.

5.1. Crowdsensing-based road congestion detection

The emergency transportation system in the most developing countries is inadequate. The road traffic net is in a bad state, and medical helicopter does not exist. A real-time road traffic congestion detection is, therefore, so important to prevent any delay in emergency transportation. Developed countries also face road congestion at the pick hours or by an accident event. The proposed crowdsensing-based road traffic congestion detection system can be adapted and thus used in the developed countries too (reverse innovation). Over the past years, many efforts in monitoring the road traffic to prevent road traffic congestion and accident are done. The IoT vehicle-to-vehicle (V2V) technology is used to implement such systems. Various research works were and are still being conducted on the topic (see [40–46]). Implementing such system in the developing countries is easier than in the developed countries since personal data protection or data privacy act is less restrictive in the developing world. Alternative solution approaches based on inter-vehicular communication with respect to the data privacy and security have been discussed in [42, 47].

The proposed congestion detection system takes into account the technological level, the ICT, and municipal infrastructure available in the developing world. Technologies like inter-vehicular communication, vehicle-to-vehicle (V2V) communication, infrastructure-to-infrastructure (I2I) communication are not implementable in these countries, though crowdsensing paradigm can be implemented since smartphones with embedded cameras are available and the regions are well covered by mobile telecommunication infrastructure. The requirements for a standard crowdsensing are met here, and thus the proposed road traffic congestion detection system can be implemented here. The system aims at combining both participatory and real-time opportunistic crowdsensing and crowdsourcing data to energy-efficiently and low-cost monitor ad hoc traffic crowds for early detection of traffic jam risks.

A cloud-based algorithm requests continuously participant's mobile phone on given routes to provide information on the traffic. These participants are requested to activate the client application installed on their mobile phones to participate in the traffic monitoring. The client application measures the density of the traffic in reporting their GSP coordinates to the cloud. The client could recognize which GSP coordinates are useful for detecting a traffic congestion.

The proposed detection system aims at detecting the congestion at a crossroad as well as measure the congestion length. Each traffic light has GSP coordinates. The detection's algorithm monitors every activity within 2 kilometers around the traffic light using all smart-phone coordinates in this circle. Thus, the speed of each vehicle or motorcycle on the given route can be determined, and, thus, traffic jam can be detected if it occurs. Similar work has been conducted and presented in [42] where the authors use the vehicle-to-vehicle paradigm to detect traffic congestion. Li Wei et al. propose in [48] a real-time road congestion detection in estimating vehicle density based on texture analysis and evaluate the system. The results demonstrate the potentiality of this approach.

As Zhu et al. in [49], the traffic is categorized, after an observational study, in peak and flat period. From 10 pm to 4 am the next day, we have a flat traffic. From 5 am to 9 am, the road congestion is high as well as the accident risk. Between 7 pm and 9 pm, road congestion can again be noted. The algorithm considers all this information in searching the appropriate route. This algorithm also uses the travel salesman algorithm in calculating the route for a quick transportation of the patient from the accident place to the next hospital. In [50] a model to optimize a network traffic flow is proposed. The model can be implemented to enable low-delay vehicular traffic flow. The proposed model shows a promise for low-delay vehicular traffic flow control from which emergency transportation can take benefit.

5.2. Federated electronic medical records (fEMR)

The patient medical record (MR) includes emergency data and medical case files and is a central piece of the concept. The clinical documentation (CD) is a digital or analog record tracking all medical treatment and related activities. MR and CD are part of the hospital information system (HIS). The clinical documentation serves as the basis and benchmark medical information document for further medical activities (e.g., treatment) or investigation on prior treatment; therefore, it must be accurate, must be timely filled, and must prevent any data privacy issues. It further can serve to create complete patient medical records including medical data from different medical institutions.

A hospital information system (HIS) must ensure that the patient medical and health records, as well as the clinical documentation, are always available, reliable, and data privacy assured. Available medical record at anytime and anywhere is an important piece in efficient, effective, and timely emergency care services delivery; beyond the availability aspect, the accuracy and the authenticity of the information/data contained in such document are very important for any further medical activities. The medical record must be up to date and well written (in the case the practitioner likes to write a medical assessment into the record).

The proposed MR (**Figure 1**) is a federated electronic MR (fEMR) equivalent to an electronic health record (EHR). It lies on a federated database system (FDB) and collects patient's medical records from all available sources. The so collected data is stored in the central database. An algorithm performs autonomously and automatically this job one to two times a day. An FDB is "a federated database system is a collection of independent, autonomous database systems, each with their own set of global users, which cooperate together to form an alliance

or federation that enables global users to access data across the participating systems in a transparent manner.” [51].

The fEMR can be connected to WSNs designed and implemented for collecting data within an emergency transportation. Once the emergency call is completed and all needed information is collected, the call center assigns an ambulance and an emergency doctor to the case. The patient’s fEMR is connected to the WSN system in the ambulance. The patient-centric information is then set and can start collecting data emanating from the patient and automatically update the EMR. Accident report unit is featured by the EMR and is filled during the emergency calling phase. The emergency doctor (ED) can add more details to accident report once he is at the accident and collect patient-centered information.

The fEMR system can be used in on- and offline mode. Offline modus is considered for regions where the access to the Internet is limited or nonexistent. The ED can then download a lightweight version of the patient’s fEMR and use it for his purposes. The data added newly to the local copy of the patient’s fEMR will then be synchronized with the cloud-hosted fEMR if the Internet access is again available. A backend routine performs this task automatically.

5.2.1. Emergency data and medical case files

Patient emergency data (PED) are medical data that are necessary rather mandatory during the golden hours in the case of emergency. It is, for example, vital in a case of emergency to

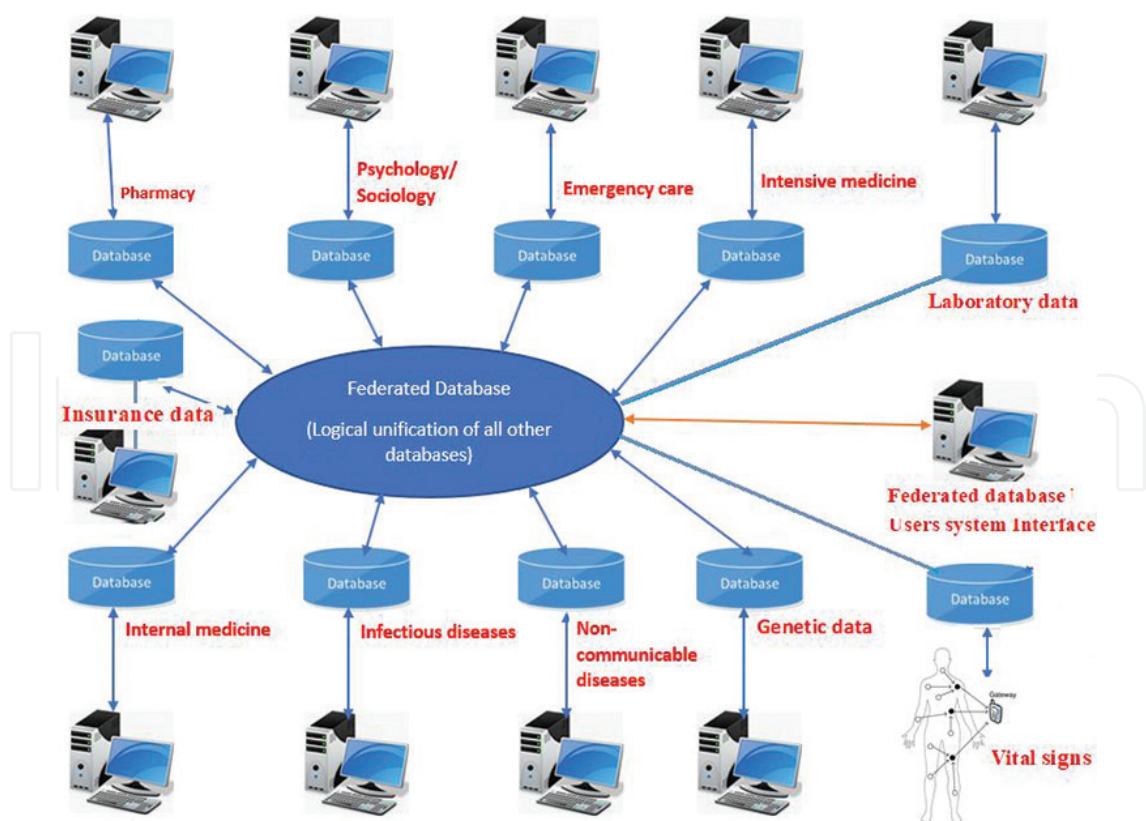


Figure 1. Architectural view of the proposed federated electronic medical records.

have accurate information on the diabetic condition of an individual or his serologic status or the list of his current medication to prevent any drug intoxication. The emergency data are created automatically set by the EMR system. Any treating physician can add emergency care-relevant information. The emergency data is stored on the patient’s electronic health card as well as in the EMR in the central database.

The emergency data includes the allergies, the medicinal treatments, the medical risks, and the avoidable medical attacks, i.e., any procedures, which are life-threatening for the patient. These data are updated regularly and must be reliable. The emergency data must be always available.

The diagnostics or medical case file includes the picture of a specific illness, the treatments performed, and the course of the illness. This information is purposely created ad hoc to facilitate the decision-making regarding any medical activity concerning the patient.

5.3. Resulting architecture

5.3.1. Connecting the unconnected (emergency room, ambulance, and fEMR)

The architectural view of a standard patient-centric emergency care delivery is illustrated in **Figure 2**. The proposed standard patient-centric and IoT-based emergency care services delivery system combine collecting vital parameters (on the patient within the transportation) using WBAN/WSN technology with the retrieving health records from the fEMR. The system filters the needed data from these different sources and presents them to the medical doctor. The data collected through the WBAN are automatically processed and stored in the fEMR.

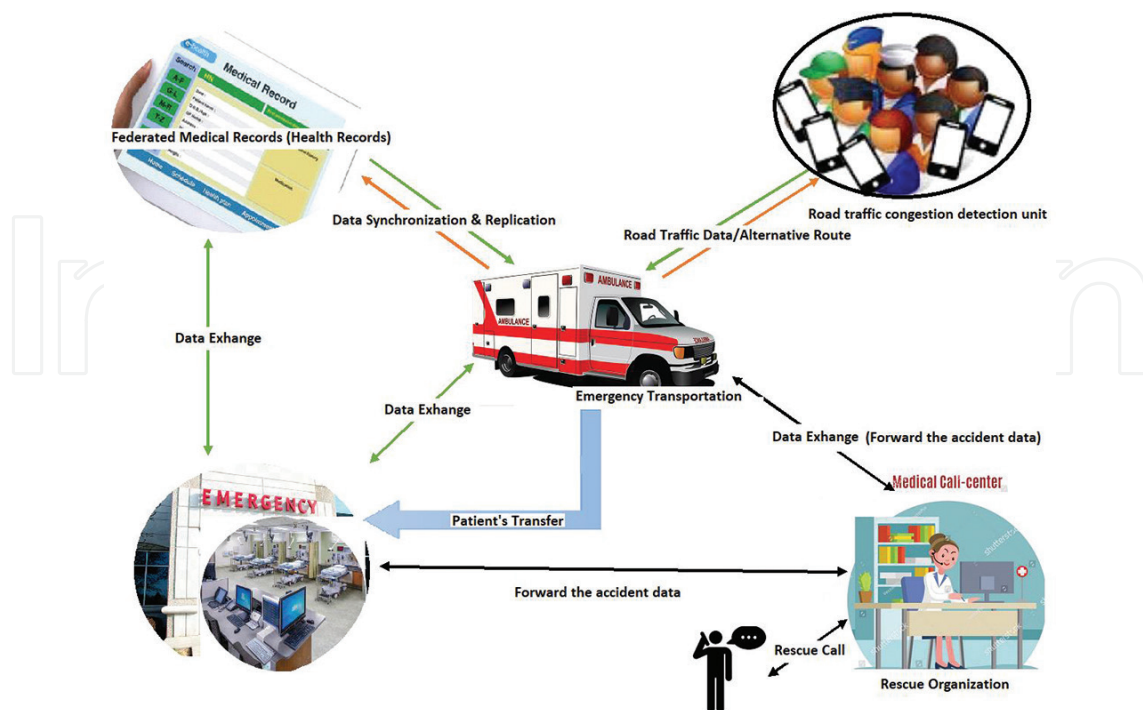


Figure 2. Standard patient-centric emergency care delivery process.

The patient-centered data or information are recorded and stored in the fEMR. A voice-based interface oversees collecting audio information and stores it local and remote.

The call center is featured with an M2M-based system that autonomously embeds the accident data in the patient's fEMR, sends it automatically to the emergency transportation unit, and determines the geo-position of the accident.

A road traffic congestion unit contributes to finding the right routes to preventing road traffic congestion. This component is specially designed for developing countries since developed countries dispose of adequate road traffic monitoring systems and can use medical helicopters to emergency transportation. As earlier described, this component fits the road nets in the developing countries and is context-aware.

There exists an ICT infrastructure gap between the developing and developed countries [6]. The concept takes, therefore, an account for this fact and proposes an adapted patient-centric and IoT-based emergency care services delivery in the case of road traffic accident. At the rural level, emergency care transportation logistics are scarce or nonexistent. Often, it is very hard to quickly attend those areas due to the bad state of the road. To overcome this challenge, the near dispensary will request a nonmedical car and remotely instruct the driver as well as the rescue caller on how to transport the injured to the next dispensary. Each care is supposed to have a well-equipped pharmacy for the first aid on board. Car drivers are also supposed to be trained to give first aid. At the same time, an ambulance will be requested from the near emergency center. This operation has the potential to save time and provide the first aid to the injured. Imagine, healthcare professionals at a dispensary must go the accident scenes that can be several kilometers far away before the injured will receive the first aid. This scenario

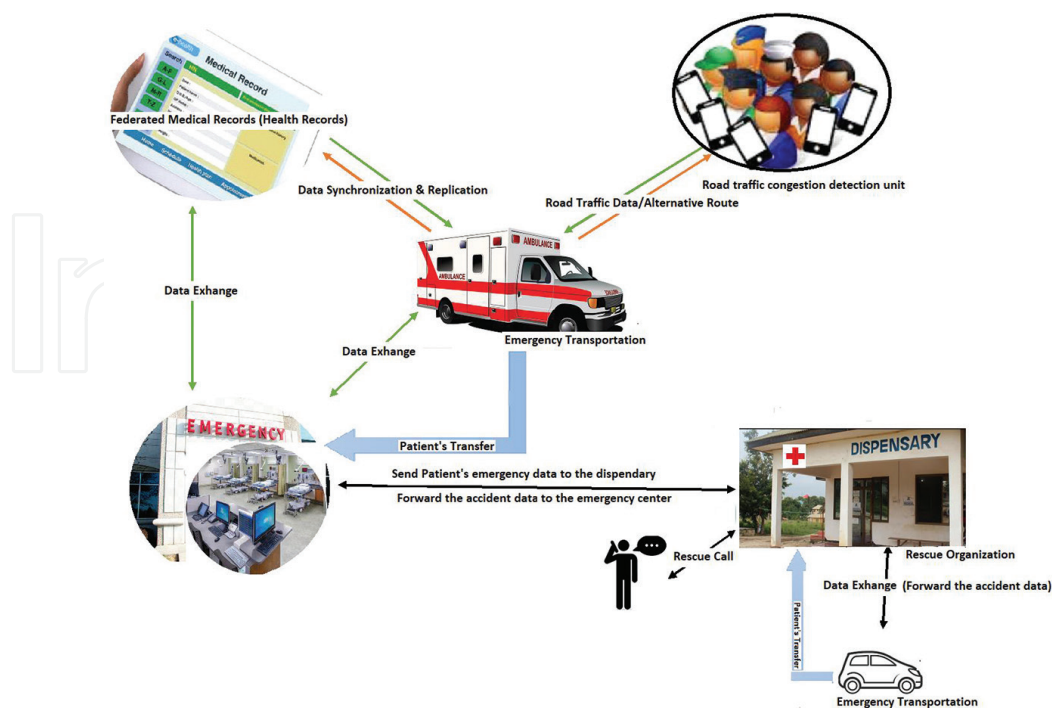


Figure 3. Patient-centric emergency care delivery process when the accident occurs in rural regions.

can lead to the injured death or cause him/her serious disability. To prevent such a situation, the dispensary personnel will remotely and accordingly instruct the relatives of the injured person with the information from the patient fEMR. The instructions are based on the patient-centric information. Once the injured person is delivered to the dispensary, an ambulance will transport him to the next emergency care center. **Figure 3** illustrates an emergency care delivery process at the rural level.

6. Experiment, methodology, and materials

This section will shortly present the conducted experiment, study methodology, and materials.

The global concept, as well as the appropriate architecture for improving the emergency care delivery, was tested at the rural level. A test cohort was built and an accident scene in a village was simulated. The area was selected according to following criteria: (i) lack of ambulance, (ii) very difficult road accessibility, (iii) the next dispensary is at 30 km, and (iv) mobile phone and telecommunication are possible.

Two car drivers, one with an approved medical first aid training and one without approved medical first aid training, and a less-educated caller are recruited. The reason why we select a less-educated call is to simulate the real situation, where the caller is often confused. The car driver without medical first aid training is selected to test the impact of the training on completing instructions received from a remote healthcare professional.

A dummy fEMR is generated. The accident scene is set up. Three data-driven emergency care delivery scenarios were simulated: (i) a patient-centric emergency care delivery, (ii) a patient-centered emergency care delivery, and (iii) emergency care delivery based on patient-centric combined with patient-centered information. **Table 1** indicates the test scenarios and outcomes with their characteristics. The impact of the first aid training on the care delivery is also investigated.

A rapid prototype of the proposed system was implemented. The server-side application was hosted on a GlassFish 4.0.1 on a laptop. A client application is used to visualize received data. The client application on the smartphone (gateway, sensors) communicates directly with the server application.

A qualitative data analysis is done using r-data analytics tool and following approaches: (i) organizing the data, (ii) identifying the framework, (iii) sorting the data into the framework, and (iv) using the framework for descriptive analysis.

The car driver with approved training in medical first aid successfully completed his assigned task in accordance with the instructions of the remote healthcare professional, and he has timely delivered the injured to the dispensary without additional damages. However, the other driver, without approved training in medical first aid, was less successful in completing his tasks despite the received instruction.

Test scenarios	Characteristics of the car driver		Origin of the information used	
	Approved training	No approved training	Patient-centric information	Patient-centered information
Test 1	x		x	
Test 2	x			x
Test 3		x	x	
Test 4		x		x
Test 5	x		x	x
Test 6		x	x	x

x means which information is used and what is the training level of the car driver involved. For example, Test 1 involves car driver with approved training and used data emanated from the patient (patient-centric information).

Table 1. Simulation scenarios for emergency medical care services delivery.

The experiment that uses patient-centric information has shown that beyond the standard emergency care, personalized care was provided through the information from the fEMR. The simulation with patient-centered information was also successful, but no personalized care was provided. Furthermore, the collected data within the emergency care were locally processed and archived at the emergency center and likely will not be used for further care provision. In contrary, data that were collected within the patient-centric emergency care provision are stored and processed in the cloud and the fEMR is synchronized and up to date. Information about the transportation duration, the quality of the primary care delivery, and the outcomes are collected.

The test’s main objective was to figure out the impact of the medical first aid training on the outcomes and impact of the quality and source of the information on the outcomes.

7. Study results and discussions

7.1. Study limitation

Worst cases, where car drivers are not up to date regarding the medical first aid training (that means he was trained but forgets the essentials) or furthermore the case where nobody at the accident scene is trained to give medical first aid, are not tested.

The test period is relatively short. Furthermore, real emergency cases were not tested, and then such cases could provide more useful data for analysis.

7.2. Results and discussions

The car driver with approved training in medical first aid successfully completed his assigned task in accordance with the instructions of the remote healthcare professional, and he has timely delivered the injured to the dispensary without additional damages. However, the

other driver, without approved training in medical first aid, was less successful in completing his tasks despite the received instruction.

The experiment that uses patient-centric information has shown that beyond the standard emergency care, personalized care was provided through the information from the fEMR. The simulation with patient-centered information was also successful, but no personalized care was provided. Furthermore, the collected data within the emergency care were locally processed and archived at the emergency center and likely will not be used for further care provision. In contrary, data that were collected within the patient-centric emergency care provision are stored and processed in the cloud and the fEMR is synchronized and up to date.

Reliability and validity: To ensure the reliability and validity of the test, each test scenario was repeated three times. The impact of the information used, as well as the training of the driver, was thus validated.

Accuracy of the collected data: Collected data must be accurate. Information about the golden hour, the collected bio-signal, and patient-provided information were valid.

Measurement errors rates: The error rates within the golden hour, in measuring bio-signal and in reporting the event at the hospital, were assessed. The error rate was negligible.

Impact of the training on the overall outcomes: The experiments have shown the impact of the training level on the overall outcome. It revealed the impact of the golden hour on the medical outcomes. Furthermore, tests involving trained drive have produced positive outcomes. The patient has high survival chance when, in addition to trained driver, nothing but patient-centric data is used, patient-centric combined with patient-centered data are used. The patient has less chances of survival when the driver is not trained and only patient-centered data is used.

Test	Outcomes
Test 1	Positive outcomes. The patient received adequate first aid due to the knowledge of the driver and the accurate patient-centric data available
Test 2	Negative outcomes. Information provided was incomplete (subject). This has negatively impacted the outcomes. The transportation was conservative, and then the driver knows how to prevent any additional medical or health damages
Test 3	Due to lack of first aid, the collected data could not be used in the golden hour. However, the patient received adequate care based on the collected data. The healthcare professionals have estimated that in real case the patient's chance to survive could be less than 40%, since he did not receive appropriate care in the golden hour and, additionally, the transportation was not conservative because the driver was not trained
Test 4	The outcome is similar to Test 3. However, the survival chance for the patient was estimated to 10%, and then the medical examinations were needed to verify the information provided by the patient
Test 5	Very positive outcome. All the needed information is available. The patient was stabilized in the golden hour. The transportation to the hospital was conservative. At the hospital, the patient received timely follow-up treatment (simulation). Timely because no medical treatment was needed. The patient-centric data is already available
Test 6	The outcomes are similar to those at Test 5. However, the transportation was not conservative, because the driver was not trained

Table 2. Test outcomes.

Table 2 summarizes the test outcomes.

8. Conclusion

Previous research works have demonstrated that health care is taking enormous benefit of the use of Internet of Things technology and paradigm in the healthcare provision. A comprehensive literature review has revealed that IoT technologies like WBAN and WSN are used for collecting, storing, and processing patient-centric data. The data processing takes a full benefit of the IoT technology, where data are autonomously and automatically collected. Fog/edge computing contributes to locally process with the collected data for quick decision-making. Quick decision-making is an important issue in the healthcare delivery regarding the time that is a critical point.

This study presents an IoT-enabled emergency medical care services delivery system working with patient-centric data (current and previously collected data) from different sources, including genomic data, which is not actually considered in medical treatment due to the high cost of genomic sequencing. The central piece of the proposed system is the federated electronic medical care that collects EMRs from different sources, adds the genomic part, and sets automatically the individual emergency care data as well as medical cases files on demand.

This system has presented a novelty. To our best knowledge, no emergency care system worldwide is using such a federated database like health record.

Conflict of interest

Author Edoh declares that he has no conflict of interest. Informed consent was obtained from all individual participants included in this study.

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