IoT in Health-care: Recent Advances in the Development of Smart Cyber-Physical U*biquitous Environments*

Abdulaziz A. Albesher

College of Computing and Informatics, Saudi Electronic University,Riyadh, Saudi Arabia

Summary
With the widespread of sensors and devices with connectivity in recent years, internet of things (IoT) has become very essential in almost every field. Its application in healthcare is one of the primary areas of research. This paper provides an overview of different aspects of IoT in healthcare. It discusses some of the major services of IoT healthcare and its benefits to the communities at large, including initiatives taken in different countries worldwide. Recent and advanced wearable health technologies are also discussed along with some state of the art IoT enabled health applications. It is preceded by a thorough discussion on security requirements and challenges in IoT healthcare. Future trends and technological directions are discussed at the end of this work.

Key words:
Ubiquitous computing, Internet of Things, Internet of Healthcare Things, pervasive networks, e-health

1. Introduction

As the world’s next-generation technological paradigm continues to shift and grow, new devices and innovative ways of their utilization and integration with the surroundings emerge like never before. Internet of Things (IoT) is such a megatrend in today’s computing environment. IoT utilizes uniquely identifiable smart devices and objects for the formation of cyber-physical smart ubiquitous networks which are also able of connect with the already existing internet framework. Hence, any device or thing can connect to other things, people or services through internet. This will increase the size of current internet by many folds. According to a prediction by Forbes magazine [1], by the year 2020 there are an expected 40.9 billion devices capable of connecting with the internet and directly communicating amongst one another. This leads to a wide range of benefits and application areas such as smart cities [2], water quality assessment [3], security [4], industrial control [5], disaster management, traffic congestion control, stampede awareness, anomaly detection and health care [6], to name a few. Among these, IoT for healthcare is one of the prime application areas using such pervasive networks [7], [8] and much recent research is focusing on it. When it come to healthcare, IoT is known as Internet of Healthcare Things (IoHT)

Earlier research endeavors in the field of IoT in healthcare started with the initial research and development activities based on wireless sensor networks (WSNs) [8]. Today, the technology is gradually transforming into lower power wireless personal area network (6LoWPAN), which is based on IPv6 [9]. This allows the smallest of the devices, with limited processing ability and power-life, to transmit information wirelessly using an internet protocol. This empowers small sensors, devices and wearable gadgets in the healthcare industry to be a part of the huge internet revolution and opens countless horizons of usability, connectivity, facilitation, research and development. It has also restructured the usage of healthcare diagnostic and imaging devices, monitoring systems, wearable devices and sensors to be an essential part of the IoT. Some of the most prominent applications in IoHT include remote patient monitoring, elderly care programs, fitness and diet control programs, mental and psychological counselling systems, drug reaction control, and indirect emergency healthcare, to name a few.

Likewise, there is a lot of potential of new, innovative and cost-effective medical applications and devices with the emergence of IoT which are expected to increase the quality of life. These systems are capable of human-to-human (H2H), human-to-machine (H2M) as well as machine-to-machine (M2M) communication without human involvement [6]. These advancements have transformed the treatment methods and the way patients are looked after. This enables the access of health data by the patient’s doctors, nurses and close relatives. In addition, the quality and efficiency of the medical services has also been greatly improved. As an example, chronically ill patients, elderly people and patients with reduced mobility can now be managed remotely. This can substantially minimize the hospital visits, thus reducing the cost and inconvenience to the patients. Healthcare monitoring wearables, such as a smart blood-pressure cuff or gadgets like BioPatch [10], can send data remotely during different times of the day. This bridges the gap between the doctor and the patient and speeds up the treatment according to the critical needs of the patient. IoT has the potential to significantly reduce mortalities and medical complications related to non-communicable diseases such as stroke, heart diseases, hyper tension, hypo and hyper glycemia, cancer, etc.

Manuscript received February 5, 2019
Manuscript revised February 20, 2019

From the point of view of device-care and maintenance, IoT has the prospects of device servicing, care and restocking the about-to-finish supplies in a timely manner. Remotely installed devices can communicate with the healthcare providers and device vendors for a possible fix or replacement before going down. This eventually saves substantial amount of downtime in which, otherwise, the patient would have been facing a risk of not being monitored.

Current research drift in IoHT is along the direction of IoHT network architectures and protocols, security, innovative applications and services, interoperability, power optimization, among many others. The focus of this work is to provide the reader an earlier insight into these research trends and future of IoT. In this work we present a brief survey of IoHT services and applications, including personalized care and wearables. We also present and analyze security and other challenges pertaining to IoHT. In addition, we present an overview of initiatives different countries have taken in IoHT and highlight the future trends and technologies in IoT health.

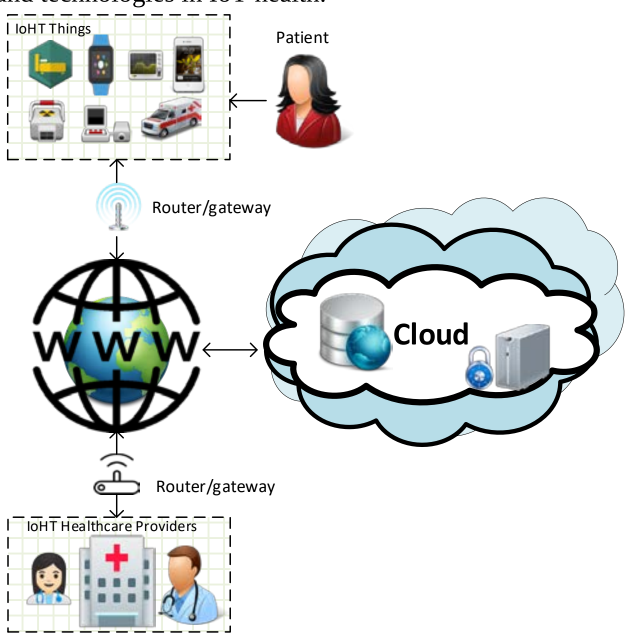

Fig. 1 General architecture of IoHT enables medical services.

The rest of this paper is organized as follows. Section 2 presents and overview of personalized healthcare applications along with insight into healthcare wearable devices. Section 3 covers security requirements and challenges faced by IoHT services and technologies. Future challenges in IoT health and country-wise initiatives for IoT are discussed in section 4. Section 5 presents conclusion of this work.

2. IoT Health Services and Applications

With the widespread of interconnected networks and propensity of devices to form ubiquitous ad hoc networks, IoHT applications have evolved with much diversity and innovation in recent decade. One of the considerable revolutions is the emergence of personalized healthcare services and widespread wearable devices in medical sector. Due to the prospective benefits of IoT in health services and applications, countries worldwide have taken plenty of measures to instigate development, adoption and use of IoT services and applications in medical sector. Figure 1 presents the general architecture of IoHT enable medical services. In the subsections that follow, we discuss these different aspects in detail.

2.1 IoT for Personalized Medical Services

Recent proliferation of IoT enabled technology has paved the path to the emergence of personalized healthcare services. Whereby, a service is a broader term encompassing a collection of solutions in a specific service domain. Some of the most noticeable healthcare services are discussed in this subsection.

One of the most beneficial IoT services is indirect emergency healthcare (IEH) [11], [12]. There are many emergency situations in which timely and effective response by a medical expert is highly desirable. Sometimes, these situations can be life threatening and the patient is remotely located. In other scenarios, the cause of a bad situation can be natural hazards such as fires, thunderstorms, earthquakes, tsunamis, etc. IEH is considered to be a dedicated service offering a set of solutions such as post-disaster actions, information availability and record keeping [8].

Ambient assisted living (AAL) is another very important service based on IoT. It promises to fulfil a long-awaited need of human societies worldwide. It is a new paradigm that deploys intelligent objects in the environment of people with less mobility and dependency, especially elderly people and people with reduced mobility, to support them and monitor them continuously. This enables them to be more independent and secure.

Another very important service that IoT has enabled in recent years is the timely management of adverse drug reaction (ADR). Once of the most important aspects of primary medical care is to make sure that patients on prolonged medication are subjected to minimal ADRs. Compliance to the drug is also another concern, as severe health issues may result if a patient abandons or neglects the prescribed dose of medicine or take it in wrong times or takes a combination of them without consulting the healthcare experts. According to a latest research, ADR prevalence in the hospitals throughout the world is 6.7 %,

with an estimated death rate of 0.32 % of the total patients [13].
Behavioral, emotional and mental health problems of children, and constant monitoring of these for their wellbeing is another important aspect that IoT is benefitting the societies at large [14]. To cater for this, specialized IoHT service known as children health information (CHI) has been developed. In addition to these, special IoT based devices and applications are designed to create an awareness among young children regarding the overall wellbeing, nutrition and healthy lifestyle.
Another very important area in which IoT has a been very effective is community healthcare (CH). Through IoT enabled devices and sensors, a network is formed in communities like neighborhoods, rural areas and remote localities. This network is connected to a centralized healthcare unit. Thus, fulfilling any medical needs or emergencies and sharing and communicating health related information.

Table 1: Most Noticeable IoHT Mobile Applications in different areas of healthcare

Healthcare Area	Apps
Diagnostics applications	MediCode, CURRENT Medical Diagonosis and Treatment, John Hopkin's Antibiotic Guide, MS diagonosis and Management, Your.MD: Sympton Checker and Health Tracker, Conn's Current Therapy
Therapy and and counseling apps	BetterHelp: Counseling and Therapy Online, Youper-Anxiety and Depression, Talkspace Counciling and therapy, Psychologist
Medical education applications	Harrison's Manual and Medicine, Diseases Dictionary, I-surgery Notebook, Netter's Anatomy Flash Cards, Oxford's Handbook of Clinical Specialities
Drug reference applications	IBM Micromedex Drug Ref, RxDrugs, FDA Drugs, Lab Values, Mosby's Drug Reference, Drugs.com Medication Guide
Clinical Communications applications	Clinical Reach, Practice Unite, Tradassan, Vocera, Emergency Medicine Program

Crowd based medical help is another very important service that IoT can provide to communities worldwide. It is regarded as a direct help by the community in cases of medical emergencies, financial issues and general health related issues. Users and devices connected to this service include healthcare seekers, practitioners and provider units. As an example, in case of an emergency blood requirement, any person from the community can communicate with the relevant node to volunteer for blood donation. In cases of natural disasters, crowd can help rebuilding and reestablishment of the communities through the information sharing by IoHT.

2.2 Health-Care Wearables

This subsection provides an insight into some of the latest IoT enabled healthcare wearable devices and applications. IoT enabled healthcare wearables are any devices or technologies that can be attached to humans in the form of utility gadgets or clothes. They then collect and communicate health related information with the medical units, remote servers, and other persons such as relatives and friends. The last one decade has seen a revolution in innovative wearable technologies which the world had never seen before.
Among the most common types of healthcare wearables are the fitness trackers and smart watches. There is a wide range of mobile applications that are available for these gadgets to connect and communicate information with remote servers, artificial intelligence (AI) based agents and healthcare specialists. Fitness trackers are especially helpful in weight loss programs, healthy lifestyle, recovery from and ailment such as a heart attack, and for the well-being of elderly people. Table 1 provides a list of some of the most prominent and highly popular applications for healthcare. These include applications for blood glucose level monitoring, blood pressure monitoring, oxygen saturation monitoring, medication management and medical education. Due to the limitation of this paper, all of these can not be discussed here. Among these traditional gadgets and applications, there is a list of somewhat unique and more noticeable ones. We discuss some of these in the following paras.
Air Louisville [15] is crowdsourcing of air quality in Louisville, United States by using smart air inhalers equipped with different sensors. It is among some of the most noticeable IoT enabled healthcare wearables. Louisville is among the worst polluted cities in the world and people with lung diseases like asthma and chronic obstructive pulmonary disease are at a constant life threat. Air Louisville enrolled 1,147 citizens of Louisville and collected 1.2 million data points, including over 251,000 medication puffs. It then combined these data with over 5.4 million environmental data points to find the reason and scenarios causing lung diseases.
Breast cancer is one of the most prevailing form of cancers for women worldwide with an estimated number of 1.7 million new cases yearly. One of the major reasons of its prevalence is failure of early stage detection due to ignorance, unavailability of radiologists on remote locations and lack of resources. Cyrcadia Health [16] developed a wearable solution known as iTBra in the form of sensor patches worn as a bra insert and collects data related to daily heat changes that correlate to elevated cellular activity due to tumors. The data then can be transferred to mobile of computer and shared with healthcare service providers.

Kardia from AliveCor [17] is another very interesting wearable that monitors the circadian rhythm of the heart and eliminates electrocardiogram (ECG) test. User can put a set of finger pads near the mobile phone, and then place their fingers on the device to take the reading which takes only thirty seconds. The device then indicates whether the user's heartbeat is normal or he is facing atrial fibrillation. Another version is in the form of a band and can use the readings from Apple watch's heart-rate sensor.

Recently, L'Oreal introduced a new wearable called La Roche-Posay UV Sense [18] that can sense and inform the users when they are exposed to high doses of ultraviolet (UV) radiation which can have adverse effects on health. The sensor is less than a centimeter, can be worn on a nail and is battery free. An NFC enable mobile phone can download its data and inform the user about the sun exposure.

The role of IoT for transforming living standards can be evident from the applications and services for people with special assistance. One such example is Aira [19]. It is a semi-automated service which consists of a camera mounted wearable glasses worn by the blind person. The camera captures real time video which is transmitted to remotely located specialized trained agents who then personally help the blind navigating through the scenes. It has many other extra advanced features like location tracking in case of a blind travelling in a rented vehicle. It is a service of its own kind and opens many other research areas.

Another very honorable mention in the state-of-the-art devices are moodables, i.e. devices with the potential of enhancing a person's mood when feeling anxious or depressed [20]. This is a very remarkable achievement as depression patients are increasing worldwide. These wearables are worn on the head and are able to transmit a controlled low intensity current to the human brain which eliminates depression. Companies like Thync [21] and Halo Neurosciences [22] have made considerable progress on such devices and it is expected that soon they will be available in the market on affordable prices.

When it comes to infant and child care, TemTraq [23] is yet another innovative IoT enabled wearable. It supports Bluetooth and monitors the body temperature of infants up to 48 hours using a soft stick-able underarms patch sensor. The readings can be monitored on a mobile device through an application interface. It also supports many advance functionalities like raising alarms when temperature exceeds critical set thresholds. Such a wearable is very helpful especially during bacterial and viral infections when temperatures can suddenly shoot up in response by the body fighting against the disease.

3. IoT Health-Care Security Requirements and Challenges

IoHT is flourishing rapidly in the medical sector and soon there will be a widespread of this concept in all areas of the medical practice. Along with these developments, there are also raising concerns of a myriad of security issues and challenges. In this section we discuss some of these important aspects concerning to security in IoHT enabled devices and networks.

Since the development of IoHT devices and applications are at the infancy level, there are many limitations presently that play a vital role in the onset of challenges faced by IoHT. These limitations include the energy limitations, memory limitations and computational power limitations. With the ongoing technological developments in the hardware, these limitations are reducing with the passage of time and devices are continuously improved with better battery-life, increased memory sizes and higher processing speeds.

Other challenges, which are more on the software side, include confidentiality of information, integrity of sensitive medical data, availability of service, fault tolerance, authentication and authorization. Confidentiality of information prevents the access of medical information to unauthorized users. For this, several techniques have been implemented and more are expected to be developed as the technology continues to enhance. Integrity of data prevents any alteration of data during its transit stage by any adversary sniffing the IoHT network. Another very important aspect when it comes to IoHT challenges is availability of service. It ensures that the healthcare services will be available to the end users when and where needed. Any downtime and denial of service would discourage the embracement of IoHT services and applications. In addition, these services should be fault tolerant. This urges the services to be still available even in the times of faults and attacks. Lastly, one of the most important challenges related to security is the mechanism for ensuring authentication and authorization. Authentication ensures that the IoHT device is communicating to the peer it is supposed to communicate and there is no false presence. Authorization ensures that only authorized nodes are allowed to utilize and access IoHT network peers and resources. For further details on these challenges the reader is referred to [8] which presents a detailed discussion on them.

Like other conventional networks, IoHT networks are also prone to a number of hostile attacks. Since mobility is a prime factor in IoHT based devices, therefore these are prone to frequent network changes with different security configuration settings which makes them highly vulnerable. These include attacks based on information interference, attacks based on host properties and attacks based on network properties. Whether the health data is in transit or on some storage device, it is always susceptible to information interference attacks such as Interruption, Interception, Modification, Fabrication and Replay attacks [8]. In case of attacks based on host properties, there could be three major types of compromises including user compromise, hardware compromise and software compromise. An attacker can steal and modify the data with malevolent intent. Lastly, for the attacks based on network, an attacker can launch attacks based on standard protocol compromise and/or network protocol stack attacks. Therefore, the IoHT services need to have a strong collaboration between them and should be dynamic to predict and countermeasure these attacks and the attacks expected in future.

4. IoHT: Country-wise Initiatives and Future Trends

Ranging from pilot projects to effective implementation of eHealth and IoHT based health services and policies have been adopted successfully in many countries worldwide. Some of the countries and their policies pertaining to these in the modern world include Japan's u-Japan health policy [24], France's mandatory service of object-naming service (ONS) which requires every product to be uniquely identifiable including IoHT enabled devices; Sweden's national strategy for health of 2010; Germany's INDUSTRIE 4.0 strategic initiative; South Korea's initiative to expands it IoT market to $28.9 billion as a result of its eHealth policy of 2008; the European Union's policay of health in 2004; China's eHealth development strategy of 2003-2010; and the United States' ongoing efforts from 2014 to introduce IoT in healthcare.

Apart from these, there are many initiatives taken for eHealth and IoHT services by lesser developed countries as well. These include Saudi Arabia's eHealth policy in accordance to its vision 2030 [25]; Pakistan's initiatives and policies in eHealth and IoHT as of 2012 [26] ; and India's promotion of ICT for health services. In addition to these, there are many efforts done by the World Health Organization (WHO) to promote the use of mHealth and eHealth in different campaigns both in the developed and developing countries.

The future of IoHT is very promising as around the globe medical sector and health related services are adopting IoHT with a greater pace. Both the hardware and the software aspects of the technology are contributing towards this shift. On the hardware side, new technologies and enhanced capabilities of devices on reduced costs are making them affordable and widespread. Similarly, innovative wearable gadgets and their utility continues to attract the users to adopt them. On the software side, innovative ways of utilizing existing hardware and facilitation of end user is making them more attracted to IoHT based medical care. In some scenarios such as remote locations and unavailability of physicians, the user see it as a ray of hope and are embracing IoHT with open arms. As the research continues in eradication of security challenges in future, and countries continue making policies and shifting towards eHealth and IoHT enabled networks, the future of IoHT is very bright.

5. Conclusion

IoT in one of the primary topics of research in these days as the world's technological and application paradigm for new and innovative technologies and applications is on a continuous shift. This paper presents an overview of IoT in healthcare with discussion and insights into a number of related issues. There is a plethora of IoT based healthcare services like indirect emergency healthcare, ambient assisted living, adverse drug reaction, children health information and community healthcare, to name a few. New and innovative wearable gadgets are also emerging. Countries around the globe are making laws and policies for including IoT in medical care practices. Along with these, there are many challenges faced by IoHT infrastructure, architectures, devices and services. The future of IoT based medical services is very promising as the research continues in IoT.

Acknowledgments

The author highly acknowledges the support provided by Saudi Electronic University (SEU) for this research.

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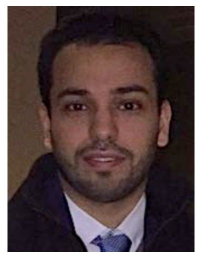

Abdulaziz Albesher received the B.Sc. degree in Information systems from King Saud University in the Kingdom of Saudi Arabia, M.Sc. degree in Information systems and PhD degree in Computer science from Brunel University in the United Kingdom. Currently, he is an assistant professor at the department of Information Technology in Saudi Electronic University. Moreover, he has held various IT positions in multiple institutions and worked as a consultant in a number of public and private organizations. Dr. Abdulaziz’s research interest are in Internet of Things (IoT), E-government, Blockchain technology and Cyber security.