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El Internet de las cosas en el cuidado de la salud

The Internet of Things in Healthcare. An Overview

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Resumen — La prestación de servicios de salud está experimentando enormes cambios alrededor del mundo. El envejecimiento de la población, la creciente incidencia de enfermedades crónicas, y la escasez de recursos se están convirtiendo en una carga pesada para los actuales sistemas de salud y podrían comprometer la prestación de servicios de salud en las próximas décadas. Por otro lado, la creciente popularidad de dispositivos para el cuidado de la salud y el bienestar, junto con avances en comunicaciones inalámbricas y en sensores abren la puerta a nuevos modelos para la prestación de servicios de salud respaldados por el Internet de las cosas (IoT). Este artículo presenta una revisión general de las tendencias que están impulsando el desarrollo de aplicaciones para el cuidado de la salud basadas en IoT, y las describe brevemente a nivel de sistema.

Palabras clave — IoT, cuidado salud, monitoreo remoto, ambientes asistidos, hospitales inteligentes, dispositivos monitoreo.

Abstract — *The provision of healthcare is experimenting enormous changes worldwide. Population ageing, rising incidence of chronic diseases, and shortages of resources are placing a heavy burden in current healthcare systems and have the potential to risk the delivery of healthcare in the next few decades. On the other hand, the growing popularity of smart devices for healthcare and wellness, along with advances in wireless communications and sensors are opening the door to novel models of health care delivery supported by the Internet of things (IoT). This paper presents a review of the trends that are driving the development of IoT-based applications for healthcare and briefly describe them at a system level.*

Keywords — IoT, healthcare, remote monitoring, ambient assisted living, smart hospitals, wearables.

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1 INTRODUCTION

The unrelenting phenomenon of population ageing is rising serious concerns about the financial pressures that health systems around the world are likely to face in the next few decades. Compared to 2017, the number of persons aged 60 or above is expected to grow more than twofold by 2050, rising from 962 million in 2017 to 2.1 billion in 2050 [1]. Furthermore, population ageing is estimated to affect globally the support ratio, defined as the number of workers per retiree. In 2017, only a handful of countries in Europe, Japan and the United States Virgin Islands had a support ratio below 3. By 2050, seven countries in Asia, 24 in Europe, and five in Latin.

America are projected to have a ratio support bellow 2 [1]. Although, there is no definition on the minimum support ratio, it is logical to infer that low scores lessen the ability of public health systems in the care of the elderly. Closely related to population ageing is the increasing incidence of non-communicable diseases (NCD) such as diabetes, coronary artery disease, Alzheimer's disease, Parkinson's disease, among others. According to projections, NCD prevalence is expected to increase in 57% by 2020 and be the cause for 75% of all deaths worldwide [2]. Furthermore, the prevalence of multiple chronic conditions per patient also raises concerns. In 2012, 24% of non-institutionalized patients in the United States suffered one chronic condition, whereas over 25% of patients presented two or more chronic conditions [3]. Ordinarily, chronic diseases require long-term treatment, continuous monitoring, and hospitalization. Because of increasing chronic-disease rates, long-term hospitalizations rise, overburdening healthcare facilities and incrementing operational costs. Furthermore, shortages in the supply of healthcare professionals add to the problem. As of 2013, the shortage of healthcare workers was of 7.2 million and projections place the same figure at 12.9 million by 2035 [4]. Increasing tendency for medical student to seek careers in better-paid specializations, such as surgery and other medical sub-specialties has led to a decline in the number of general practitioners. In addition, the consolidation of a global labor market in health care is causing rich countries to raid less affluent nations for staff to meet shortfalls in their healthcare workforce [5]. As healthcare parties struggles to meet the needs of a growing aging population, there is an increasing in the popularity of healthcare devices for monitoring exercise, sleep, heart rate, blood pressure, among other biological signals [6]. This evidences a shift in consumer behavior towards the appropriation of the management of their own health. This trend is getting a lot of attention by public and private sectors. For instance, governments are actively promoting the development of self-managed, and self-monitoring systems in initiatives like Individualized Medicine in the United Kingdom and Precision Medicine in the United States [7]. On the other hand, popular commercial wearables such as Fitbit health monitor, Pebble smartwatch, and Google Glass, are becoming instrumental in allowing self-management, and self-monitoring. Moreover, they are increasingly incorporated to electronic health records and office systems [8]. Healthcare industry is changing at a rapid pace both in the demand of services and in the way these services are expected to be delivered. Some effects of these changes are already at sight and others are soon to arise. One exciting development in healthcare is the increasing application of the concepts of the Internet of things (IoT) to the medical domain.

The potential incursion of IoT solutions in healthcare has motivated a great deal of research. On one hand, a significant portion of works has focused in examining the prospective role of connected devices in enhancing the delivery of care to patients with chronic diseases, and patients that require continuous monitoring [9-11]. On the other hand, extensive research has been conducted on technological aspects related to IoT. Surveyed topics range from commercially available products [12], sensor technology [13], related technologies and, infrastructure [14, 15]. Although previous works present in-depth discussions of relevant aspects to the application of IoT in healthcare, every topic is discussed in isolation which makes difficult to understand how different technologies add to a complete system. This paper does not discount previous work but build on it to examine key components in the context of an overarching IoT-based system for healthcare.

The remainder of this paper is organized as follows, Section II introduces IoT, and the motivations driving its application in healthcare. Section III presents an overview of common use cases, discussing major components at system level. Section IV discusses latest related enabling technologies highlighting their potential to enhance IoT-based applications for healthcare. Section V discusses ethical and privacy concerns related to personal data in IoT systems. Lastly, section VI presents the conclusions and recommendations for future work.

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2 BACKGROUND

2.1 The Internet of Things

The Internet of things is a broad concept defining the convergence of a wide variety of technologies, and systems that leverages the increasing trend of physical devices (things) connected to the Internet. IoT is projected to consolidate an ecosystem like that of personal communications through the Internet but connecting real-world objects with each other and using well-known web technologies. In that context, IoT is expanding the existing Internet beyond human interaction to a new scenario where everyday things exchange information with people, systems, and other real-world assets to support decision making and to create knowledge. Ambitious initiatives such as Health 4.0 [16], SENSEI 2013 [17] and CityPulse 2013 [18] envision IoT as a mean to enrich business processes and services. IoT is expected to consolidate a technological platform that not only provides sensor data, but also contextual data sourced from geographic information systems and social media. A prime example of IoT application is personal wellbeing, specifically stress-monitoring. Thanks to the increasingly availability of commercial fitness wearables like bands and smart watches, measuring bio-signals has been suggested as a readily opportunity to reduce health risks in the workforce. Several studies note stress as main contributor to health issues including high cholesterol, overweight, and high alcohol consumption [19], [20]. Common approaches to quantify stress rely on measuring the heart rate and the galvanic skin response (GSR). Commercially available products on the market can measure these bio-signals, however the information collected via such devices is limited in that ordinarily sensor can only provide

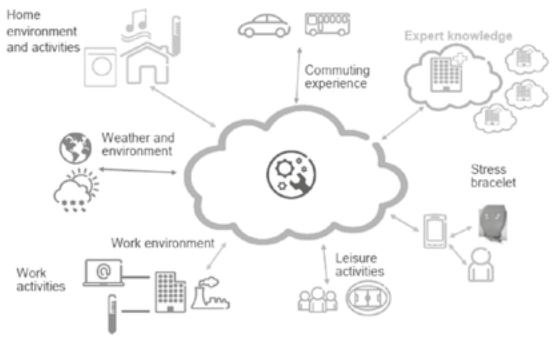

Fig. 1. IoT-based stress monitoring application [20].

the intensity of the signals but they do not inform about the context, e.g. high readings of GSR or heart rate can be caused by stress but also by increased physical activity (e.g. exercise). This ambiguity renders devices prone to false alarms. By contrast, an IoT application can approach the same situation with a broader data coverage providing information sourced from the subject environment, e.g. family, workplace, and other activities that a single sensor would not capture by itself.

Added information from several sources is instrumental in obtaining insight into the person's environment, and their contextual situation. Such a scenario is illustrated in Fig. 1, the illustration depicts an IoT application with various data sources and the available information for collection, aggregation, and analysis. Environmental factors like noise level, air quality, and temperature, as well as work activities such as meetings, phone calls, and e-mail reading, all can impact people well-being and hence increase their stress. On the other hand, recreational activities including exercise, meditation, and leisure time may have a positive impact on people performance and health. Having the ability to record and catalog positive and negative factors, can lead to proactively propose changes to control stress, e.g. increase physical activity, or adjusting bedroom temperature.

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3 IOT IN HEALTHCARE

The emerging paradigm of the Internet of things brings a wide range of capabilities supported by pervasive connectivity. This approach provides everyday objects with connectivity and computing capabilities to communicate between each other, virtually with no human involvement. IoT connects devices such as consumer objects, sensors, and equipment to the network to manage the physical world through ubiquitous computing, advanced networks, machine-to-machine methods, and other approaches. IoT allows for a variety of connections scenarios including connected cities, connected homes, wearables, industrial Internet, among others. All these scenarios have in common a user-oriented development where personal computer, tablets, and smartphones have a central role. Moreover, this user-centered philosophy is helping to develop a more personalized way of care via the interconnection of sensors, medical equipment, and consumer devices. IoT applications for healthcare are rapidly emerging addressing the equally rising demand for provision of care outside of the established hospital-based model. Projections of the market growth health care estimates that it will reach 348.5 USD billion by 2025 with an important participation of IoT applications and services. The following sections present an overview of trending use cases of IoT in the medical domain described at system level.

3.1 Remote Monitoring

An increasing need in healthcare is moving the delivery of care from hospitals to private environments such as the patient's home. In many countries, especially in the less affluent, budget cuts result in health workers shortages and overburdening of healthcare centers. This is particularly evident during and after seasonal-disease strikes where the influx of people to points of care spikes. One way to overcome this is to acquire patient's vitals at their side and then transmit those signals to the interested parties (physicians, parents, nurses, and others). As a result, physician reduce their workload, hospitals cut their costs, and patients receive timely care. Remote monitoring can also support the care of chronic conditions and patients who live in distant areas.

The basic blocks of a remote monitoring system comprise sensors for acquisition of bio-signals, user interfaces including smartphones, tablets, workstations, and a communication infrastructure. Fig. 2 illustrates a monitoring system consisting of a body area network (BAN), a personal digital assistant as one of the user interfaces, and the medical tier at the healthcare provider end. In addition, the system includes two segments of communication: Short-range for communication between sensors within the BAN, and long-range communications to connect the BAN to the health-provider's facilities. There exists a wide variety of short-range communications standards, however Bluetooth Low Energy (BLE) and ZigBee dominate IoT market. Table I summarizes the main features of these two standards.

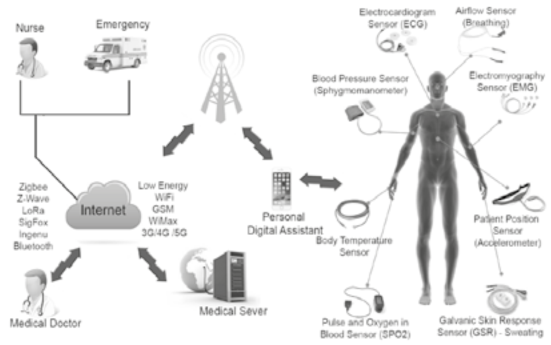

Fig. 2. Remote healthcare monitoring system [21].

3.2 Ambient Assisted Living

Ambient assisted living (AAL) is an IoT-based service designed to provide continuous care for the elderly, patients with chronic diseases, and patients with special needs. One key benefit of AAL is that it allows continuous monitoring with less human involvement. In addition, AAL improves patient's quality of life by allowing them to dwell autonomously in their desired environment. Applications of AAL include remote monitoring, drug management, behavior modification, hand hygiene compliance, chronic disease management, and others. The overall architecture of AAL comprises smart objects such as wearables, bio-medical sensors, motion sensors, among others. Fig. 3 illustrates an AAL system for mobility support

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comprising a smartphone application, for processing the bio-signals from the chest band sensor, ambient assisted living message queue (AALMQ) for managing the communication between the devices, and sensor, ambient assisted living message queue (AALMQ) for managing the communication between the devices, and wearables (smartshoes, and kshirt). The AALMQ communicates with web services and the database through a service bus (mobile gateway) and with the smartphone via Wi-Fi or mobile network [22].

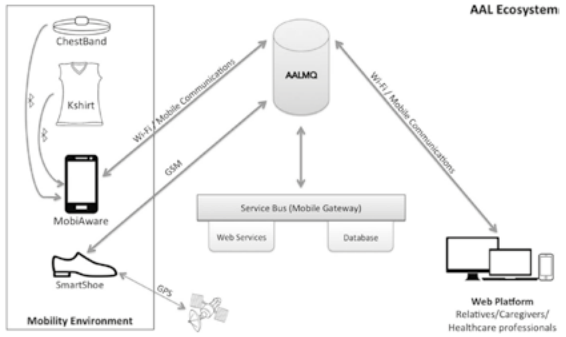

Fig. 2. Remote healthcare monitoring system [21].

3.3 Connected and Smart Hospitals

Smart and connected hospitals involve a broad range of scenarios such as predictive maintenance, connected healthcare devise, and tracking of people and devices. These use cases are cross-industry, and include applications like smart buildings, facility management, and real-time analytics from the data generated by device and patients.

TABLE I. DOMINANT STANDARDS FOR SHORT-RANGE COMMUNICATIONS [24]

	Bluetooth	ZigBee
Operation band	2.4 GHz	2.4 GHz
Range	150 m	30 m
Topology	Star	Mesh
Data rate	1 Mbps	250 kbps
Security	128 AES encryption Secure pairing prior to key exchange Network key shared within network	128 AES encryption (optional) Two keys for authentication Optional link key to secure application layer
Suitability for healthcare	High	Moderate

These use cases are cross-industry, and include applications like smart buildings, facility management, and real-time analytics from the data generated by device and patients. A recent survey on the current use of IoT in healthcare found that 70% of respondents are using IoT for monitoring and maintenance, and 50% for remote operation and control. In addition, 67% of interviewees plan to connect their devices using wireless connections [23]. Fig. 4 illustrates a smart-hospital architecture based on IoT.

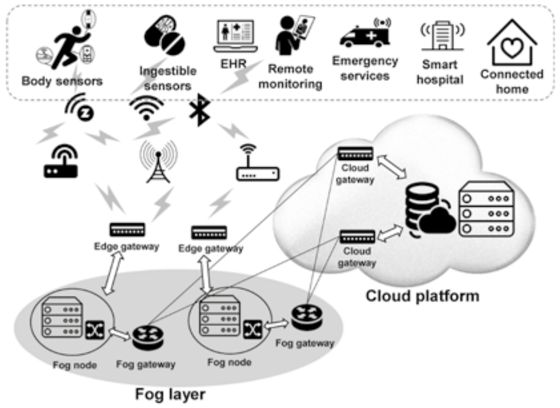

Fig. 4. Smart hospital architecture based on IoT [26].

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The architecture comprises four layers where the sensing layer collects and sends data to the base station (BS) layer. Next, the edge serving (ES) layer provides an interface between the BS and the cloud computing (CC) layer, to meet requirements of low latency, and real-time processing. Lastly, CC layer handles data analysis and the control of the system. Use cases of this system include:

- Intelligent parking, booking of parking spaces through mobile devices.
- Access control to restricted areas through wearable-based authentication.
- Ward care real-time collection of physiological signals via wearables or sensors, and transmission to monitoring center through wireless communication.
- Telemedicine and remote monitoring.

4 ENABLING TECHNOLOGIES

4.1 Cloud Computing

IoT-enabled devices typically possess limited capabilities of storage and processing which prevent them to provide real-time analytics, particularly in the context of a data-intensive domain like healthcare. Cloud computing emerge as a convenient solution to bridge the gap between data collection and data exploitation by providing high processing, and scalability. The integration of cloud computing to IoT for healthcare applications would provide ubiquitous access to medical data for collaboration, and decision-making support.

An example of such an application is The Collaborative Cancer Cloud, a cloud-computing-based platform designed to aggregates patient data from several distributed parties. The platform allows participant organizations to share large volumes of data sourced from all over the world to support Cancer research in the discovery of potential life-saving breakthroughs [25].

4.2 Machine learning

Machine learning and artificial intelligence can help practitioners to extract knowledge from vast, complex databases. Medical records comprise not only bio-signals such as blood pressure, and heat rate, but also unstructured text that can be analyzed via machine learning techniques like natural language processing. The field of machine learning applied to medical diagnosis is very active, specifically with regards to the applications of deep learning to medical image processing including CT, MRI, or X-ray scans.

The integration of sensor data to existing data processing frameworks might enrich significantly the field of computer aided diagnosis by means of providing contextual data to supplement medical records. Deep learning algorithm's performance depends on volume but also variety of data, the opportunity to increase both dimensions will grow as the pervasiveness of IoT-enabled devices increases.

4.3 Edge Computing

Patient data collected at hospital bedside or captured by wearable devices are commonly processed in on-premises facilities or in the cloud. While this approach is a mainstay in applications where latency and bandwidth congestion are not a concern, it is not a good fit for time-sensitive scenarios such as those in medical practice.

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Edge computing emerges as a suitable alternative to bring analytics close to where data are generated or to the sub-system located in between the connected devices and the cloud (fog layer). Thanks to continued sensor miniaturization and increased processing power, connected devices enable health providers to respond faster to emergencies, and automate repetitive tasks, e.g. data collection for regulatory compliance and reporting [27].

In addition, distributed processing may support continuous real-time patient monitoring [28], shifting care delivery from reactive to proactive [29]. Use cases include but are not limited to:

• Chronic disease management, the combination of IoT and edge computing will greatly impact the delivery of at-home care allowing uninterrupted monitoring of patients suffering from chronic conditions such as diabetes or respiratory diseases.

• Closed-loop systems, intensive care units employ sensor systems to maintain physiological homeostasis, by continuously monitoring insulin levels, neurological activity, cardiac rhythms, and others. Edge computing can analyze these data instantaneously enabling prompt action.

• Safety and recovery monitoring, cameras and sensors that oversee patient safety and treatment compliance to decrease readmissions. For instance, connected pill bottles to ensure discharge instructions are followed, and motion sensors to reduce fall risk.

4.4 5th Generation networks

Standardized 5G technology is expected to arrive by 2020, and provide improved connectivity, with speeds of over 100 megabits per second, fewer delays, and cloud-based storage [30]. 5g networks are foreseen to be the backbone of a mobile IoT, which will bring together billions of devices and sensors and open the door for innovative applications and services in healthcare, education, agriculture, transportation, among others. The application of IoT principles to healthcare systems is shifting the delivery of care towards patient-centered scenarios where network requirements are more stringent such as high definition video streaming and transmission of high-resolution medical images. These network requirements fall into two broad categories:

1) Requirements related to quality attributes of the communication such as:

• Data rate and latency
• Fault tolerance
• Continuous mobility
• Context awareness

2) Requirements related to the network operation like:

• Scalability
• Capacity
• Energy efficiency
• Security
• Coverage

5G technology promises to fulfill these requirements through network advancements including radio communications in high-frequency bands, software-defined networks (SDN) and network function virtualization (NFV). In addition, 5G enhanced connectivity, and data capabilities have the potential to enable advances in healthcare in areas like imaging, diagnostics, data analytics and treatment [26].

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5 SECURITY AND ETHICAL ISSUES

The protection and care of sensitive data in IoT-based applications for healthcare rise serious concerns. Ethical considerations regarding personal data in health records have a long tradition of privacy protection. Several guidelines have been issued worldwide in this regard, including the World Health Organization "Handbook for good clinical research practice (GCP)", Helsinki Declaration of 1964 for conduct of clinical research, and the UNESCO Universal Declaration on Bioethics and Human Rights among others.

Lack of security standards for IoT devices poses a risk for the security of user's data which are ordinarily transmitted over insecure connections. A recent study found that 84% of IoT deployments have security flaws which ended into some level of security breach. More of 50% of the respondents in the same study regarded external attacks as a barrier to further adoption of IoT [31].

Another source of concern is the exposure of information systems handling patient's records on the Internet. A search on Shodan search engine reveals over a thousand DICOM devices accessible through the Internet Fig. 5. Should these devices be poorly managed, malicious actors could gain access to hundreds of thousands of personal health records.

Healthcare systems are exposed to the same type of threats as information systems in general. System management must be aware of malicious parties constantly looking for system vulnerabilities to compromise the security of patient's data. A secure healthcare system should ensure at least the safeguarding of the CIA triad:

• Confidentiality, access to health records is granted only to authorized users. In addition, the system must protect confidential data from eavesdropping.

• Integrity, store records must not be altered, corrupted, or lost. The system must put controls in place to ensure the integrity of data during transmission as well.

• Availability, management must ensure that the system and the health records contained in it are always available to authorized users.

Fig. 5. Statistics of DICOM devices connected to the Internet worldwide. Top countries: United States 768, India 262, Brazil 248, China 171, Iran, Islamic Republic of 153. Source: shodan.io/search?query=dicom

Ordinarily IoT devices have limited memory, computational power, and power autonomy. Such constraints impose design choices that privilege power savings for data collection, and communications rather than performing costly security protocols. Security updates are also affected by power policies that refrain IoT devices from being on during idle states. Another weak spot has to do with the wireless nature of the communication channel, which is typically more susceptible to eavesdropping than its wired counterpart. Attacks to IoTbased healthcare systems may appear at different user levels and exploit hardware and software vulnerabilities within the network, communication channels, and devices. Common attacks include but are not limited to the following:

• Denial-of-service (DoS), this attack compromises availability of the information system, disrupting the communication infrastructure, e.g. by flooding communication links with spurious requests to prevent genuine requests from being fulfilled.
• Replay, an attacker intercepts and replays messages within the network aiming to gain access to secret keys or forwarding messages to other communication nodes.
• Interception, this attack compromises the confidentiality of the information by eavesdropping poorly protected channels such as wireless hot spots located on zones accessible to the public.
• Software exploits, this attack leverage vulnerabilities in outdated software including operating system, firmware, or applications in hosts and clients. This type of attack can compromise confidentiality, integrity, and availability of the healthcare system.

6 CONCLUSIONS

Rapid changes in demographics and consumer behavior are shifting the focus of healthcare from hospital-based models to user-centered approaches. The extension of the principles of the internet of things to healthcare is supporting the realization of novel forms of healthcare delivery that break the barriers of distance such as telemedicine, self-management, and self-monitoring.

IoT is expected to alleviate the impact of population ageing and shortages of healthcare workers that healthcare systems are facing in the next few decades. Applications like remote monitoring, and ambient assistive living can be instrumental in expanding the provision of care to the elderly and to patients with special needs.

Enabling technologies including machine learning, edge computing, and 5th-generation networks push the expansion of IoT in healthcare even deeper, which will allow care providers to deliver high-quality care in real time and at affordable prices.

On the other hand, confidentiality and privacy are aspects that are not well protected in current state of IoT development and need to be swiftly addressed to assure the protection of sensitive information.

Future work should focus on testing the application in conjunction with the latest enabling technologies to existing IoT-based systems, e.g. real-time computer aided diagnosis supported by deep learning, edge computing and 5th-generation networks. Another avenue to future work is in enhancing information security across all components of the system, at present adding robust encryption to connected is challenging due to storage and processing constraints.

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