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The internet of things in healthcare: An overview

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ABSTRACT

Extensive research has been dedicated to the exploration of various technologies such as information technologies (IT) in complementing and strengthening existing healthcare services. In particular, the Internet of Things (IoT) has been widely applied to interconnect available medical resources and provide reliable, effective and smart healthcare service to the elderly and patients with a chronic illness. The aim of this paper is to summarize the applications of IoT in the healthcare industry and identify the intelligentization trend and directions of future research in this field. Based on a comprehensive literature review and the discussion of the achievements of the researchers, the advancement of IoT in healthcare systems have been examined from the perspectives of enabling technologies and methodologies, IoT-based smart devices and systems, and diverse applications of IoT in the healthcare industries. Finally, the challenges and prospects of the development of IoT based healthcare systems are discussed in detail.

1. Introduction

The growing rate of the aging population has brought about many challenges in healthcare service. For example, the service of after stroke rehabilitation for the elderly is an emerging challenge, which requires a long-time commitment of medical and human resources [1]. Medical rehabilitation is a relatively new subject, which was introduced in the middle of the 20th century, and has been treated as a new branch of therapy aiming at alleviating or curing physical or mental dysfunctions by remedying or re-constructing disabilities. It has been recognized as an effective means in improving physical functions of many types of patients. However, the promotion of medical rehabilitation to a wider scope of applications faces a few obstacles. Firstly, the majority of rehabilitation treatment needs long-term and intensive therapy. Secondly, additional assistive facilities are required to provide patients with easy access to rehabilitation service. Thirdly, the availability of rehabilitation resources is becoming relatively scarcer due to the faster increasing pool of the aging population in current society.

One promising method to alleviate the aforementioned problems is to adopt the Internet of Things (IoT) technologies and intelligentize the medical service systems. In recent years, applying Internet-based technologies for rehabilitation services has become popular after introducing some new concepts, such as Smarter Planet and Smart City [2]. The concept of "Smarter Planet" was proposed by the International Business Machines Corp. (IBM) in 2008. It was initially introduced to deal with the needs of real-time sensing, effective information exchange, the reduction of energy consumption, and the increase of productivity and efficiency of the company [3]. Following the idea of 'Smarter Planet', a similar concept of 'Smart City' was introduced and has attracted considerable attention. For example, many cities in China have regarded building an IoT-based smarter city as their long-term strategic plans [4]. IoT allows a pervasive connectivity, i.e., public facilities and resources in cities are seamlessly networked. In this way, pervasive interactions exist among things, humans, or both. In IoT, radio frequency identification tags (RFID), sensors, and personal digital assistants (PDAs) are made ubiquitous in order to acquire real-time data and support decision-making activities. With the smart perception within an IoT, smart cities are capable of improving the performance of public services and business infrastructure in the ways that real-time data can be collected and analyzed promptly, abrupt and emergent events can be acknowledged and responded timely, and resources in the cities can be managed and controlled appropriately. As far as the healthcare services, such as medical rehabilitation, are concerned, an IoT-based system makes it possible to provide 'one stop' service to the residents conveniently even at remote locations. In contrast to conventional on-site rehabilitation service at local hospitals, all the related resources are shared within communities through smart rehabilitation to provide flexible and convenient treatment to patients. In this way, the utilization of rehabilitation resources can be maximized [5,6], and it can be anticipated that the IoT-based intelligent technology would become an irreplaceable tool in modern healthcare systems.

Numerous progresses have been made in healthcare monitoring and control [14], interoperability and security [15], pervasive

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healthcare [9,10], and drug interaction checking [11], etc. These achievements have demonstrated the effectiveness and promising future of IoT-based healthcare system. Despite the existent success, ambiguity and technical challenge still exist with regard to the question of how to rapidly and systematically establish as well as deploy an intelligent IoT-based healthcare system that involves big data management.

Aiming at maximizing the capabilities of IoT in healthcare systems, more and more researchers and organizations have been devoted to the development of IoT-based technologies for medical applications [12,13]. The motivation of this paper is to summarize the history and advancement of state-of-the-art studies in IoT-based healthcare systems, and to provide a systematic review of enabling technologies and smart healthcare devices in IoT. In particular, the implementation strategies and methodologies encompassing ontology-based resource management, knowledge management and big data management, etc. have been discussed based on our understanding. Finally, the future trends and directions of the future research in this field are identified.

The structure of the paper is arranged as follows: Section 2 briefly introduces the application history of IoT technology in healthcare industry. Section 3 is focused on the enabling technology of IoT, including identification technology, communication and location technology, sensing technology and the service-oriented architecture. Section 4 introduces both smart healthcare devices and systems. Section 5contributes to the implementation methodologies, such as resource management, knowledge management, big data management, as well as strategies for building tele-health and tele-rehabilitation systems. Section 6 provides a case study of IoT-based smart rehabilitation system. Concluding remarks are presented in Section 7.

2. The origin and development of IoT in healthcare

2.1. The origin and development of IoT

IoT was first proposed by Ashton [14] and Brock [15] who founded the Auto-ID center at the Massachusetts Institute of Technology (MIT). The term 'Auto-ID' can represent any type of identification technologies for various applications, such as error reduction, improvement of efficiency, and automation. The relevant Electronic Product Code (EPC) network was launched by the Auto-ID center in 2003 at its executive symposium [16]. Objects can be tracked when they move from one place to another. As commented by Meloan [17], the release of EPC network allows one to imagine the big time of the IoT paradigm as a global mainstream commercial means, in which microchips will be networked and form the IoT [18]. The successful development of RIFD indicates that IoT would go out of the laboratory and lead a new IT era in both academy and industry [19].

In 2002, National Science Foundation (NSF) published a report on convergent technology [16], which was focused on integrating nanotechnology with information and communication technology (ICT) to dramatically improve the life quality of people and the productivity of nations. In the first report of the International Telecommunications Union (ITU) in 2005 [20], IoT was suggested to be combined with technologies in object identifications, wireless networks, sensors, embedded system and nanotechnologies to connect things in the world, so that things could be tagged, sensed, and controlled over Internet. IoT consists of a set of technologies to support the communication and interaction among a broad range of networked devices and appliances [19,21,22]. IoT-based enterprise systems have been developed for various applications [23] such as healthcare systems [24], industrial environment [25], and public transportations [23,26]. Great interest exists in developing countries as well. For example, a national research center of IoT was established in 2009, and the Chinese former Premier gave a national speech to promote the research and development of IoT [27,28]. Since then, over 90 Chinese cities have developed their strategic plans in developing smart cities [16], and a number of national big companies, such as China Unicom, China Mobile, and China Telecom, have associated their businesses closely with the implementation of smart cities.

2.2. IoT in healthcare

IoT-based smart rehabilitation has been introduced very recently to alleviate the problem of scarce resources due to increasing aging population [7,8]. It can be viewed as a sub-system under the Smart City. An IoT-based healthcare system connects all the available resources as a network to perform healthcare activities such as diagnosing, monitoring, and remote surgeries over the Internet [24]. The topology of the IoT-based rehabilitation system is shown in Fig. 1. The whole framework has been dedicated to extending the healthcare services from hospitals and communities to homes. Wireless technology has been widely applied to integrate monitoring devices, the front-end of which is treated as a network manager. The system connects all the available healthcare resources in the communities (e.g., hospitals, rehabilitation centers, doctors, nurses, ambulances, assistive devices, etc.) with patients. The server is equipped with a centralized data base. An intermediary processing proxy is responsible for data analysis, consolidation, detection of critical events, and creation of rehabilitation strategies. All the things are networked to the Internet and supported by the programs based on RFID technology [29,30]. An automated resource allocator is developed to figure out rehabilitation solutions promptly to meet a set of specific requirements from individual patients.

The paradigm of IoT for healthcare has been gradually formed, as shown in Fig. 2. The paradigm consists of three parts: Master, Server and Things [31]. Master includes the doctors, nurses, and the patients, who have their specific permission to the system by end-user devices (e.g. Smartphone, PC, or tablet). Sever acts as the central part of the entire healthcare system. It is responsible for prescription generation, data base management, data analysis, subsystem construction and knowledge base management. Things refer to all the physical objects (including the patients and human resources) that are connected by WAN, multi-media technology or Short Message Service (SMS). Furthermore, normal devices that cannot be connected to the network but commonly used in current rehabilitation conditions are also included in the smart rehabilitation system and made compatible to the network. The effectiveness of the proposed architecture has been verified by some pioneering exoskeleton applications [31–37].

3. Enabling technologies of IoT

Presently, the hardware and software systems for sensing, communication, and decision-making activities have become increasingly more versatile and affordable. To promote the innovations of human in various IoT applications, enabling technologies are indispensable.

3.1. Identification technology

A practical IoT may include a large number of nodes, each of which is capable of generating data, and any authorized node can access data no matter where it is located. To achieve this goal, it is essential to locate and identify the nodes effectively. Identification aims to assign a unique identifier (UID) to a corresponding entity, so that the information exchange through this node is unambiguous. For the system shown in Fig. 1, every resource such as