Recent Advances in IoT-Based Wearable Systems for Biosignals Monitoring – Application to Elderly Care

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Abstract—**The evolution of the Internet of Things (IoT) ecosystem has been based on the advances of miniaturized, cheap, but powerful wearable sensors that can be used in various applications, including the real-time monitoring of elderly people's health condition. The sensing capabilities of wearable devices along with the communication capabilities offered by sophisticated wireless techniques and protocols intend to improve the quality of elderly people's life. This paper aims to review recent research work on sensor deployments and wearable technologies for biosignals monitoring for elderly care. Emphasis is also given on the advanced wireless technologies that are used for relevant healthcare IoT applications.**

Keywords-Communication protocols; elderly people monitoring; Internet of Things (IoT); wearables; Wireless Sensor Network (WSN).

I. INTRODUCTION

In recent years, the number of smart devices, wireless technologies, networking protocols, and wearables has rapidly increased and the Internet of Things (IoT) has emerged as a key enabler for the provision of challenging healthcare applications [1]. As the healthcare IoT will significantly affect the IoT-driven healthcare industry, the wearable technology has been widely adopted by the scientific community [2], in order to fabricate assisting devices that focus on various categories, such as elderly people, athletes, workout users, workers, and patients.

The wearable systems contain non-invasive sensors, which are used to measure physiological or biomechanical signs and strongly support welfare and critical healthcare IoT applications for elderly people [3], [4]. Typical examples of these sensors are bioelectric sensors (e.g., Electrocardiography (ECG), Photoplethysmography (PPG), Electromyography (EMG)), acoustical sensors (e.g., microphones) mechanical sensors (e.g., accelerometer gyroscope), chemical sensors (e.g., PH, perspiration), and thermal sensors (e.g., thermistor). Various physiological information can be extracted from biosensors analysis. Specifically, skin temperature, blood pressure, heart rate, respiration rate, and oxygen saturation are some of the parameters that can be determined.

On the other hand, wearable monitoring systems and IoT have been directly linked to wireless communication technologies [5], [6], which enable the data interaction of devices worn by elderly people in real time with other proximate or remote wireless nodes, thus creating Wireless Sensor Networks (WSNs) that collect physical data (e.g., body temperature, blood pressure, heart rate, oxygen saturation (SpO_2), and ECG). More importantly, adoption of advanced communication technologies facilitates the efficient, flexible, and cost-effective data collection from biomedical sensors and then the transmission of health data to central IoT nodes. Using wireless communication protocols, elderly people's vital signals can be remotely monitored [7] and aging population can be served by medical diagnosis and telemonitoring via IoT-powered In-Home Healthcare (IHH). Moreover, medical personnel and patients can interact though videoconferencing, whereas real-time medical imaging and remote robotic surgery are viable by exploiting high bandwidth wireless communication links.

Motivated by the aforementioned observations, this paper focuses on shedding light on recent advances on IoT-based wearable systems for biosignals monitoring of elderly people in a remote manner. In this direction, wearable healthcare devices, sensors deployments and various IoT based bio-monitoring systems are reviewed, mainly focusing on the field of elderly care. In addition, relevant communications technologies and wireless standards that can be used in healthcare monitoring applications are described and the main open issues in the field are underlined.

The rest of the paper is organized as follows. Section II describes recent advances on wearable systems and devices, followed by a presentation on their application on elderly care. Section III presents the advanced wireless technologies that intend to enrich the capabilities of IoT-based wearable systems for biosignals monitoring. Finally, conclusions and future research directions are drawn in Section IV.

II. IOT WEARABLE SYSTEMS FOR BIOSIGNALS MONITORING

Recently, new sensing elements came up in biosensing technology and monitoring of vital signs through wearable systems to predict the physiological state of elderly people. In [8], a system that can store and monitor vital signs was demonstrated. This system ('Abuelometro') was used in an elderly care facility to help caregiving staff monitor elderly residents. Moreover, a biometric wearable device from Hexiwear was used in [9], capable of measuring skin temperature, oxygen saturation, and heart rate. Based, on this device, a platform was fabricated that storage vital signs with extra information, such as exercise time, sleep time eat time, etc. In addition, an abnormal condition detection system was proposed in [10] with the aim of helping the elderly. The system observed ECG, triaxial acceleration and skin temperature featured in a wireless wearable biosensor developed by Medical electronics Science Institute (MESI). The device communicated with a personal computer (PC) and the corresponding data was analyzed by a custom-made software. In case of abnormal conditions being detected, caregivers and relatives were notified by email. The ECG circular pads had to be placed near the heart, in order to determine heart rate with the required precision. The embedded triaxial accelerometer was used to examine body position. Also, fall detection algorithms that analyze accelerometer measurements were responsible for alerting users in an abnormal fall case.

In [11], a device that can monitor vital signs in real time was fabricated. The sensor device included an optical sensor using the Photoplethysmography (PPG) method, in order to monitor the blood change of the vessels [12], as well as a printed Radio Frequency (RF) antenna. The communication protocol used was the Mi-Wi. All data derived from the sensors, travel through the gateway to the smartphone app and are uploaded to the cloud. Furthermore, in [13], a wearable device was implemented that was able to record blood pressure via ECG electrodes along with body and environmental temperature. Both measurements were transmitted wirelessly using a Bluetooth module. By processing the measured data various parameters were extracted, such as heart rate, breath frequency, blood pressure, air, and skin temperature. Additionally, hand and arm movements could be determined by the accelerometer response. In [14], a system capable of monitoring vital signs and alerting caregivers in case of an emergency was presented in [14]. This system consists of a health watch with an attached optical sensor for PPG measurements, smart clothes (vest) constructed of conductive fiber, in order to collect the ECG signals and a body tag, incorporating a 3-axis accelerometer and gyroscope for body movements monitoring. Moreover, this system can communicate through a Bluetooth Low Energy (BLE) to Wi-Fi gateway and send the raw data from sensors to cloud. The system can provide daily data on user sleep quality, heart rate, change in blood oxygen concentration change, and walking steps.

An optical cuffless PPG sensor was fabricated in [15], in order to continuously monitor blood pressure and heart rate in real time consists of a Light-Dependent Resistor (LDR) and a circuit with a Light Emitting Diode (LED) enclosed in an elastic material held to the user's finger by Velcro. The device achieved an accuracy of 5% in the determination of real arterial blood pressure. In [16] a vital signs collector and a wearable device called "smart clothing" were proposed. More specifically, a T-shirt with embedded a Negative Temperature Coefficient (NTC) thermistor for temperature monitoring was fabricated. In addition, an optical sensor was used to capture oxygen saturation, whereas an ECG sensor was used to measure the heart rate using dry textile dry electrodes. Additionally, using Machine Learning (ML), the ECG signals were analyzed, in order to emotionally detect the user's mood. In [17], the SMARTA project was demonstrated. This project developed and tested a personal health system by integrating environmental sensors and wearable devices, in order to telemonitor vital signs and detect anomalies. In this regard, a wearable with an ECG sensor and an accelerometer was used that could monitor arterial pressure, oxygen saturation, and detect anomaly cases (e.g., user fall, immobility, etc.). Also, a wearable device for the purpose of monitoring the elderly people was presented in [18]. This device could be worn by the individual to collect physical activity data in a memory card. An accelerometer, a gyroscope and a heart rate sensor were used to track activities and vital signs. The heart rate device consisted of an acoustic sensor to pick up the beating sound of the heart. The device is worn in a belt and placed close to the heart. Figure 1 illustrates the aforementioned wearable devices, while Table I provides details about them.

III. WIRELESS TECHNOLOGIES FOR BIOSIGNALS MONITORING

In order to transmit the acquired information and obtain a reliable wireless connection between wearables and other IoT entities, various communication mechanisms can be implemented, such as Device-to-Device (D2D), device to human and vice versa, and device to distributed storage [6]. However, the wearables inherently have constraints in terms of computation, memory, energy, and operational cost. Thus, appropriate lightweight protocols (e.g., Constrained Application Protocol (CoAP), Message Queue Telemetry Transport (MQTT), and Extensible Messaging and Presence Protocol (XMPP)) have been adopted to enable the interaction among devices. On the other hand, signal attenuation, fading, and interference may affect signal propagation, whereas spectrum regulatory restrictions may exist. Thus, choosing the proper wireless technology and frequency band is of paramount importance. Generally, the local connectivity in IoT-based wearable systems is provided by means of a Wireless Local Area Network (WLAN) or short-range wireless networks, such as the Wireless Personal Area Network (WPAN). In this respect, one or multiple appropriate radio access technologies can be used, e.g., BLE, ZigBee, and IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN).

In recent years, various works have been various works adopting wireless technologies for biosignal monitoring. In [19], an Arduino-based deployment with Bluetooth capabilities for ECG measurement was described, whereas a low-cost and energy-efficient TI MSP430 microcontroller with a ZigBee/Bluetooth module was exploited in [20] to monitor heart rate, temperature, humidity and accelerometric data. Additionally, a Raspberry Pi was employed in [21] for remote elderly care and the health information was transferred using a WLAN or a PAN and a Bluetooth modem. Extended connectivity for measuring ECG, heart rate, body temperature and blood pressure was obtained in [22] using IEEE 802.11 Wi-Fi, Global Positioning System (GPS) and Radio-Frequency Identification (RFID) technologies along with the ThingSpeak IoT platform. In [23], a large number of patients was connected to the computer systems using a nRF24L01+ low power transceiver and the Enhanced ShockBurst protocol, whereas the measured data was visualized using the NI LabVIEW.

Several wireless technologies (i.e., 6LoWPAN, ZigBee, BLE) and protocols (i.e., CoAP and MQTT) were combined in [24] to obtain reliable sleep apnea diagnosis. In this respect, experiments were conducted and the results underlined that the 6LoWPAN protocol had the highest latency values, compared to ZigBee and Bluetooth.

As far as wearable systems are concerned, the WPANs are transformed into Wireless Body Area Network (WBANs), which have been recently evolved because of to the advances in microelectronics, System on Chip (SoC) design, and intelligent low-power sensors. By using WBANs consisting of in-body and on-body area networks, affordable and smart health care systems can be developed that support diagnostic procedures and the collection of sensitive and life-critical data without constraining the normal life of elderly people. To enable data transmission, the WBANs utilize the Wireless Medical Telemetry Services (WMTS), Ultra-wideband (UWB) and Medical Implant Communications Service (MICS) bands. Besides, the licensed Medical Implant Communication System (MICS) band (402-405 MHz) can be used for implant communications, whereas the wireless standard IEEE 802.15.6 represents the international standard for WBAN. A monitoring system for elderly care was implemented in [25] using a Zigbee-based Body Sensor Network (BSN) as well as the patients' smartphones to store and send the measured health information to remote servers.

On another front, long-range wireless connectivity can be achieved using conventional, i.e., Fourth Generation (4G) and Fifth Generation (5G) cellular networks, satellite networks, and Low-Power Wide Area Network (LPWAN) technologies, e.g., Long Range (LoRa), Sigfox, and Narrowband-IoT (NB-IoT). A Global System for Mobile Communications (GSM)/GPS-based module was utilized in [26] to enable mobile monitoring and attribute in real-time the stress levels of patients by measuring the heart rate, skin resistance and body temperature. Moreover, a cost-effective IoT system and a LoRa-based gateway were used in [27] to monitor the health condition of elderly people located in their residence, thus improving their quality of life. Also, the combination of LoRa and the MQTT protocol was studied in [28]. Figure 2 depicts wireless technologies for ubiquitous health and activity monitoring of elderly people. Although current technologies can facilitate the provision of healthcare IoT services, there are several issues that require further investigation, such as mobility, heterogeneity, interoperability, scalability, security, and privacy.

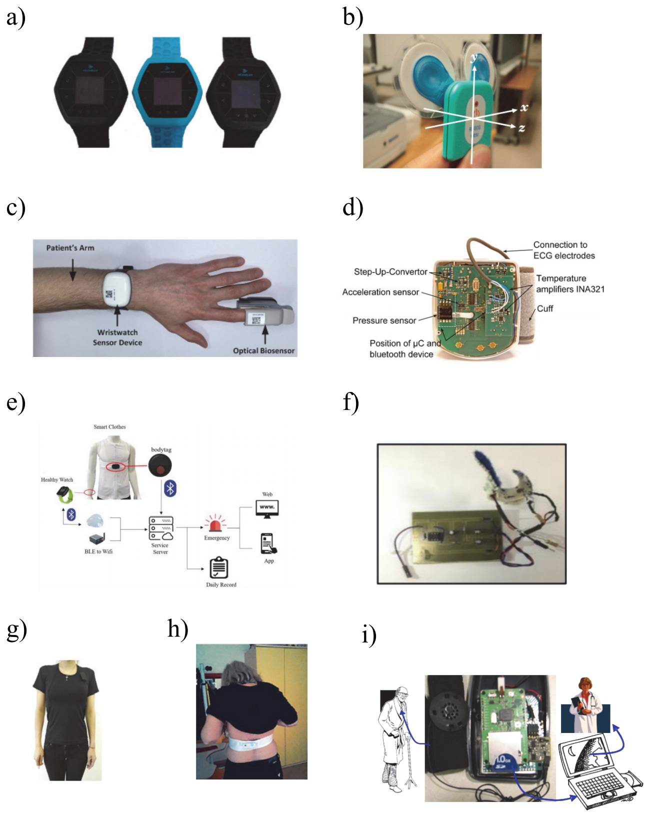

Figure 1. A simple representation of the described wearable devices a) [8] b) [10] c) [11] d) [13] e[14] f) [15] g) [16] h) [17] i) [18]

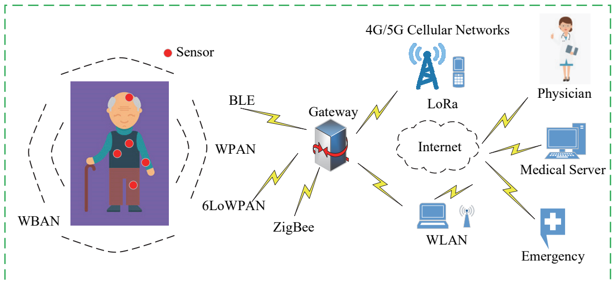

Figure 2. A simple representation of a wearable sensor network and relevant short-range and long-range wireless communication technologies for biosignals monitoring of elderly people.

TABLE I
DEVICES FOR IOT-BASED WEARABLE SYSTEMS

Ref.	Sensors	Monitoring Parameter	Housing	Communication Protocol
[8]	PPG optical sensors, temp. sensor	body temperature, oxygen saturation	strap	BLE
[10]	ECG electrodes temp. sensor	body temperature, heart rate	suction cup	USB
[11]	PPG optical sensor	pressure, heart rate, oxygen saturation	strap	Mi-Wi
[13]	ECG electrodes, temp. sensor	blood pressure, body temperature	Cuff	Bluetooth
[14]	PPG optical sensor, ECG electrodes	heart rate, oxygen saturation	vest	BLE
[15]	PPG optical sensor	blood pressure, heart rate	finger Velcro	Bluetooth
[16]	PPG optical sensor, ECG dry textile electrodes, thermistor	blood pressure, skin temperature, oxygen saturation	T-shirt	Bluetooth
[17]	ECG electrodes	blood pressure, oxygen saturation	belt- patch	BLE
[18]	Acoustic sensor	heart rate	belt	memory card

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IV. Conclusion and Future Work

In this paper, the role of advanced wearables and wireless technologies in the IoT-based biosignals monitoring area for effective elderly care has been described. Additionally, the system implementation of various wearable devices was presented, including the sensors, measurement techniques, vital signs detection methods, communication process, and fabrication forms. Since reliable and ubiquitous short- and long-range connectivity is required, both conventional and low-power wireless technologies can drastically change the landscape of medical industries and strongly support the evolution of IoT-based wearable systems.

Evolution of IoT and biosensors will radically change the perspective of wearables usage as a major tool for biosignals monitoring. Thus, aiming to foster more developments towards implementing advanced wearables, further work should be conducted in the future. An interesting research area stands for the application of ML algorithms to accurately predict risk and dangerous or harmful situations for elderly people. Also, jointly adopting D2D and Mobile Edge Computing (MEC) to enhance the computation capacity of the network is also envisioned.

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