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Enabling Technologies for the Internet of Health Things

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ABSTRACT The Internet of Things (IoT) is one of the most promising technologies for the near future. Healthcare and well-being will receive great benefits with the evolution of this technology. This paper presents a review of techniques based on IoT for healthcare and ambient-assisted living, defined as the Internet of Health Things (IoHT), based on the most recent publications and products available in the market from industry for this segment. Also, this paper identifies the technological advances made so far, analyzing the challenges to be overcome and provides an approach of future trends. Through selected works, it is possible to notice that further studies are important to improve current techniques and that novel concept and technologies of IoHT are needed to overcome the identified challenges. The presented results aim to serve as a source of information for healthcare providers, researchers, technology specialists, and the general population to improve the IoHT.

INDEX TERMS Ambient assisted living, Internet of Things, Internet of Health Things, mobile health, remote healthcare monitoring, wearable.

I. INTRODUCTION

A new network infrastructure is being planned and proposed considering continuous increment of the number of connected devices. The academy and industry proposed a new vision of the Internet with the Internet of Things (IoT), considering the next generation of the Internet. IoT offers intelligence to objects by adding them the capacity to collect and store data from different types of sensors, to perform actions autonomously based on actuators, coordinate functions, and share information considering the connectivity among nodes, for example, [1], [2]. To illustrate the IoT vision, one can imagine a home heating system being controlled by a smartphone or a car driving its user to his/her work autonomously. This scenario describes a simple remote control and a machine-to-machine (M2M) communications that also support IoT. These applications can be suited in industry domains, such as transportation [3], healthcare [4], smart home [5], industry automation [6], smart grid [7], among others [8].

Many research companies present perspectives and trends for the future of IoT as well as research community proposes a Future Internet of Things [9]. International Data Corporation (IDC) predicts that IoT will reach about a US$ 1.7 trillion market by 2020. Gartner expects 25 billion connected devices by 2020 while Cisco mentions about 50 billion. And Harvard Business Review expects 28 billion ''things'' connected to the Internet [10].

Healthcare industry is among the fastest to embrace IoT-based solutions. It is being considered one of the key industry drivers and a special concept for it, considering the IoT application on e-Health, aka Internet of Health Things (IoHT). There is also a 2020 projection made for IoHT.

"MarketsAndMarkets" predicts that IoHT will be worth US$ 163.2B, commercial report claims a spending of $117B, and McKinsey estimates an economic impact of more than US$ 170B. All this caused by cost savings, quality of life improvement for patients with chronic disease, and health monitoring, which prevents disease complication [10]. It is a fact that IoHT will create a big economy impact in the world. Then, given this scenario, this review will present a detailed study of the literature and relevant proposals from industry on IoHT. The main contributions of this work are the following: (i) review of the main available contributions proposed by the research community and industry, (ii) discussion about the stage of deployment of IoHT in the world, and, (iii) identification of open issues to be explored in further research works. Thus, this review has adopted aspects related to the scientific fields of Internet of Things, Biomedical Engineering, and Medicine as well as the real needs in the daily life of a hospital, clinic, or homecare environments, for example. Thus, due to the approach adopted in this review, it can be considered by both a beginner and experienced researchers, professors, specialists, hobbyists, as well as health professionals who wishes to know the latest and recent techniques studied in the IoHT.

The rest of the paper is organized as follows. Section 2 elaborates on Internet of Health Things and reviews the most relevant proposals available in the literature. Section 3 presents the most relevant IoHT industry proposals. Section 4 presents a discussion considering both academic and industry research proposals. Section 5 concludes the work and suggests further research works to explore on the topic.

II. INTERNET OF HEALTH THINGS

Internet of Health Things (IoHT) is basically an IoT-based solution that includes a network architecture that allows the connection between a patient and healthcare facilities as, for example, IoT-based e-Health systems for electrocardiography [11], heart rate [12], electroencephalogram [13], diabetes [14], and other different kinds of monitoring of body (vital) signs based on biomedical sensors. It includes pulse, oxygen in blood (SPO2), airflow (breathing), body temperature, glucometer, galvanic skin response, blood pressure, patient position (accelerometer), and electromyography [15]–[19].

The data input from patients can be collected through sensors and processed by applications developed for a user terminal, such as computers, smart phones, smart watches or, even, a specific embedded device [4]. The user terminal is connected to a gateway through short coverage communication protocols, such as, Bluetooth low energy (BLE), Bluetooth, or 6LoWPAN (IPv6 over Low Power Wireless Personal Area Networks) over the IEEE 802.15.4 standard [20]. This gateway connects to a (clinical) server or cloud services for data processing and storage. In the other hand, patients' data can be stored in a health information system using electronic health records and, when the patient visits a medical doctor, he/she can easily access the clinic history of the patient.

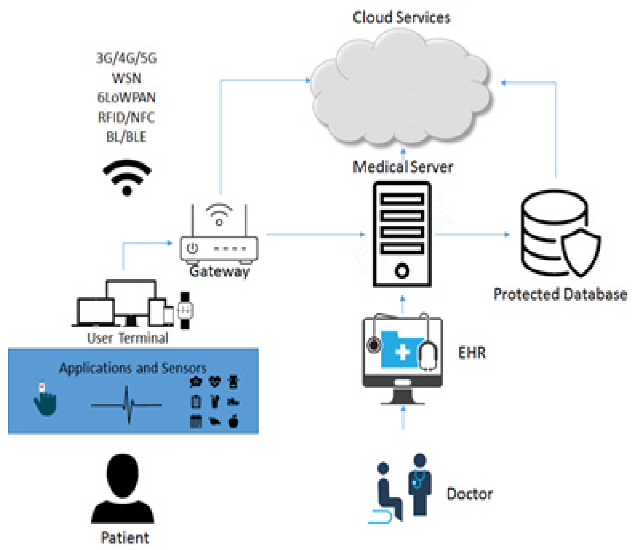

FIGURE 1. Illustration of an IoHT-based solution architecture.

Figure 1 presents an illustration of an IoHT-based solution.

IoHT can support many medical conditions including care for pediatric and elderly patients, the supervision of chronic diseases, and the management of private health and fitness, among others. For a better study of this extensive topic, this review classifies the IoHT in four generic categories: i) remote healthcare monitoring; ii) healthcare solutions based on smartphones; iii) ambient assisted living; and iv) wearable devices. Next sub-sections elaborate on each one.

A. REMOTE HEALTHCARE MONITORING

Remote health monitoring technologies are normally adopted by homecare, clinicians, and hospitals environments to remotely monitor the vital signs of an individual communicating in real-time to patients, parents and physician a possible abnormality, reducing the clinician time, decreasing hospital costs, and improving quality of care. Remote healthcare monitoring can be performed by applications that acquire physiologic data from the patient to be accessed remotely. Basically, these applications include a user interface (smartphones, tablets, and computers), a data collector (biosensors), and Internet connectivity. In this regard, it can be performed with the integration of IoT, mobile computing and cloud storage, and a data communication infrastructure as suggested by Machado *et al.* [21]. This approach aims to capture, transmit, store, and turn available the visualization of biomedical signals, in real-time. In the same context, EcoHealth is a middleware platform developed for IoT that connects patients, healthcare providers, and devices [22]. It is a Web-based platform that allows data management and aims to simplify and standardize IoT applications development, addressing issues like interoperability between different devices. Similar approach was developed by Serafim [23], an IoT-based

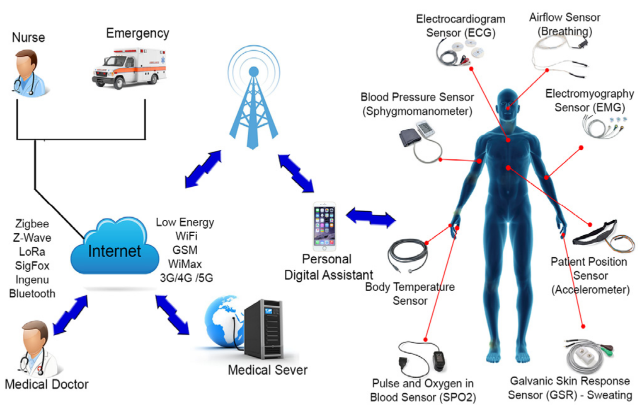

FIGURE 2. **Illustration of an architecture for remote healthcare monitoring system.**

network to monitor patients in rural and low population density areas. Healthcare providers may analyze the data from patients in remote locations and request emergency assistance if necessary. Another solution, called U-Healthcare, is based on a mobile gateway for ubiquitous healthcare systems that collects data, processes it and stores it in the cloud for remote access [24].

An infrastructure composed by wireless body area network, personal server using intelligent personal digital assistant, and medical server tiers for remote healthcare monitoring system is illustrated in Figure 2.

Some solutions are developed with low cost technology, such as the prototype proposed by Lima *et al.* [25]. Receiving pre-processed data, the supervisor system displays it in a simple and cohesive way. The results show an improvement of the individuals' quality of life. An embedded system able to measure blood with low cost technology is described in [26]. Hosted by a device, a Webpage displays the stored data in a useful way. Healthcare providers may check the information simply by accessing the Internet.

More specific solutions are also being discussed. A remote body pressure monitoring system is proposed by Matar *et al.* [27]. Applicable in sleep studies, anesthetic surgical procedures, and other areas that wish to determinate body posture while lying down. A non-invasive glucose level sensing is proposed by Istepanian *et al.* [28], sending patient data to healthcare professionals in real-time. Using a humidity sensor and a heart rate sensor, the prototype proposed by Senthilkumar *et al.* [29], monitors patients with Sjögren syndrome. A system that monitors knee flexion on total knee arthroplasty patients is proposed by Msayib *et al.* [30]. The flexion angles data generated by exercise is sent for remote analysis, preventing the need of going to the hospital several times a week. Also, an mHealth platform capable for patients monitoring that seek cardiac rehabilitation is discussed in Kitsiou *et al.* [31]. Data collected is sent to the cloud for remote access by healthcare providers. A body sensors platform is discussed by Khan [32]. Sensors are directly connected to the users' smartphone to receive the collected data. The data is processed and stored in the cloud to allow access and monitoring by the healthcare providers.

Qi *et al.* [33] published a review on advanced Internet of things enabled personalized healthcare systems (PHS) considering current works about IoT enabled PHS, and enabling technologies, major IoT enabled applications and successful case studies in healthcare, besides main challenges and future perspectives about IoHT.

Alshurafa *et al.* [34] developed a prediction system (Wanda - cardiovascular disease, CVD) to aid peoples in reducing detected CVD risk factors, in which the individuals received instructions by six months of technology support and reinforcement. A prediction tool can aid clinicians and scientists in identifying participants who may optimally benefit from the remote health monitoring (RHM) system, once that presented results satisfactory (F-score of 0.92), identifying the behavior (using activity and blood pressure signals, as well as questionnaires) during the first month of intervention that help determine outcome success.

Abawajy *et al.* [35] presented a patient health monitoring (PPHM) system integrated cloud computing and Internet of Things technologies, and applied in the real-time monitoring of a patient suffering from congestive heart failure using ECG, showing be a flexible, scalable, and energy-efficient remote patient health monitoring system very promising.

Ara *et al.* [36] proposed a secure privacy-preserving data aggregation approach based on bilinear ElGamal cryptosystem for RHM systems to improve data aggregation efficiency and data privacy. Security analysis demonstrates that the proposed method preserves data confidentiality, data authenticity, and data privacy and also is resists passive eavesdropping and replay attacks.

Nkenyereye and Jang [37] evaluated the performance of a server-side JavaScript for healthcare hub server in RHM System being 40 % faster than Apache Sling, presenting high-performance, asynchronous, event-driven healthcare hub server to handle an increasing number of concurrent connections for RHM environment in remote places without local medical aid to local medical care.

Mamun *et al.* [38] developed a cloud system for detecting and monitoring Parkinson patients that will enable healthcare service in low resource setting.

Ganapathy *et al.* [39] evaluated a remote self-monitoring of blood pressure to detect raised blood pressure in pregnancy (50 women), in which 45 of them agreed that the remote monitoring adopted is easy to use and 39 women prefer the proposed model of testing at home.

B. HEALTHCARE SOLUTIONS USING SMARTPHONES

Many IoHT solutions use smartphones. Moreover, nowadays, healthcare or ambient assisted living solutions cannot be proposed and designed without considering mobile health support [40]. In this work, applications that support diagnosis, clinical communication, providing drug references or medical education are defined as healthcare solutions using smartphones. It aims to create a connection between sensors,

FIGURE 3. Smartphone for healthcare system to store and process electrophysiological data.

smartphones, and the healthcare team. Since security is one of the main issues on IoHT, a project concerning healthcare data access is proposed by Murakami *et al.* [41], and aims to test mobile devices used to access data. In Figure 3 is illustrated the mobile devices and apps for smartphone healthcare.

A simple and effective solution is proposed by Costa *et al.* [42] to work as a medical check reminder. It automatically sends a text message to the patient's phone one day before the scheduled appointment with the physician. HealtheBrain is a more specific application, proposed by Shellington *et al.* [43]. It focuses on allowing the square-stepping exercise to be done by elderly people in their place of living without cognitive loss.

Crema *et al.* [44] proposed a local biosensor virtualization based on a simplifying the wearables as, for example, relying only on simple analog front ends and communication interfaces, and exploiting the computational capability of the smartphone, not only for implementing gateway features but also for processing raw biosignals as well, increasing the potentiality of mhealth applications. The virtual sensor was evaluated in electrocardiogram signals analyzing the hearth and respiratory rates.

Aranki *et al.* [45] developed a smartphone-based system for real-time tele-monitoring of vital signs and general cardiovascular symptoms thought physical activity in patients with heart disease, being the main challenge to apply in diabetes and hypertension and other chronic disease.

Barret and Topol [46] investigated the possibilities in which smartphones and the Internet of medical things can improve medicine, believing that smartphones has a direct influence on individual's everyday life, which can bring great contributions to the healthcare field.

Lorenzi *et al.* [47] proposed a m-health wearable wireless sensing system for monitoring human motion disorders as, for example, freezing of gait (FoG) in Parkinsonian, and timely provide rhythmic auditory stimulations to release the gait block, assisting the individual during the daily activity. Ren *et al.* [48] also proposed a user verification system leveraging unique gait patterns derived from acceleration readings (embedded within smartphones) to detect possible user spoofing in m-healthcare systems. Silsupadol *et al.* [49] assessed in 34 healthy adults the performance of a smartphone-based accelerometer in quantifying spatiotemporal gait parameters when attached to the body or in a bag, belt, hand, and pocket. Pepa *et al.* [50] used a smartphone app to acquire, process, and store inertial sensor data and rotation matrices about device position for gait parameters estimation during daily living.

Osmani *et al.* [51] carried out a study with patients diagnosed with bipolar disorder to detect episodes and identify behavior changes using smartphones.

Alshurafa *et al.* [52] developed a novel approach to improve smartphone battery consumption and examine the effects of smartphone battery lifetime on compliance for RHM system. The same authors developed the WANDA method, which remotely evaluate the risk of cardiovascular disease using wearable smartphone for cardiac abnormality recognition.

Seeger *et al.* [53] validated a middleware targeted for medical applications on smartphone-like platforms that relies on an event-based design to enable flexible coupling with changing sets of wireless sensor units, while posing only a minor overhead on the resources and battery capacity of the interconnected device.

Poon and Friesen [54] proposed an automatic detection system of chronic wounds (color and size features) for healthcare environment using image analysis and processing and machine learning techniques embedded in a mobile app (m-health system). Wang *et al.* [55] considered the same approach developing a novel wound image analysis system implemented solely on the Android smartphone.

Velikova *et al.* [56] developed the StripTest reader, a smartphone interpreter of biochemical tests based on paper-based strip colour using image processing techniques, using camera phone for acquisition, processing the images within the phone and comparing them with gold standard.

Higgins [57] carried out a study on benefits of using medical app evaluating smartphone applications for patients' health and fitness, discussing limitations of apps and future trends.

Matarazzo *et al.* [58] discussed the confluence of emerging technologies, which can provide regular infrastructure data streams, within structural health monitoring procedures for the immediate goal of system identification and towards automated maintenance of bridges from vibration data.

Firth *et al.* [59] published a review of all randomized clinical trials reporting the effects of psychological interventions delivered via smartphone on symptoms of anxiety (sub-clinical or diagnosed anxiety disorders), observing, among others, a significantly greater reduction in total anxiety scores.

Chao *et al.* [60] proposed and evaluated the used of smartphones applied for skin monitoring and automatic melanoma detection, showing that an early intervention,

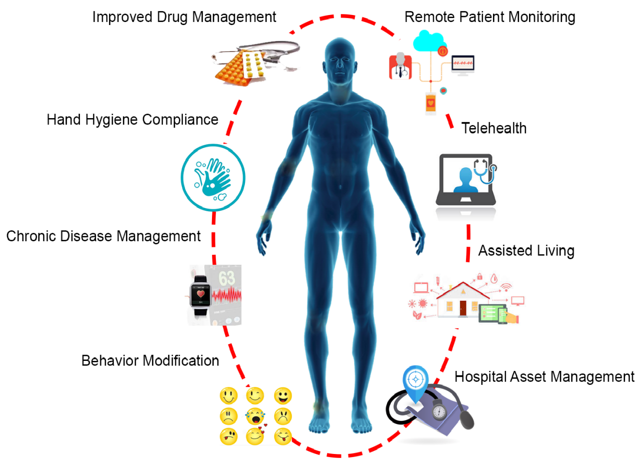

FIGURE 4. Illustration of an ambient assisted living system.

through a pre-diagnosis at home, can successfully treat this disease.

Brayboy *et al.* [61] developed a free smartphone, named Girl Talk, containing comprehensive sexual health information, and determine the application's desirability and appeal among teenage girls.

C. AMBIENT ASSISTED LIVING

Ambient assisted living (AAL) is an IoT-based service that supports care of elderly or incapacitated patients. These solutions wish extend the independent life of the individuals in their homes by providing more safety [62]. Connecting users to smart objects, such as blood pressure sensors and motion sensors, it is a common use of this service. AAL not only provides a safer environment but also increases autonomy and stimulates the user to have a more active life [63]. In Figure 4 is presented an ambient assisted living system overall physical architecture.

An IoT based architecture for AAL is proposed by Valera *et al.* [64]. It is developed to solve problems, such as mobility and security in medical environments. M-hub is another IoT software architecture, which uses cloud for AAL [65]. It is a middleware used in mobile devices that automatically finds and connects smart objects. In this regard, H3IoT is an architectural framework for monitoring health of elderly people [66]. It is composed by five IoT based layers that include sensors interconnectivity, microcontrollers, communication channels, and several applications.

Regarding patient's location and mobility, a fall detection system for elderly patients is shown in several contributions, such as in [67]–[69]. It monitors and detects activities such as walking, running, sitting or standing up, lying down, and falling. Artificial intelligence integrated to IoT architecture is used to categorize each activity, in [71], as well as for intrusion detection in computer networks [72] and [73]. Similar approach is described in [70] a real-time location monitoring system for elderly people.

Keeping in mind that drug compliance in AAL is one of the most important issues, new devices can be regarding patient safety to support diabetes therapy management, for example. This solution controls patient's personal data and connects it to the healthcare professional.

Bleda *et al.* [74] explained the smart sensory furniture sensory layer (ambient assisted living system that allows inferring a potential dangerous action of an elderly person living alone at home) distributed signal processing technique in a network of sensing objects massively distributed, physically coupled, wirelessly networked, and energy limited.

Liu *et al.* [75] proposed a logical correlation-based sleep scheduling mechanism (LCSSM) to implement energy-efficient wireless sensor networks in ambient-assisted homes (AAH). LCSSM analyzes sensory data generated by different human behaviors to detect the logical correlations between sensor nodes in an AAH.

Rafferty *et al.* [76] introduced a new method to implementing assistive smart homes based on an intention recognition mechanism incorporated into an intelligent agent architecture. The method was performed across three scenarios: (i) considered a web interface, focusing on testing the intention recognition mechanism, (ii) and (iii) involved retrofitting a home with sensors and providing assistance with physical activities.

Schwiegelshohn *et al.* [77] evaluated the robots in assisted living environments with different solutions for combining robotics and home automation/smart home for use in ambient assisted living.

Zdravevski *et al.* [78] proposed a generic feature engineering approach for selecting robust features from a variety of sensors, which can be used for generating reliable classification models, reducing reduce the cost of AAL systems by facilitating execution of algorithms on devices with limited resources and by using as few sensors.

Bi *et al.* [79] modeled and analyzed a multi-tier AAL applications, and aims to optimize resource provisioning while meeting requests' response time constraint, demonstrating achieve dynamic resource provisioning while meeting the performance constraint.

Yao *et al.* [80] analyzed several real-world experiments conducted for AAL-related behaviors with various users, showing that the Big Bang–Big Crunch interval type-2 fuzzy-logic-based systems (BB-BC IT2FLSs) outperform the type-1 fuzzy logic system counterparts, as well as other conventional nonfuzzy techniques, and the performance improves when the number of subjects increases.

Erden *et al.* [81] published a survey on signal analysis and processing techniques employed with different types of sensors, such as pyro-electric infrared, and vibration sensors, accelerometers, cameras, depth sensors, and microphones, analyzing the increase of diseases and healthcare costs, shortage of caregivers, and a rise in the number of individuals unable to live independently.

Hossain *et al.* [82] highlighted the AAL communication from several message change perspectives and developed a general tool of alert/response with dependable RESTful communication throughout the message trail within a local and cloud-based environment, offering a lightweight option to address the variability of message change in AAL.

Parada *et al.* [83] considered the RFID intelligent system to identify user-object interactions using machine learning techniques to enable an AAL system in a retail store with accuracy rate of 86 %.

Machado *et al.* [84] analyzed a method to allow AAL systems to identify and predict situations that may endanger users in their living environment, proposing a complementary and alternative to acquire comprehension of a former person's behavioral providing this knowledge when cognitive impairments will occur, improving to traditional expert systems applied to AAL.

Zschippig and Kluss [85] suggested to extend the concepts of AAL, active ageing and ageing in place to the garden. They evaluated the motivations and possible benefits of gardening, especially in regard to managing health and well-being dynamically adapting AAL garden.

Wickramasinghe *et al.* [86] used heuristic and machine learning techniques to recognize 'long-lie' situations, reducing the influence of outliers in the RFID information from location of a fall on the smart carpet with F-score of 0.93.

Garcés *et al.* [87] provided a survey on quality models (QM) and quality attributes (QA) that are important for the AAL field, investigating how QM and QA are defined, evaluated, and adopted in the studies, making available an analysis of the maturity of the works selected.

Roy *et al.* [88] proposed an activity patter recognition method via possibilistic network-based classifiers with uncertain observations, achieving with accuracy 79 % of a proposed activity.

Demir *et al.* [89] proposed an integrated system design that allows collection, recording and transmission through Internet of Things approach, where information from smart things around us can be evaluated and transmitted over the internet, of the data from different sensors placed in a house of a person having dementia.

Dobbins *et al.* [90] collected information from tri-axial accelerometers and a heart-rate monitor to distinguish different physical activity using supervised machine learning algorithms.

D. WEARABLE DEVICES

Wearables are smart devices that can be attached, for example, to the body, such as watches, shoes, or body sensors, as showed in Figure 5. Those devices should be able to connect to physiological transducers to display patient's signals, such as body temperature, heart rate, blood pressure, and others [91].

A common use of wearable devices is the use for monitoring user's physical activity, such as the system proposed by Portocarrero *et al.* [92]. Devices that can be worn are also used to take care of elderly people. In this context, a system developed for vital signs monitoring on elderly people in rest homes is described in [93]. Sensors located on the patient clothes collect data used to monitor their health parameters.

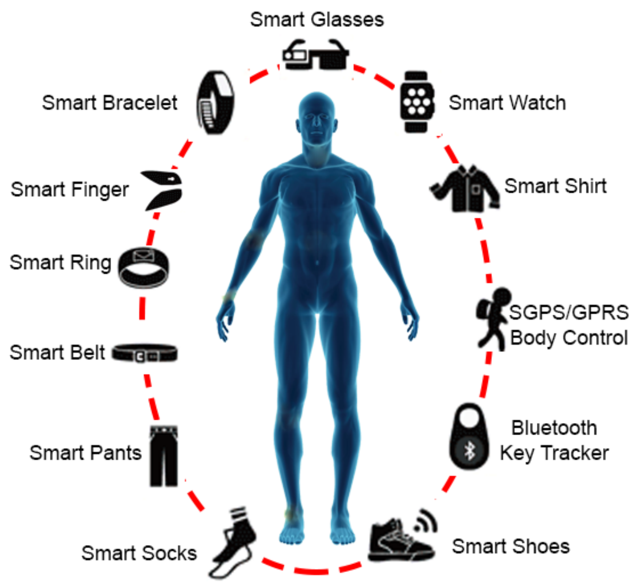

FIGURE 5. **Different types of wearable technology.**

Also, a ubiquitous system for monitoring elderly patients with Alzhheimer's is described in [94]. When needed, the patient presses a button and sends important data, such as oxygen saturation, blood pressure, and heart rate to the healthcare professional for analysis.

More specific wearable devices are also found in the literature, such as the system proposed by Chen *et al.* [95]. It enables real-time data access in the cloud and monitors blood pressure, temperature, electrocardiogram (ECG), and oxygen saturation. Regarding another very specific use, UCC is a ubiquitous health monitoring system for cardiac arrhythmias detection [96]. Data is captured using wearable ECG sensors and it is sent to cardiologists for analysis. More generic systems are also found, in which sensors capture data to be stored and accessed in the cloud, in real-time.

Thapliyal *et al.* [97] published a survey on Internet of Things and medical devices as alternative technologies to recognize stress and manage using cloud-based services, smartphone apps and wearable smart health devices to aggregate and compute large data sets that track stress behavior over long periods of time.

Spanò *et al.* [98] proposed an electrocardiogram remote monitoring system dedicated to long-term residential health monitoring integrated with Internet of Things.

Liu and Sun [99] published a survey on available attack approaches on intelligent wearables, as well as the corresponding countermeasures, from the perspectives of data integrity, authenticity, and privacy, once that the intelligent wearables are vulnerable to various cyber-attacks, bringing up unprecedented security challenges in terms of privacy leakage, financial loss, and even malicious invasion of other connected IoT components and applications.

Huang *et al.* [100] evaluated the wearable devices embedded into individual to realize their displacement vector in mobile environments, thus estimating their own locations with main aim of walking prediction mechanism to increase localisation accuracy, demonstrating that the used approach achieves lower localisation error in various moving speeds.

Guía *et al.* [101] investigated the benefits of using wearable and Internet-of-Things technologies in streamlining the creation of such realistic task-based language learning scenarios, showing that the use of these approaches will prove beneficial by freeing the instructors of having to keep records of the tasks performed by each student during the class session.

Cirani and Picone [102] analyzed the characteristics of wearable applications for IoT scenarios and describe the interaction patterns that should occur between wearable or mobile devices and smart objects, as well as presented an implementation of a wearable-based Web of Things application used to evaluate the described interaction patterns in a smart environment, deployed within their department's IoT testbed.

Pasluosta *et al.* [103] carried out a detailed review and discuss the existing wearable devices and the Internet-of-Things infrastructure used to Parkinson disease, prioritizing how this technological tool may lead to a shift in paradigm in terms of diagnostics and treatment.

Arias *et al.* [104] analyzed the question of the possibility and effects of combination between Internet of Things and wearable devices on traditional design practices and their implications for security (Google Nest Thermostat) and privacy (Nike+ Fuelband) fields, approaching how current industry practices of security as an afterthought or an add-on affect the resulting device and the potential consequences to the user's security and privacy.

Lomotey *et al.* [105] seeked out to streamline the process by proposing a wearable IoT data streaming infrastructure that offers traceability of data routes from the originating source to the health information system. To overcome the complexities of mapping and matching device data to users, they used an enhanced Petri Nets, tracking and the possible detection of medical data compromises.

Sood and Mahajan [106] proposed a method to detect and monitor the outbreak of chikungunya virus based on IoT and fog concepts in RHM system. To diagnose infected users and generate emergency alerts from fog layer the Fuzzy-C means algorithm is considered.

Cui *et al.* [107] applied a connective and semantic similarity clustering algorithm and a hierarchical combinatorial test model based on finite state machine to solve the problem of smart wearable systems due numerous states usually lead to various unanticipated problems. The FSM model of user manipulations is usually used to model the system design specification of a smart phone for black-box testing

III. IoHT INDUSTRY STATUS

The growing of IoHT is experiencing a great debate and exploration. New start-ups, companies, and multinationals corporations are taking a step towards that might be a giant market and empowering products and advances. Table 1 presents a compilation of these solutions for better understanding the IoHT solutions available now. For each identified solution, it is considered the provided service, the company and the available product as well as a brief description of its characteristics.

TABLE 1. More relevant known IoHT solutions from industry.

Service	Company	Product	Brief description
Ambient assisted living	Assisted Living Technologies Inc.	BeClose Remote Monitoring System	BeClose Remote Monitoring System offers a sense of comfort and independence to both the caregiver and the individual that needs their support.
Ambient assisted living	Fade	Fade: Fall Detector (App)	Fade is an application for Android mobile devices capable of detecting and sending an alarm message when a person suffers a fall.
Healthcare Solutions Using Smartphones	Mcare	Mcare (App)	Mcare is a bracelet that informs parents whenever the child moves away.
Healthcare Solutions Using Smartphones	Safe Heart	iOximeter (App)	An oximeter for smartphones.
Healthcare Solutions Using Smartphones	Medisafe	Medisafe (App)	Medisafe is a product that acts as a medication reminder.
Healthcare Solutions Using Smartphones	OnTrack	OnTrack Diabetes (App)	OnTrack allows quickly and easily keep tracking of everything needed to manage diabetes.
Remote Healthcare Monitoring	EarlySense	EarlySense All-in-One	Continuously monitors heart and respiratory rate, fall prevention, early detection of patient deterioration and pressure ulcer prevention.
Remote Healthcare Monitoring	NovaSom	AccuSom	Simple device used to monitor people sleeping.
Remote Healthcare Monitoring	Hi Technologies	Tele-ECG	System of records of electrocardiogram.
Remote Healthcare Monitoring	Proteus Digital Health Inc.	Proteus Discover	Proteus Digital Health consists of ingestible sensors, a small portable sensor patch, an application on a mobile device and a provider. In this case, the pill dissolves in the stomach and produces a small signal that is picked up by a sensor used in the body, which again relays the data (patient health information) to a smartphone application.
Wearable	MC10	BioStampRC	Body sensor so flexible and soft used to collect data from the patient to help in researches.
Wearable	Apple	Apple Watch	The Apple Watch Series is a wearable that allows the developers community to build an infinite number of new applications for Healthcare.
Wearable	Bittium	Enterprise	"Enterprise" provides customized, secure IoT solutions and engineering services for industrial, healthcare, and wearable sports device manufacturers.
Wearable	Qardio	QardioCore	Device capable of tracking your complete heart health on your smartphone and share data with your doctor.
Wearable	Owlet	Smart Sock 2	Smart Sock 2 uses pulse oximetry to track your infant's heart rate and oxygen levels while they sleep.
Wearable	Monica Healthcare	Monica AN24	Solution for home clinical management and remote monitoring.

IV. DISCUSSION

Previous sections presented relevant works proposed by the industry and the related literature for IoHT. However, it is necessary to make sure that IoHT is not only a promise but also a real solution. This section identifies the best works searched among research publications performed by the authors. A technological analysis is performed to consider the industry needs.

TABLE 2. Technology used in the selected research publications.

Reference	Security Mechanisms	Heterogeneous Technologies and Communication	Hardware Platform and/or OS
Al-Taee et al. [120]	Cryptographic Algorithm	Bluetooth, 3G/LTE and Wi-Fi	Java
Gomes et al. [65]	SDDL	DDS, MR-UDP, S2PA	Android
Jara et al. [121]	Symmetric-key encryption AES-CBC	NFC, 6LoWPAN, RFID	SkyeModule M2 and Jennic JN5139
Machado et al. [21]	ECDH, SSL	Bluetooth, WiFi	Android and Arduino
Maia et al. [22]	JAAS	RestFul APIs	Arduino
Mainetti et al. [70]	Enterprise Service Bus (ESB)	BLE, GPS and GPRS	Raspberry Pi
Mano et al. [69]	SSL	SFTP	Android, Raspberry Pi
Matar et al. [27]	SSL	Bluetooth and Wi-fi	Computer
Murakami et al. [41]	SSL	GSM, GPRS, CDMA and WiFi	Computer
Ray [66]	BT SSP	Bluetooth, ZigBee, XBEE and 2G/3G/4G	MicaZ and Libelium

The criteria used to select the considered best research contributions/publications are the following: security mechanisms, supported communication technologies, and hardware/OS (operating system) platform. Table 2 presents the best qualified works following those criteria. Moreover, their importance is discussed. For each one, it is mentioned the reference where it is published, its used mechanisms, communication technologies, and hardware platform and/or used operating system. Works that did not mention any security and privacy mechanism were excluded from this analysis since it is considered a major issue on e-Health systems.

Security and privacy mechanisms are important to be considered in IoHT applications since they are working with critical personal data. It is almost impossible that a contribution may result in a real product if security and privacy issues are not considered.

IoHT devices are associated both to near field and worldwide communications systems through an extensive plethora of MAC layer network technologies, such as Zigbee, Z-Wave, LoRa, SigFox, Ingenu, Bluetooth, Bluetooth Low Energy, WiFi, GSM, WiMax, and 3G/4G described in [108] and [109]. Wireless channel attributes of these systems make conventional wired security schemes less suitable. Accordingly, it is hard to locate a complete security convention that can treat both wired and wireless channel qualities similarly [4].

An important aspect to consider on IoT is the scalability of the solution since the quantity of IoHT devices will expand continuously. More devices are getting associated with the worldwide data arrange. In this manner, planning a profoundly adaptable security plot without bargaining security prerequisites turns it a testing assignment. Another important aspect to be evaluated in the considered related literature is the hardware platform. As shown in Table 2, the research works used hardware prototyping platforms, such as Arduino and Raspberry Pi, indicating that the selected works are in early stage of development.

A. INDUSTRY STATUS DISCUSSION

An important goal of this survey is the analyzes of the IoHT real status: who is using it? is it necessity? where is it used? is it good in terms of usability? and, finally, what is the best solution in each category? This sub-section discusses these topics and elects the best solution on each category based on those criteria.

The products presented for remote healthcare monitoring are used by patients who need to be continuously monitored, but not necessarily inside a hospital. They can be at home using a device for monitoring their condition and send the data to be analyzed by a health professional remotely. Being able to be at somewhere else other than the hospital increases patient's comfort, reduce costs and hospital infection. As proposed in Pourhomayoun *et al.* [110] remote healthcare monitoring frameworks may be an effective way to reduce hospital readmission rates. Among the solutions selected by the authors for remote healthcare monitoring, EarlySense is the one that offers the most complete solution [111]. It monitors heart and respiratory rate, has a fall prevention system, detects early patient deterioration, and prevents pressure ulcer. The aspects taken into consideration were security and how much the solutions explored the possibilities within IoHT. Additionally, EarlySense publishes their studies on the company's Website; great results are shown. However, the solution is not available worldwide and only has offices in USA and Israel.

Fall is one of the main causes of fatal injury in elderly people, turning these patients lives more dependent of care [112]. The Fade App aims to solve the elderly falls problem [113]. For being simple, easy to use, and addressing such an important issue in ambient assisted living environments, Fade is very effective in this topic. In 2010, in USA, a study proved that 21.649 deaths were caused by fall and 5.402 of them are associated with people with more than 65 years old [112]. The increasing number of elderly population gives importance to the existence of Apps, such as Fade and many other solutions for AAL environments. According to the Global Health Observatory [114], healthy life expectancy at birth was 63.1 years in 2015; more than available mobile Apps it is necessary to give assistance to this growing population. There are some devices specifically built for the AAL market. BeClose monitoring system is an example of a solution that combines several sensors with artificial intelligence approaches providing more freedom to elderly people [115].

When it comes to wearable devices, many possibilities emerge. In USA, 15% of the healthcare consumers use wearable devices, such as, smart watches and fitness devices. It is predicted that 110 million of wearable devices will be sold by 2018 [116]. The goal is always to make the user as much comfortable as possible to provide quality healthcare. Therefore, the main aspects taken into consideration to analyze the previously presented wearable solutions were patient's comfort, data security, and usability. Although MC10 offers a state-of-the-art body sensor capable of gathering complex physiological data [117], Bittium's smart watch takes the leading position in the context of this paper, offering a solution that covers more users [118]. The smart watch is capable to measure vital signs, monitoring patient location, detecting body positioning and medicine dosage, and timing management. As security is necessary in all IoHT solutions, Bittium also offers a solution that ensures the secure data transfer between sensor devices and cloud services, being a company specialized in the development of reliable, secure communications, and connectivity solutions. Although not elected as the best solution in this work, it is also important to mention the Apple Watch as a wearable development platform [119]. This device allows a great number of new Apps for healthcare. Through it, it is possible to easily obtain the body mass index (BMI), body surface area, estimated glomerular filtration rate (eGFR), and several scores used in cardiovascular diseases. An important data is that, only in 2016, 6 million devices were sold.

Healthcare solutions using smartphones has become increasingly common these days. These solutions range from a simple application to remind the patient to take a medicine or an oximeter. According to Saúde Business [122], it is estimated that there are more than a hundred million mHealth Apps around the world. The number of people with diabetes has risen from 108 million (in 1980) to 422 million in 2014. According to the World Health Organization, this scenario is likely to increase considerably. It requires some care to avoid unpleasant aspects caused by diabetes. One very good solution related to diabetes is On Track Diabetes [123]. OnTrack Diabetes is an App for people with type-2 diabetes. It helps users better manage their conditions by performing blood glucose, blood pressure, exercise, food, medication, pulse and weight checks.

V. CONCLUSION AND FUTURE WORKS

Internet of Things is bringing innovations to many segmentations of the industry. One of the fastest industries to embrace this opportunity is healthcare, turning available a new market based on IoHT. That fact led the authors to develop a comprehensive survey to analyze the state of the art on the topic. To accomplish this goal, the most recent IoHT publications and products were identified, described, and analyzed. It is possible to conclude that there are many services and applications for IoHT, these solutions attend the society needs, but are growing isolated. The discussion on this paper may help developers and entrepreneurs to build solutions that embrace all the society. Additionally, this paper can be considered as a source of information for healthcare providers, specialists, and the general population interested in IoHT.

Nevertheless, this review does not provide a deep understanding about some fundamental topics, including topologies, architectures, and platforms for IoHT; security requirements, challenges, and proposed models. There are other technologies which are not explored in this review and could be explored further, such as big data, augmented reality, and cognitive systems. Finally, policies and regulations are very important in the healthcare sector and should be considered in future researches.

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