

Wearable Internet of Things :

Concept, Architectural Components and Promises for Person-Centered Healthcare

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Abstract—The proliferation of mobile devices, ubiquitous internet, and cloud computing has sparked a new era of Internet of Things (IoT), thus allowing researchers to create application-specific solutions based on the interconnection between physical objects and the internet. Recently, wearable devices are rapidly emerging and forming a new segment—“Wearable IoT (WIoT)” due to their capability of sensing, computing and communication. Future generations of WIoT promise to transform the healthcare sector, wherein individuals are seamlessly tracked by wearable sensors for personalized health and wellness information—body vital parameters, physical activity, behaviors, and other critical parameters impacting quality of daily life. This paper presents an effort to conceptualize WIoT in terms of their design, function, and applications. We discuss the building blocks of WIoT—including wearable sensors, internet-connected gateways and cloud and big data support—that are key to its future success in healthcare domain applications. We also present a new system science for WIoT that suggests future directions, encompassing operational and clinical aspects.

Keywords—Internet of Things; Wearable Sensors; Person-Centered Healthcare; Mobile Health; Pervasive Healthcare

I. INTRODUCTION

The rising cost of healthcare, the increase in elderly population, and the prevalence of chronic diseases around the world urgently demand the transformation of healthcare from a hospital-centered system to a person-centered environment, with a focus on citizens’ disease management as well as their wellbeing. The development of personal mobile devices such as smartphones and tablets is helping establish a model of mobile health (mHealth) that can facilitate a continuum of person-centered care by relying on these mobile devices as a medium of sensing, interaction, and communication. Although, smartphones are embedded with an array of sensors that can track a user’s motion, location, activity, and so forth, these devices still lack the capability to collect fine-grain information of a user’s bodily health. A wide array of wearable devices has recently been developed to extend the capabilities of mobile devices, especially in the area of body and behavior sensing.

According to ABI Research [1], in 2014 consumers are estimated to buy 90 million wearable computing devices used for healthcare, wellness, and sport applications. This number is projected to increase even more in the coming years. Wearable devices encompass a variety of functions including data collection from on-body sensors, preprocessing the data, momentary data storage, and data transfer to internet-connected immediate neighbors such as mobile phones or to a remote

server. It is the characteristic of wearability that adds value to these devices and allows customizing the collection of body’s physiological or motion data depending upon the end-user application. While wearable sensors offer significant advantages to healthcare by automating remote healthcare interventions that include diagnostic monitoring, treatments and interoperability between patients and physicians, they face barriers such as the requirement to work in close proximity to other computing devices to compensate for low computing power, short battery life, and short communication bandwidth.

The concept of Internet-of-things (IoT) provides a solid framework for interconnecting edge computing devices—wearable sensors and smartphones—and cloud computing platforms for seamless interactions. This paper seeks to define the concept of wearable internet of things (WIoT), discusses its architectural components and the potential of these systems to provide person-centered healthcare.

II. THE CONCEPT OF WEARABLE INTERNET OF THINGS

Nowadays, internet connectivity is ubiquitous and has given birth to a whole new paradigm—The Internet of Things (IoT), namely the concept of interconnecting physical objects to each other or to the internet to create domain-specific intelligence through seamless pervasive sensing, data analytics and information visualization with cloud computing [2]. Over the years, as we moved from basic internet services to social networks to wearable web, the demand for interconnecting smart wearables has increased.

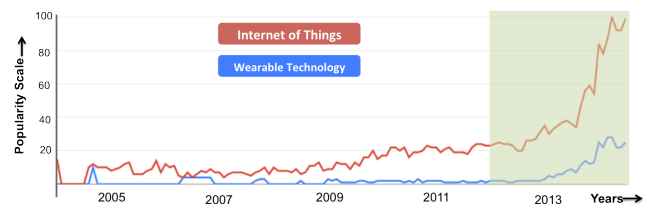


Figure 1: Google search (since 2004) for the terms — “Wearable Technology” and “Internet of Things”. (Source: Google Trends, Google Inc.)

The Google search trend shown in Figure 1 confirms that there is the concurrent growth and popularity of wearable technology and IoT over the past few years. This emergence of wearable devices is giving a new dimension to IoT by creating an intelligent fabric of body-worn or near-body sensors communicating with each other or with the internet. In other words, Wearable IoT (WIoT) can be defined as a technological infrastructure that interconnects wearable

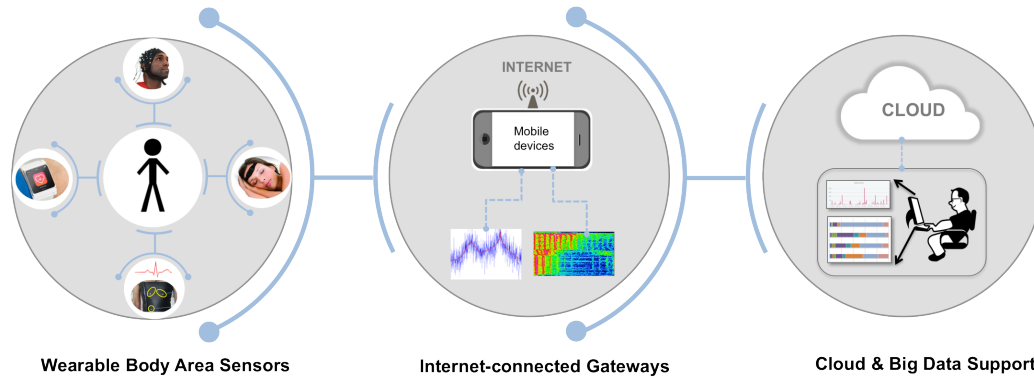


Figure 2: Architectural Elements of Wearable Internet-of-Things

sensors to enable monitoring human factors including health, wellness, behaviors and other data useful in enhancing individuals' everyday quality of life.

WIoT aims at connecting body-worn sensors to the medical infrastructure such that physicians can perform longitudinal assessment of their patients when they are at home. For example, built-in motion sensors of a smartwatch are used to track disease symptoms such as tremors in Parkinson patients for tele-interventions [3]. WIoT is still in its infancy period and therefore, demands a chain of developments in order to boost its successful evolution and to enable its widespread adoption in the healthcare industry.

III. ARCHITECTURE OF WEARABLE IOTs

It is no longer sufficient to design standalone wearable devices but it becomes vital to create a WIoT ecosystem in which body-worn sensors seamlessly synchronize data to the cloud services through the IoT infrastructure. A novel integrative framework for WIoT is currently being built on top of the IoT architecture. The following describes all components of WIoT architecture and their interconnections, a system that would benefit the healthcare industry in various ways.

A. Wearable Body Area Sensors

Wearable body area sensors (WBAS) are frontend components of WIoT and unobtrusively envelop the body to capture health-centric data. WBAS are primarily responsible for 1) collecting the data either directly from the body through contact sensors or from peripheral sensors providing indirect information of body and its behaviors (see Figure 2) and 2) preparing the data for either on-board analysis for close-loop feedback or remote transmission for comprehensive analysis and decision support.

WBAS, whether commercial or laboratory prototypes, are packaged with miniaturized sensor hardware, an embedded processor with storage capability, power management, and optional communication circuits depending on application. For example, peripheral wearable sensors such as the BodyMedia armband (Jawbone Inc., USA) are fitness monitors that work on computationally less intensive algorithms with minimum hardware requirements, and their goal is to encourage users to maintain an active lifestyle. Most of the contact-type wearable sensors contain decent electronics and computing capabilities due to the fact that they are required to provide accurate, high-

resolution clinical information of patients in real-time. Novel interface between sensor and body is key to successful data acquisition in wearable technologies. Ring sensor for pulse oximetry [4], chest-worn ECG monitor [5], and attachable Bio-Patch [6]—all are a few examples of novel sensor locations that provide continuous access to the body's vital signs. Smart textiles represent the forefront of wearable electronics woven into the clothes' fabrics in order to provide unobtrusive health monitoring for patients living in their homes, away from hospitals and doctors. Smart clothes embedded with textile-based sensors were found useful in monitoring the autonomous nervous system response [7].

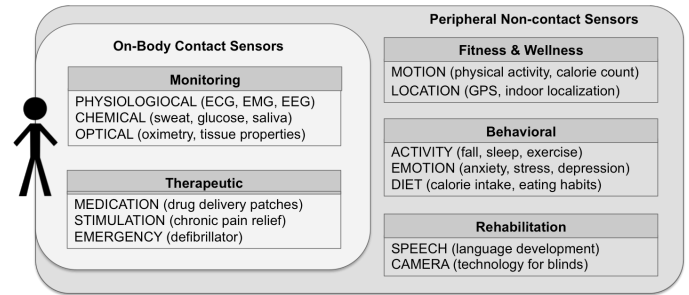


Figure 3: Categorization of wearable body area sensors

Regardless of their end-user applications, WBAS are required to meet global quality standards to ensure their long-term operation with minimum supervision and management. The need for wearable sensors has led to hardware miniaturization and development of efficient ways to reduce power consumption while operating at clinically acceptable standards. Data management for wearable sensors remains a challenge for researchers, because such data needs to be annotated with information such as time, activity, and location.

B. Internet-connected Gateways

WBAS are rarely standalone systems due to their limited computing power and communication bandwidth. Therefore, they need to transmit data to potent computing resources that are either companion devices such as smartphones, tablets, and laptop PCs, or remotely-located cloud computing servers. In either case of data communication, companion devices are used as gateway devices, thus representing an important class of WIoT that enables the information to flow from the sensors to the cloud or server centers for storage and further analysis. The Gateway devices comprise of short-range communication

technology such as Bluetooth, used to exchange data with wearable sensors, and of heterogeneous networks, such as WIFI and GSM, used to send the data to the cloud. Some Gateway devices have the capacity to store data, to run some pre-processing algorithms evaluating whether the data is clinically relevant, and to send the data intermittently to remote servers.

Research has shown that weight scales transmit data to a mobile smartphone that forwards the information to a cloud based server, so that clinicians can assess weight management in youth [8]. Smartphones sync with the cloud servers to monitor fall detection in elderly individuals [9]. These few examples show that how wearable or devices used by the person interact with smartphone or phones to send information to remote servers. In order to improve the performance and the battery life of smartphones, the paradigm of Mobile Cloud Computing (MCC) optimizes mobile computing and networking protocol to minimize the burden of computing for smartphones [13]. WIoT can benefit significantly from MCC since it enables the data storage and the data analysis to happen on the cloud platforms.

C. Cloud & Big Data Support

The congruence of close companions—wearable sensors and smartphones—will flood the cloud centers with medical data at an unprecedented rate. Gaining knowledge from this data is as important as acquiring the information from the body. Patients only benefit from wearing sensors when intelligent algorithms process the data and offer some actions to take.

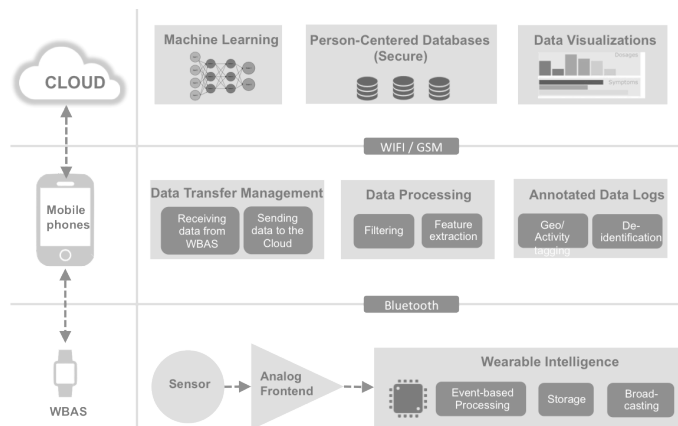


Figure 4: A functional block diagram of cloud-assisted BAS.

A cloud computing infrastructure can facilitate the management of wearable data and can support advanced functionalities of data mining, machine learning, and medical big data analytics. Cloud-assisted BAS (CaBAS) is emerging as a promising technology that provides integration of MCC and WBAS to facilitate the growth of scalable, data-driven pervasive healthcare [10]. As shown in Figure 4, WIoT can receive significant benefits from CaBAS such as 1) energy-efficient routing protocols that can network smartphones and wearable sensors for handshaking and seamless data transfer, 2) event-based processing that can reduce unwanted data processing on resource constraint wearable sensors, 3) annotated data logs that can add activity-level information on top of clinical data for enhancing the accuracy of machine

learning algorithms on the cloud, 4) person-centered databases that can store the personalized data of patients securely for longitudinal analysis, and 5) data visualization that can channelize the data to end-users such as physicians and patients to provide decision support and patient-physician interactions.

IV. WEARABLE IOT'S FOR PERSON-CENTERED CARE: FUTURE DIRECTIONS

The prevalence of chronic diseases, such as diabetes, obesity, or cardiovascular disorders, affects the lives of millions of people around the world. Therefore, there exists a stringent demand to provide a solid foundation for creating wearable IoT technologies to deploy large-scale wearable sensors that are networked with remote medical infrastructure, to increase the treatment outcomes' efficacy and effectiveness. Below, we present a new system science for WIoT's to suggest future directions encompassing operational and clinical aspects:

Patient-Friendly Wearable Design

Consumer usability studies have changed the design of new wearable devices (e.g. wrist accelerometer in the form of a jewelry), the development of interactive interfaces, and the abstraction of the information presented to the patient. Patients can interact with these systems and feel like they can actively modify some of these parameters. In addition, preventive healthcare initiatives by both publicly funded health systems and private health insurances are interested to increase the health and activity levels of patients. Some private insurance companies may even provide incentives to encourage the use of pedometers and to reward good health results in annual checkups.

Patient-Physician Interaction

Nowadays, doctors desire to monitor patients beyond the physical boundaries of the clinic. Additionally, physicians intend to make their patients more proactive with respect to their health and medical conditions. Interconnections found in WIoT's among wearable sensors, mobile phones and medical infrastructure enable efficient communication between physicians and patients, allowing them to discuss digitally about micro-managing interventions, feedback on symptoms, and ability to adapt to new treatments. The level of information provided to the patient can vary depending on the individual's interest: 1) an application may only provide one line actions such as "walk briskly" or "run for 30 minutes today," 2) an application can be made more detailed in terms of asking the patient to do an aerobic activity of 20 minutes and an anaerobic activity of 10 minutes, 3) in addition to the information in option 2 additional reading material or online education material can be shared with the patient to inform them about the clinical practice or recent research, and 4) provide a contact to chat with a clinical support person or talk to a physician in an emergency situation. On the clinician's side, the information about a certain patient can also be varied to provide brief and then detailed case information for the clinician to help the patient make a decision on an intervention or treatment. Clinical guidelines and range of acceptable values can be provided to the clinician in real-time to assist the clinician when offering treatment.

Treatment Personalization

WIoTs can play a key role in personalizing treatment. Each disease manifests a unique set of symptoms that differ in intensity and in their spatiotemporal pattern based on the patient. For example, in the treatment management for chronic diseases, physicians face challenges when evaluating medication plans, because their patients may respond to prescribed medications differently. Moreover, medication adherence monitoring is another aspect that WIoT can help patients with. Future research can focus on health pattern identification, where the algorithms in the wearable sensors and the gateways can detect a health aberration or an impending emergency. This is possible as the WIoT are in the vicinity of the patient.

Management and Maintainence of Wearable Systems

Efficient management of wearable sensors on daily bases is an inherent issue due to their limited battery life that requires recharging periodically. Elderly citizens who face major health-related challenges are projected to become first target users of WIoT. New technologies such as inductive fast charging may reduce the burden of remembering to plug and unplug the devices on a regular basis. Also, new methods of intelligently sampling the sensors may prolong the devices' life.

Standards & Regulations

WIoT need to meet international quality standards to cross the boundary from consumer gadgets to medical devices. The regulations imposed by US Food and Drug Administration (FDA) are applied to mainstream medical devices and, therefore, wearable sensors are classified as wellness/lifestyle tracking devices in order to circumvent FDA's rigid standards. However, the trend is changing, and wearable sensors are approved by the FDA for their use in consumer industry [11]. FDA has recently issued guidelines for wireless medical devices to ensure they address major safety critical risks associated with radio-frequency wireless systems, short and long range communication, and secure data transmission [12]. Over the next few years, it is anticipated that the FDA and other agencies dealing with medical device regulations will define WIoT in terms of their regulatory compliance and their use for medical interventions. Since the wearable sensors are powered electronic systems worn by humans, regulatory standards will be derived from large-scale clinical trials.

Security & Privacy

As the internet evolves, it continues to pose issues of privacy and security. Earlier, desktop PCs were prone to cyber attacks, while, mobile phones and wearable devices are now under constant threat of highly-skilled, organized hackers. WIoT deal with data collected from, and provided to humans. Although collected from innocuous wearable sensors, such data is vulnerable to top privacy concerns. For example, some wearable devices collect sensitive information such as the user's absolute location and movement activities that compromise the user's privacy if this information is not safeguarded during the processes of storage or communication. To mitigate the risk of cyber attacks on WIoT, we need strong network security infrastructure for short- and long-range communication. In each passing layer in WIoT, from the

wearable sensors to the gateway devices to the cloud, careful precautions are desired to ensure users' privacy and security.

V. CONCLUSIONS

The Wearable Internet of Things (WIoT) is an emerging technology ideal for influencing healthcare domain by creating an ecosystem for automated telehealth interventions. We presented a concept of WIoT that identifies its architectural components including wearable sensors, internet-connected gateways and cloud and big data support to monitor human health and behaviors unobtrusively. To achieve multidimensional success, WIoT needs not only to overcome the technical challenges of generating a flexible framework for networking, computation, storage, and visualization, but also needs to consolidate its position in designing solutions that are clinically acceptable and operational. We believe that over the next 10 years, WIoT will transform healthcare practices for which the cost of treatments is low; early detection of illnesses is possible; efficient treatment is easy to administer remotely; and patients do not need to see their physicians so often.

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