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From Fitness Trackers to Medical Devices: Wearable Technologies

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Abstract

Wearable technology, wearables, fashion technology, smart wear, skin electronics, or fashion electronics are smart electronic devices. Wearable technology has various applications that grow as the field expands. It appears prominently in consumer electronics with the popularization of the smartwatch and activity tracker. A popular activity tracker called the fit bit is widely used in the fitness industry to track calories and health-related goals. A popular smartwatch in the market is the Apple Watch. Apart from commercial uses, wearable technology is incorporated into navigation systems, advanced textiles, and healthcare. As wearable technology is being proposed for critical applications, it must be vetted for its reliability and security properties. Applications based on Wireless Sensor Networks (WSN) for Internet of Things (IoTs) scenarios are rising. The multiple possibilities they offer have spread towards previously hard-to-imagine fields, like e-health or human physiological monitoring. An application has been developed for its usage in scenarios where data collection is applied to smart spaces, aiming at its usage in firefighting and sports. This application has been tested in a gymnasium with real, non-simulated nodes and devices. A graphic user interface has been implemented to suggest a series of exercises to improve a sportsman/woman s condition, depending on the context and their profile. This system can be adapted to a wide variety of e-health applications with minimum changes, and the user will interact using different devices, like smartphones, smartwatches, and/or tablets.

Keywords: Accelerometer, Magnetometers, Heart rate sensors, Energy harvesting, Healthcare, BSNs, Wearable sensors, Nanotechnology, ZigBee.

1 | Introduction

The Wireless Sensor Network (WSN) technologies have the potential to change our lifestyle with different applications in fields such as healthcare, entertainment, travel, retail, industry, dependent care, and emergency management, in addition to many other areas. The combination of wireless sensors and sensor networks with computing and artificial intelligence research has built a cross-disciplinary concept of ambient intelligence in order to overcome the challenges we face in everyday life [1]. Wearable sensor technology is a growing field as more clinicians, researchers, and developers learn of the potential benefits and possibilities it offers. From athletes to the elderly, those with medical conditions or injuries will soon benefit from wearable technology if they have not done so already. Basic forms of wearable medical technology have already been made commercially available over the last couple of years. Examples of these include electronics or smartphone applications that encourage

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physical activity by measuring the user's daily step count, but this is merely a taste of what's to come. Wearable technology can also come in the form of a WSN, also known as a wearable Body Sensor Network (BSN), or even a Wearable Health Monitoring System (WHMS) [2]. In a WSN, multiple sensors communicate with one another to form a network, and the more sensors used in a system, the greater the potential that the system will have to offer. In the medical field, future WSNs will have the capability to capture data needed to diagnose serious medical problems with greater precision than that of current methods and may even allow clinicians to find solutions where there previously were none. The entertainment industry will be impacted by WSNs as well. Continuous advances in wearables, sensors, and smart wireless body area network technologies have precipitated the development of new applications for on-, in-, and body-to-body wearable communications for healthcare and sport monitoring [3]. Progress in this cross-disciplinary field is further influenced by developments in radio communication, protocols, synchronization aspects, energy harvesting and storage solutions, and efficient processing techniques for smart antennas. This book covers various scenarios and solutions using sensor devices and systems for activity recognition and their applications, including wearable communication, smart sensing, RF propagation, and measurement. The authors illustrate conceptual aspects and applications and provide a new vision in characterizing wearable technologies and the need for interoperability. Energy harvesting within wearable solutions is a key issue addressed here as it helps increase energy efficiency and reliability in wearable antennas and sensor devicesm [4].

2 | Literature Review

Wearable Body Sensor Networks

The world of wearable sensors and WSNs is growing, and the opportunities presented by this technology are undeniable. Added benefits to the entertainment industry and arts are welcome, but perhaps the most important use of this technology will be in the medical field as it expands the capabilities of today's healthcare system to meet tomorrow's needs [5]. With new machine-learning algorithms being created to classify human activities and new energy saving techniques, future WSNs are likely to become smaller and more powerful than ever before. The issue with many of these studies is the minimal amount of testing done. Ideally, studies on wearable sensors or health monitoring systems should make sufficient testing a priority to derive realistic results and should include testing on large numbers of people of diverse backgrounds and age groups [6].

Maintaining the integrity of the specifications

The smart wearable body sensors include a wide range of wearable devices and sensors such as accelerometers and gyroscopes, smart fabrics and actuators, wireless communication networks and power supplies, and data capture technology for processing and decision support. Having a wearable device decreases the restrictions placed on their motility and daily activities, allowing monitoring in the environment of the patients directly home and at work [7].

The most used and well-known sensor accelerometers are electrochemical sensors that measure the acceleration of objects in motion along reference axes and provide basic step and activity counts used as a quantitative assessment of physical activity. This data can be used to obtain velocity and displacement by merging the data with respect to time [8].

3 | Wireless Body Sensor Networks Architecture

A WBSN is a sub-field of a WSN that interconnects sensor nodes or actuator capabilities in, on, or around a human body [9]. WPANs, like Bluetooth low energy (IEEE 802.15.1), Wi-Fi (based on 802.11b), Ultra-Wide Band (UWB) based on the 802.16.5 standard, and Zigbee (IEEE 802.1.5.4 Standard) can be used to ensure compatibility between nodes and the base station. All WBSN network architectures consist of several connected nodes, performing the tasks of communication detection and data processing [10]. With respect to the application requirements in sports, games, and fitness, generally, two to three specific sensors, such as an accelerometer, gyroscope, heartbeat, sweat, etc., are used, which can operate stand-alone without any external communications. Often there is no requirement for a more powerful coordinating node [11]. On the other hand, rescue and critical applications require more resources, much better quality of service, and reliability. In such systems, body-to-body and off-body communications are necessary, adding explicitly different requirements and constraints. For example, four to five sensors are typically used to monitor the health, orientation, and movement of fire-fighters along with support of multiple functions and multi-standards based coordinator [12]. To represent all the applications in terms of their requirements, we present a global view based on a number of different parameters. In *Table 1*, we classified the target applications as medical and non-medical. As discussed earlier, it covers a broad range of applications and presents a corresponding data range of various physiological signals, frequency, accuracy, and data rates [13].

One of the most commonly used sensor types in WSNs is known as the Inertial Measurement Unit (IMU). This sensor collects gyroscope, magnetometer, and accelerometer data and have been used extensively [14].

SEMG and ECG measurements are how clinicians measure one's muscle activity and heartbeat, respectively.

Heart Rate (HR) is a standard vital sign and has become a routine measurement in both healthcare and fitness/sport activities. The monitoring of this signal provides information about the physiologic status by indicating changes in the heart cycle. This vital sign can be easily extracted from the ECG (R-peak) or Photo Plethysmo Graphy (PPG) signals [15].

4 | Discussion

In low-rate wireless network applications, access delay is also an important metric. Generally, total delay in a communication network includes processing delay, queuing delay, access delay, and propagation delay. The total successful packet transmission time as TS and the packet collision time as TC with ACK are assigned. TS is computed when there is no retransmission attempt due to the data collision or packet lost. It does not include back-off time period and channel sensing time. Also, successful packet transmission time without ACK is described as TNACK [16].

$$T_S = T_{Packet} + \delta + T_{W\_ACK} + T_{ACK} + \delta + T_{IFS},$$
$$T_C = T_{Packet} + T_{ACK\_Time\_Out},$$
$$T_{NACK} = T_{Packet} + \delta + T_{IFS},$$

where T_{Packet} is the total time of packet length including packet overhead and data payload, δ is the propagation delay, TW_ACK is the waiting time to receive the ACK frame from the receiver, TACK is the length of the ACK frame time, TIFS is the IFS time, and TACK_Time_Out is the timeout of the ACK. The IFS time depends on the length of the data frames and TW_ACK is in the range between TTA and TTA + TUB.

I. The high price for both individual and corporate consumers is one drawback for the wearable trend.
II. Wearable technology is usually linked to separately standing smart devices due to the smaller processer size in the wearable device. Think of the fitness trackers which must be coordinated with a corresponding app on a Smartphone, tablet. Again, this may mean further expense for a business owner if they are to be provided to employees [17].
III. Experts have expressed concern that wearables may pose serious health risks to users of these devices. Wearables increase exposure to radio waves to those who are already carrying Smartphones, laptops, and tablets.
IV. App providers often seek to share information gathered via their corresponding wearable devices, and 82% of employees are concerned that the use wearables may ultimately violate their privacy.

V. Similar to other forms of technology, wearables make it easier for people, in general, to perform specific tasks. However, necessary precautions should be taken to ensure that these devices are not hacked and employees' privacy and sensitive information are not compromised.
VI. Robustness is also a major concern of WSNs. Sensor nodes should ensure their long running time and performance regardless of the environment and the conditions they are facing.
VII. Power is now a day's considered as a top most priority challenge, as WSN although need less power but they need continuous power in order to give good performance
VIII. An excellent style manual for science writers is [1].

Nonetheless, the miniaturization trend, portability, wireless communication, energy-efficient computing, and advanced display technologies have been combined to create state-of-the-art smart devices. The patriarch of these devices, a smartphone, was released back in [19], and intelligent media are now ready to lead the next great wave of innovation. Comparing traditional smartphones with wearables, both have their pros and cons. A traditional smartphone's main advantage is its higher accuracy in various performance metrics due to less power consumption limitations as a general trade-off to size. On the other hand, wearables are highly battery-constrained devices, yet they have the potential to change the world as we know it-just as mobile devices did over the past 20 years. It is expected that they will improve the technological and socio-cultural parts of our lives. Moreover, wearables also have the strength to improve well-established sectors, such as the smartphone industry and other hand-held devices. This trend is confirmed by many recent studies and will be discussed in this survey.

Table 1. Typical wearable sensors and data rates [20].

Application	Signals	Data Rang	Frequency (Hz)	Accuracy (Bits)	Data Rate
	Glucose concentration	0-20 mM	40	12	480 bps
	Blood flow	1-300 ml/s	40	12	480 bps
	ECG	0.5-4 mV	500	12	6K bps
	Respiratory rate	2-50 breaths/min	20	12	240 bps
	Pulse rate	0-150 BPM	4	12	48 bps
	Blood pressure	10-400 mm Hg	100	12	1.2 Kbps
	Blood pH	6.8-7.8 pH units	4	12	48 bps
	Body temperature	32-40°C	0.2	12	2.4 bps
	High quality audio	-	-	-	1.4 Mbps
	Voice	-	-	-	100 kbps
Non-medical	Video	-	-	-	Mbps
	GPS positions	-	1	32	96 bps
	Motion sensor	-	100	16	4.8 Kbps

Head-mounted wearables: those are mainly focused on perception and control aspects. The group related to vision covers: AR/VR/XR/MR glasses, relaxation masks as well as HMD and personal entertainment systems. Audio-related devices include headsets, personal assistants, bass systems. A standalone group is related to neural interfaces.

Body-worn devices: those have much broader functionality and could also be divided into the following subgroups:

- *Near-body and sport: a segment for the devices supplementing existing wearable ecosystem, such as e-patches, smart bands, supplementary activity tracking sensors, etc.* [21].
- *On-body: EEG and ECG monitors, posture correcting devices, safety devices, various smart clothes, etc., form this subcategory* [22].
- *In-body: the most significant niche from a medical perspective includes implantable, smart tattoos, etc.*
- *Lower-body devices: this group is still in its infancy but already includes some wearables such as smart shoes, belts, insoles, etc. Most of them carry specific monitoring functionality for professional sport or medical purposes* [20].

– *Wrist-worn and handheld wearables: those are the most widely adopted and market-filled niche covering smart rings, wrist bands, smartwatches, and gesture control devices beyond others* [23].

Fig. 1. Examples of some wearable health devices [23].

Fig. 2. Uses of WSN on the human body.

Fig. 1 presents a collection of wearable health devices that showcase the diverse range of technologies available in this field. The devices depicted include ear sensors, smartwatches, and chest straps, each equipped with sensors that can monitor various physiological parameters. For example, the Google Contact Lens can measure glucose levels in tears, while the BioPatchTM can monitor heart and respiratory rates. The QardioCore chest strap records ECG and HR variability, and the Vital Jacket® t-shirt tracks breathing rate, skin temperature, and body posture. These sophisticated sensors highlight the potential for wearable technology to provide personalized insights into health and wellness, allowing individuals to monitor and improve their well-being.

In *Fig. 2*, we see how WSN can be deployed on the human body. The figure depicts a variety of sensors that can be placed on the chest, wrist, ankle, or other parts of the body, which can monitor vital signs, track physical activity, and provide real-time feedback on technique. WSNs can also be used to remotely monitor patients with chronic illnesses, enabling clinicians to provide proactive and personalized care. In addition, WSN can facilitate remote patient monitoring, enabling patients to receive care from the comfort of their homes. Overall, *Fig. 2* highlights the potential of WSN to improve health outcomes and enhance patient care, from personal fitness tracking to medical diagnosis and treatment.

5 | Conclusion

In conclusion, this paper has provided a comprehensive overview of Wearable Wireless Sensor Networks (W-WSN), including their applications, standards, research tracks, and open research opportunities. The potential for W-WSN to transform healthcare, sports, and fitness is immense, and continued research and development in this field can lead to significant advancements in these domains. Exploring various standards and research tracks highlights the complexity and challenges associated with W-WSN and the potential for innovation and progress in this area. Reliable and effective communication, privacy and security, and accurate modeling are key areas for future wearable WSN research. We hope this paper is a valuable resource for researchers and practitioners in this field and inspires further innovation and collaboration to advance the state-of-the-art in W-WSN.

In addition to the valuable technical insights provided in this paper, it is important to consider the potential impact of W-WSN on society as a whole. With the increasing focus on health and wellness, wearable technology has become more popular than ever before. W-WSN has the potential to provide unprecedented insights into the human body and to facilitate the development of personalized health and fitness plans that can improve overall well-being. W-WSN can also enable real-time monitoring of patients with chronic illnesses like diabetes, heart disease, and hypertension. This can lead to more proactive and effective interventions, reducing hospitalizations and improving patient outcomes. In addition, W-WSN can be used to monitor the elderly and those with disabilities, enabling them to live independently and safely for longer periods of time. Despite the potential benefits of W-WSN, there are also ethical and social implications that must be considered. For example, privacy concerns and data security issues must be addressed to protect personal information. Additionally, access to technology and data must be ensured for all, regardless of socioeconomic status, to avoid exacerbating existing health disparities.

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