Challenges Associated with Wearable Internet-of-Things Monitoring Systems for E-Health

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REVIEW ARTICLE

Abstract- Wearable Internet-of-things (IoTs) monitoring systems provide several benefits that tend to secure diagnostic connection with health care providers thereby potentially influencing people's orientation to accessing healthcare services. The goal of this overview is to explore the challenges associated with wearable Internet-of-Things (IoT) monitoring Systems for e-health. Wearable devices are integrated with IoT to enable health managers provide hospital setting to many localities, groups and individuals. Thus, wearable devices become imminent infrastructure for IoT deployment. To develop wearable-based IoT ecosystem, enabling techniques, architecture and other matters relating to IoT should be investigated and then their integration should be embraced. In this paper, we look at the challenges connected with wearable health monitors by system functionality, enabling technologies, security and privacy issues, and the prospect of integration of wearable technology and applications. Finally, we envisage that with the growth of e-health ideas, wearable devices will perform superior role in the arena of health care service and become well integrated into patients' regular lives. Device interoperability, secured connection/communication to mitigate intermittent signal outages for point-to-point networks, providing advocacy in its usage among the generality of the populace and its deployment in requisite institutions – government and private, are some declared recommendations.

Keywords- Disease, e-Health, Internet-of-Things (IoT), Impedance, Revolution, Sensor, Wearable System

1 Introduction

A wearable system is broadly recognised as a mobile electronic device that can be unobtrusively embedded in the user's outfit as part of the clothing or as a wearable accessory (Sagahyroon, *et al*., 2009). When considered with information gathering capabilities regarding vital signs and other metrics related to health conditions (Deepseadev.com, 2023) they become classified as wearable Internet-of-Things (IoTs) devices. Wearable health monitoring devices provides several benefits that impact lives and make health care readily accessible. This in a way makes health care givers dispense health services conveniently by helping to reduce costs in service (Balakrishna et al., 2019) delivery. According to Prieto-Avalos *et al*. (2022) and Prieto-Avalos, Sánchez-Morales & Alor-Hernández (2023) wearable health devices are classified as commercial and non-commercial wearables. The commercial wearables include smartwatches, patches, smart wristbands, et cetera. These generally monitor components such as the blood oxygen saturation, heart rate and electrocardiogram data. The non-commercial wearables are used for monitoring photoplethysmography and electrocardiogram (ECG) data as well.

Wearable devices are embedded with various type of sensors depending on their design functions and specifications. These embedded components make the wearable devices smart in nature. Wearable sensors in medical health applications, according to the principle of measurement, are divided into physical and chemical measurement (Cheng, Wang & Xu, 2021).

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According to Kim (2014), recent advances in technology in wearable sensors, low-power integrated circuits, and wireless communications have enabled medical science to monitor significantly physiological signals in heart and respiration rate, using electroencephalogram (EEG), ECG, body temperature, oxygen saturation, galvanic skin response, blood pressure, blood glucose, and other areas of medical healthcare. One common denominator is that data monitoring is in real-time medical health technology application must be 'patient centred' in manner that conceptualizes the deployment of best, efficient, reliable and immediate health care service to needy patient whenever, wherever and whoever needs them. In achieving this, wearable health device with Wireless Sensors Network (WSN) and other embedded systems in an IoTs ecosystem must be assembled and deployed to provide hospital setting to many localities and specific groups and individuals.

The drawbacks in their functionality and deployment have posed some common challenges. In this section, we take an overview on some of these challenges associated with wearable IoT devices and the impact on healthcare delivery. This is focused on five main areas that are associated all type of wearable devices: a) sensor associated difficulties b) healthcare revolution c) power adaptability problem d) inadequacy in system testing and e) security and privacy.

2 Related Works

Balakrishna *et al*., (2019) worked on challenges of wearable health monitors while focusing on sensors and signalling, data processing, communication and printed circuit integration using foetal ECG wearable garment. Achieving a precise signal retrieval was proffered. Kim *et al*. (2014) and Baig *et al*. (2019) discussed challenges in wearable monitoring sensors for healthcare deployment and solutions for multifunctional wearables based on design techniques for circuit implementation in order to discard direct current (dc) counterbalance. They concluded with system having the competence to at once acquire numerous biomedical signals. Dian, Vahidnia & Rahmati (2020) as well as Canali, Schiaffonati & Aliverti (2022) overviewed applications, opportunities and the main functions of wearable technology for health: monitoring, screening, detection, and prediction. Some concerns in the application of wearables device for these functions were identified as: data quality, balanced estimations, health equity and fairness.

Mark (2019) wrote on power challenge in wearable devices and opined that efficient design and architectures are key to current wearable devices where battery capacity is limited by the need for small size and low weight. Lobelo *et al*., (2016) viewed the increasing diversity of available wearable technologies and the absence of an all-inclusive guiding framework (Haghi & Deserno, 2020) as key challenges for data collection standardization, integration and security (Devender & Rashmi, 2021). Anita & Oliver (2018) opined that the marketing, development and deployment of this technology promotes important ethical consequences for therapeutic dealings and safety of patient while Etemadi *et al*. (2023) considered the scenario for the elderly in the world.

3 Challenges

3.1 Sensor Associated Difficulties

Sensors require specific signal processing functions to match the characteristics of both sensors and systems (Mcadams *et al*., 2013). Figure 1 shows key features associated with wearable technology as we conceptualised its operation. Detection of specific ailment or disease components are challenging in wearable devices due to the following components.

i. *Weak amplitude in signals generated*: The measurement of wearable device signals mainly depends on amplitude and spatial resolution. Owing to the fact that detection of such signals from patients vary from device type. The problem of threshold signal requirement to indicate appropriate diagnosis is a challenge.

ii. *Frequency domain region that conflict with other devices frequencies*: The symptoms of frequency interference issues can easily be mistaken for indication of other problems by the device. This noise can lead to incorrect or incomplete value chain in disease diagnosis.

iii. V*oltages of other similar or related devices*: The need to have lower operating voltages and power consumption in wearable heart device sensors have made the development of smart wearable devices a challenge. This is necessary to avoid the problem of high impedance characteristics in component design and to provide safety in device usage on human body.

iv. *Mechanical resistivity*: According to Heikenfeld *et al*., (2018) highly anisotropic composition of the human skin results in the skin producing a non-linear stress–strain curve when elongated. When the human skin is stimulated with a variable mechanical input, the mechanical resistivity of the skin is said to change with respect to frequency. If wearable devices sensors are not properly synchronised in design stage this could provide false actuation.

v. *Intrinsic noise*: The noise from wearable mechanical sensors is of two folds - sensor intrinsic noise and motion induced noise (Heikenfeld *et al*., 2018). Sensor intrinsic noise is a challenge in wearable mechanical and electrical measurements such as temperature noise for resistive sensors and parasitic noise in capacitive sensors, electrophysiological recordings and skin electrodes.

Motion induced noise is challenging for applying mechanical sensors in use cases, such as body movement during respiration rate measurement, or bending effects during pressure measurements. Electrical noises such as affecting the signal quality and statistical power of wearable (Heikenfeld *et al*., 2018) devices are challenges that must be eliminated.

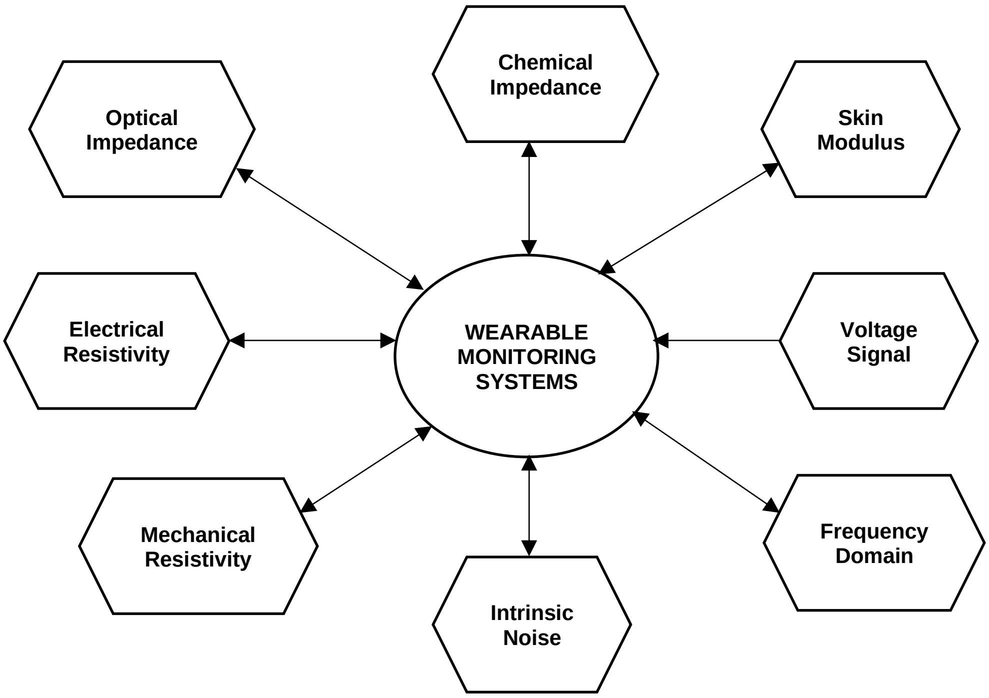

Fig. 1: Key Features and Functions of Wearable Technology

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vi. *Electrical resistivity*: The human body possesses quantum amount of resistance. Fluid from underlying skin are good electrical conductors. One challenge is the insensitivity associated with the electrical signal linking the skin (Abe & Nishizawaa, 2021). At certain conditions which affects wearable devices due to electrical properties of the underlying skin.
vii. *Skin Modulus*: The skin is said to have sweat minerals which has been shown to accumulate in the superficial layers of the epidermis and possibly in the sweat duct itself prior to sweating events. This in effect create imbalance in device recording as well as supply error reading to healthcare giver.
viii. *Optical impedance*: The skin offers a passive window as an optical interface to underlying vascular structure and organ systems. Absorption, attenuation, radiation, reflection and scattering are some impedances that can affect wearable devices.
ix. *Chemical impedance and interaction*: The skin serves as a barrier to transport of chemicals. The superficial layers of the epidermis are the major domains to chemical impedance of the skin layer (Heikenfeld *et al*., 2018; Abe & Nishizawaa, 2021). The skin also contaminates analyte concentrations during the collection of sweat, blood and interstitial fluid samples (Heikenfeld *et al*., 2018).
x. *Maintenance phase*: Activities of wearable devices require monitoring which bears its impact on short-term human behaviours when deployed in disease diagnosis, but the increase in physical activities is gradually attenuated through the maintenance phase (Keats *et al*., 2023).

3.2 Healthcare Revolution

Several technical subjects are being introduced to address all aspects of healthcare delivery and accommodate the envisaged revolution happening in health care sector. This revolution would enable deliberate and effective out-of-hospital management of chronic disease within and outside the reach of care givers or medical personnels. However, this revolution is not without its challenges. Some of these factors are:
i. *Interoperability*: Lack of data integration is a thing of concern. For now, data cannot be integrated and used together with other types of data because they are collected by different types of devices or different sensors (Canali, Schiaffonat & Aliverti, 2022). Software and hardware of different wearable devices are yet to be synchronised for system adaptability with emerging technologies.
ii. *Disruptive Revolution*: Demarketing available wearable devices owing to poor quality and inefficiency in previously used devices. Non-smart devices that are not measuring to desired output. Users' distrust of this technology would be some of the causes that would derail this revolution (Canali, Schiaffonat & Aliverti, 2022).
iii. *Resistance to Change*: Wearable device anxiety negatively affects a person’s device usage, perceived enjoyment, and perceived usefulness. When users are faced with a new service, they may be reluctant to switch from one service to an alternative one (Tsai, 2020). These are the common experience of healthcare givers and patients.

3.3 Power Adaptability Problems

Power of wearable device for e-health often experience battery drain with susceptibility to shortening battery life as one of the primary challenges of wearable device design (Mark, 2019). But for these devices to be portable and comfortable for in-users with cutting-edge features and extended runtimes in between charging then device battery health must be low with long life. Regrettably, some of the design specifications often conflict with other established devices. Some have rapid charging and others having advanced Power Management Integrated Circuits (PMICs) installed to make best use of available energy.

3.4 Inadequacy in System Testing

Some of these wearable devices are inadequately and clinically untested and probably inappropriate for any targeted clinical application (Prieto-Avalos, Sánchez-Morales, & Alor-Hernández, 2023). Inadequate testing is a factor to why software and hardware of wearable devices are typically delivered with defects between expectations and reality.

3.5 Patient Reluctance to Use of Technology

In general, acceptance is the positive decision to use an innovation. Two main challenges were identified in the Theory of Planned Behaviour (TPB) model (perceived behavioural control, subjective norm, and behavioural attitude) (Tahadoost, 2017) as one, one’s reluctance to use of wearable technology is the accessibility of a computer system. Two, the revised TPB may be viewed as the more suitable theoretical framework which is influenced by the degree of individual’s voluntariness that choose or not to choose the use of information technology in the workplace.

3.6 Interoperability of M-Health Applications with Different Software

Many m-health-related apps have increased intensely over the last couple of years as a result of its deployment by many agencies, institutions and health professionals.

3.7 Security and Privacy

One major concern with wearable IoT communications is security and privacy. Users’ security and privacy must not be compromised (Bhushan & Agrawal, 2021), absence of industry standards, numerous technical bottlenecks are challenges envisaged in wearable IoT systems. Public hospitals, individual users and other groups using these wearable devices for health-related reasons are susceptible to data theft, information loss and copyright infringement.

4 Roadmap to Wearable IOT Device Implementation

4.1 Wearable IOT Mitigation Strategy

In the business of wearable device interoperability, the deployment of IoT communication protocol such as the IoT data protocol and the Network protocol have brough the needed leverage to ease the constraints among various wearable devices. IoT data protocol such as Advanced Message Queuing Protocol (AMQP), Data Distribution Service (DDS), HyperText Transfer Protocol Secure (HTTPS), Constrained Application Protocol (CoAP), Message Queue Telemetry Transport (MQTT), WebSocket and Transmission Control Protocol (TCP) are needed to mitigate poor interoperability, industry standard, hardware and software compatibility in the application and network layer of the Open System Interconnection (OSI) model. The AMQP provides message alignment, queuing, routing, reliability and security being point-to-point and publish-and-subscribe scheme, CoAP provides nodes communication internet by similar protocols, DDS are object management group for machine-to-machine standard, MQTT is publisher-subscriber pattern for machine-to-machine connection, HTTPS accomplishes secure connection/communication over the Internet and TCP guarantee reliable transmission of packets. WebSocket provides the Application Program Interface (API) for creating and managing connections.

Their usage is a factor of wearable system design architecture. While for Network protocols such as Bluetooth Low Energy (BLE) – improved Bluetooth with much low power consumption, Wireless Fidelity (WiFi) – operates in the 2.4 to 5 GHz frequency range and distance coverage of 100m range, Near Field Communication (NFC) – operates in 0.04m (4 cm) range, ZigBee – similar to Bluetooth with 200m range. Z-Wave and LoRaWan provide reliability and compatibility signal strength though the later has longer range and better power efficiency. Also, their usage depends on the wearable system configuration such as device-to-device, device-to-gateway, gateway-to-data-centre, gateway-to-cloud or communication between data centres.

Electrical conductance can adequately monitor skin hydration in which fine electrodes ensure firm electrical contact with air permeability at the same time for deployed several wearable IoT devices. Further amplification of the mechanism to validate the benefit of its use in the treatment of chronic skin abnormalities associated with reduced barrier function can be made. Electrical impedance of the skin can then be approximated using equivalent circuit models that consist of parallel and series combinations of resistors (R) and capacitors.

5 Conclusion

This work assessed challenges in wearable devices technologies as it relates health care services. To ensure device handshake among devices, privacy and security of sensitive health records as well as appropriate sensors responses to needed patient information for accurate diagnosis in e-health systems, device configuration, architecture models and software standards are the bedrock for robust wearable IoT monitoring system. We envisage that with the growth of e-health ideas, wearable devices will perform superior role in the arena of health care and turn out to be well integrated into patients' regular lives.

6 Recommendations

However, more study is needed to discover other peculiar challenges associated with these devices and their applications in the health-related areas. Other recommendations include: device interoperability, ensuring secured connection/ communication to mitigate intermittent signal outages for point-to-point networks or data centres, ensure advocacy in wearable devices usage among the generality of the populace and its deployment in requisite institutions – government and private. It is our belief that this overview would provide useful information for the expansion of wearable e-health monitoring devices.

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