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WEARABLE COMPUTING TECHNOLOGIES AND THEIR APPLICATIONS

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Abstract: Wearable computers are fast becoming an integral component of our everyday life. They are gaining wide acceptance in virtually every sphere or domain of everyday activities ranging from sports, health, entertainment, fashion and even the military. They augment our daily routines without significantly affecting other activities. They are portable, accessible and seamless in operation. Wearable computing is incorporated into the personal space of the wearer, controlled by the wearer, always on and accessible thus creating a new form of interaction between humans and computers, that is an integration of man and system. This paper explained wearable computing technology, the features, applications and challenges affecting the growth of the technology.

Keywords: *Wearable computer, wearables, wearable technology, wearable devices, military, health, sports and fitness.*

1.0 INTRODUCTION

Wearable computing or electronic gadgets have seen tremendous growth in diversity and market penetration in the last decades. Consumer devices such as wearables have become some of the fastest growing Internet of Things (IoT) products (Gajaria and Adegbija, 2021). The day to day use of electronic gadgets has increased astronomically over time, and the goal of wearable computing is to miniaturize electronic components and circuits for robust implementation of this emerging and new trending technology. Dobbelstein (2016) envisions that in the future miniaturization will allow for wearable devices whose form factor and appearance are unobstructive. According to (Yadav et al, 2020), the growing quest for portability and size reduction of computer hardware led to the birth of Wearables.

Wearable computing technology introduces an added layer of digitization into our everyday routines, skills and knowledge (Lawo and Herzog, 2011). It follows us around and merges into our lives and daily interactions unlike a laptop or PDA, supporting people based on wireless networks to ubiquitously access information. The wearer is the focus of the design of a wearable computing device by ensuring that in the first place, it is safe to wear, and secondly, it is usable (Shrestha and Saxena, 2017). Wearable computing systems provide the wearer with access to information and the capability to communicate with other computing gadgets like mobile devices, laptops, etc. Wearable devices have the advantages of portability and multi-functionality and are considered the basic hardware of the future, showing great potential in many application domains such as medicine, healthcare, robotic systems, prosthetics, visual realities, professional sports, navigation systems as well as entertainment, (Liu and Hong, 2019; Domb, 2019). Wearable devices clearly bring immense benefits to society and boast of improved quality of life for wearers ranging from virtual interaction in augmented reality (AR) to “fitness data”-inspired healthier lifestyles. They enable a number of applications in various spheres of life, ranging from personal and medical to business operations.

Wearable devices are being extensively designed in various forms, shapes, and sizes, including those that are “head-worn” (e.g., glasses and headsets), “eye worn” (e.g., contact lenses), “wrist-worn” (e.g., watches, bracelets, and wristbands), “feet worn” (e.g., shoes), and “body-worn” (e.g., e-textiles and smart fabrics). They find a wide range of applications in different facets of life. According to Knight et al (2006), in mounting a computer on the body, the computer's weight, size, shape, placement and method of attachment can elicit a number of effects. An inappropriate design may limit or hinder a wearer from performing specific tasks or achieving certain goals. Overload on the body results in the perception of discomfort which inadvertently raises concerns on health and safety. Wearable computing goes beyond devices but combines the use of mobile computing and sensors, with characteristics such as being hands-free, always on and sensing. It makes a computer an embedded and invisible part of our daily lives by building it into clothing and everyday items, such as eyeglasses (Aleksy et al, n.d). It is a device that is always with the user, and into which the user can always input commands, and can do so while walking around or doing other activities. As Hull et al, (2002) put it Wearable computing has the potential to deliver a rich variety of engaging user experiences that enhance everyday activities and situations through context-sensitive media and interaction.

One dominant area of wearables is health (Domb, 2019). It is aimed at acquiring and processing physiological and environmental data towards the prediction and treatment of common diseases, allowing consumers to be better at converting personal, biological and environmental data into valuable consumer insights. It transmits the data to and from the consumer at the appropriate time, creating new consumption experiences that can improve health and fitness on continuous real-time monitoring and operational efficiency.

2.0 Definition of Wearable Computing

There is a general acceptance that wearable computers are smart, portable, seamless and friendly communication devices. “Wearables,” “wearable devices,” “wearable technology,” and “wearable computing” all refer to the emerging computing paradigm that is incorporated into items of clothing and accessories that can be comfortably worn by the users (Shrestha and Saxena, 2017; Jhaharia et al, 2014). Billinghurst (2003) described wearable computing as a human-computer symbiote with circuitry embedded in his clothing, an electronic monocule for display and a one-handed input device.

Mann (1997) defines a wearable computer as a computer that is subsumed into the personal space of the user, controlled by the wearer, and that is always on and accessible. A wearable computer is a computer that is engulfed into the personal space of a user, controlled by the user, and has both operational and interactional constancy, Arunlal (2005). DARPA (1996) defined wearable computing as "data gathering and disseminating devices which enable the user to operate more efficiently, carried or worn by the user during normal execution of his/her tasks. Wearable technologies are networked devices that collect data, track activities and customize experiences to users’ needs and desires, Domb, (2019). They can also be seen as a group of devices that can be worn by people to track and communicate colorful information with the outside world (Sözüdoğru and Tuncay, 2019). According to (Yadav et al, 2020), the term wearable computing refers to any computing device which can be carried with a user and operated at any time.

Summarily, Wearables can simply be defined as devices that are worn by humans on any part of their body that continuously accepts inputs using sensors and process such input using embedded micro-computers, interacting with the wearers to monitor and control pre-defined systems or carry out other activities.

3.0 Features of Wearable Devices

The authors in (Mann, 1997; Arunlal, 2005; Jhaharia et al, 2014) highlighted three basic modes of operation and six fundamental attributes or features of wearable computing. The three operational modes that define the interaction between humans and wearable computers are:

1. Constancy: meaning that the computer must run continuously and ever ready to interact with the user. That is the signal flow from human to computer and vice versa provides a constant user interface.
2. Augmentation/Enhancement: In wearable computing the assumption is that the user can be engaged in other tasks while simultaneously computing, thus the computer serves to expand the intellect or sense. Hence, the notion of wearable computing that computing is NOT the primary task, as it is for traditional computing.
3. Mediation: wearable computers allow for a greater degree of encapsulation than traditional computers like laptops and PDAs. There are two aspects of this encapsulation which are
    - Solitude: Wearable computer functions as an information filter, allowing us to block out offensive and unwanted materials like undesired advertising and replace them with desired contents thus altering our perception of reality in a mild way.
    - Mediation allows us to prevent or modify information from leaving our encapsulated space. The wearable computer serves as an intermediary for interacting with untrusted systems, such as third party digital anonymous cash "cyberwallet" the same way that ordinary clothing prevents others from seeing our naked bodies.

On the other hand, the six informational or signal flow paths associated with this new human-machine synergy which is described as the attributes of wearable computing are:

1. Un-monopolizing of the user's attention: Unlike virtual reality games, wearable computers do not take the user out of the world. It is designed to enhance sensory capabilities bearing in mind that computing is a secondary activity. Hence, the user can attend to any other job while using the apparatus.
2. Unrestrictive to the user: Wearable computer is ambulatory, mobile etc. it can be used while doing other things. For example, a user can type while jogging.
3. Observable by the user: It can get your attention continuously if you want it to. The screen is visible throughout, except when you close your eyes.
4. Controllable by the user: It is highly responsive, that is a user can take control of it as he wishes.
5. Attentive to the environment: It is environmentally aware (multisensory). As such, it gives the user an increased situational awareness.
6. Communicative to others: It can be used as a medium of communication when needed. It doesn't limit or prevent users from expressing their feelings.

4.0 Applications of Wearable Devices

Perhaps the earliest form of wearable computer was a device created for the noblest of pursuits: gambling (Hong and Baker, 2014; Randell, 2005; Sözüdoğru and Tuncay, 2019; Yadav et al, 2020). Ed Thorp considered the possibility of applying mathematics to beat roulette. Working with renowned scientist Claude Shannon, they built a device that could be strapped around the waist, with the tap of the shoe as input and a small earpiece as output. The shoe input was used to mark a reference point for the roulette ball, and the audio was used to signal one of eight possible quadrants where the ball was most likely to land. During tests in a lab, the pair found that the device could give them a 44 percent edge, which led them to try out the device in a real casino.

Areas that different researchers have applied wearable computing as highlighted by (Hong and Baker, 2014) include:

i. Animated sweater: had different designs, all having a clever pocket for holding a smartphone. The smartphone showed different animations like a fireplace with a lively fire or a cat that can move its eyes around, with the running of an application. A creative use of wearable computing wherein the wearer simply puts his or her smartphone in the right place, runs an app, and instantly has animated clothes.
ii. A smart wig: It has a built-in laser pointer and offers some input capabilities for advancing slides.
iii. The navigation wig: uses GPS and vibration to guide wearers
iv. Sensing Wig: used to sense data such as temperature and blood pressure (Hong and Baker, 2014).
v. The teeth-embedded sensors that can measure and model a variety of oral activities, including chewing, drinking, speaking, and coughing.
vi. **Zackees**: these are gloves with LEDs in them that can be activated using a simple contact switch between the thumb and index finger. The LEDs are positioned to form a left and right arrow on the left and right gloves respectively as shown in fig.1. The electronics are also protected so that the gloves can be washed normally. They can be used for signalling in bicycling or skateboarding and increasing visibility at nighttime while jogging.

Figure 1.Animated Clothes and Zackees (Hong and Baker, 2014).

4.1 Wearables for Health Monitoring.

Wearable technologies provide support for continuous health monitoring of people with a wide range of diseases including psychological and physical. Wearables in the health care domain are the most advanced, and with the highest number of production implementations, (Domb, 2019). According to

Tahir et al (2018) wearable devices often operate in a group setting. That is, a single device can be categorized into two or more domains of life. In Lind et al, (1997), considering that the health and well-being of military service personnel are paramount and require special attention, the sensate liner developed at the Georgia Institute of Technology was designed to specifically monitor the vital signs of combat casualties, as well as automatically detect and characterize a wound in real-time using bullet entry detection.

Health monitoring wearables seem to be the most ubiquitous wearable computing technologies. **The SensVest** is one of such wearables, Woolley, et al (2003)**.** It is a wearable data logging system that senses and records body motion, heart rate and temperature.

Figure 2: The SensVest - Left the vest and right the electronic enclosure and cable kit. (Woolley, et al, 2003)**.**

The data processing is carried out by a 16-bit microcontroller, the Mitsubishi M16C. As shown in Figure 6, the SensVest electronics are contained in a lightweight aluminium case with a simple menu LCD interface system. It can connect directly to a PC or other RS232 serial device, or PDA. The vest has pockets to hold the modules, and tubes for the wiring. The weight is distributed over the back with the lion’s share of the weight on the shoulder blades for comfortable use.

In recent times health monitoring wearables are in vogue in the form of Body media range of products. Jhajharia et al, (2014) highlighted wearables that are based around an armband, designed with sensors for detecting movement, heat flux, skin temperature, near-body temperature, and galvanic skin response. Data can be viewed either in real-time via a wireless link or downloaded for analysis using the Internet. A new healthcare system that is aimed at prevention is the Metria Wearable Sensor. The wearer attaches the wearable sensor, which uses "skin-friendly" cohesive; the sensor collects data, such as the breaths per minute and number of hours slept and breaths per minute. Another health monitoring wearable is The Remote Monitoring System (RMS) which was developed in collaboration with Mayo Clinic. It uses designs to support remote monitoring of patients with cardiac problems. Examples include the Electroencephalography (EEG), BodyTel Products and BioMan t-shirt.

Leutheuser, (2019) in his thesis presented three different wearable computing applications aimed at addressing different non-communicable diseases which include: mobile breathing analysis; mobile electrocardiogram (ECG) analysis and inertial measurement unit (IMU)-based activity recognition. The introduction of wearables is a potential solution to addressing non-communicable diseases.

Respiratory inductance plethysmography (RIP) provides an unobtrusive and mobile method for measuring breathing characteristics, avoiding the measurement with flowmeters (FMs) as with them the natural breathing pattern is altered.

Liu and Hong, (2019) discussed the use of strain and pressure sensors, which correspond to two main mechanical stimuli. According to them among the different types of sensors available such as single functional sensors like temperature, pressure, strain, optical, and electrochemical sensors, to multifunctional sensors like tactile and electronic skin, wearable electromechanical sensors including strain and pressure sensors have attracted more and more attentions due to their simple mechanism, low cost, low power consumption, and high performance. Watanabe and Terada (2020) proposed a framework to manipulate auditory perception which is one of the most important human senses. They focused on earphone-type wearable computers (hearable devices) that not only have speakers but also microphones. A hearable device is a new kind of wearable computer that uses earphones. It is designed for multiple purposes ranging from listening to music to medical monitoring, fitness tracking, translation, and personal identification.

Yadav et al, (2020) proposed a new architecture of a wearable computer where all possible devices are wirelessly interfaced using a central Internal Processing unit (I.P.U.). According to them the I.P.U. with a proposed internal life of 20 years, will be surgically planted in the body, and would become an integral part of the human being supplementing his capabilities in big and small ways.

4.2 Wearables for Military and Security

Wearable devices play an important role in improving the capabilities of soldiers. The rising need for soldiers' coordination, training and health, increase in asymmetric warfare, suspected geopolitical conflicts and soldiers' modernization programs, are among some of the factors fueling the growth of military wearable devices (Sharma et al, 2020). Hence, it has become imperative to develop wearable devices with diverse functions for the military. Soldiers have become point nodes of information collection and resource control on the battlefield with the growth of the Internet of Battlefield Things (IoBT) which involves the full realization of ubiquitous sensing, communication, and computing (Shi et al, 2019).

In Randell, (2005) a Quantum3D Expedition that uses augmented reality to provide a wearable computing training resource for the military was presented. Using accurate simulations of fabricated situations, including visuals, sound, and voice command, the Expedition wearable computer design provides immersive training for the armed services and emergency response workers.

Figure 3. The Quantum3D Expedition (Randell, 2005).

Kodam et al, (2020) in their paper reviewed the application of smart wearables using WSN (Wireless Sensor Network) technology to provide safety for soldiers in the battlefield. These smart wearables Smart Vest, Smart Helmet and Smart Strap, equipped with Body Sensor Network (BSN) are able to determine the various psychological parameters and mental state of the soldiers. In addition to monitoring the health of the soldiers, they have the ability to track the live location in real-time, by this, information about an injured soldier can be transmitted to the control unit in no time using LoRaWAN (Long Range Wide Area Networking) and to the nearby soldiers using Zigbee module by forming a Mobile Ad-hoc Network (MANET), so that the control unit can take necessary actions for saving the life of the soldier.

4.3 Wearables for Sports and Fitness

In sports and fitness wearables have been largely influenced by passion and interest. Optimum performance monitoring and management, activity tracking, goal management, direction data and location sharing are some of the typical functions of such wearables. The BioHarness is a compact monitoring module that enables the transmission and capture of physiological data from the wearer via mobile and fixed data networks enabling genuine remote monitoring of human performance and condition in the real world (Johnstone, 2012). The Smart Training Shoes is another example of a next-generation wearable computer. It is an athletic shoe with radio frequency identification (RFID) tags, motion sensors and accelerometers allowing the user to customize the looks, fit and responsiveness of their kicks. It is also fitted with an activity tracker(Jhajharia et al, 2014). Other wearables for sports include sports sunglasses and headgears like sportii that gives the athlete real-time performance feedback like heartrate, miles etc; lumo lift which vibrates as a warning alert to you when your posture is wrong; the swimming tracker that gives audio feedback; smart socks for taking the physiological parameters in running; sweatband for heart rate monitoring; cycling wearable coach; boxing wearable that keeps track of the number of punches, smart pants, wearable pods and wearables on the wrist (Apac Business, 2022).

Figure 4: Nike Smart Training Shoes. (Jhajharia et al, 2014)

4.4 Other Wearable devices

Safety on the road cannot be overemphasized, hence Kyung et al, (2011) proposed a versatile wearable computer for drivers (VWCD) which is a promising solution to provide safety-related information for drivers using wearable devices mounted on or integrated into eyeglasses. Kunze et al.(2014) proposed wearable devices for adults.

Figure 5: VWCD Prototype. Kyung et al, (2011)

5.0 Wearability, Vulnerability and security of wearable devices.

Wearable devices are hurriedly being marketed in an attempt to capture an existing market(Tahir et al, 2018). Sequel to this, some devices do not adequately address the need for security. Knight et al (2006) developed a methodology for assessing the wearability of any wearable computer. According to the authors, physical effects that should be assessed to determine the wearability of a device include physiological energy expenditure, the biomechanical effects due to changes in movement patterns, posture and perceptions of localized pain and discomfort due to musculoskeletal loading, and perceptions of wellbeing through comfort assessment.

To protect personal integrity and privacy, confidentiality in information and communications wearable devices require a high level of information security. As regards security, wearables have limited processing power, memory, local storage facilities and possibilities for add-ons making it herculean to set up a security baseline for needed security services as would be required by the users' organizational IT/information security policy. Shrestha and Saxena (2017) provided an exposition of the security and privacy of wearable computing, studying dual aspects, that is, both attacks and defenses. They concluded that though wearables remain almost constantly attached to the body of the wearer, they have also raised unique security and privacy vulnerabilities.

Wearables pose various security and privacy threats, such as unfettered access, sensor sniffing and side-channel attacks, wearers' and bystanders' privacy risks, and information leakage through social media and other channels. These threats have raised the demand for the design and implementation of appropriate defense mechanisms on wearable devices to mitigate, if not eliminate, the risks due to the existence of such threats. While wearables introduce new security and privacy vulnerabilities, they also promise to improve the existing security, privacy, and safety paradigms in unique ways while preserving the system's usability, especially in the context of authentication and user safety.

6.0 Challenges to the increase in Wearable Devices

As Woolley, et al (2003) puts it, in spite of all the advances in wearable computing, there are still numerous engineering challenges yet to be addressed. Consumer wearable devices are expected to perform a wide range of tasks within stringent area and energy constraints. When computers are networked, there is the potential that information could be compromised. Some of the challenges affecting the growth of the wearable computer market include issues of size, weight, safety, privacy and security (Knight et al, 2006). Some obstacles posed by factors like battery life, processor power, display brightness, network coverage and form factor have led to a delay in the widespread introduction and application of wearable computers (Jhajharia et al, 2014). The risk of hacking is a serious security concern for wireless network communication. One of the most important design considerations of mobile devices is power consumption. The size of a wearable device is often a design limitation, which means that the size of the batteries is also constrained together with the heat dissipation that becomes a problem as the size decreases. However, recent progress in Lithium-polymer cell chemistry technology offers greater possibilities because a battery base is no longer needed and the cell can be flat, very light and robust. This opens up an interesting idea of embedding the batteries into clothing or other irregular shapes.

7.0 Conclusion

Wearable devices perform numerous everyday functions described as mobile information processing like emailing, fitness tracking, navigation, health monitoring and so on. Essentially wearable computers have become an integral part of our daily space, redefining our activities in seamless fascinating ways. The user is the focus of the design of a wearable computing device, therefore portability, safety and security are a major concern in their use. As widely acceptable as wearables are becoming, certain constraints like energy management and effective wireless communication devoid of hacking has been a major drawback in its full implementation. As advancement in research and technology continue to grow, we will in the nearest future see to a surmounting of these challenges for a widespread introduction and application of wearable computing to virtually every domain of life.

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