Learning Enhancement in Higher Education with Wearable Technology

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Abstract—Wearable technologies have traditionally been used to measure and monitor vital human signs for well-being and healthcare applications. However, there is a growing interest in using and deploying these technologies to facilitate teaching and learning, particularly in a higher education environment. The aim of this paper is therefore to systematically review the range of wearable devices that have been used for enhancing the teaching and delivery of engineering curricula in higher education. Moreover, we compare the advantages and disadvantages of these devices according to the location in which they are worn on the human body. According to our survey, wearable devices for enhanced learning have mainly been worn on the head (e.g. eyeglasses), wrist (e.g. watches) and chest (e.g. electrocardiogram patch). In fact, among those locations, head-worn devices enable better student engagement with the learning materials, improved student attention as well as higher spatial and visual awareness. We identify the research questions and discuss the research inclusion and exclusion criteria to present the challenges faced by researchers in implementing learning technologies for enhanced engineering education. Furthermore, we provide recommendations on using wearable devices to improve the teaching and learning of engineering courses in higher education.

Index Terms—Wearable technology, Engineering education, Technology enhanced learning, Learning technologies.

I. INTRODUCTION

Wearable devices are now becoming an integral part of our daily lives. Thanks to advances in technology, these devices are enabling users to seamlessly interface and interact with machines and computers. Through this interaction, users can participate in various tasks via interfaces such as the desktop computer, smartphone or any touch or gesture-based system or more advanced types of technologies such as Virtual Reality (VR) [1], and Augmented Reality (AR) [2].

In the early 21st century, a wearable device such as a wristwatch was more of an industrial design than an enabler for human-computer interaction. In fact, wearable technologies are defined as small digital devices designed to be worn on the human body [3], [4]. They can incorporate wireless connectivity to access and exchange contextually relevant information seamlessly [5].

Wearable devices are increasingly prevalent in various applications including health monitoring [6], [7], gesture recognition [8], [9], entertainment [10], gaming [11], and fashion [12].

More recently, wearable devices have been used for educational purposes [13]. Due to their imperceptibility and direct contact with the human body, wearables can play a significant role in learning and education [14]. Previously, a Special Issue consisting of seven articles was devoted to advances in wearable technologies for education [15]. However, six of these manuscripts mainly focused on pre-university learner experiences. The aim of this manuscript is therefore to further review recent developments in wearable technologies for learning and to focus on their deployment in a higher education environment.

VR headsets were among the first use cases of wearable devices in education, particularly for teaching abstract subjects such as mathematics and geometry [14] [16]. According to the literature, such VR technology expedited the development of immersive and collaborative learning in the classroom [17]. Furthermore, with the expansion of wearables in education, digital augmentation of physical activities have been used for virtual field trips [18]. This work by abandoning the conventional view of IT and education, and reconceptualising information and technology in terms of "digital augmentation
of physical activities”, benefits of collaborative discovery and exploration, where collecting of data and reflecting on learning was done together. In addition, other types of wearables like head-mounted display was offered to view historical events to enhance learning through experiencing and feeling history as reality [19].

The literature therefore suggests that student learning has improved as a result of using wearable devices in the classroom [20], [21]. Benefits were demonstrated for a wide variety of subjects and age limits, from K-12 education to tertiary level higher education. Our manuscript aims to present a systematic survey of wearable technologies that have been used in higher education, especially for engineering education. Based on their location, we have divided these wearables into three broad categories, which are: head-worn, wrist-worn and chest-worn, as shown in Fig. 1. We will therefore discuss the merits and disadvantages of devices worn on each of these locations.

This paper is organised as follows: Section II provides history, market and opportunities of wearable devices in higher education in details. In contrast, Section III discusses the system architecture and implementation. The methodology using inclusion and exclusion criteria described in Section IV. Section V presents the results and discussion by summarising the advantage and disadvantage of different wearable devices in education. Section VI draws the conclusion and future work.

II. WEARABLES IN HIGHER EDUCATION

A. History of wearable technology

The first wearable was a cigarette pack sized timing device, which was hidden in shoes (Fig. 2) and invented in 1955. The device was designed to predict roulette wheels in casinos and was publicly introduced in 1966 [22]. Since then, Wearable devices have evolved into various forms of accessories, watches, headsets, phones and glasses, as shown in Fig. 2.

In the mid-1970s, the wearable industry and market began to grow, thanks to the introduction of calculator watches [23]. By the end of the 1970s, this market significantly expanded to the entertainment sector via the introduction of the Sony Walkman cassette player. It also expanded to the workplace via the introduction of pager devices in the 1990s. However, the boom in wearable technology only took off in 2010, thanks to the introduction of casino data bank watches [10].

B. Market of wearable technology for education

The education technology (edtech) is a multi-trillion dollar industry [24] that is growing each year. Many countries in the Organisation for Economic Co-operation and Development (OECD) are devoting more than 10% of their public spending on education [25]. The emergencies (e.g. COVID-19 pandemic over last year) have often been a catalyst for reform in many divisions, including education [26]. The COVID-19 stimulated educational organisations to implement hybrid or fully remote schooling based on emerging edtech. Such digital technologies (e.g. video conferencing tools, or online learning management software to be used on portable laptop, tablet and smartphone) usually occur within years, while due to the pandemic circumstances and physical teaching limitations, they progressed within months [27]. In future, in case of any lock-downs like pandemics the edtech require to provide full remote learning and teching.

Furthermore, public spending on edtech is projected to increase as more countries increase their public spending on education. For example, low- and middle-income countries plan to increase spending on education from the current US$1.2 trillion per year to US$3 trillion [28]. As mentioned in the Incheon Declaration, countries need to allocate at least 4% to 6% of their gross domestic product (GDP) on education; and/or allocate at least 15% to 20% of public expenditure to education [29].

In addition to this projected growth in the educational sector, the wearable technology market is growing sharply and is strongly correlated with advances in globally connected devices. These are predicted to increase from 593 million devices in 2018 to 929 million devices by 2021 [30]. In 2020, the wearables market was estimated to be worth 5 billion dollar [31].

In 2020, Vandrico INC compiled a database of companies and wearable products. According to their research, there were 266 registered companies, which have produced 431 different wearable products [32]. They also divided wearables according to 7 different categories, which were: Entertainment, Fitness, Gaming, Industrial, Lifestyle, Medical and Pets. None of these
categories included education, despite the literature showing a clear use of wearables in this field. Our work therefore goes beyond the state of the art, since it aims to review the range of technologies used for educational purposes. According to their investigations, the majority of these wearables are in the lifestyle sector, with products that include SAMSUNG GEAR S3 [33], XIAOMI MI BAND 2 [34] and iHeart Internal Age fitness tracker [35]. The fitness sector is at the second place with products like Garmin ivosmart [36], Fitbit [37], Withings Hybrid Smartwatch [38].

C. Education

According to Statista and the National Purchase Diary Panel Inc (NPD Group), wearable devices are popular among the younger generation, typically those aged between 18-39 [39], [40]. Therefore, in recent years, universities have been interested in introducing wearable devices in their educational curricula [41]. Despite the rapid growth in using wearable devices in healthcare, entertainment and other applications, using wearables for education are still in their infancy.

Wearable devices can be worn on different body parts such as the head, neck, chest, torso, shoulders, arm, wrist, hand, finger, legs and feet. The majority of existing devices are worn on the wrist and are mainly used for fitness purposes. Wearable comfort and familiarity could be the reason for their success. Furthermore, wearable devices such as head-mounted displays, smart glasses and smartwatches were proven beneficial for educational purposes. The locations of these wearable devices on the body is shown in Fig. 1. In fact, these devices were used for different educational activities such as medical training, student engagement and authentic learning.

In the following section, we will discuss the technical architecture and specifications of wearable devices that have been exploited for educational applications.

III. SYSTEM OPERATION AND IMPLEMENTATION

Wearable devices can be divided into several main building blocks, as shown in Fig. 3. These include ‘sensors’ for detecting the signals, ‘electronics’ for data processing and communications, ‘power management circuitry’ and an ‘energy harvester’. The sensors are designed according to the signal frequency and parameter range attached to adjacent human organs. They are generally placed on three sensitive body locations of head (e.g. electroencephalography: EEG), wrist (e.g. electromyography: EMG) and chest (e.g. electrocardiography: EMG), as summarised in Table I.

TABLE I: Technical specifications for various wearable sensors to collect the necessary physiological biosignals required in educational studies, namely, ECG and heart rate variability, EMG and EEG.

| Sensor Type             | Signal frequency | Parameter range |
|-------------------------|------------------|-----------------|
| Chest-worn e.g. ECG sensor | 250 Hz          | 0.5-4 mV        |
| Wrist-worn e.g. EMG sensor | 10-5000 Hz      | 0.01-15 mV      |
| Head-worn e.g. EEG sensor   | 0.5-60 Hz       | 0.0003 mV       |

Furthermore, wearable sensors should be designed to have enough sensitivity and resolution to capture the required output voltage at a specific frequency. Besides, the electronics unit plays an essential role in recording signals and cancelling unwanted noise such as motion artefacts. In addition to wearable hardware devices, software-based subsystems are needed to process and analyse the data collected by wearable sensors. The wearable hardware input and output interact with a computing device over the software interface. Wearable hardware and software need to be harmonised to enable high speed and low latency computer output.

In the following section, we will describe our approach in gathering data regarding the use of wearable devices for teaching in a higher education environment.

IV. METHODOLOGY

This section defines our research methodology in collecting and synthesizing evidence on wearable technology application in higher education. We have demonstrated in the literature the history and evolution of wearables used in the purpose of education in universities.

First, similar to the methodology described in [42], and our previous research in [43] and [44], we outlined the research questions (RQs) and the inclusion criteria (InC) and exclusion criteria (ExC) of our search.

Then we will go through the advantages and disadvantages of different wearable devices used in higher education, their placement on the body, and the ideal location to be placed. The RQs are:

RQ 1. what wearable used in higher education?

RQ 2. which area on the body is best for placement of wearable?

The InCs are:

InC 1. Wearable devices used for teaching and learning in any discipline.

InC 2. The higher education level of study (undergraduate).

InC 3. Only include programs conducted in English.

The ExCs are:

ExC 1. Smartphone as a type of wearable device.

ExC 2. Wearable in medical purposes.

ExC 3. Professional certificates or extra-curricular activities.

To collect research papers that match our criteria, we have used Web of Science and Google Scholar for surveying the literature. We have used the descriptors and synonyms summarised in Table II for our search. Four considered descriptors include "wearable", "higher education", "undergraduate" and "engineering".

V. RESULTS AND DISCUSSION

As previously mentioned, there has been a steady growth in the number of publications related to wearable devices. A similar trend is apparent for the number of publications related to wearable devices and education, as evidenced by Fig. 4, which shows the number of research publications related to wearables. Clearly, the literature shows an increased interest in wearable devices since the 1970s. A comparable but
The main hardware building blocks of a wearable device are the sensors, readout circuit interface, the energy harvester as well as the power management and telecommunications units. The software component can be programmed to drive the wearable’s hardware according to different subsystems and inputs from sensors e.g. video, audio, gesture and speech.

### Table II: Descriptors and synonyms

| Descriptor                  | Definition                                                                 | Synonyms                        |
|-----------------------------|-----------------------------------------------------------------------------|---------------------------------|
| Wearable Technology         | This is a category of electronic devices that can be worn as accessories, embedded in clothing, or even tattooed on the skin. | Body attached technology        |
| Higher Education            | Refers to a level of education following secondary or high school. It takes places at universities and Further Education colleges and includes undergraduate and postgraduate study. | Tertiary education             |
| Undergraduate               | Refers to education conducted after school and prior to postgraduate education and includes all post-secondary programs up to the level of a bachelor’s degree. | Bachelor’s degree               |

### Table III: Wearable devices in higher education and main features.

| Main category | Sub category                  | Application targets                                                                 | Reference |
|---------------|-------------------------------|-------------------------------------------------------------------------------------|-----------|
| Head-worn     | Head-mounted and Glasses       | EEG, cognitive and brain science, surgical training, simulation-based training atmospheric scientists or detail hurricanes, environmental education | [45]–[58] |
| Wrist-worn    | Watches and Wristband         | Estimate stress in students, motion-based metrics to improve clinical education, ECG signal | [59], [60], [61] [62] |
| Chest-worn    | Patch sensors                 | Occupational stress, collaboration quality and creative fluency                     | [63] [64] |

delayed trend can be noticed with the number of publications on wearables in education, since academic interest in this area only began in 1994. From Fig. 4, it is noteworthy to mention that interest in wearables for education follows a similar trend to wearables, which is scaled down by a factor of approximately 143.

However, a total of 20 studies matched our InC and ExC criteria, which were defined in the Methodology Section. As previously mentioned in the Introduction, we have classified wearable devices for higher education according to three categories: head-worn, wrist-worn and chest-worn. A summary of each of these technologies is presented in Table III. In this section, we discuss the wearable technologies that have been implemented in each category for higher educational purposes.

#### A. Head-worn Devices

Head-worn devices or displays have come a long way since the early 1970s [70], [71]. In 1968, Ivan Sutherland demonstr-
Advantages

First person point of view [53] [51], access to difficult and impossible places [65], seamless and fast access to information [54], spatial and visual awareness [66], students feeling a deeper connection with learning materials, deeper student analysis and understanding of scenario-based practices [65] [47], record and retrace interpersonal communication skills and nonverbal behaviours [51] video recording [50].

Disadvantages

Cyber sickness [66], lack of content [66], technical limitation [66], privacy concern [54] [67], connectivity issues [54], hardware failure [51], physical discomfort [57].

Table IV summarises the main advantages and disadvantages of wearable devices in higher education

| Categories   | Advantages                                                                                                                                                                                                 | Disadvantages                                      |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| Head-worn    | First person point of view [53] [51], access to difficult and impossible places [65], seamless and fast access to information [54], spatial and visual awareness [66], students feeling a deeper connection with learning materials, deeper student analysis and understanding of scenario-based practices [65] [47], record and retrace interpersonal communication skills and nonverbal behaviours [51] video recording [50]. | cyber sickness [66], lack of content [66], technical limitation [66], privacy concern [54] [67], connectivity issues [54], hardware failure [51], physical discomfort [57]. |
| Wrist-worn   | Data collection from large group of students [59], automatic data collection [59], low maintenance [59], no disruption to classroom [59], increases student engagement by collecting their own physiological data [61], easy functionality easy to interpret [61]. | Disconnection between wristband and secondary device [59], hardware-related issues such as compromised sensor sensitivity, battery life [59] and wearer movement [61]. |
| Chest-worn   | Collect data automatically and without interruption [64], for collection of social interactions data [64], continuous record heart-rate, heart-rate variability, respiration, and physical activity [68]. | Lack of user privacy [69]. |

1) Advantages of Head-worn Wearables: Head-worn wearable devices such as head-mounted displays (HMD) offer alternate learning styles with the use of VR, for students who are mainly visual, active, and global learner [74] [75]. The use of before-mentioned wearables has been grown by advancing in technical specifications. For instance, the significant changes in the application of HMD happened in 2016, when their ‘field of view’ expanded from 25 and 60 degrees to above 100 degrees [76]. This new feature gives the first-person experience and sense of presence to the user. It makes it possible to experience, situations that are either inaccessible or problematic, e.g. in space studies [66] [77].

2) Disadvantages of Head-worn Wearables: On a different note, because of web access and the collection of personal data, privacy is of significant concern regarding wearables such as HMD and glasses [54], [73]. In addition to privacy and security, the head-worn wearable devices can be complicated to use for individuals with no prior knowledge. Therefore, this complexity requires establishing a professional training session for both learner and educator [66]. Another disadvantage of head-worn wearable devices is related to their high cost. For example, producing a VR simulation is expensive and educators will usually use VR simulators available in the market that are not explicitly made for that content [66]. These simulations are not usually specialised for teaching deployment in a classroom but can be used for self-learners. As the last drawback, head-worn wearable devices can cause cybersickness, because of the extended amount of time used [66].

B. Wrist-worn:

Devices worn on the wrist can be traced back to the beginning of the 20th Century, when Louis Cartier invented the wristwatch for the Brazilian aviator Alberto Santos-Dumont's [78]. Currently, due to their unobstructiveness to the wearer, various types of wearable devices have been developed, which have also been used for educational purposes. Examples include:

- Wristbands: wearable wristband include sensors that can collect bio-signals that can be used to estimate stress in students [59]
While wrist-worn wearables are quite popular, they might experience some drawbacks. For example, the wireless connection between wearable and smartphone may be broken during the test, and this could result in inaccurate data [59]. Moreover, if the wearable is places on the forearm, it reduces the ability to move around quickly [61]. Whether it is worn tight or loose, the distance between sensor and skin can change the collection of data. Another shortcoming is affected by the wrist-worn battery life; depending on the functions used, the battery can require recharging, or exchanged, regularly.

C. Chest-worn:

Examples of chest-worn devices used for educational purposes include the wearable chest plate. In a study, students and faculty from engineering and nursing developed a wearable Tracheostomy Overlay System (TOS), shown in Fig. 5D, for use with standardized patients. This device was designed to improve the education of health professional students while learning assessment and care of a patient with the tracheostomy in clinical practice [63]. Another study used sociometric badges with wearable sensors to collect social interaction data for predicting collaboration quality and creative fluency outcomes [64].

1) Advantage of Chest-worn Wearables in Education:
Chest-worn wearables are embedded with different sensors that can collect and store data such as heart rate, heart rate variability, and respiration. Sociometric sensors are one type of chest-worn wearable that are applied to collect social interaction data. The sociometric badges combine sensor technologies including Bluetooth and infrared sensors, an accelerometer, and microphones, to capture several variables about speech and conversation dynamics, body movement and posture, and social proximity. [64]. Chest-worn wearables were also employed to track stress within nursing students that enabled assessment of physiological changes and the collection of subjective responses to the origin of stress. [68].

2) Disadvantages Chest-worn Wearables in Education:
Chest-worn wearables, such as social interaction sensors, can collect a comprehensive picture of users’ social networks and performance. Approval of these sensors extensively depends upon assuring users’ privacy as the primary concern.

A summary of our findings on wearables for higher education purposes is presented in Table IV.

VI. RECOMMENDATIONS

As demonstrated from our literature review, there is a strong interest in using wearable devices to improve the teaching and learning of engineering courses in higher education. Curriculum developers have been experimenting with a range of devices on three main body parts: the wrist, head and chest. In comparison to the healthcare industry, their integration in engineering curricula has not been validated, nor standardised, and there is still evidence to suggest that the application of such technologies improves student satisfaction or performance. Therefore, an implementation route, or validation process is required to ensure that curriculum developers fully exploit the benefits of integrating wearable devices in a higher education setting.

Fig. 5: Various head-worn wearable have been used for educational purpose including A) Emotiv EPOC EEG system [47] B) Google Glasses in [49] and . C) Wearable wrist-worn like Apple Watch used in [60] and D) wearable chest-worn studied in [63]
As previously mentioned, such validation processes have been reported for wearable devices used in the healthcare industry [80]. Therefore, for the full adoption of wearable devices, there is a need for developing comprehensive guidelines to standardise their use in a higher education environment. Here, as shown in Fig. 6, we recommend a three-step acceptability route that includes (1) content validation, (2) feasibility and features, and (3) implementation.

We summarise these steps as follows:

1) **Content Validation:** This step includes problem analysis, which is utterly necessary in order to identify and understand the teaching and learning issue. The factors and elements that affect the process of student learning need to be considered. Furthermore, this step assesses both students and instructors needs via a process of identifying and defining them. Such needs assessments are important so that a careful state-of-the-art review in wearable technology is evaluated [81]. Through this literature review, different types of wearable devices can be identified and their risks can be assessed. The risk assessment involves defining and analysing potential events that may negatively affect students, instructors, and the overall learning environment. Carefully constructed surveys and questionnaires can be used to identify general opinions in this step.

2) **Feasibility and Features Study:** Data security is the first item to be considered in this step. For example, it is important to protect both student and student’s personal data from unauthorized access, since this is among the major concerns of using wearable devices in higher education [65]. In addition, the physical size and mobility features of wearable devices to ensure maximum comfort and wearability need to be considered for an extended time. Cost effectiveness should also be considered for comparisons with traditional learning that do not involve wearables. Cost might also be important with respect to digital poverty. A situation that has been highlighted and exacerbated by COVID-19 and online learning, where not all students have access to the digital technology required to have equal access to the learning. Furthermore, long battery-life and large data storage specifications of wearable devices improve the feasibility of their educational deployment. Short-battery life and inconvenience of recharging is time-consuming, and insufficient storage capacity for collecting a continuous stream of data cause inaccuracy in the learning and training scheme. The last term to accomplish this step is adaptability of wearable devices to suit students, lectures and different settings [82].

3) **Implementation:** This step covers the standardisation of wearable devices to attain the certainty that processes associated with their creation and performance are delivered within set guidelines. In this regard, expert opinions will be collected to get a better quality end product. For example, external examiners who are experts in wearable devices might be needed. Afterwards, will be evaluated against a gold standard; an advanced standardised wearable device in each classification of wearables that the rest of developing devices can be compared with [80], [83]. Lecturers and instructors, who are considered the primary source of knowledge need to be familiarised with the wearable devices and their affordances before introducing them to students. They also need to be trained and familiarised with inclusive and active teaching approaches that effectively engage the learner [84], [85]. The last item in the implementation step to be executed is rules and regulations that are systematically arranged around the production and application of wearable devices [86].

**VII. Conclusions**

With daily advances in engineering research, there is potential for these novel wearable devices to be implemented for educational application, enhance the students learning and schooling skills, and provide better alternatives for the future. This study investigated the advantages and disadvantages of wearable technologies in higher education. We presented the challenges associated with employing wearable devices in engineering education to enhance learning. We have recommended an acceptability route to implement wearable devices in the higher education environment. We believe that introducing wearables into the classroom is now feasible, and a game-changer technology in engineering education. Expectedly, our data collections motivated by this study will suggest additional investigative methods of supplementing the wearable technology curriculum with appropriate real-world cases.
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