Wearable Electronics for Neurological Applications: A Review of Undergraduate Engineering Programmes

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Abstract— **Neuroscientists accept that we are indeed faced with an overwhelming challenge in understanding how the brain works. A better understanding of the brain will ultimately enable us to appreciate how well our students have grasped their learning materials. It will also enable us to diagnose and treat neurological disorders more effectively. Designing and developing the next generation of wearable devices is an important steppingstone towards this endeavor. Consequently, interdisciplinary efforts are required in co-creating educational materials that enable future neuro-engineers to develop these new devices. The aim of this article is to present a review of current undergraduate programmes that deal with this issue. Moreover, we provide recommendations for how new programmes in this field can be organized and delivered to ensure effective benefit for transnational students.**

Keywords—Engineering Education, Wearable Electronics.

I. INTRODUCTION

According to Prof. Michael O'Shea, the brain is one of the most complex machines in the human body [1]. Understanding how the brain works could guide our efforts in developing optimized learning materials for students. According to Prof. Donald Clark, "A window into the mind gives teachers and students unique advantages in learning" [2]. Moreover, because an unhealthy brain leads to brain disorders, understanding how the brain works enable us to develop effective treatments for neurological diseases. Neurological disorders can be grouped into eight main categories, which include: neurodegenerative, developmental, metabolic, cerebrovascular, trauma, convulsive, infectious and brain tumors [3]. The financial commitment required for treating such disorders is already a major social and economic burden for Europe, with costs approaching EUR 800 billion each year [4].

Thus, further advancements in wearable electronic devices are needed for this undertaking. Such devices will need to sense, communicate and sometimes administer important drugs for treating neurological diseases. In future, such devices may also be used to detect certain "bio" or "neural markers" associated with learning [5, 6]. In all cases, rapid advancements in wearable electronics are needed. Undoubtedly, this will require redesigning curricula to meet the needs and graduate attributes of the next generation of "neuro-engineers". Such curricula will also need to be taught using modern 21st tools and techniques.

Wearable technologies have been used to monitor, track and record vital human signs. They have recently been demonstrated on a contact lens platform [7]. They have also been used to facilitate human computer interaction. For example, wearable bracelet devices have been used to accurately detect hand gestures [8, 9]. As shown in figure 1, these devices typically consist of five main building blocks, which are the interface, the communications module, the energy supply module, the data management module and integrated circuits [10]. The "interface" module is responsible for collecting information via sensors or other input devices, as well as presenting output information to the wearer. Similarly, the communications module is responsible for transferring this information between the wearable and its wearer, or a healthcare professional. The energy supply and conditioning module is responsible for harvesting and managing the energy required to meet the needs of these components. The data management module is responsible for processing, storing and managing the data collected from the interfacing module. Finally, the integrated circuit module is required to connect, and efficiently manage these modules together.

Thanks to advancements in packaging and nanofabrication, it is now possible to embed these components into a small area and at a relatively low cost. Despite all this recent progress, there are no specific undergraduate engineering programmes that train students in the field of wearable electronics for sensing and treating diagnosed neurological diseases. Thus, engineers and scientists need to collaborate with physicians to understand patient requirements and to provide valuable feedback on the diagnostic approach as well as the overall design of these products. In our opinion, preparing the next generation of "neuro-engineers" will require training in five key themes or tracks, which are Microelectronics, Artificial Intelligence, Neuroscience, Integrated Circuits, and Communications Systems. Henceforth, these topics will be referred to as "MANIC". We believe that any neuro-engineering undergraduate programme should contain elements of these five themes to advance the progression of wearable technologies, as suggested in Figure 2.

Furthermore, another important aspect is the distribution of these programmes worldwide. As our review of undergraduate programmes indicates, which will be detailed in Section III, many of these programmes are concentrated around North America. On the other hand, half of all Parkinson's patients are located in China [8]. Therefore, the need for transnational academic and industrial partners is of paramount importance for these programmes.

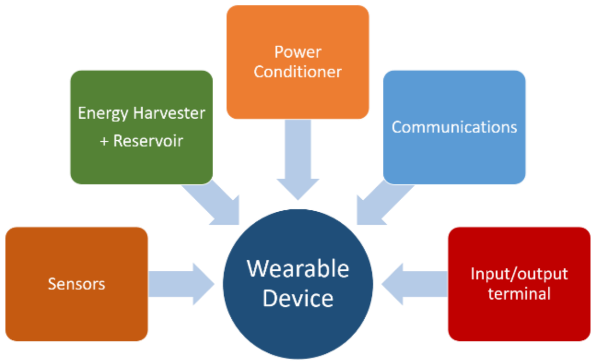

Figure 1. Building blocks of a wearable device.

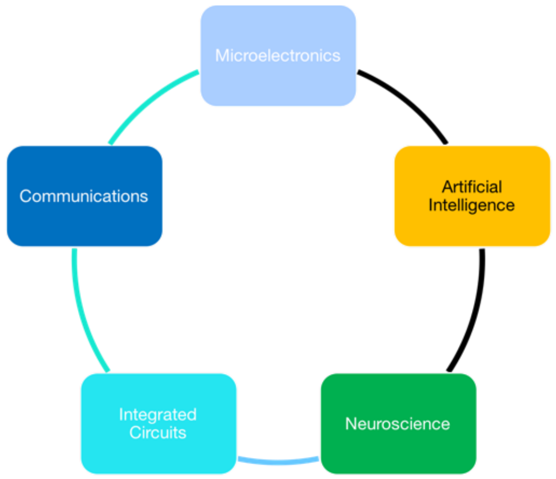

Figure 2. Suggested components of the MANIC tracks.

II. Methods

In this section, we define our research methodology in collecting and synthesizing evidence on neuro-engineering undergraduate programmes using clearly defined criteria. For example, there are many traditional bio-engineering undergraduate programmes that provide a basic understanding of signal processing for biological signals, but very few exploit modern signal processing techniques such as artificial intelligence. Communications, microelectronics and integrated circuits are also rarely studied, in addition to a sound grounding in the Internet of Things is crucial for the development of wearables.

Similar to the methodology described in [11], we first defined the research questions and the inclusion criteria of our search. Second, we selected relevant programmes that met some of these criteria. Third, we analyzed and interpreted our search results. In this case, we defined the following research questions (RQ):

RQ1: Who are the prominent educators in this field?

RQ2: What are the universities that offer these programmes?

RQ3: What is the ranking of these universities?

RQ4: In which countries are these programmes offered?

RQ5: How many programmes satisfy all five MANIC theme areas?

Based on the above questions, the following inclusion criteria (InC) were defined. Any programmes outside these criteria were excluded:

InC 1: Programmes are conducted in English;

InC 2: Programmes related to one of the MANIC Themes;

InC 3: It is a certified or accredited undergraduate degree programme.

Having defined our research questions as well as our inclusion criteria, we defined our approach in searching for undergraduate programmes. We used "Google" and Bachelor's Portal for our search using the descriptors summarized in Table I.

TABLE I. Descriptors and Synonyms Used for Our Search

Descriptor	***Definition***	***Synonyms***
Neuro-engineering	Involves the manipulation of neurons and their sub-cell components to regulate their networks and their function in the nervous system. This eventually controls the functioning of the entire human body. This allows engineers to develop means and tools to control, enhance, or inhibit their function.	Neural Engineering
Microelectronics	The technology dealing with the design, development and fabrication of electronic systems using solid-state devices.	Microsystems, Electronics.
Artificial Intelligence	The capacity of a computer to perform operations that are similar to humans.	Machine Learning.
Neuroscience	The study of scientific disciplines related to the nervous system.	Neural science.
Integrated Circuits	The interconnection of circuit components consisting of transistors, resistors and capacitors on a semiconductor platform.	VLSI.
Communications	A branch of technology concerned with communication via a particular medium.	Telecoms, Information Theory, Signal Processing.

Again, similar to the methods using in [11], we developed search strings using Boolean operators (AND, OR) to connect these descriptors.

III. Results & Discussions

We reviewed the learning resources that have been developed according to the previously mentioned criteria. In our opinion, each of these tracks play an integral role in the development of engineers specialized in wearable devices for neurological diseases, and should be pursued concurrently, not in isolation. According to our review, the undergraduate educational programmes that cover these tracks is shown in Table II.

For example, the programme offered by the University of Utah aligns most naturally with a combined education of Biomedical Engineering and Electrical & Computer Engineering, which lays a solid foundation in signal processing principles. This track prepares students for careers in brain-computer interfaces, neural stimulators, and neuroprosthetics.

TABLE II. Review of Undergraduate educational programmes

Programme	Awarding University	Ref.	Tracks				
			M	***A***	***N***	***I***	***C***
Neuro-engineering	Carnegie Mellon University	[12]	✗	✗	✓	✗	✓
Biomedical Engineering	Illinois Institute of Technology	[13]	✓	✓	✗	✓	✓
Neural Computation & Enginering	University of Washington	[14]	✗	✓	✓	✗	✗
Neural Engineering with Psychology	University of Essex	[15]	✓	✓	✓	✓	✓
Biomendical Engineering with Neuro-engineering minor	University of Alabama at Birmingham	[16]	✗	✓	✓	✗	✗
Biomedical Engineering Minor	Massachusetts Institute of Technology	[17]	✓	✓	✓	✓	✓

Moreover, the programme offered by Illinois Institute of Technology uses fundamental and applied engineering techniques to help solve basic and clinical problems in the neurosciences. At the fundamental level, it attempts to teach students the behavior of individual neurons, their growth, signaling mechanisms between neurons, and how populations of neurons produce complex behavior. Such information has broad application to a better understanding of the communication that occurs between the various parts of the nervous system and the brain. For example, such an understanding can be applied to the development of replacement parts for impaired neural systems, such as the auditory, visual, and motor systems, as well as achieving a better understanding of how normal and diseased systems work.

Similarly, the undergraduate programme in Neural Computation Engineering at the University of Washington has been designated to bring together students majoring both in biological and mathematical sciences. The programme helps students acquire or deepen the knowledge and skill required to integrate mathematical approaches into a study of the nervous system, and to develop biologically motivated and grounded models of brain function.

The biomedical engineering minor offered by MIT enables students to take a number of courses, which include neuroscience and data science. Consequently, students majoring in Electrical Engineering can cover all five MANIC tracks.

Interestingly, the University of Utah and John Hopkins University offer undergraduate programmes in Biomedical Engineering, but deliver graduate programmes in Neuroengineering. For example, in the University of Utah, the Neuroengineering track trains student in the fields of basic and applied neuroscience and neuroengineering. Its goals include the application of engineering approaches to the treatment of neural dysfunction, and conversely, the discovery of effective strategies utilized by biological nervous systems and their application to traditional engineering problems. Students in the Neuroengineering Track are expected to have general knowledge in the fields of basic and applied neuroscience.

The undergraduate degree in Neural Engineering provided by the University of Essex is the only educational programme offered by a European institute in English. Moreover, this programme satisfies all the MANIC track requirements.

IV. Recommendations

According to our review, we have found that there are many undergraduate programmes in the area of bioengineering. However, apart from the programmes offered by the University of Essex and MIT, many of these programmes did not meet all our inclusion criteria. Moreover, some programmes partially cover these criteria. Therefore, a better approach for indicating how well the criteria have been met is required. Therefore, there are clearly gaps to be filled. Consequently, new undergraduate and postgraduate programmes are required to meet these needs.

In particular, following the MANIC concept, we observe that most neuro-engineering, bio-engineering or biomedical engineering programmes are well stablished in the neuroscience field, with at least one track towards this area. However, microelectronics and integrated circuits skills are only superficially explored. For instance, energy harvesting and system-on-a-chip approaches are particularly important for the development of wearable devices for neurological applications [10, 18].

In addition, basic understanding of signal processing for neurological signal is widely adopted by all programmes in Table II. Nevertheless, there is a strong development in terms of artificial intelligence as powerful signal processing tools for neurological signals [19]. The basic training in these techniques is crucial, once neural engineers will undoubtedly deal with these applications in current and future wearable technologies. Finally, the communications systems are hardly explored in these programmes, while the Internet of Things and 5G communication systems are key enablers for the wearables wireless infrastructure [20].

Technology can also be used for the delivery of these programmes in an international or transnational method. For example, we have previously shown that ICT technologies can be used for successfully supervising these undergraduate students [21]. These can also be used to improve and maintain student engagement [22]. Undoubtedly, the role of technology will play a major role in pedagogy and university education due to the spread of the COVID-19 pandemic. Active learning techniques can also be used to ensure that these materials are studied in a real world engineering environment [23]. The positive impact of such active learning methods on transnational Chinese students has been demonstrated in [24].

V. Conclusions

In this manuscript we have highlighted the need for new undergraduate programmes that train engineers in developing the next generation of wearable electronic devices, targeted towards understanding the human brain. We have defined the MANIC concept, encompassing the five key tracks of Microelectronics, Artificial intelligence, Neuroscience, Integrated circuits, and Communications systems. In addition, we have specified a set of criteria for identifying the programmes that meet these needs. According to our review, we have only identified a handful of programmes that partially meet these needs. Moreover, we observe that these programmes are mainly clustered around North America. Thus, new programmes developed in collaboration between transnational partners are required.

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