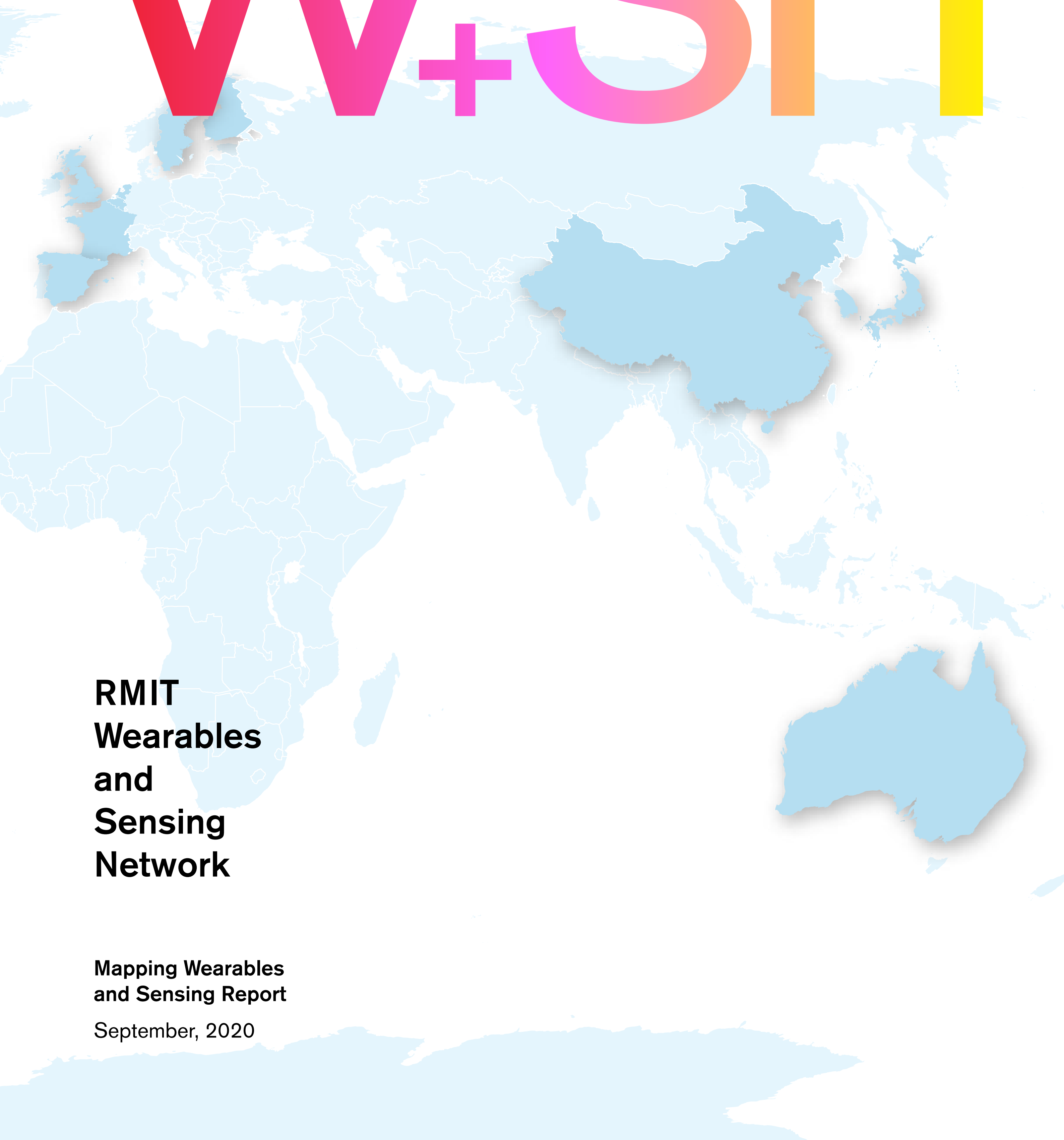

RMIT Wearables and Sensing Network

Mapping Wearables and Sensing Report

September, 2020

Wearables and Sensing Network

RMIT UNIVERSITY

Mapping Wearables and Sensing Report

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In order to understand the commercial and research environment in which W+SN is located we have undertaken an extensive mapping of labs and research centres. The research is helpful in enabling us to identify potential collaborators and to understand what our unique offerings might be.

Wearable and sensing technology within the health and medical industries are ubiquitous. The range of applications within this area alone range from implantable devices through to Personal Protective Equipment (PPE) and specialised equipment used within healthcare and medical practice. To best understand the growing market of wearable and sensing technologies, major categories of the sector have been defined. These categories include:

- Microtechnology & Nanotechnology
- Biosensors
- Biomedical Signal Processing
- Diagnostic & Therapeutic Systems
- Telemedicine & Telehealth
- Implantable Technologies
- Genomics
- Brain Computer Interface
- AI + Datafication, VR
- Mechatronics
- Health & Performance Monitoring
- Smart textiles
- Biomaterials

The industry is expansive, and constantly developing through the endeavours of research institutions and commercial industry on a global scale. This section will discuss and outline the scope of research and development in the area of wearable and sensing technologies in both commercial and institutional settings. The examples provided demonstrate the dynamic nature of the industry and allow the identification of trends occurring in the market.

Broken down into two broader categories of Commercial Labs and Research Labs, each company or institution is classified according to the most prominent aspect of their product and research outcomes. The categories are:

A closeup of lady's hand using a smart watch. Photo by Solen Feyissa on Unsplash.

- Material Innovation & Fabrication
- Devices and SWSS
- Sensors
- User Centred Design
- Nanotechnology
- AI, Machine Learning & Datafication

Key trends surrounding sustainability are emerging, largely involving ethical and environmental concerns around the production and disposal of technologies. Not only does the production of these technologies entail significant energy expenditure across product manufacture and life cycle, its use phase also requires energy, and options for disposal are limited, resulting in greater contribution to waste streams and climate change as a whole (Artem Golev, 2019; Manjula Shantaram, 2014).

In some respects, these sustainability trends are beginning to be addressed by investigations into alternate power sources, energy harvesting, as well as biomaterial alternatives. There appears to be a distinct need for further development in this area, to enable wearable health technologies to achieve optimal performance with minimal social impact.

Machine learning and the potential for AI integration into health technologies also presents as a growing trend. The development of data processing methods and translation may lead to more efficient and effective feedback mechanisms with the potential to create more user-friendly experiences for users and medical practitioners alike.

Conversely, trends around data are largely becoming focused on user centred design and by integrating such approaches to design, the user experience can be tailored and personalised to provide better or more holistic outcomes. More significantly, Datafication, a by-product of the growing market, presents as a gap in the market that is only beginning to gain warranted attention. In particular, data collection mechanisms, automation, data security and data management that have become an inherent component of wearable health technologies now appear at the forefront. With wearable technologies on the rise, it is evident that further development of data systems will be required in future to enable the utilisation of health devices and ecosystems.

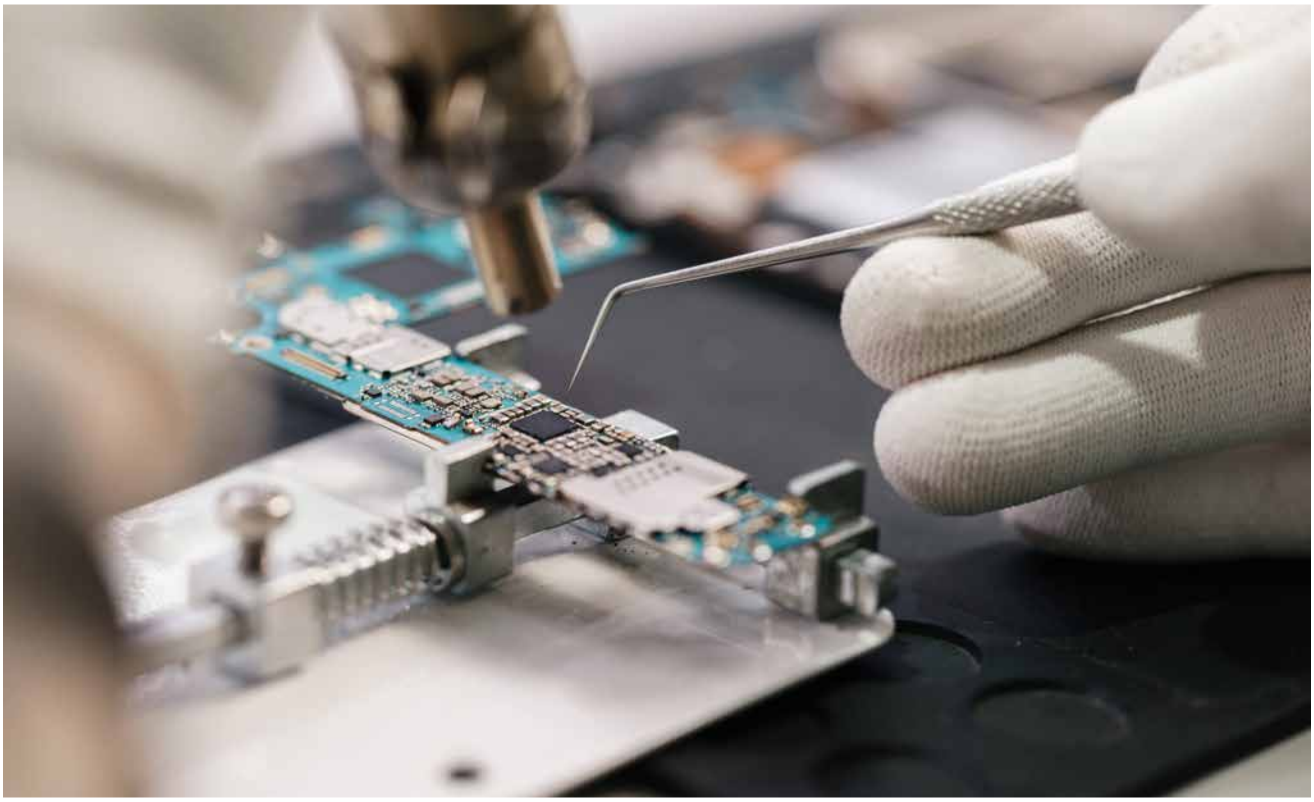
Additionally, these developments in data handling will call for investigation and deeper understandings of the ethical dimensions that exist around technologies developed in the wearable technology paradigm. Therefore, ethics and regulation present as upcoming trends that are progressively gaining traction.

Datafication also poses a risk of becoming an "asocial" form of technology, describing the loss of control of our data through various avenues as it is continuously compiled and gathered through devices and new sensing technologies. Not only does this lead to issues surrounding privacy and data ownership, but it also questions the value of data and how that concept alone could impact users' lives. Insurance structuring in the future, data platforms or aggregators, legal and operational hurdles surrounding the use of prospective wearable and sensing technologies, all require regulation and infrastructure in a relatively new and developing sector.

On a global scale, there is considerable innovation occurring in materials and fabrication technologies. This trend often pairs with the development of novel devices and SWSS that address broad themes of health and wellbeing, data, and sustainability in the market.

In terms of health and wellbeing, areas beginning to come to the forefront of wearable and sensing technology development include disability, mental health, and ageing as our global population ages. Coupled with human-centric methodologies, the need for responsive and inclusive technologies that tackle critical areas such as health and ageing is evident. This encompasses technologies capable of detection, prevention and intervention or action to improve health outcomes and morbidity status.

Overall, the wearable and sensing market has the potential to generate massive impact within the global community in all facets of healthcare and wellbeing.



Microelectronics device

Microtechnology & Nanotechnology

The study of Nanotechnology is a multidisciplinary scientific field that targets the manipulation of matter on a molecular and atomic level. The terms micro and nanotechnology are often used interchangeably (EMBS, 2019c) and denote technologies involving the miniaturization of mechanical processes and devices. This is inclusive of microcomputer parts, microdevices, microelectronics and applications for microsurgery. Such compact devices and processes enable practitioners to explore advanced methods of drug delivery, transdermal delivery systems, tissue and cell engineering, restoration of DNA and a myriad of other applications (Langer, 2018) within the medical industry alone. Techniques utilised within the scope of nanoengineering and technology include nanomanipulation, nanomeasurement, nanofluidics, nanomechanics and nanofabrication (K.-K. Liu & Chan, 2011).

Biosensors

Biosensors can be defined as any hardware (EMBS, 2019b) that is able to respond to defined biochemical or biological reactions within a biological or physiological system in order to generate a measurable signal (Lowe & Potter, 1989) for either diagnostic or therapeutic purposes. Typically, a biosensor will comprise of two elements; a surface-linked biological compound and a transducer for detection (Szunerits & Boukherroub, 2018). The associated biological compound is attached to the transducer surface using methods of absorption, entrapment within a polymer matrix and the formation of other molecular bonds through cross-linking or covalent bonding (Kiran & Misra, 2015). In essence, the compound utilised create a bioreceptor designed to interact with a specific target, converting biochemical data derived from an event or change in state, into a measurable output (Kiran & Misra, 2015).

The data generated through the use of biosensors can then be processed using biomedical signal processing (EMBS, 2019b) techniques to then enable interpretation or automatic response mechanisms.

With constant development and research into the field of biosensors, this particular aspect of the wearables and sensing market remains competitive (Grand View Research, 2019).

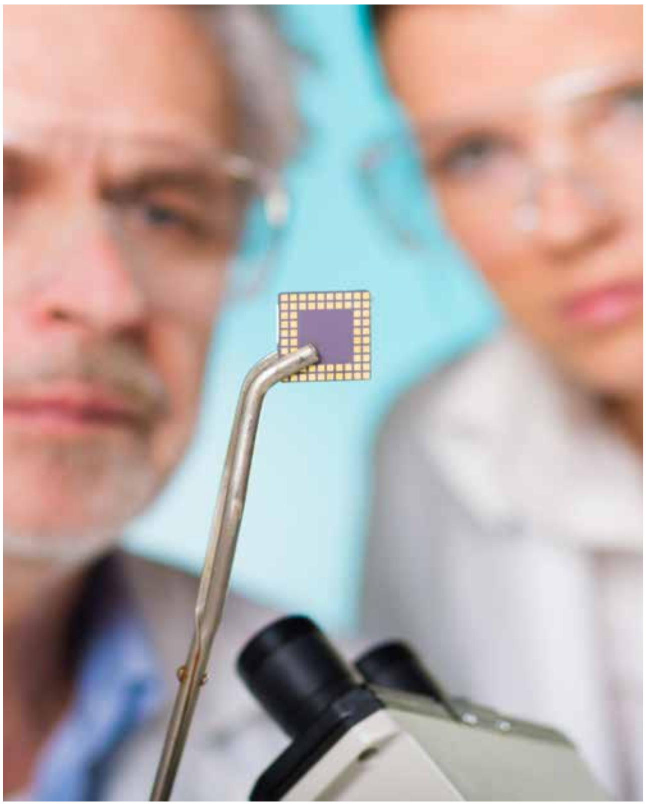
Diagnostic & Therapeutic Systems

Diagnostic and therapeutic devices or methods are developed in tandem and require a multidisciplinary approach in order to create holistic diagnostic systems to treat patients and respond to data generated. Such systems form a sort of ecosystem of physical sensing commonly referred to as diagnostic or therapeutic systems. Used in conjunction with various data collection and management mechanisms, such systems enable diagnosis by another external party or, perhaps initialise automated responses to treat or assist the patient/user. Typically, such diagnostic and therapeutic systems are integral in the context of hospital and surgical care. As technology evolves, new diagnostic systems are being developed on a nanoscale, including bio-microelectromechanical systems (Cheung & Renaud, 2005). Such systems entail the use of implantable biomedical microdevices or "lab-on-a-chip" diagnostic systems to monitor and detect conditions from within the body (Cheung & Renaud, 2005). These advances have the potential to generate new forms of therapeutic treatments.

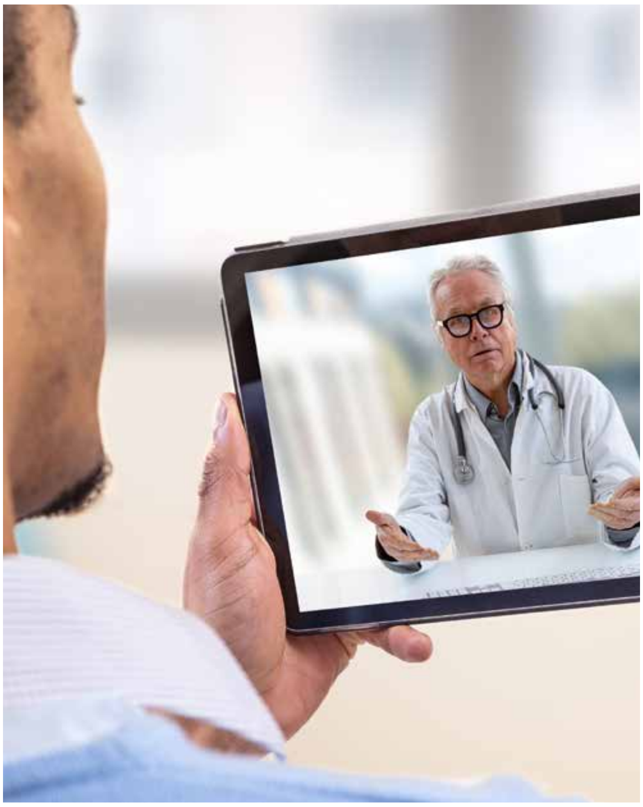
Telemedicine & Telehealth

Telemedicine is defined as an "integrated system of healthcare delivery that employs telecommunications and computer technology" (Bashshur, 2009) in place of direct contact between provider and client. More specifically, telemedicine enables the provision of remote healthcare services, clinical services, and education from afar to ultimately advance patient's overall health status. In the absence of localised services, telemedicine permits remote consultations and remote expertise to become vastly more attainable.

In modern practice, telemedicine now encompasses a wider array of services and capabilities (ATA, 2019) including machine learning, AI, and virtual reality simulations. Conversely, telehealth is defined as remote non-clinical services, that is able to provide and



Lab-on-a-chip diagnostic system



Virtual live chat between young male patient and doctor in telemedicine or telehealth.

facilitate practitioner training, administrative capabilities, and medical education, in addition to clinical services (Eren & Webster, 2015). Simply put, telehealth is all-encompassing, providing technology-enabled health and care management and delivery systems that in effect, extend capacity and access to improve upon the experience and health of a patient.

Biomedical Signal Processing

Biomedical Signal Processing is the analysis and interpretation; human or automated, of observed signals generated by physiological activities of organisms. Activities observed can range from monitoring and analysis of gene and protein sequences, to neural and cardiac rhythms, to tissue and organ images (Hsun-Hsien Chang, 2010). This process involves the analysis of collated real-time data to provide useful information to assist clinicians and patients alike in determining responses to health concerns. Biomedical Signal Processing has enabled the utilisation of more sophisticated means of analysing patient health (EMBS, 2019a) through more non-invasive measures. Biomedical Signal Processing pertains to real-time monitoring, cloud computing and Multi-scale Signal Processing.

Implantable Technologies

The term implant is used for devices that replace or act as a part of an existing biological structure. Implantable technologies or devices are defined as such if it is partially or totally introduced, medically or surgically, into the body with the intention that it remains following the procedure (Joung, 2013). Implantable devices exist in numerous forms and can be embedded throughout the human body and provide structural, functional and mechanical support (Wahid Khan, 2014).

Implantable devices with computational capability are typically characterised by an autonomous power supply capable of measuring and transmitting data from inside the human body (Eren & Webster, 2015) and are constrained by specific set of requirements in order to function and embed successfully in the body. Common applications include pacemakers, monitoring technologies for the heart and Parkinson's Disease, dermally implanted sensors, and extend towards new technologies in drug delivery systems and neural prosthetics (Wahid Khan, 2014).

Sobot (2018) categorises the diverse ecosystem of technological devices within distinctive categories, based on the proximity to the body itself, the final categories being indicative of implantable devices from the present into the future.

1. External technology: technologies that exist in close proximity to the body and have become personal commodities. For example, technologies such as mobile phones, computers, and smart watches, amongst other things.
2. Internal technology (temporary): technologies that temporarily cross the traditional external boundary line of our body, and can easily be put in, or conversely, removed, by the user. The device is only in contact with the body for a limited time frame. For example, contact lenses and ingestible biotelemetric capsules.
3. Internal technologies (permanent): Inclusive of implantable technologies that are designed to co-exist within the human body with its natural organs for the duration of the user's lifetime. The device is permanently inserted via a medical procedure and no further user intervention is possible. Examples include pacemakers, and cochlear implants.
4. Bio-mechanical integrated technology: This category infers the possibility of complete

X-ray of permanent pacemaker in a chest.

integration between a biological being and implantable technology. In the future, this could emerge in the form of cybernetic technologies where artificial entities or body parts are able to seamlessly co-exist with the natural body and its systems.

Genomics

As an emerging medical discipline, genomics encapsulates the use of an individual's genomic information to offer pathways to personalised clinical care through targeted diagnostic and therapeutic analysis (National Human Genome Research Institute, 2019). With the development of this field, there are now opportunities to create personalised medicines (Baba, 2002). In the fields of oncology, pharmacology, and disease and medicine, genomics has the potential to generate considerable impact through the analysis of genetic material.

Brain Computer Interface

BCI is a form of wearable technology that enables the restoration of the body's ability to detect proper neural or muscular activities above the level of injury. Such devices can be either invasive, partially invasive, or non-invasive (Shih, Krusienski, & Wolpaw, 2012), depending on the form of disability and the device's proximity to the body. Essentially, the BCI device enables lost body or communication functions through the detection of voluntary changes in brain activity. A range of sensors and imaging modalities are able to detect such changes.

These changes in effect act as signals that create an input to the BCI that can in turn be encoded as patterns and converts the defined activity onto command controls (Sen, Datta, & Mitra, 2018). BCI's are adaptive technologies with predictive capabilities, so that over time the user's operation becomes more streamline, similar to muscle memory.

AI + Datafication, VR

With the introduction of wearable health devices that possess the ability for data collection, data transmission and processing, the datafication of data-driven medical research and public health infrastructures, clinical health care, and self-care practices has become a critical point of contention.

An Electroencephalogram (EEG) head cap to measure EEG signals for Brain Computer Interfaces.

Although this does not constitute a physical artefact, it is a prevalent feature of a market defined and saturated by the presence of digital capability.

Datafication raises questions pertaining to data security and accessibility to personal information, data infrastructure, accountability (Hoeyer, Bauer, & Pickersgill, 2019), as well as the growing impact of algorithms in data processing applications (Foot, Boczkowski, & Gillespie, 2014). Whilst the technology in the realm of wearables and sensing have grown exponentially, the concern surrounding these themes of security and autonomy have begun to emerge (Mittelstadt, Allo, Taddeo, Wachter, & Floridi, 2016; Ruckenstein & Schüll, 2017).

Alongside datafication, Artificial Intelligence (AI) and Machine Learning (ML) in healthcare encompasses the use of complex algorithms and software to emulate human cognition in the analysis and processing of medical data. Traditionally, statistical methods have approached this task by characterising patterns within data as mathematical equation (Buch, Ahmed, & Maruthappu, 2018), however, through Machine Learning, AI is able to uncover complex associations within data streams that cannot be reduced to a linear equation. The integration of AI technologies also raises lines of enquiry surrounding data protection and accessibility.

VR technologies are also an emerging entity in the wearables and sensing markets with a range of potential applications. Currently, VR is proving a useful tool in education within the medical sector as well as offering an additional form of communication in telemedicine systems. There are also potential future applications for VR, particularly in the surgical field, with capabilities of providing assistance to surgeons through augmentation, real-time assessment, layered technologies and the implementation of parallel and disruptive technologies (Medivis, 2020).

Doctor using virtual reality glasses.

Mechatronics

Mechatronics is a specialised field within mechanical engineering that focuses on the integration of electronics, computing capabilities, and hardware to create "smart" devices. It is an extensive field of knowledge, impacting a majority of industries worldwide (Davim, 2011).

Mechatronics in the medical and healthcare fields plays an integral role in the improvement of healthcare services and devices. In terms of medical applications, mechatronic capabilities can be implemented in the design and improvement of real-time data analysis, electric and mechanical systems design, Machine Learning application, biosignal sensing, and assistive and rehabilitative systems (Y.-H. Liu, Moratal, Escudero, & Huang, 2018).

Current trends in this field include the continued simplification of miniaturised systems, making them lighter, more efficient, and cost effective to produce. As with other wearable devices in medicine and healthcare, the ability to dispose of such devices remains at the forefront as consumer electronics decrease in cost ("Mechatronics Improves Design & Operation", 2013).

Furthermore, there continues to be emphasis placed upon the patient user experience, ranging from comfort, usability and aesthetics of mechatronic devices as human centred design methodologies become more and more integral to the development of these products.

Despite the positive impact possible within mechatronic advances, contemporary developments associated with automation, artificial intelligence (AI), robotics, data, next-generation internet, and social and mobile media networks raise profound questions about the relationship between technology and society, and how these technologies are becoming integrated into everyday life in Australia and elsewhere (Davim, 2011).

Robotic hand

Woman checking her pedometer while walking.

Health & Performance Monitoring

Devices for monitoring physical activity and performance are somewhat synonymous with modern day smart devices. Pedometers, heart rate monitors are geolocation tracking very readily at a user's disposal, being inbuilt into personal accessories and cellular devices. However, the market for more targeted performance and health monitoring is expanding. For example, performance monitoring for professional athletes has shifted towards smart textiles and holistic product systems that enable data collection, real time analysis and intelligent processing to maximise the effectiveness of personalised training programs.

In terms of health monitoring, there are numerous conditions where a form of wearable or sensing technology could benefit the maintenance and diagnosis of that condition. In this respect, such devices encapsulate any combination of processes, technologies and physical forms under the broad umbrella of wearable and sensing technologies.

Smart textiles

Smart textiles can be defined as textiles that are able to sense and respond to changes in their environment. They may be divided into three classes: passive, active, and Very Smart textiles.

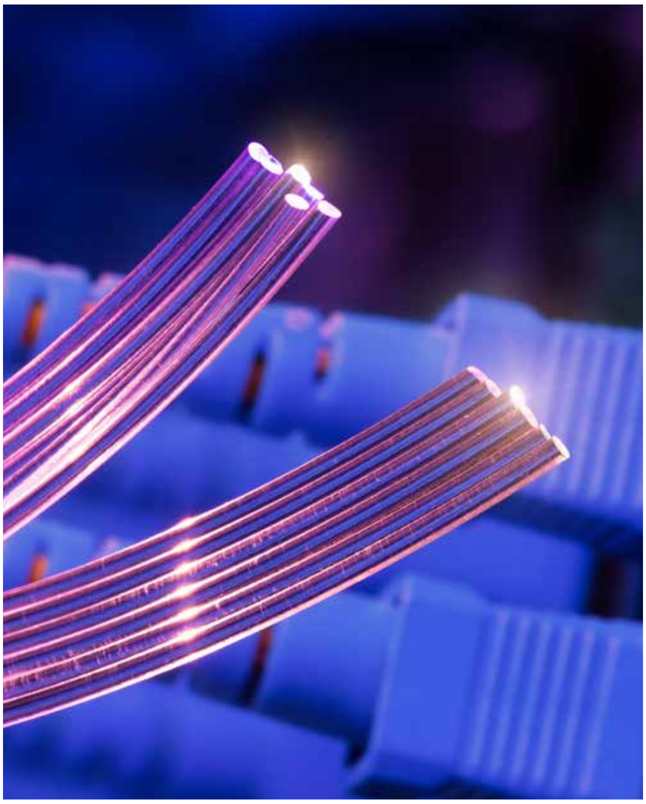
Passive Smart Textiles constitute the first generation of smart textiles found in garments, which can detect environmental and/or body conditions. Active Smart Textiles refer to the second generation which has the ability to both sense and react to stimuli through the provision of both actuators and sensors. Very Smart Textiles as the third generation not only sense and react like its predecessor, but also adapts to a given stimuli (Koncar, 2019).

Smart textiles refer to a broad field of research and products that increase the functionality of common fabrics. This encompasses textile products such as fibres, filaments, yarns that are woven, knitted or nonwoven structures, which can interact with an environment and/or user (Weng, Chen, He, Sun, &

Peng, 2016). Within smart textiles, there is also the convergence of textiles and electronics – E-Textiles. With the addition of electronic components, the capability of smart textiles increases exponentially. Essential components in smart textiles include sensors, actuators, data processors, communication units, and a dedicated energy supply.

Examples of applications for smart textiles include: photosensitive materials, fibre optics, conductive polymers, thermal sensitive material, shape memory materials, intelligent coating materials, chemical responsive materials, micro-capsules, micro and nanomaterials, and biomimicry.

Smart textiles as a wearable and sensing technology provide a non-invasive method for monitoring, measurement, and other medical applications.



Fibre optic technology for application in smart textiles.

Biomaterials

Biomaterials are defined as biocompatible materials –being natural, synthetic, alive or lifeless, that offer a number of potential biomedical applications such as the augmentation or replacement of natural function. Biomaterials may include synthetic materials such as metals, polymers, ceramics and composites, but also biological matter such as proteins, cells and tissues (Ruys, 2013). The scope of Biomaterials is broad, with key areas of inquiry and development including (Ruys, 2013):

- Implantable technology including artificial joints, ligaments and tendons, hearing and dental implants, grafts, stents and valves, as well as for nerve stimulation.
- For the purpose of regenerating tissues, Biomaterials may be used in the creation of scaffolds, cells and bioactive molecules to stimulate growth as well as tissue engineering. Examples include a bone regenerating hydrogel, as well as lab grown organs. By extension, biomaterials can also be used to promote healing. For example, materials used for wound closure and dissolvable dressings, also fall under this category.
- Molecular Probes and other nanoparticles are utilised in imaging and therapeutic techniques on a cellular level.
- Biosensors
- Drug delivery systems are another application well-suited to biomaterials as they are used to carry or apply drugs to a disease target within the body.

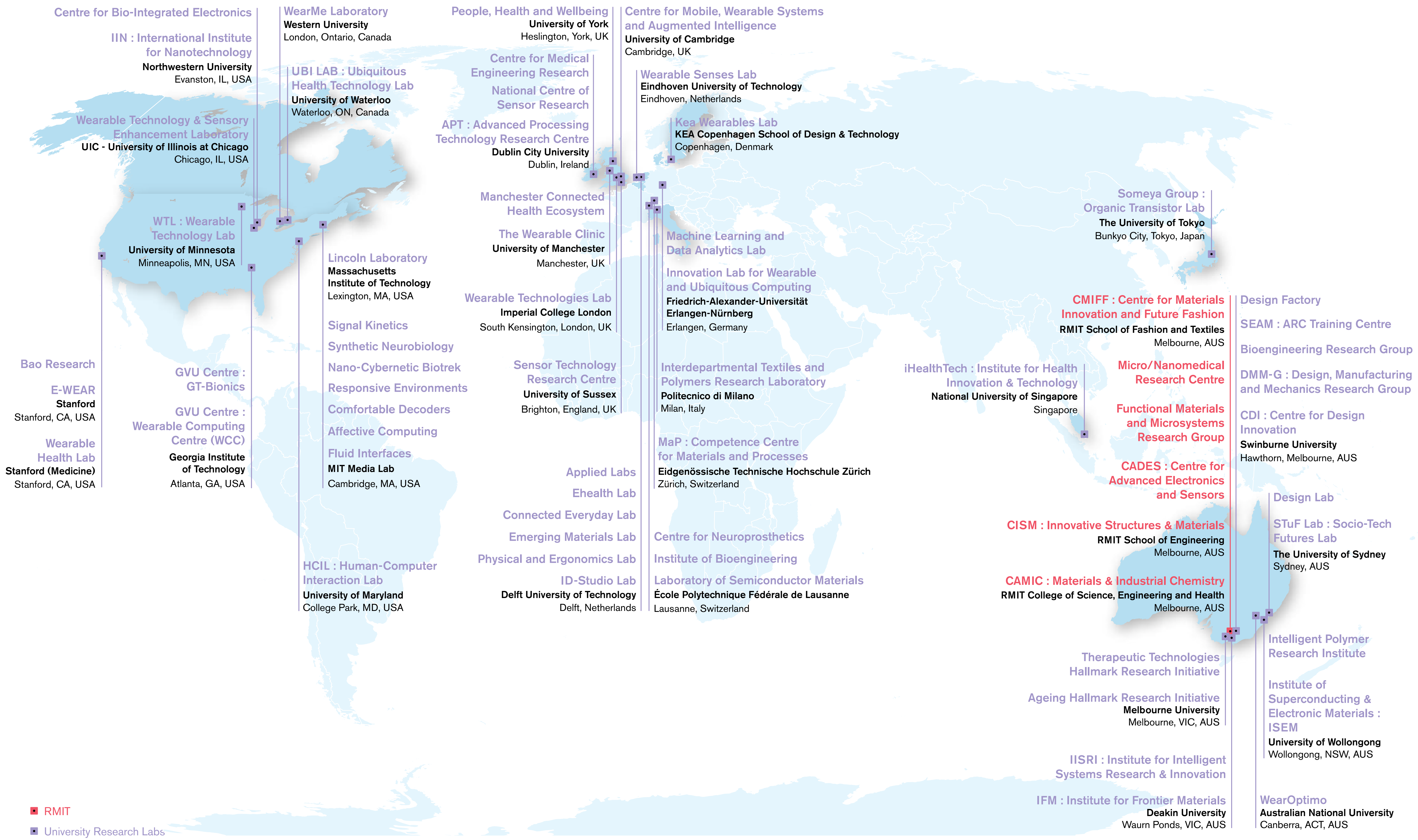


Figure 1:
University Research Labs Mapping

This map provides a snapshot of Universities worldwide that are conducting research into fields that fall within the wearable health technology space. The visualisation is available at ws-network.com.au/resources. We welcome your input to this mapping to ensure it is up to date.

Established University Research Labs

On a global scale, exciting developments and avenues of research are being undertaken to further advance current technologies in wearable and sensing technologies.

Major categories of innovation include:

- Material Innovation and Fabrication
- Devices and Smart Wearable Sensing Systems (SWSS)
- Nanotechnology
- Sensors and Sensing Capabilities
- User Centred Design
- AI, Machine Learning & Datafication

Detailed below are outcomes and areas of research undertaken by established research labs such as those situated within university research bodies, as well as commercial labs within the broader industry.

Material Innovation & Fabrication

Wearable Technology Lab - University of Minnesota

WTL from the University of Minnesota has generated a series of projects surrounding dynamic compression technologies. Able to be remotely controlled to provide specific pressure or pressurised action, the technologies explored look into shape adapting materials that are able to be integrated in various fashions in benefit health outcomes (Wearable Technology Lab, 2020). One such projects focuses on the development of garments suited to cardiovascular applications and for the treatment of Sensory Processing Disorder (SPD).

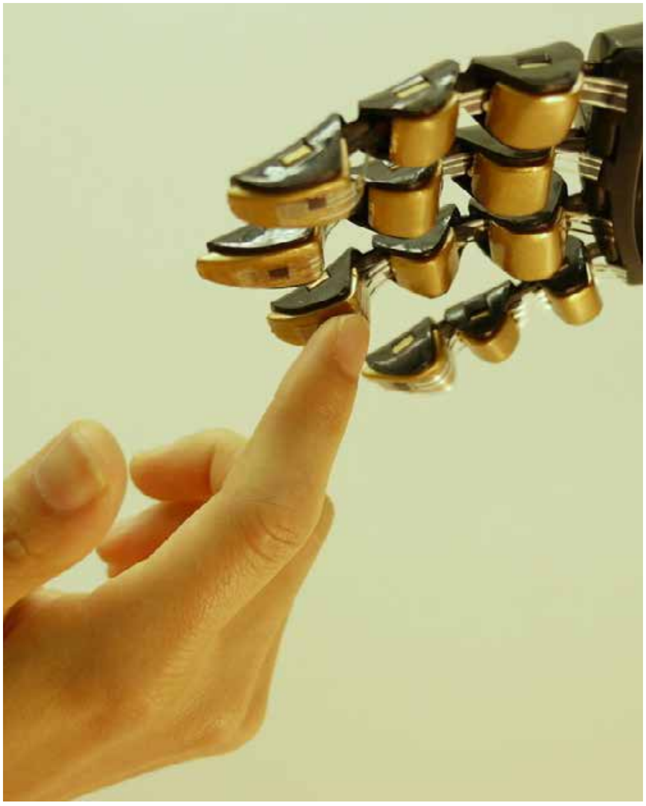
Bao Research - Stanford University

Hailing from Stanford University, the Bao Research body explores new methods and technologies surrounding fabrication and material innovation for wearable health technologies. Their approach is multidisciplinary, with active involvement from fields of expertise such as chemistry, chemical engineering, biomedical engineering, materials science and engineering, physics, and electrical engineering.

Central to the Bao Group's research is the investigation of functional organic and polymer materials and how they can be synthesised for targeted use in health monitoring and treatment (Bao Group, 2016). This includes the development and fabrication of organic electronic devices such as organic carbon solar cells and electronic skins, in addition to research surrounding possible applications for new organic electronic technologies.

In 2018, the Group undertook an investigation into flexible organic electronics that have potential applications in neurorobotics and neuroprosthetics (Kim et al., 2018). The project generated an artificial device to mimic the functions of sensory nerves within the body. Able to collect and process simultaneous pressure data inputs, the device can also detect movement and has been further developed for applications that require the actuation of muscles (Hwang et al., 2012).

Current endeavours at the Bao Research group focus on fundamental areas surrounding nano-scale electronics, creation of alternative energy sources, disposable sensors, and large area flexible plastic circuits and screens, and cost-effective production. Within this scope, the group has generated devices including organic and carbon nanotube thin film transistors, organic photovoltaic cells, chemical and biological sensors, and molecular switches (Son et al., 2018).



Bottom right: Zhenan Bao, a chemical engineer at Stanford University, is working to invent an artificial skin from plastic that can sense, heal and power itself. The thin plastic sheets are made with built-in pressure sensors (Bao Research Group, n.d.)

Emerging Materials Lab - Delft University of Technology

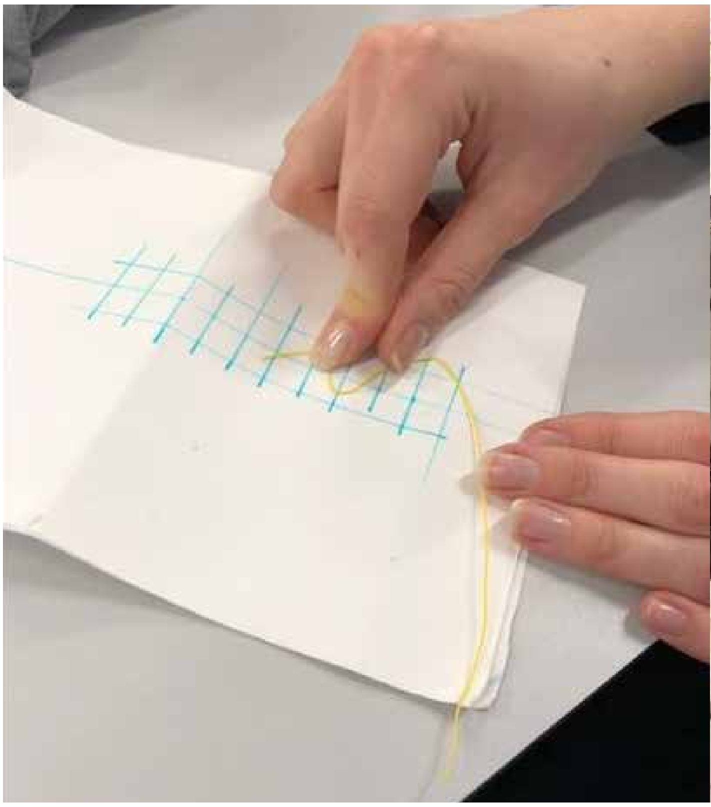
The Emerging Materials Lab from Delft University of Technology generates research and product development focusing on environmentally sensitive materials, and shape morphing materials under the broader construct of Smart materials. The Lab maintains a holistic approach to its research, by encompassing the end user and their experiences, considerations around societal impacts, and fabrication and materiality in order to facilitate meaningful and successful application outcomes. Starting in 2018, the project Citius Altius Sanius began, looking into how a reduction in hamstring injuries for athletes could be affected using smart textiles (Faculty of Industrial Design Engineering, 2018). The subsequent form was a smart sensing short, embedded with soft sensors able to monitor movement occurring around the hip and knee joints during exercise (Jansen, 2019). The combination of sensors and measurement data system put in place was able to accurately measure local knee and hip angle movements as per the highest bracket standard on local motion measurement.

Laboratory of Semiconductor Materials - École Polytechnique Fédérale de Lausanne

The Laboratory of Semiconductor Materials specialises in semiconductor technologies in relation to health applications of the future. Through the synthesis and characterisation of novel materials and structures, the Laboratory investigates methodologies for solar energy harvesting and computing capabilities on a Nano scale (Laboratory of Semiconductor Materials, 2020). In terms of fabrication, the Lab seeks to develop standardisation in the production and implementation of nanowires used in conjunction with silicon surfaces (McIntyre & Fontcuberta Morral, 2020).

iHealthTech : Institute for Health Innovation & Technology - National University of Singapore

The Institute for Health Innovation & Technology is an interdisciplinary space that facilitates collaboration between engineering, science and medicine to inform innovation and outcomes in healthcare. The Institute targets a broad range of applications and end users, ranging from medical facilities, communities, to singular



Smart Sensor Shorts Version 1
(Emerging Materials Lab, n.d.)

patients and practitioners. Integral technologies within iHealthTech's practice include smart textile applications, prosthetic skins and robotic and sensing technologies.

A key outcome for the Institute includes the development of a wireless body sensor network that can be readily incorporated into clothing to dynamically connect several wearable devices at once (Tian et al., 2019). The use of conductive fabrics, or metamaterials, in its given form, creates a radiative network that exists as "surface waves" around the body rather than being radiated out and away from the body as per traditional radiative networks (Draper, 2019). As a result, the wireless body sensor network enables wearable devices to consume much less power, as well as amplifying their ability to detect weaker signals. Additionally, the network is able to confine wireless communication within 10 cm of the body as well as amplify battery life of devices within immediate proximity (Tian et al., 2019).

Institute of Superconducting & Electronic Materials (ISEM) - University of Wollongong

The Institute of Superconducting & Electronic Materials at the University of Wollongong focuses their research primarily on superconducting and electronic materials science and technologies. Ranging from vehicular applications to Terahertz technologies, ISEM works towards the technological and commercial development of advanced energy solutions.

In relation to medical applications, ISEM studies the possibilities of applied superconductivity for electrical and medical devices; methods for energy conversion and transmission on various scales; spintronic and electronic materials, in addition to nanostructured materials. Wearable "energy–smart" ribbons (Li et al., 2016) was one such project developed by ISEM proving to be a promising energy source for various wearable applications that would enable the device to function whilst simultaneously harvesting and storing energy. due to the highly flexible nature of the resulting ribbon, the energy-smart material is also able to be woven directly into fabrics (Li et al., 2016).

Someya Group, Organic Transistor Lab - The University of Tokyo

Based at the University of Tokyo, the Organic Transistor Lab, works towards the design and fabrication of organic transistors, flexible electronics, plastic integrated circuits, large-area sensors, and plastic actuators for a range of applications, primarily within the healthcare bracket. The Organic Transistor Lab has begun extensive investigation into Organic Photovoltaics (OPVs). OPVs are lightweight and flexible in nature and offer options for saleable fabrication, as well as high energy conversion efficiency (Yu et al., 2019). Through research and further development of materials, structure, and integration methods, the Lab is working towards a self-powered actuator for a tactile feedback system.

The potential of long-term electrophysiological monitoring is also being explored, with the development of an ultrathin OECT based wearable electrophysiological sensor using an electrolyte gel. The device can take continuous readings from the body and shows stable performance even after multiple reuses beyond several days (Lee et al., 2019).

Devices and SWSS

Nano-Cybernetic Biotrek - MIT MEDIA LAB

The Nano-Cybernetic Biotrek group from MIT Media Lab, investigates and develops disruptive technologies on a nanoscale and in turn creates new paradigms for life-machine symbiosis (D. Sarkar, 2019). Alongside the study of scalable and efficient nanoelectronics, and biosensors for point-of-care applications, the Biotrek group conducts a great deal of research into Nano-implants for energy harvesting and wireless sensing capabilities.

An example of this line of research is one of Biotrek's latest projects, that explores the potential capability for devices to conduct internal analysis of a biological system whist enabling remote monitoring, electrical stimulation and potentially site-specific drug delivery (Sarkar, Wassie, Piatkevich, & Boyden, 2018). A key function of these proposed devices is the ability to harvest its own energy, to enable autonomous function and enable communication of data from targeted sites. The development of Nano devices using metamaterials allows Biotrek to investigate possible medical applications such as (D. Sarkar, 2019):

- monitoring and recording brain activity recording at a large scale with the precision of a single neuron
- monitoring and recording of the peripheral nervous systems
- monitoring tumours and their corresponding microenvironment
- observing treatment response
- and observing stimulus responses.

Biotrek believe the possible applications for such technology is endless, and in terms of medical treatment; possibly game changing.

MIT Comfortable Decoders - MIT MEDIA LAB

MIT's Comfortable Decoders from the MIT Media Lab researches novel approaches to create micro and nanoscale electromechanical systems with the ability to conform to or integrate closely with the chosen object of interest. Through the exploration of materials, methods of fabrication (Wicaksono, 2019) and development of physical forms, Comfortable Decoders are able to generate mechanically adaptive technologies that enhance a user's interactions with their body, environments and others.

By collecting and converting data from observations of nature and the body, the said data then informs the development of conformable Decoders various consumer electronics, biotechnology and engineering outcomes.

An example of a Comfortable Decoders project within the scope of wearable and sensing technologies includes the Miniaturized Neural System for Chronic, Local Intracerebral Drug Delivery (MiNDS). MiNDS is a miniaturised neural drug delivery system that enables dynamic adjustment (Obidin, Tasnim, & Dagdeviren, 2020) of dosage. The development of this system enables the adjustment of therapeutic drug delivery to the brain with pinpoint spatial accuracy. The device is an invasive method; taking the form of an implantable device that can be remotely controlled whilst simultaneously recording neural activity to better inform feedback control (Oran, 2019).

Synthetic Neurobiology - MIT MEDIA LAB

MIT Media Lab's Synthetic Neurobiology group develops novel nanoelectronics and computational devices as well as smart textiles and nano-materials to explore possibilities for probing, sensing and moderating capabilities for therapeutic applications relating to the body and brain (Bando, Chen, Cai, Boyden, & Gyu, 2019).

The SensorKnits project utilised the accessible and highly flexible manufacturing process of digital machine knitting to fabricate smart textile outcomes (Oran, 2019). Through the design and creation of various textile structures embedded with conductive and dielectric yarns, it was found that the resistance

MiNDS connected to two wireless micropumps (Brauer, M. S. n.d.)

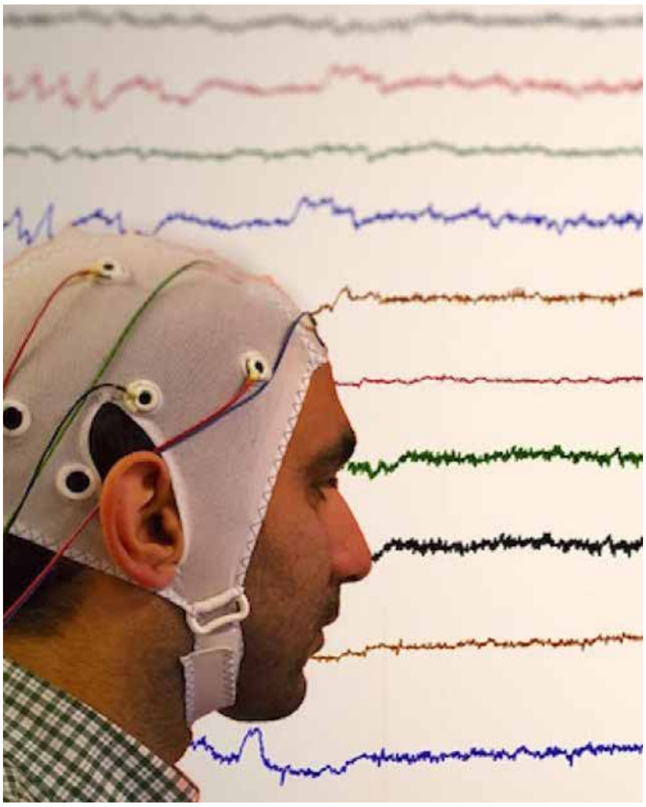
A tablecloth rheostat with magnetic balls to set the resistance (Oran, n.d.)

of the knitted fabric was able to be controlled through programming. Rather than positioning the project as further investigation into interaction design, the project explores the correlation between the knitted structure and electrical properties of a textile.

Wearable Technologies Lab - Imperial College London

Based at the Imperial College of London, the Wearable Technologies Lab specialises in monitoring technologies primarily concerned with cardiac and respiratory function within the personal healthcare space (Wearable Technologies Lab, 2019). Currently, key projects focus on epilepsy, sleep conditions and respiratory medicine with a strong attention to ergonomic design and how to best integrate these technologies into patients' lives.

In the area of respiratory function and illness, the Lab works towards developing products and methods to reduce health, financial, and social burdens to improve overall quality of life for a patient as well as speeding up the diagnosis process (Pramono, Imtiaz, & Rodriguez-Villegas, 2016). A recent outcome for the Lab includes an algorithm designed to analyse cough audio signals in



Intelligent signal processing and algorithms for health management (Wearable Technologies Lab - Imperial College London, n.d.)

children to provide automatic diagnosis of Pertussis.

The algorithm undertakes three main tasks, performing an automatic cough detection, cough classification and whooping sound detection. Throughout the testing phase, the Lab found that the algorithm was able to "diagnose all pertussis successfully from all audio recordings without any false diagnosis" (Pramono et al., 2016). There is potential for the algorithm to be used with smart devices for quick identification and early detection.

Centre for Medical Engineering Research - Dublin City University

The Centre for Medical Engineering Research at Dublin City University centres their research around the translation of engineering and materials research into viable healthcare solutions for the commercial market. Operating as a multidisciplinary practice, the Centre comprises of three main branches; materials science, biology, and engineering (Centre for Medical Engineering Research, 2019). Through research, the MEDeng Centre develops a range of products ranging including biomaterials, drug delivery systems, biomechanics, and surface engineering and coating technologies.

The Centre for Medical Engineering Research primarily focusing on medical devices and implantable technologies used to promote tissue repair and regeneration.

For example, the MEDeng Centre developed a coronary stent fabricated from poly(L-lactic acid) that resulted in illuminating the potential for a high stiffness (Blair, Dunne, Lennon, & Menary, 2018), polymeric expandable scaffold appropriate for the application of coronary stents.

KEA Wearables Lab - KEA Copenhagen School of Design & Technology

The KEA Wearables Lab heralding from the KEA Copenhagen School of Design & Technology provides access and facilities to students to provide education programs about basics in electronics and sensing technologies to create an environment where fabrication skills and conceptualisation can grow together within a collaborative space (KEA, 2019). The Lab also has connections to external businesses to produce potentially market ready products and apply research knowledge through design partnerships. The KEA Lab

Valo, a wearable compass to guide the user back to a specific location or person (Johansen, Gravesen, & Stenalt, n.d.)

has a strong presence in jewellery and textile wearable design with a focus on sustainability (KEA, 2019).

Living Lab - Melbourne University

The University of Melbourne's Living Lab centres on wearable and sensing technologies based around behavioural and healthcare applications.

The Lab developed the Smart Hospital Living Lab that creates an immersive experience for the conceptualisation and testing of practical solutions for healthcare providers through quick prototyping and iteration in situ in partnership with Industry members (The University of Melbourne, 2019).

The project focused on mobile and wearable technologies including new system architectures, wearable materials, novel sensor and machine learning techniques, in order to develop interactive systems and intelligent sensing solutions to improve hospital safety and logistics (The University of Melbourne, 2019).

Issues surrounding security and privacy, and geographical data analytics are also broached, the ultimate goal to generate a human-centred, real-world approach to creating impact within the context of hospitals and the healthcare industry.

The Pillbox was a part of the Living Lab and its outcomes, exploring the potential for the use of Near-Infrared Spectroscopy technology (NIRS) scanners for the identification of pharmaceuticals (The University of Melbourne, 2019) before being administered to patients. The product would work to minimise the financial and human costs incurred from medication mismanagement and error.

Sensor Technology Research Centre - University of Sussex

The Sensor Technology Research Centre of the University of Sussex undertakes extensive research into wearable computing and embedded intelligent systems, flexible and stretchable electronics, mobile and wireless communication, IoT and vehicular networks, electrophysiology (Prance, Watson, Prance, & Beardsmore-Rust, 2012) and the fundamentals of sensor technologies. This research facilitates further endeavour into developing wearable/IoT sensing platforms, smart textiles and considered objects to formulate holistic product and system outcomes (University of Sussex, 2019). Under the STRC banner, there are additional groups working within the wearable and sensing technology space including, flexible and stretchable electronics, wearable and embedded technologies and sensor fundamentals.

Sensors

Responsive Environments - MIT MEDIA LAB

Research from the Responsive Environments group of MIT Media Lab encompasses the development of sensor networks, energy harvesting capabilities, and power management techniques within wearable computing and medical applications. Through this research the Lab investigates human experience, perception and interactions within a number of fields.

Space Skin is a project undertaken by the Lab to develop aerospace grade electronic textiles, a material that would be able to detect hypervelocity impact and directly monitor and measure local conditions (Cherston, 2019). The material is woven, with sensory fibres embedded throughout. The resulting prototype exhibited the smart textile being woven into Teflon-coated fiberglass, which is used as the outermost skin of the International Space Station. The combination of materials and application gives the overall design the ability to both sense and protect (Cherston, 2019). In further development of the project, manufacture methods and necessary material properties for aerospace applications are to be explored in addition to the possible inclusion of secondary sensing systems to support the optimal function of the skin itself (Cherston & Paradiso, 2019).

National Centre of Sensor Research - Dublin City University (DCU)

The NCSR focuses primarily on the science behind chemical and biosensors and their respective applications. Currently, such technologies are suited to providing more accurate medical diagnoses, improving the ability of industries to monitor processes, improve energy efficiency and the state of the environment. The NCSR works across a multitude of fields, including environmental, biomedical, material innovation, and imaging. In the way of medical applications, NCSR focuses predominantly on biomolecule isolation and purification, micro instruments, sensors and systems, disease diagnosis and monitoring, and point of care applications.

An example of NCSR's work includes a project based on biomimetics, involving the manipulation of surface microstructures to inhibit the settlement or attachment of identified microorganisms for antifouling technology applications (Sullivan, McGuinness, Connor, & Regan, 2014). The concept of engineering cell surfaces enables the ability to potentially control cellular behaviour. The exploration of this concept was undertaken using cells from the crustacean Cancer pagurus, enabling the creation of model surfaces to facilitate the investigation and understanding of cell-surface interactions.

User Centred Design

Ubiquitous Health Technology Lab (UBI Lab) - University of Waterloo

The UBI Lab explores wearable and sensing technologies through the lens of human-centred design, data-driven design, and population-level health outcomes. The focus is to create outcomes that place minimal burden on the user, whilst maximising effectiveness of "zero-effort sensors and technologies" to provide reliability and strong user experience outcomes. Remote patient monitoring and data analytics form the basis for a number of UBI Lab's outcomes.

A recent project documented by UBI Lab involves the adaptation of electromagnetic radars as a means to enable remote sensing of biosignals as opposed to wearable devices that require immediate contact (Alizadeh, Shaker, Almeida, Morita, & Safavi-Naeini, 2019). This form of remote sensing was explored in order to evaluate the effectiveness of this technology when monitoring respiratory and heart rates, particularly in the context of in-home care. The technology modified and tested by the Lab showed promising result correlations as compared to baseline testing.

Design Factory Melbourne – Swinburne

Swinburne's Design Factory encompasses student body, researchers, and industry partners who together through collaboration work produce innovative solutions for forecast future scenarios (Design Factory Melbourne, 2019a).

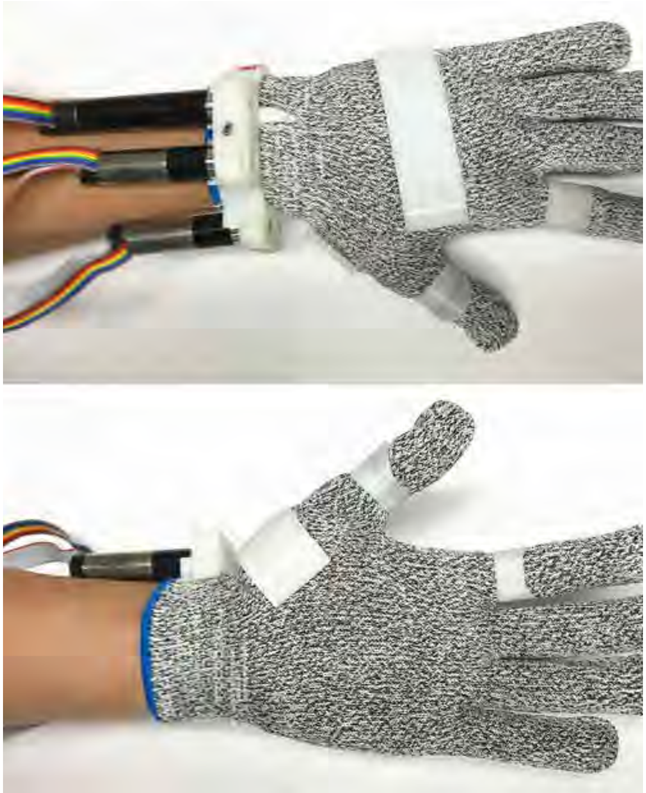
A concept prototype was generated through an industry–engaged research project called the Customer Adaptive Room Environment (CARE). Designed with hospital environments 25 years into the future, the designed space offers a user experience that improves the emotional and social aspects associated with a hospital stay (Design Factory Melbourne, 2019b). The design integrated patient programmable wall panel displays that feature circadian lighting, and an inclusion of storage and space, allowing a sense of ownership of what traditionally is an impersonal space.

Physical and Ergonomics Lab - Delft University of Technology

The Physical and Ergonomics Lab of Delft University studies the nature of human-product-interaction and therefore the physical and environmental factors at play, that ultimately influence user experience and product effectiveness. An example of this is wearables that exist within patient care scenarios.

The Designed to Fit project involved the development of an anthropometric database of children's heads and faces for the purpose of designing efficient and effective ventilation masks for children below the age of 6 years (Goto, 2019). The project

Designed to Fit Ventilation Masks
(Physical and Ergonomics Lab - TU Delft, n.d.)



Development of a Wearable Tremor Suppression Device (WTSD) (WearMe Laboratory - Western University, n.d.)

utilised 3d scanning technology to generate content for the digital database, that would enable ease of access to better inform the design of tailored ventilation products necessary for effective treatment.

WearMe Laboratory - Western University

The Wearable Mechatronics Laboratory from Western University seeks to develop novel design solutions for the rehabilitation of Musculoskeletal Disorders (MSDs).

Through extensive research, patient-centred design, and the iterative prototyping stages, the Lab endeavours to minimize weight and size of devices, improve sensing capability, and enhance human–device communication (Wearable Mechatronics Lab, 2019). Control system development is evident across a range of such projects, from wearable mechatronic braces for the upper and lower body, as well as limb monitoring devices.

The development of a wearable tremor suppression device (WTSD) was conceived by the WearMe Laboratory in 2018. The project was developed in order to provide a non-invasive solution for suffers of pathological tremors; unintentional, oscillatory movements of the body or limbs (Zhou, Jenkins, Naish, & Trejos, 2018).

The suppression device was designed to suppress upper limb tremors whilst maintaining the user's ability to move voluntarily. Alongside the device, a control algorithm was devised to maximise suppression of unwanted motion, whilst minimising its influence on voluntary motion (Zhou et al., 2018).

Nanotechnology

Querrey Simpson Institute for Bioelectronics - Northwestern University

The Querrey Simpson Institute for Bioelectronics primarily studies bio-integrated electronic systems that seamlessly integrate with living biological materials such as organs and other tissues. The ability to create devices that can link the both mechanical and biological systems offer extraordinary diagnostic, therapeutic and surgical potential within biomedical research and clinical healthcare (Querrey Simpson Institute of Bioelectronics, 2019).

The institute is prolific, generating new research and works into skin-like electronics, injectable electronics, wireless wearables, multidimensional electronic networks, as well as bioresorbable electronics.

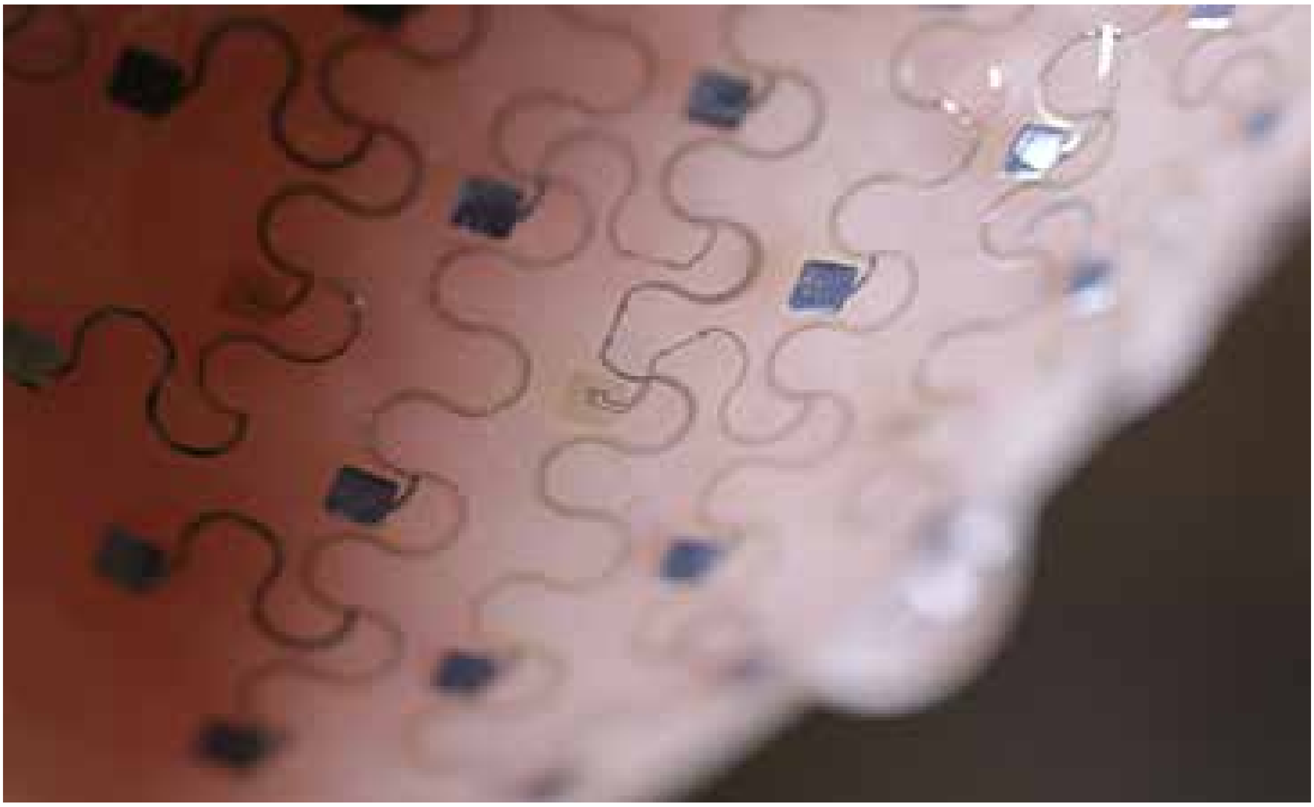
Bioresorbable electronic technologies are a developing area within the scope of sensing technologies. The emerging devices exhibit excellent biocompatibility in cell level toxicity studies and additional trials. Devices tested possessed sensing capability, wireless data transmission, power supply and actuation (Hwang et al., 2012). Bioresorbable electronics offer solutions in emergency medical treatment, recovery and rehabilitation in addition to bypassing the need for secondary surgical intervention for surgical extraction. Possible applications include temporary pacemakers, nerve and bone growth stimulators for enhanced rates of healing and intracranial sensors for monitoring users who have experienced traumatic brain injury (Lee et al., 2019).

Centre for Neuroprosthetics - École Polytechnique Fédérale de Lausanne

The Centre for Neuroprosthetics is a multidisciplinary practice that integrates engineering, physics, chemistry, computer and life sciences to develop greater understanding the relationship between biological systems and innovative technology platforms that can benefit clinical applications (EPFL, 2018).

The scope of research covered by the Centre is expansive, with major categories including (EPFL, 2018):

- Tissue engineering for therapeutic applications
- Biomedical micro-devices and image processing tools for intervention and diagnosis
- Biosensors and neuro-electrodes
- Soft bioelectronic skins and brain-machine interfaces
- Sensory and motor neuroprosthetics
- Biorobotics, biomechanics and cardiovascular modelling
- Movement and/or gait measurement and assessment
- Biotechnology for therapeutic protein production



Epidermal Skin-like Electronics
(Querrey Simpson Institute for Bioelectronics, n.d.)

A subdivision of the Centre works primarily towards assisting patients with optical disability, namely blindness. By creating and implementing novel technologies towards sight restoration, the Centre hopes to translate research and testing into viable clinical practice. In 2018, an injectable epiretinal prosthesis was developed entitled POLYRETINA with initial results showing positive translation of the device (Ferlauto et al., 2018). An additional device for optic nerve stimulation was also successfully trailed, confirming that an intraneural electrode, OpticSELINE; was able to restore sight to the blind.

AI, Machine Learning & Datafication

Affective Computing – MIT MEDIA LAB

Affective Computing from MIT Media Lab addresses machine learning and recognition, and the modelling of human emotional expression. The data collected can inform the development of new digital tools that aid in communication and management of emotional information (Zhang, Weninger, Björn, & Picard, 2019), additionally providing insight into emotional impacts on health, social interaction, and other human action such as learning, memory and behaviour.

The Hol-Deep-Sense project aims to create a holistic machine perception of human phenomena through AI technology, enabling machine to recognise emotion as well as analysing contextual information to improve recognition and response (HOL-DEEP-SENSE, 2019).

The technology would allow personal attributes such as age, gender, emotion, health status, as well as cognitive and physical states, to be recognized and factored into AI frameworks (Zhang et al., 2019).

Signal Kinetics - MIT MEDIA LAB

Similarly, to Affective Computing, the Signal Kinetics group of MIT Media Lab centre development and research around machine learning, in addition to signal processing, hardware design, network infrastructure and actuation.

An example of the groups work in relation to actuation and alternative energy sources, is the Battery-Free Subsea Internet-of-Things. The project brought about the Piezo-Acoustic Backscatter (PAB) that enables backscatter networking in underwater environments whilst enabling communication and harvesting its own energy from underwater acoustic signals (Day, 2019).

Future applications may include ocean exploration, marine life sensing, and underwater climate change monitoring.

Machine Learning and Data Analytics Lab - Friedrich-Alexander-Universität Erlangen-Nürnberg

The Machine Learning and Data Analytics Lab (MaD Lab) primarily investigates human computer interaction, machine learning, modelling and simulation, and wearable computing (Friedrich-Alexander-Universität, 2019). The Lab seeks to generate research that ultimately provides a positive impact on human wellbeing. Applications include physical performance and rehabilitation, and monitoring disease.

FallRiskPD was a project undertaken by the MaD Lab in 2018 to 2019. The project investigates novel machine learning algorithms that enable the wearable device to determine and alert a Parkinson's disease patient of fall risk using data captured by shoe integrated inertial sensors (Haji Ghassemi et al., 2019).

The sensors used create a continuous gait monitoring system, that identify specific movement or changes that occur in the PD patients to a high degree of dependability.

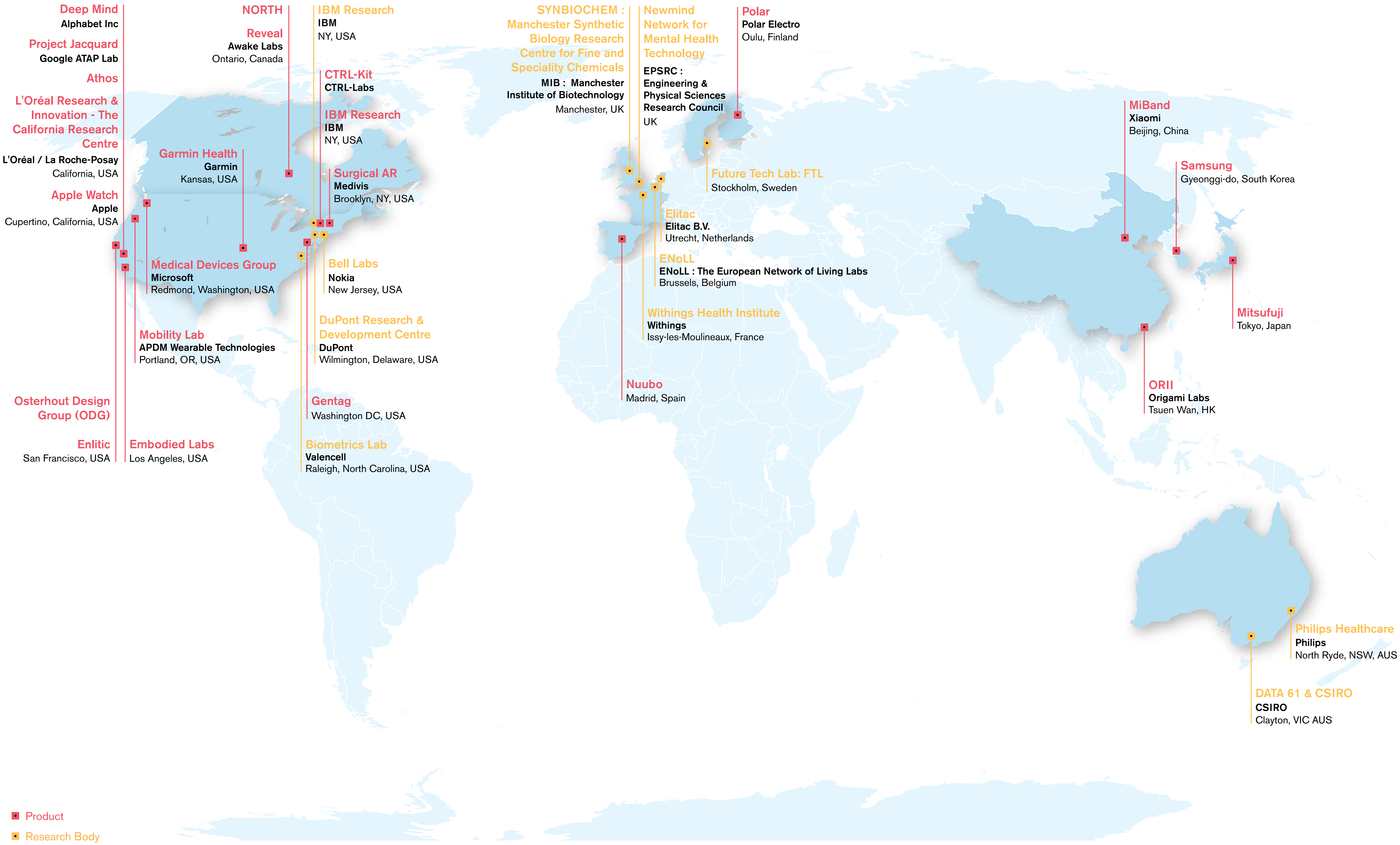


Figure 2:
Commercial Products and Research Mapping

This map provides a snapshot of developments and research into wearable technologies within the commercial space. This encompasses marketed products and services in addition to commercialised research bodies. The visualisation is available at ws-network.com.au/resources. We welcome your input to this mapping to ensure it is up to date.

Commercial Outcomes

Material Innovation & Fabrication

Google

In a cross collaboration between Google and clothing label Levis, Project Jacquard was the first example of a full-scale digital platform created specifically for a smart clothing product for the purpose of enabling seamless interaction with the digital world whilst navigating the day to day life (Poupyrev et al., 2016).

The garments surface itself replaces the interface of our personal digital devices such as smart phones, for example, enabling the user to accept a phone call or skip to the next song using a series of touch gestures across the garments various surfaces (Google, 2020).

Origami Labs

ORII is a Smart ring device that uses bone conduction to enable the wearer to by-pass their smartphone and operate completely screen-free. The bone conduction transducers used by ORII convert electrical signals into vibrations that are able travel directly through the bone and directly to the inner ear (Origami Group, 2020). The device has only gesture and voice controls that acts as an extension of smartphone devices.

Future Tech Lab (FTL)

Future Tech Lab (FTL) are a self-described disruptive movement of innovators bringing together fashion and science fields to create projects founded on the ideals of sustainable futures. FTL enables various practitioners to connect and therefore encourages spaces for cross collaboration and creative innovation; with a particular focus on new technologies and sustainable innovation (Future Tech Lab, 2019). Key examples of outcomes created from FTL's collaborative endeavours include textile recycling technologies and biofabricated materials such as the patented Microsilk. In collaboration with beauty brand Eighteen B ("Connecting Fashion and Science With Miroslava Duma", 2018), a biofabricated silk fibre was created bringing a revolutionary bioengineering concept to life. Based on proteins found in nature, such as collagen and elastin, the material generated can be used to form a protective, breathable barrier for the skin, in essence mimicking skin itself. There is potential for the material to

ORII Smart Ring (Origami Labs, n.d.)

become integrated into medical practice to be used to help heal wounds.

DuPont

DuPont's Research & Development Centre works across a vast array of fields, with significant development and focus in food production, apparel, electronics and alternative energy applications (DuPont, 2019). The Centre maintains in-house discovery, research, and development of all outcomes. DuPont™ Intexar™ is a notable product of DuPont's Research and Development Centre. Intexar™ is an innovative electronic ink and film device that seamlessly transforms fabric into smart clothing, given its soft and seamless design ("DuPont's Intexar Owlet Band", 2019). This innovative textile technology has the potential to deliver advances in the wearable healthcare space with possible applications in monitoring, telemetry, heat therapy, and management of respiratory disorders.

The pregnancy monitor, the Owlet Band; enables mothers to track their pregnancy and foetal health, all made possible through the implementation of Intexar™ technology.

Elitac

Elitac are another wearable innovation lab based in the Netherlands actively collaborating with various commercial partners, Elitac specialise in stretchable electronic circuitry, complimentary operating systems and a significant wealth of knowledge and expertise around agile wearable technology. Elitac also works closely with designers and research institutions to develop and generate new innovation in the integration of electronics into textiles. With its own in-house team specialising in hardware, electronics and textiles, Elitac is able to facilitate and improve and verify collaborators wearable project development and outcomes (Elitac, 2020a).

A key project generated by Elitac's lab is the Mission Navigation Belt developed in 2013 in collaboration with the Royal Netherlands Army (Elitac, 2020b). The product was designed to improve soldiers "situational awareness during complex operations in the field", by employing a series of vibration motors integrated into the belt to enable the wearer to "feel" direction.

In the context of day or night scenarios in the field, the wearer is able to follow a programmed route, and feel the direction and distance of the next waypoint through changes in vibration. This communication of information to the user is therefore discrete and highly intuitive, enabling the wearer to react immediately in critical situations without impeding physical action.

Mission Navigation Belt (Elitac, n.d.)

Similar technology was adapted to create the Sentaz system a tactile navigation system in vehicles. In this instance, the operator is able to receive navigation signals through vibration feedback in the driver's seat of the vehicle (Elitac, 2020c). The navigation is determined by third party software and then translated into a physical stimulus. The use of an intuitive vibration system would reduce the need of the driver to navigate using visual or auditory queues (Elitac, 2020c). In the context of military applications, this would effectively allow an operator's eyes and ears to be available for other tasks.

Polar

Polar focus on devices within the realm of athletic training & general fitness, the company being best known for developing the world's first wireless heart rate monitor (Blons et al., 2019). Ranging from sports training computers, to sensors used in performance monitoring, Polar provides holistic systems based on scientific enquiry into physiological and sports medicine research (Polar Global, 2020). The company conducts its research and development through its own in-house facilities in addition to maintaining relationships with a number of research institutions worldwide as well as the greater scientific community. To further encourage innovation within the industry, Polar offers co-operative research programmes to external partners to further support studies into exercise science. The research body of Polar covers a broad range of research areas including animal studies (Jorquera-Chavez, Fuentes, Dunshea, Jongman, & Warner, 2019), targeted demographic approaches (Perdomo, Balzer, Jakicic, Kline, & Gibbs, 2019), nutrition and psychological and physiological aspects that can be impacted through the implementation of wearable technologies.

Athos

The development of the Athos Training System targets professional athletes, providing a highly comprehensive method for users to collate and extract data to better inform training and physical development

Athos Training System (Athos, n.d.)

of athletes (MAD Apparel, 2020). Athos has developed a proprietary method to measure muscle activity that works in conjunction with motion tracking technologies embedded within the user's garments. These inbuilt cores enable real-time monitoring of the wearer's performance and technique, with data being recorded and readily analysed through a designed online platform and/or app (Lynn, Watkins, Wong, Balfany, & Feeney, 2018). The combined product and online platform aid athletes and coaches to generate highly effective and personalised physical training plans to facilitate optimum performance (Lynn et al., 2018).

Athos partners extensively with professional and collegiate football programs in the United States as well as top performance institutes such as ProActive (Los Angeles), and FastTwitch (Miami).

L'Oréal Research & Innovation - L'oreal / La Roche-Posay

L'Oréal Research and Innovation body seeks to transform how consumers interact with the beauty market by bringing together innovative beauty products alongside devices and smart digital services.

The company is actively exploring a range of projects, delving into "flexible electronics, non-linear optical tools for in vivo imaging, tissue engineering, biophysics, synthetic biology, biochemistry, clinical biology, and new functionalized cell models" (L'Oreal Research & Innovation, 2018).

In one such project, in collaboration with La Roche-Posay, L'Oréal's research and innovation centre Open Innovation has developed sensing technology that is able to continuously measure a wearers exposure to both UVA and UVB rays in addition to pollution, pollen and humidity (McNeill, 2019). The sensor transmits the collected data and can be readily accessed via the My Skin Track UV app. Taking into consideration other key factors such as the users skin colour and type, the combined data generates personalised advice to best protect and limit negative levels of exposure.

Apple

The Apple Watch and accompanying systems include health applications for monitoring and data feedback, giving clinicians the potential to provide optimised support through more in-depth analysis of data procured from the patient.

The device offers the ability to identify and track irregular heart rhythm that can be suggestive of arterial

Apple Watch Series 4 ECG Screen (Apple, 2018)

fibrillation using photoplethysmography technology (Apple, 2020). The optical heart sensor detects the pulse wave at the wrist. This measures the beat-to-beat intervals when the user is in an active state, resting or sleeping. If the algorithm detects an irregular pattern suggestive of Arterial fibrillation, the user receives a notification along with the date, time, and in-depth record of the occurrence in the Health App (Apple, 2020).

The ECG app uses the electrical heart sensor built into the device to record the equivalent data similar to a Lead I ECG. The ECG application monitors and records any incidence of sinus rhythm, arterial fibrillation or inconclusive readings which then prompt the user to input further information about symptoms, such as rapid or pounding heartbeat, dizziness, nausea or fatigue (Apple, 2020).

The waveform, results, date and time and any other symptoms are recorded and are able to be exported via the Health App to be shared directly with a clinician (Perez et al., 2019).

The company initiated a large-scale study to Identify atrial fibrillation using the apple watch device. The study was used to determine whether smartwatch applications were able to identify atrial fibrillation during use when coupled with the optical sensors embedded in the device (Moon, 2019). In the event of a pulse notification algorithm identifying a possible atrial fibrillation, the user was notified as well as a clinician, the patient then being assessed professionally and given an ECG patch to use over a period of 7 days (Perez et al., 2019). The main objectives of the trial were to determine if the technology offered highly reliable readings in proportion to the number of participants notified of atrial fibrillation activity. In addition to data collected from the week-long trials, surveys were also conducted to fortify results.

Neue Labs

Neue Labs is based in Stockholm and offers brands, universities, and designers a platform to develop exploratory wearable technology outcomes all the way through to a market ready standard. This platform, known as Playground, provides a singular space to help companies or start-ups design and generate connected smart garments, develop associated content and services that enable customer adaptation where possible (Neue, 2020). Neue has a very strong footing in the fashion industry and is geared towards helping companies typically from this industry to overcome the innovation barrier and optimise their product for production.

The designed product and end function are fully facilitated through the capabilities of technology provided through the Neue Playground platform. An example of a Neue outcome is the F/ACT Movement (Neue, 2020), a project that explores user behaviour around garment consumption and utilisation using AI analysis and a range of sensing technologies to monitor and track garments and garment use. Potential applications relate to sustainability, development of future business models, and overall longevity.

Sensors

Microsoft

The Medical Devices Group of Microsoft are a multidisciplinary body that presents major projects surrounding wearable devices for cardiovascular health. Using novel sensors and other sensing technologies coupled with AI and Machine Learning capabilities, MDG creates ergonomic designs that operate within a holistic system to enable relevant alerts and data exchange to take place. Through the combination of signal processing and Machine Learning, long term patterns procured from the data enable the identification of actionable insights that can benefit the life of the user.

Mobility Lab

The Mobility Lab of APDM explores novel technologies that enable the scientific research community to conduct higher quality research into movement sciences. In doing so, the Mobility Lab generates technologies that can be used in performance, fitness and elite sports, as well as physical therapy, and clinical research and trials (APDM Wearable Technologies, 2019).

APDM develops and provides the market with viable commercial solutions for the quantification of human movement through the utilisation of wearable technologies for the purpose of research (Washabaugh, Kalyanaraman, Adamczyk, Claflin, & Krishnan, 2017).

Coupled with a proprietary motion analytics platform, The Mobility Lab generates wearable sensors that offer gait and balance monitoring (Mancini & Horak, 2016), kinematic inputs and continuous recording capabilities for numerous applications across a range of markets.

Gentag

Gentag provides specialised knowledge in sensing technologies, with a directive to create disposable wireless sensor technologies that are affordable and accessible to the worldwide medical community.

Gentag's efforts aim towards producing printed, flexible, and organic sensor formats that can be used for multiple applications, including NFC sensor technology, disposable NFC and biomarker patches, Lab-on-a-Chip, and nanoscale sensors (Gentag, 2020). These applications can then be extrapolated further, resulting in solutions for discharge and home monitoring kits, other forms of monitoring such as temperature, health and fitness, as well as drug delivery systems.

Valencell

An US-based company, Valencell is concerned with biometric technology and actively develops biometric sensor technology for wearables sensing

SensorLinker, a customized in-home mobile compliance and diagnostics sensor hub (Gentag, n.d.)

applications, as well as providing Benchmark sensor systems to consumer electronics manufacturers in various industries as readymade components to adapt into wearable concepts. Additionally, the Biometrics Lab affiliated with Valencell, offers testing services of prototypes through a battery of testing protocols and activity sets (Valencell, 2020). Through the analysis and validation of data captured with consideration paid to real-world scenarios, the Biometrics Lab can identify and promote improvements of products design and performance prior to going to market.

Valencell also offers the Ecosystem – a community of contract manufacturers, original design manufacturers, in addition to the Biometrics Lab, that combined; incorporates supply and manufacture alongside a certification program. Therefore, Valencell enables the generation of market ready products by providing extensive R & D services (Valencell, 2020). This action also contributes to Valencell's own research and development of technologies for the fitness and health industries, personal health applications, and military solutions.

User Centred Design

Reveal

Awake Labs implements wearable sensing technologies to aid people in understanding anxiety and thereby improving quality of day to day life. The Lab is currently working towards building a fully resolved platform that enables real-time data collection of heart rate, motion and physiological arousal, in order to provide a level of support in the care of neurological disorders such as autismThe Labs latest campaign Reveal, Empowered Care for Autism; uses a clinically validated algorithm coupled with a wearable device to enable the wearer to self-monitor anxiety by providing real-time feedback (Awake Labs, 2019), prompting the user to implement strategies to prevent further escalation. The ability for the user to self-regulate enables users to remain autonomous and work towards health outcomes in collaboration with medical practitioners.

The European Network of Living Labs

The European Network of Living Labs uses the living lab methodology, as per their name, to create collaborative environments to best resolve given design problems. The concept of a living lab utilises four main activities: co-creation, exploration, experimentation, and evaluation (Popova, 2014). Throughout these stages, designers and users alike are able to identify emerging market opportunities, behaviours and conventions surrounding a given activity.

Live scenarios can then be staged with a community of users for the purpose of experimentation and evaluation of a concept, product or service (ENoLL, 2020).

Assessment can then be made through the lens of socio-ergonomic, socio-cognitive and socio-economic criteria.

ENoLL enable networking and communication with professional communities, as well as offering learning, training and knowledge to partners surrounding best practice and legal concerns.

ECHAlliance

ECHAlliance is a not-for-profit organisation that connects communities, institutions and organisations on a global scale to bring about innovation in the field of digital health.

The organisation provides not only business and research opportunities, but also delivers insights into market sectors, latest technology trends and other information to facilitate activity across its network (ECHAlliance, 2019a). ECHAlliance aims to develop educational opportunities, to support and engage collaborative R&D in support of broad scale connected health outcomes.

ECHAlliance's ability to connect communities has led to the creation of ECHAlliance Ecosystems across the world (ECHAlliance, 2019b). These Ecosystems are regionally focused, permanent, multi-stakeholder partnerships located globally, that are working together to develop innovative solutions that improve the quality of health and wellbeing of the community, as well as the effectiveness of healthcare systems. RMIT is a current partner of the network as part of the Melbourne Ecosystem. The relationship provides significant international collaboration opportunities (Johnston, 2019).

Newmind Network for Mental Health Technology

The NewMind Network for Mental Health Technology operates as a research council, offering multidisciplinary workshops involving researchers, clinicians, charities, service users and industry partners. The Network targets mental health issues including serious forms of mental illness, mood and affective disorder, dementia, and developmental disorders (NewMind Network for Mental Health Technologies, 2020a).

Through workshops, road mapping, and proposal development through sandpit workshops, stakeholders work towards developing real world solutions in the form of human-centric systems, sensing systems, information management and data analytics (NewMind Network for Mental Health Technologies, 2020b).

The Network also provides a series of frameworks to provide a structured approach to health outcomes and ethical approaches that clearly defines core principles which guide researchers working in this field.

AI, Machine Learning & Datafication

CTRL-Labs

The CTRL-Kit from CTRL-Labs is a non-invasive neural interface platform that enables the integration of neural control into XR, productivity, robotics, and clinical research applications. The Lab has recently merged with Facebook Reality Labs, extending their potential capability with the introduction of additional researchers, developers, and engineers working in augmented and virtual reality. The Lab works towards finding new ways in which humans may relate and interact with machines through new and intuitive devices such as the CTRL-Kit (CTRL-LABS, 2019).

Launched by the creator of Microsoft Internet Explorer, Thomas Reardon, and his partners, CTRL-Labs developed a novel approach for a brain–computer interface (BCI) using their own technology (Fields, 2018).

The CTRL-Kit device detects voltage bursts that are derived from the contraction of muscle fibres in the body, and in real-time, these electrical discharges are analysed, using the data to calculate the motion and force required. A computer-generated virtual limb then initiates the very same motions (Fields, 2018).

Google

DeepMind is a multi-faceted AI system able to be implemented in health and medical diagnostic applications. Working to develop algorithms specific to targeted datasets, DeepMind has generated viable

CTRL-Kit (CTRL-Labs, n.d.)

solutions to the diagnosis of a number of medical conditions (Senior, Jumper, Hassabis, & Kohli, 2020).

An example of one such outcome is the development of an algorithm that can automatically differentiate between healthy and cancerous tissues in head and neck areas.

An extension of this line of investigation was an international evaluation of breast cancer screening using AI technologies.

The study found that the artificial intelligence (AI) system developed through DeepMind was capable of besting radiologists in breast cancer prediction by an absolute margin of 11.5% (McKinney et al., 2020). In the event of a double-reading process for diagnosis, not only did the AI system continue to demonstrate enhanced performance, but it also "reduced the workload of the second reader by 88%"(McKinney et al., 2020).

In addition to the AI system, DeepMind also developed an app called Streams, which enables communication of data and alerts to clinicians about patients at risk of acute risk injury. In 2018, DeepMind's health division and the Streams app was absorbed into Google Health (DeepMind, 2020).

Medivis

The Surgical AR platform, developed by Medivis, is a visualisation tool that can be used in situ to guide surgical navigation. The goal is to improve patient outcomes and safety through the advancement of surgical accuracy. This is made possible through the ability to create holographic overlays increase surgical precision and potentially reduce time spent in the operating room (Shieber, 2019). The AR capabilities of the platform also enable data to be viewed in a hands-free spatial environment; a tool that could aid in on the spot decision making in surgical contexts (Fornell, 2019). This also offers true depth perception, and therefore can enhance the visuospatial understanding of various scenarios.

The Surgical AR Platform integrates within any legacy infrastructure within healthcare organisations, and enables surgeons to directly sync and integrate with hospital picture archiving and communication systems (PACS).

An extension of Medivis' work includes AnatomyX; an educational VR platform that utilises augmented reality and artificial intelligence to generate surgical visualisation with potential applications in surgical planning, training and performance (Medivis, 2020).

Embodied Labs

Embodied Labs has developed a virtual reality (VR) experience to facilitate training for caregivers and medical students for care and treatment of Lewy Body Dementia (LBD), and Parkinson's Disease amongst others. The program is entitled the Dima Lab, that provides users with a library of virtual experiences simulating key problems and situations that arise in the care of older adults suffering such conditions.

The technology is shown to develop empathy and compassion in participants (Adam, 2019) and represents an integral part of treating conditions such as dementia. The Dima Lab simulates "users experience of different types of dementia-related conditions through protagonists with diverse backgrounds" (Bushak, 2019). It also enables participants to experience the physical symptoms of diseases to better understand how to manage and treat patients in real life situations (AI MED, 2018).

The technology has also been extrapolated to deal with other aspects of ageing healthcare, including end of life conversation and other prominent diseases such as Alzheimer's disease.

*Embodied VR Experiences for Caregiver Training (*Embodied Labs. n.d.)

Philips Healthcare

Philips Healthcare works towards developing holistic system solutions for medical and clinical practice, alongside wearable and sensing technologies to provide improved health futures, compliance, and sustainable solutions for the future. Philips is currently developing cloud-based telehealth applications for home and hospital contexts, partnering with Salesforce to create a new clinical application, Philips eCareCoordinator (Philips, 2020).

The platform is defined as a “connected care application” that would enable clinicians to collaborate and monitor thousands of patients in real-time (Eddy, 2020).

In the way of devices, Philips has also developed proof of concept of a Brain Computer Interface (BCI) device that would enable ALS patients, or any person with limited muscle and speech function; to communicate and initiate commands without the use of vocalisation or physical movement (HospiMedica, 2019). The device provides users this ability “through a custom-built tablet application and wearable display interface”.

DATA 61 & CSIRO

ReMoTe (Remote Mobile Tele-assistance) is hands free, wearable, technology that connects remote experts with on site operators to provide real-time assistance when problems arise. An online cardiac rehabilitation program that can improve program completion rates and patient health outcomes. Emergency Situation Awareness software.

DATA 61 represents leading data innovation in Australia, seeking to address the challenge of developing a precision health ecosystem to service individuals and the broader medical community.

Part of the CSIRO, Data 61 collaborates with government and industry partners to harness knowledge in advanced analytics, AI and Machine Learning, and 3d modelling (Data61, 2019). Through research and development, outcomes generated provide applications that address access to health-related data in real-time, and non-invasive patient outcomes.

ReMoTe (Remote Mobile Tele-assistance) is one such outcome. It is a hands free, wearable device, that connects remote experts with operators to provide real-time assistance. The ReMoTe is not designed for a singular scenario or purpose. It has the capacity to be utilised in a number of fields such as (Data61, 2019):

- offering remote medical assistance for field health workers,
- remote vocational training programs which require physical and manual skills,
- cultural programs that link experts in remote Aboriginal communities with art students,
- remote inspection of product conformance for the manufacturing industry,
- emergency response scenarios,
- remote delivery of expert services for small and medium enterprises.

ReMoTe is designed to connect an operator and “helper” via wearable computing devices that provide visual and audio links through a near-eye display. The physical gestures and instruction of the helper can be seen through the point of view of the operator, with virtual gestures visible though the display (Alem, 2011).

RMIT

Micro/Nanomedical Research Centre

The Micro/Nanomedical Research Centre at RMIT works towards solving public health problems, in particular, the availability, accessibility and affordability of point-of-care diagnostics, drug delivery and advanced medical equipment. By developing advance tools and making them accessible to health practitioners and providers, there is potential to dramatically alter public health through effective diagnosis, prognosis, and treatment.

Applied research undertaken by the Centre has led to the successful development of “integrated low-cost portable devices for drug delivery and ultrasensitive chemical detection”. Such technology could be used in the detection of illicit drug use in varied scenarios (RMIT University, 2020c).

As the Centre continues its work, current studies are underway such as the exploration of acoustically-driven microfluidics for biotechnological applications, phononic and photonic nanostructures for enhanced biomolecular detection (Rezk, Manor, Friend, & Yeo, 2012), and Inhaled gene and nanomedicine for therapeutic treatments.

CAMIC : Materials & Industrial Chemistry

The Centre for Advanced Materials and Industrial Chemistry (CAMIC) investigates materials and industrial chemistry. The research Centre brings together the fields of industrial chemistry, materials chemistry, nanotechnology, catalysis and electrochemistry to facilitate the research and development of multifunctional materials, sensing technologies, and nano-biotechnology outcomes (RMIT University, 2020a). The Nanotechnology and Sensing group in CAMIC commonly focuses on multifunctional materials for chemical sensing, focusing on the development of various surface patternation (Sabri, Kandjani, Ippolito, & Bhargava, 2015). Patternation techniques are varied and can involve the deliberate arrangement of molecules at macro-scale, through etching, film deposition and electrochemical patterning processes. The resulting pattern corresponds with a particular function such as energy harvesting applications.

CMIFF : Centre for Materials Innovation and Future Fashion

The Centre for Materials Innovation and Future Fashion (CMIFF) investigates solutions for the production, design, and consumption of fashion and textiles. Ranging from textile fibres and yarns, apparel systems, and emerging textile technologies, CMIFF participates in interdisciplinary research through collaborative projects with sport, electronic engineering, aerospace engineering, product design and textile technology cohorts (RMIT University, 2020b).

From such research pathways, a multitude of applications are possible, including

Smart materials and wearable technologies, advanced materials and technologies for defence, functional apparel for sports and human performance technologies, and materials innovation to address real-world problems.

'High Risk Dressing / Critical Fashion': Opening Night. Collaborators: Professor Robyn Healy, Dr Fleur Watson, Kate Rhodes, Nella Themelios, Sibling Architecture, Studiobird, Caitlyn Parry, WOWOWA, Andre Bonnice and Ziga Testen (Titz, 2017)

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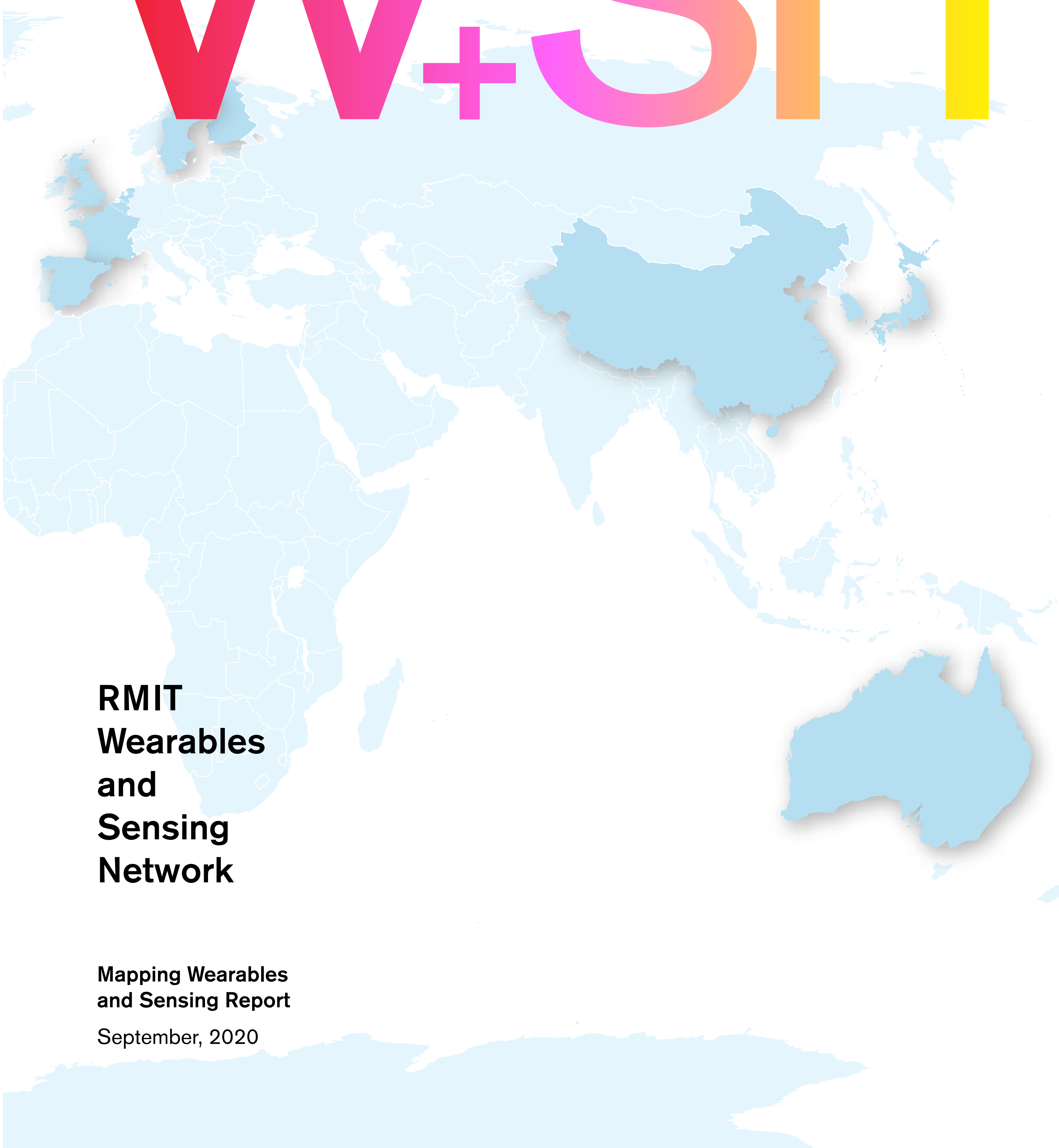


RMIT Wearables and Sensing Network

Mapping Wearables and Sensing Report

September, 2020

Wearables and Sensing Network | RMIT UNIVERSITY

Mapping Wearables and Sensing Report

Jaki Pokrovsky and Dr Jude Glover, School of Design

In order to understand the commercial and research environment in which W+SN is located we have undertaken an extensive mapping of labs and research centres. The research is helpful in enabling us to identify potential collaborators and to understand what our unique offerings might be.

Wearable and sensing technology within the health and medical industries are ubiquitous. The range of applications within this area alone range from implantable devices through to Personal Protective Equipment (PPE) and specialised equipment used within healthcare and medical practice. To best understand the growing market of wearable and sensing technologies, major categories of the sector have been defined. These categories include:

- Microtechnology & Nanotechnology
- Biosensors
- Biomedical Signal Processing
- Diagnostic & Therapeutic Systems
- Telemedicine & Telehealth
- Implantable Technologies
- Genomics
- Brain Computer Interface
- AI + Datafication, VR
- Mechatronics
- Health & Performance Monitoring
- Smart textiles
- Biomaterials

The industry is expansive, and constantly developing through the endeavours of research institutions and commercial industry on a global scale. This section will discuss and outline the scope of research and development in the area of wearable and sensing technologies in both commercial and institutional settings. The examples provided demonstrate the dynamic nature of the industry and allow the identification of trends occurring in the market.

Broken down into two broader categories of Commercial Labs and Research Labs, each company or institution is classified according to the most prominent aspect of their product and research outcomes. The categories are:

A closeup of lady's hand using a smart watch. Photo by Solen Feyissa on Unsplash.

- Material Innovation & Fabrication
- Devices and SWSS
- Sensors
- User Centred Design
- Nanotechnology
- AI, Machine Learning & Datafication

Key trends surrounding sustainability are emerging, largely involving ethical and environmental concerns around the production and disposal of technologies. Not only does the production of these technologies entail significant energy expenditure across product manufacture and life cycle, its use phase also requires energy, and options for disposal are limited, resulting in greater contribution to waste streams and climate change as a whole (Artem Golev, 2019; Manjula Shantaram, 2014).

In some respects, these sustainability trends are beginning to be addressed by investigations into alternate power sources, energy harvesting, as well as biomaterial alternatives. There appears to be a distinct need for further development in this area, to enable wearable health technologies to achieve optimal performance with minimal social impact.

Machine learning and the potential for AI integration into health technologies also presents as a growing trend. The development of data processing methods and translation may lead to more efficient and effective feedback mechanisms with the potential to create more user-friendly experiences for users and medical practitioners alike.

Conversely, trends around data are largely becoming focused on user centred design and by integrating such approaches to design, the user experience can be tailored and personalised to provide better or more holistic outcomes. More significantly, Datafication, a by-product of the growing market, presents as a gap in the market that is only beginning to gain warranted attention. In particular, data collection mechanisms, automation, data security and data management that have become an inherent component of wearable health technologies now appear at the forefront. With wearable technologies on the rise, it is evident that further development of data systems will be required in future to enable the utilisation of health devices and ecosystems.

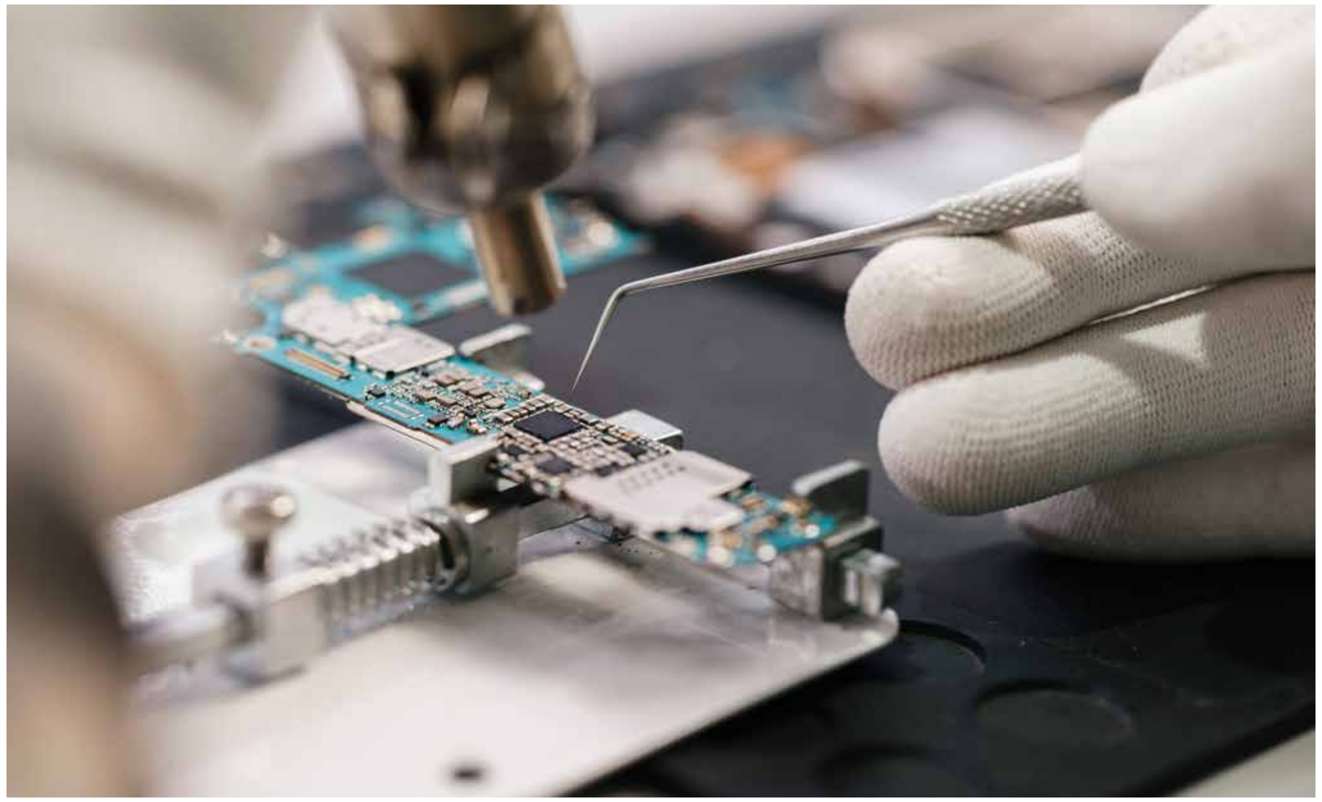
Additionally, these developments in data handling will call for investigation and deeper understandings of the ethical dimensions that exist around technologies developed in the wearable technology paradigm. Therefore, ethics and regulation present as upcoming trends that are progressively gaining traction.

Datafication also poses a risk of becoming an "asocial" form of technology, describing the loss of control of our data through various avenues as it is continuously compiled and gathered through devices and new sensing technologies. Not only does this lead to issues surrounding privacy and data ownership, but it also questions the value of data and how that concept alone could impact users' lives. Insurance structuring in the future, data platforms or aggregators, legal and operational hurdles surrounding the use of prospective wearable and sensing technologies, all require regulation and infrastructure in a relatively new and developing sector.

On a global scale, there is considerable innovation occurring in materials and fabrication technologies. This trend often pairs with the development of novel devices and SWSS that address broad themes of health and wellbeing, data, and sustainability in the market.

In terms of health and wellbeing, areas beginning to come to the forefront of wearable and sensing technology development include disability, mental health, and ageing as our global population ages. Coupled with human-centric methodologies, the need for responsive and inclusive technologies that tackle critical areas such as health and ageing is evident. This encompasses technologies capable of detection, prevention and intervention or action to improve health outcomes and morbidity status.

Overall, the wearable and sensing market has the potential to generate massive impact within the global community in all facets of healthcare and wellbeing.



Microelectronics device

Microtechnology & Nanotechnology

The study of Nanotechnology is a multidisciplinary scientific field that targets the manipulation of matter on a molecular and atomic level. The terms micro and nanotechnology are often used interchangeably (EMBS, 2019c) and denote technologies involving the miniaturization of mechanical processes and devices. This is inclusive of microcomputer parts, microdevices, microelectronics and applications for microsurgery. Such compact devices and processes enable practitioners to explore advanced methods of drug delivery, transdermal delivery systems, tissue and cell engineering, restoration of DNA and a myriad of other applications (Langer, 2018) within the medical industry alone. Techniques utilised within the scope of nanoengineering and technology include nanomanipulation, nanomeasurement, nanofluidics, nanomechanics and nanofabrication (K.-K. Liu & Chan, 2011).

Biosensors

Biosensors can be defined as any hardware (EMBS, 2019b) that is able to respond to defined biochemical or biological reactions within a biological or physiological system in order to generate a measurable signal (Lowe & Potter, 1989) for either diagnostic or therapeutic purposes. Typically, a biosensor will comprise of two elements; a surface-linked biological compound and a transducer for detection (Szunerits & Boukherroub, 2018). The associated biological compound is attached to the transducer surface using methods of absorption, entrapment within a polymer matrix and the formation of other molecular bonds through cross-linking or covalent bonding (Kiran & Misra, 2015). In essence, the compound utilised create a bioreceptor designed to interact with a specific target, converting biochemical data derived from an event or change in state, into a measurable output (Kiran & Misra, 2015).

The data generated through the use of biosensors can then be processed using biomedical signal processing (EMBS, 2019b) techniques to then enable interpretation or automatic response mechanisms.

With constant development and research into the field of biosensors, this particular aspect of the wearables and sensing market remains competitive (Grand View Research, 2019).

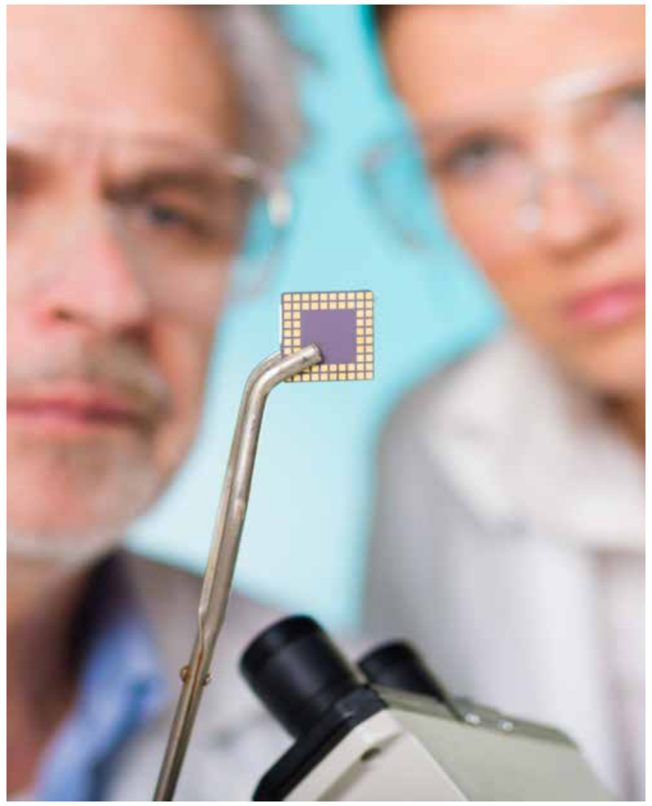
Diagnostic & Therapeutic Systems

Diagnostic and therapeutic devices or methods are developed in tandem and require a multidisciplinary approach in order to create holistic diagnostic systems to treat patients and respond to data generated. Such systems form a sort of ecosystem of physical sensing commonly referred to as diagnostic or therapeutic systems. Used in conjunction with various data collection and management mechanisms, such systems enable diagnosis by another external party or, perhaps initialise automated responses to treat or assist the patient/user. Typically, such diagnostic and therapeutic systems are integral in the context of hospital and surgical care. As technology evolves, new diagnostic systems are being developed on a nanoscale, including bio-microelectromechanical systems (Cheung & Renaud, 2005). Such systems entail the use of implantable biomedical microdevices or "lab-on-a-chip" diagnostic systems to monitor and detect conditions from within the body (Cheung & Renaud, 2005). These advances have the potential to generate new forms of therapeutic treatments.

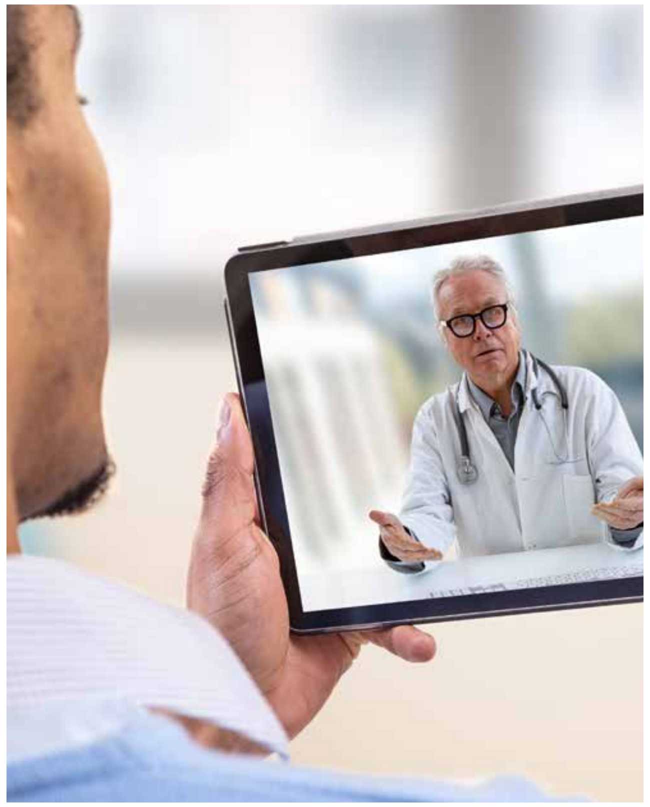
Telemedicine & Telehealth

Telemedicine is defined as an "integrated system of healthcare delivery that employs telecommunications and computer technology" (Bashshur, 2009) in place of direct contact between provider and client. More specifically, telemedicine enables the provision of remote healthcare services, clinical services, and education from afar to ultimately advance patient's overall health status. In the absence of localised services, telemedicine permits remote consultations and remote expertise to become vastly more attainable.

In modern practice, telemedicine now encompasses a wider array of services and capabilities (ATA, 2019) including machine learning, AI, and virtual reality simulations. Conversely, telehealth is defined as remote non-clinical services, that is able to provide and



Lab-on-a-chip diagnostic system



Virtual live chat between young male patient and doctor in telemedicine or telehealth.

facilitate practitioner training, administrative capabilities, and medical education, in addition to clinical services (Eren & Webster, 2015). Simply put, telehealth is all-encompassing, providing technology-enabled health and care management and delivery systems that in effect, extend capacity and access to improve upon the experience and health of a patient.

Biomedical Signal Processing

Biomedical Signal Processing is the analysis and interpretation; human or automated, of observed signals generated by physiological activities of organisms. Activities observed can range from monitoring and analysis of gene and protein sequences, to neural and cardiac rhythms, to tissue and organ images (Hsun-Hsien Chang, 2010). This process involves the analysis of collated real-time data to provide useful information to assist clinicians and patients alike in determining responses to health concerns. Biomedical Signal Processing has enabled the utilisation of more sophisticated means of analysing patient health (EMBS, 2019a) through more non-invasive measures. Biomedical Signal Processing pertains to real-time monitoring, cloud computing and Multi-scale Signal Processing.

Implantable Technologies

The term implant is used for devices that replace or act as a part of an existing biological structure. Implantable technologies or devices are defined as such if it is partially or totally introduced, medically or surgically, into the body with the intention that it remains following the procedure (Joung, 2013). Implantable devices exist in numerous forms and can be embedded throughout the human body and provide structural, functional and mechanical support (Wahid Khan, 2014).

Implantable devices with computational capability are typically characterised by an autonomous power supply capable of measuring and transmitting data from inside the human body (Eren & Webster, 2015) and are constrained by specific set of requirements in order to function and embed successfully in the body. Common applications include pacemakers, monitoring technologies for the heart and Parkinson's Disease, dermally implanted sensors, and extend towards new technologies in drug delivery systems and neural prosthetics (Wahid Khan, 2014).

Sobot (2018) categorises the diverse ecosystem of technological devices within distinctive categories, based on the proximity to the body itself, the final categories being indicative of implantable devices from the present into the future.

1. External technology: technologies that exist in close proximity to the body and have become personal commodities. For example, technologies such as mobile phones, computers, and smart watches, amongst other things.
2. Internal technology (temporary): technologies that temporarily cross the traditional external boundary line of our body, and can easily be put in, or conversely, removed, by the user. The device is only in contact with the body for a limited time frame. For example, contact lenses and ingestible biotelemetric capsules.
3. Internal technologies (permanent): Inclusive of implantable technologies that are designed to co-exist within the human body with its natural organs for the duration of the user's lifetime. The device is permanently inserted via a medical procedure and no further user intervention is possible. Examples include pacemakers, and cochlear implants.
4. Bio-mechanical integrated technology: This category infers the possibility of complete

X-ray of permanent pacemaker in a chest.

integration between a biological being and implantable technology. In the future, this could emerge in the form of cybernetic technologies where artificial entities or body parts are able to seamlessly co-exist with the natural body and its systems.

Genomics

As an emerging medical discipline, genomics encapsulates the use of an individual's genomic information to offer pathways to personalised clinical care through targeted diagnostic and therapeutic analysis (National Human Genome Research Institute, 2019). With the development of this field, there are now opportunities to create personalised medicines (Baba, 2002). In the fields of oncology, pharmacology, and disease and medicine, genomics has the potential to generate considerable impact through the analysis of genetic material.

Brain Computer Interface

BCI is a form of wearable technology that enables the restoration of the body's ability to detect proper neural or muscular activities above the level of injury. Such devices can be either invasive, partially invasive, or non-invasive (Shih, Krusienski, & Wolpaw, 2012), depending on the form of disability and the device's proximity to the body. Essentially, the BCI device enables lost body or communication functions through the detection of voluntary changes in brain activity. A range of sensors and imaging modalities are able to detect such changes.

These changes in effect act as signals that create an input to the BCI that can in turn be encoded as patterns and converts the defined activity onto command controls (Sen, Datta, & Mitra, 2018). BCI's are adaptive technologies with predictive capabilities, so that over time the user's operation becomes more streamline, similar to muscle memory.

AI + Datafication, VR

With the introduction of wearable health devices that possess the ability for data collection, data transmission and processing, the datafication of data-driven medical research and public health infrastructures, clinical health care, and self-care practices has become a critical point of contention.

An Electroencephalogram (EEG) head cap to measure EEG signals for Brain Computer Interfaces.

Although this does not constitute a physical artefact, it is a prevalent feature of a market defined and saturated by the presence of digital capability.

Datafication raises questions pertaining to data security and accessibility to personal information, data infrastructure, accountability (Hoeyer, Bauer, & Pickersgill, 2019), as well as the growing impact of algorithms in data processing applications (Foot, Boczkowski, & Gillespie, 2014). Whilst the technology in the realm of wearables and sensing have grown exponentially, the concern surrounding these themes of security and autonomy have begun to emerge (Mittelstadt, Allo, Taddeo, Wachter, & Floridi, 2016; Ruckenstein & Schüll, 2017).

Alongside datafication, Artificial Intelligence (AI) and Machine Learning (ML) in healthcare encompasses the use of complex algorithms and software to emulate human cognition in the analysis and processing of medical data. Traditionally, statistical methods have approached this task by characterising patterns within data as mathematical equation (Buch, Ahmed, & Maruthappu, 2018), however, through Machine Learning, AI is able to uncover complex associations within data streams that cannot be reduced to a linear equation. The integration of AI technologies also raises lines of enquiry surrounding data protection and accessibility.

Doctor using virtual reality glasses.

VR technologies are also an emerging entity in the wearables and sensing markets with a range of potential applications. Currently, VR is proving a useful tool in education within the medical sector as well as offering an additional form of communication in telemedicine systems. There are also potential future applications for VR, particularly in the surgical field, with capabilities of providing assistance to surgeons through augmentation, real-time assessment, layered technologies and the implementation of parallel and disruptive technologies (Medivis, 2020).

Mechatronics

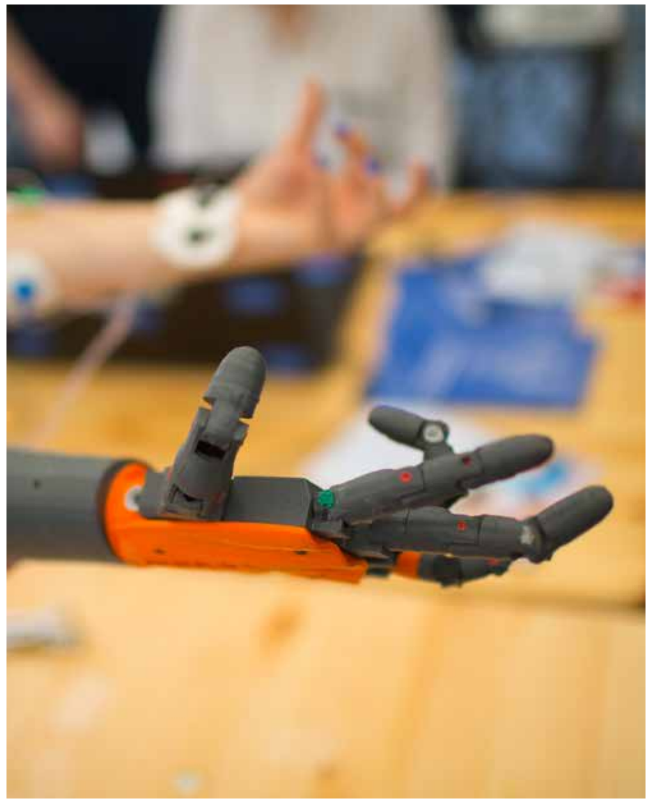
Mechatronics is a specialised field within mechanical engineering that focuses on the integration of electronics, computing capabilities, and hardware to create “smart” devices. It is an extensive field of knowledge, impacting a majority of industries worldwide (Davim, 2011).

Mechatronics in the medical and healthcare fields plays an integral role in the improvement of healthcare services and devices. In terms of medical applications, mechatronic capabilities can be implemented in the design and improvement of real-time data analysis, electric and mechanical systems design, Machine Learning application, biosignal sensing, and assistive and rehabilitative systems (Y.-H. Liu, Moratal, Escudero, & Huang, 2018).

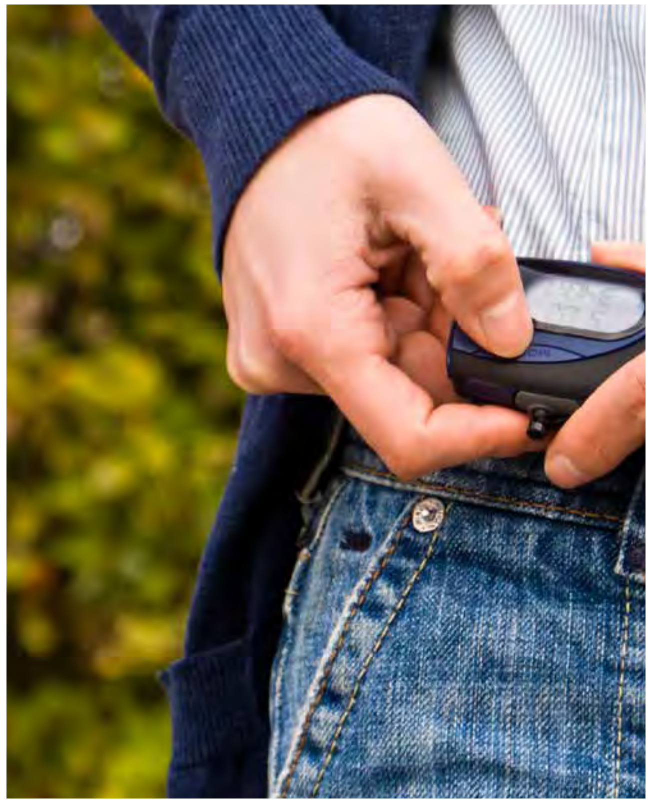
Current trends in this field include the continued simplification of miniaturised systems, making them lighter, more efficient, and cost effective to produce. As with other wearable devices in medicine and healthcare, the ability to dispose of such devices remains at the forefront as consumer electronics decrease in cost (“Mechatronics Improves Design & Operation”, 2013).

Furthermore, there continues to be emphasis placed upon the patient user experience, ranging from comfort, usability and aesthetics of mechatronic devices as human centred design methodologies become more and more integral to the development of these products.

Despite the positive impact possible within mechatronic advances, contemporary developments associated with automation, artificial intelligence (AI), robotics, data, next-generation internet, and social and mobile media networks raise profound questions about the relationship between technology and society, and how these technologies are becoming integrated into everyday life in Australia and elsewhere (Davim, 2011).



Robotic hand



Woman checking her pedometer while walking.

Health & Performance Monitoring

Devices for monitoring physical activity and performance are somewhat synonymous with modern day smart devices. Pedometers, heart rate monitors are geolocation tracking very readily at a user's disposal, being inbuilt into personal accessories and cellular devices. However, the market for more targeted performance and health monitoring is expanding. For example, performance monitoring for professional athletes has shifted towards smart textiles and holistic product systems that enable data collection, real time analysis and intelligent processing to maximise the effectiveness of personalised training programs.

In terms of health monitoring, there are numerous conditions where a form of wearable or sensing technology could benefit the maintenance and diagnosis of that condition. In this respect, such devices encapsulate any combination of processes, technologies and physical forms under the broad umbrella of wearable and sensing technologies.

Smart textiles

Smart textiles can be defined as textiles that are able to sense and respond to changes in their environment. They may be divided into three classes: passive, active, and Very Smart textiles.

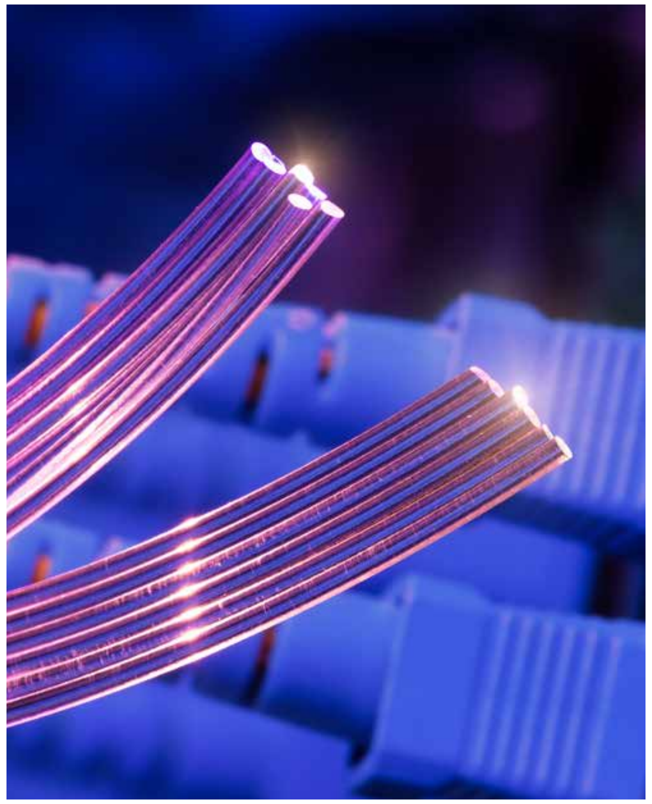
Passive Smart Textiles constitute the first generation of smart textiles found in garments, which can detect environmental and/or body conditions. Active Smart Textiles refer to the second generation which has the ability to both sense and react to stimuli through the provision of both actuators and sensors. Very Smart Textiles as the third generation not only sense and react like its predecessor, but also adapts to a given stimuli (Koncar, 2019).

Smart textiles refer to a broad field of research and products that increase the functionality of common fabrics. This encompasses textile products such as fibres, filaments, yarns that are woven, knitted or nonwoven structures, which can interact with an environment and/or user (Weng, Chen, He, Sun, &

Peng, 2016). Within smart textiles, there is also the convergence of textiles and electronics – E-Textiles. With the addition of electronic components, the capability of smart textiles increases exponentially. Essential components in smart textiles include sensors, actuators, data processors, communication units, and a dedicated energy supply.

Examples of applications for smart textiles include: photosensitive materials, fibre optics, conductive polymers, thermal sensitive material, shape memory materials, intelligent coating materials, chemical responsive materials, micro-capsules, micro and nanomaterials, and biomimicry.

Smart textiles as a wearable and sensing technology provide a non-invasive method for monitoring, measurement, and other medical applications.



Fibre optic technology for application in smart textiles.

Biomaterials

Biomaterials are defined as biocompatible materials –being natural, synthetic, alive or lifeless, that offer a number of potential biomedical applications such as the augmentation or replacement of natural function. Biomaterials may include synthetic materials such as metals, polymers, ceramics and composites, but also biological matter such as proteins, cells and tissues (Ruys, 2013). The scope of Biomaterials is broad, with key areas of inquiry and development including (Ruys, 2013):

- Implantable technology including artificial joints, ligaments and tendons, hearing and dental implants, grafts, stents and valves, as well as for nerve stimulation.
- For the purpose of regenerating tissues, Biomaterials may be used in the creation of scaffolds, cells and bioactive molecules to stimulate growth as well as tissue engineering. Examples include a bone regenerating hydrogel, as well as lab grown organs. By extension, biomaterials can also be used to promote healing. For example, materials used for wound closure and dissolvable dressings, also fall under this category.
- Molecular Probes and other nanoparticles are utilised in imaging and therapeutic techniques on a cellular level.
- Biosensors
- Drug delivery systems are another application well-suited to biomaterials as they are used to carry or apply drugs to a disease target within the body.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of Semiconductor Materials
chnique Fédérale de Lausanne
witzerland
Someya Group : Organic Transistor Lab
The University of Tokyo
Bunkyo City, Tokyo, Japan
iHealthTech : Institute for Health Innovation & Technology
National University of Singapore
Singapore
CMIFF : Centre for Materials Innovation and Future Fashion
RMIT School of Fashion and Textiles
Melbourne, AUS
Micro/Nanomedical Research Centre
Functional Materials and Microsystems Research Group
CADES : Centre for Advanced Electronics and Sensors
CISM : Innovative Structures & Materials
RMIT School of Engineering
Melbourne, AUS
CAMIC : Materials & Industrial Chemistry
RMIT College of Science, Engineering and Health
Melbourne, AUS
Design Factory
SEAM : ARC Training Centre
Bioengineering Research Group
DMM-G : Design, Manufacturing and Mechanics Research Group
CDI : Centre for Design Innovation
Swinburne University
Hawthorn, Melbourne, AUS
Design Lab
STuF Lab : Socio-Tech Futures Lab
The University of Sydney
Sydney, AUS
Intelligent Polymer Research Institute
Institute of Superconducting & Electronic Materials : ISEM
University of Wollongong
Wollongong, NSW, AUS
Therapeutic Technologies Hallmark Research Initiative
Ageing Hallmark Research Initiative
Melbourne University
Melbourne, VIC, AUS
IISRI : Institute for Intelligent Systems Research & Innovation
IFM : Institute for Frontier Materials
Deakin University
Waurn Ponds, VIC, AUS
WearOptimo
Australian National University
Canberra, ACT, AUS

Established University Research Labs

On a global scale, exciting developments and avenues of research are being undertaken to further advance current technologies in wearable and sensing technologies.

Major categories of innovation include:

- Material Innovation and Fabrication
- Devices and Smart Wearable Sensing Systems (SWSS)
- Nanotechnology
- Sensors and Sensing Capabilities
- User Centred Design
- AI, Machine Learning & Datafication

Detailed below are outcomes and areas of research undertaken by established research labs such as those situated within university research bodies, as well as commercial labs within the broader industry.

Material Innovation & Fabrication

Wearable Technology Lab - University of Minnesota

WTL from the University of Minnesota has generated a series of projects surrounding dynamic compression technologies. Able to be remotely controlled to provide specific pressure or pressurised action, the technologies explored look into shape adapting materials that are able to be integrated in various fashions in benefit health outcomes (Wearable Technology Lab, 2020). One such projects focuses on the development of garments suited to cardiovascular applications and for the treatment of Sensory Processing Disorder (SPD).

Bao Research - Stanford University

Hailing from Stanford University, the Bao Research body explores new methods and technologies surrounding fabrication and material innovation for wearable health technologies. Their approach is multidisciplinary, with active involvement from fields of expertise such as chemistry, chemical engineering, biomedical engineering, materials science and engineering, physics, and electrical engineering.

Central to the Bao Group's research is the investigation of functional organic and polymer materials and how they can be synthesised for targeted use in health monitoring and treatment (Bao Group, 2016). This includes the development and fabrication of organic electronic devices such as organic carbon solar cells and electronic skins, in addition to research surrounding possible applications for new organic electronic technologies.

In 2018, the Group undertook an investigation into flexible organic electronics that have potential applications in neurorobotics and neuroprosthetics (Kim et al., 2018). The project generated an artificial device to mimic the functions of sensory nerves within the body. Able to collect and process simultaneous pressure data inputs, the device can also detect movement and has been further developed for applications that require the actuation of muscles (Hwang et al., 2012).

Current endeavours at the Bao Research group focus on fundamental areas surrounding nano-scale electronics, creation of alternative energy sources, disposable sensors, and large area flexible plastic circuits and screens, and cost-effective production. Within this scope, the group has generated devices including organic and carbon nanotube thin film transistors, organic photovoltaic cells, chemical and biological sensors, and molecular switches (Son et al., 2018).

Bottom right: Zhenan Bao, a chemical engineer at Stanford University, is working to invent an artificial skin from plastic that can sense, heal and power itself. The thin plastic sheets are made with built-in pressure sensors (Bao Research Group, n.d.)

Emerging Materials Lab - Delft University of Technology

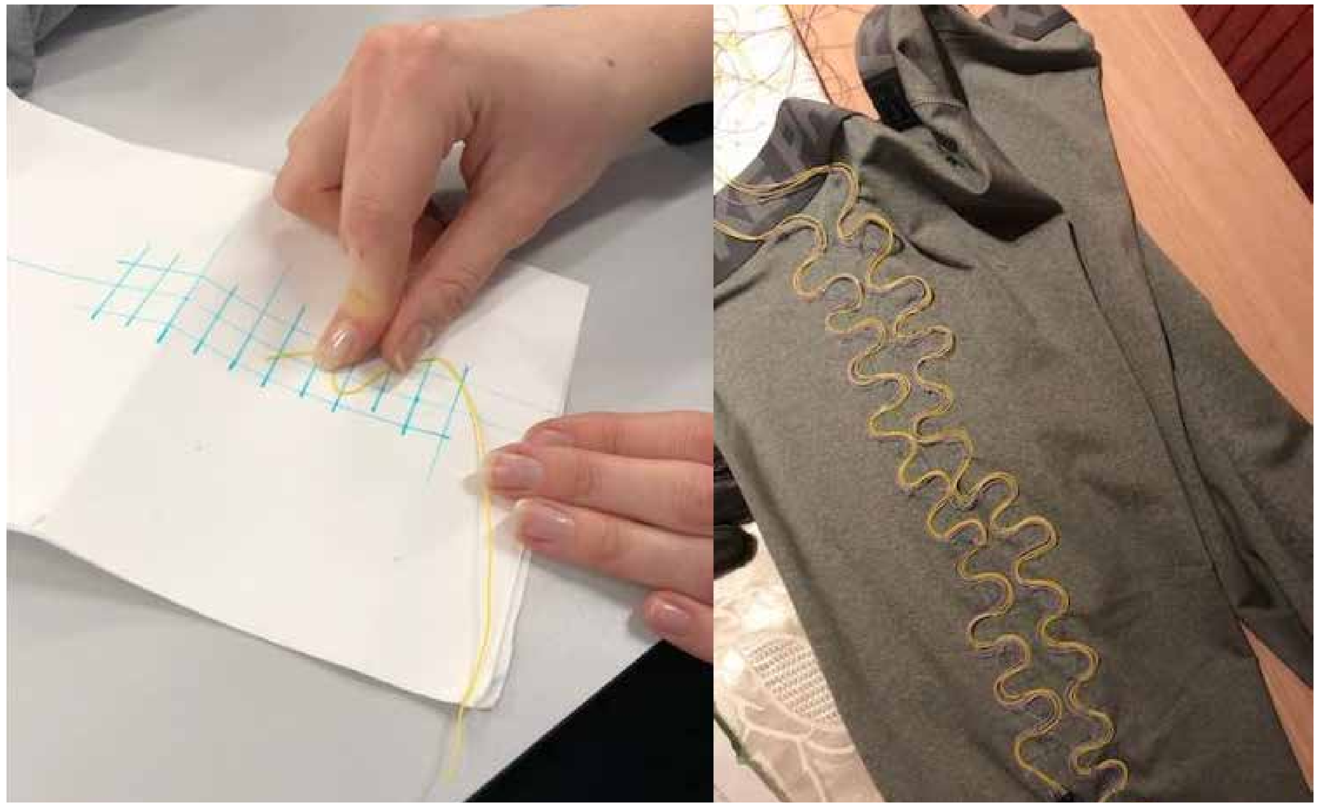
The Emerging Materials Lab from Delft University of Technology generates research and product development focusing on environmentally sensitive materials, and shape morphing materials under the broader construct of Smart materials. The Lab maintains a holistic approach to its research, by encompassing the end user and their experiences, considerations around societal impacts, and fabrication and materiality in order to facilitate meaningful and successful application outcomes. Starting in 2018, the project Citius Altius Sanius began, looking into how a reduction in hamstring injuries for athletes could be affected using smart textiles (Faculty of Industrial Design Engineering, 2018). The subsequent form was a smart sensing short, embedded with soft sensors able to monitor movement occurring around the hip and knee joints during exercise (Jansen, 2019). The combination of sensors and measurement data system put in place was able to accurately measure local knee and hip angle movements as per the highest bracket standard on local motion measurement.

Laboratory of Semiconductor Materials - École Polytechnique Fédérale de Lausanne

The Laboratory of Semiconductor Materials specialises in semiconductor technologies in relation to health applications of the future. Through the synthesis and characterisation of novel materials and structures, the Laboratory investigates methodologies for solar energy harvesting and computing capabilities on a Nano scale (Laboratory of Semiconductor Materials, 2020). In terms of fabrication, the Lab seeks to develop standardisation in the production and implementation of nanowires used in conjunction with silicon surfaces (McIntyre & Fontcuberta Morral, 2020).

iHealthTech : Institute for Health Innovation & Technology - National University of Singapore

The Institute for Health Innovation & Technology is an interdisciplinary space that facilitates collaboration between engineering, science and medicine to inform innovation and outcomes in healthcare. The Institute targets a broad range of applications and end users, ranging from medical facilities, communities, to singular



Smart Sensor Shorts Version 1
(Emerging Materials Lab, n.d.)

patients and practitioners. Integral technologies within iHealthTech's practice include smart textile applications, prosthetic skins and robotic and sensing technologies.

A key outcome for the Institute includes the development of a wireless body sensor network that can be readily incorporated into clothing to dynamically connect several wearable devices at once (Tian et al., 2019). The use of conductive fabrics, or metamaterials, in its given form, creates a radiative network that exists as "surface waves" around the body rather than being radiated out and away from the body as per traditional radiative networks (Draper, 2019). As a result, the wireless body sensor network enables wearable devices to consume much less power, as well as amplifying their ability to detect weaker signals. Additionally, the network is able to confine wireless communication within 10 cm of the body as well as amplify battery life of devices within immediate proximity (Tian et al., 2019).

Institute of Superconducting & Electronic Materials (ISEM) - University of Wollongong

The Institute of Superconducting & Electronic Materials at the University of Wollongong focuses their research primarily on superconducting and electronic materials science and technologies. Ranging from vehicular applications to Terahertz technologies, ISEM works towards the technological and commercial development of advanced energy solutions.

In relation to medical applications, ISEM studies the possibilities of applied superconductivity for electrical and medical devices; methods for energy conversion and transmission on various scales; spintronic and electronic materials, in addition to nanostructured materials. Wearable "energy–smart" ribbons (Li et al., 2016) was one such project developed by ISEM proving to be a promising energy source for various wearable applications that would enable the device to function whilst simultaneously harvesting and storing energy. due to the highly flexible nature of the resulting ribbon, the energy-smart material is also able to be woven directly into fabrics (Li et al., 2016).

Someya Group, Organic Transistor Lab - The University of Tokyo

Based at the University of Tokyo, the Organic Transistor Lab, works towards the design and fabrication of organic transistors, flexible electronics, plastic integrated circuits, large-area sensors, and plastic actuators for a range of applications, primarily within the healthcare bracket. The Organic Transistor Lab has begun extensive investigation into Organic Photovoltaics (OPVs). OPVs are lightweight and flexible in nature and offer options for saleable fabrication, as well as high energy conversion efficiency (Yu et al., 2019). Through research and further development of materials, structure, and integration methods, the Lab is working towards a self-powered actuator for a tactile feedback system.

The potential of long-term electrophysiological monitoring is also being explored, with the development of an ultrathin OECT based wearable electrophysiological sensor using an electrolyte gel. The device can take continuous readings from the body and shows stable performance even after multiple reuses beyond several days (Lee et al., 2019).

Devices and SWSS

Nano-Cybernetic Biotrek - MIT MEDIA LAB

The Nano-Cybernetic Biotrek group from MIT Media Lab, investigates and develops disruptive technologies on a nanoscale and in turn creates new paradigms for life-machine symbiosis (D. Sarkar, 2019). Alongside the study of scalable and efficient nanoelectronics, and biosensors for point-of-care applications, the Biotrek group conducts a great deal of research into Nano-implants for energy harvesting and wireless sensing capabilities.

An example of this line of research is one of Biotrek's latest projects, that explores the potential capability for devices to conduct internal analysis of a biological system whist enabling remote monitoring, electrical stimulation and potentially site-specific drug delivery (Sarkar, Wassie, Piatkevich, & Boyden, 2018). A key function of these proposed devices is the ability to harvest its own energy, to enable autonomous function and enable communication of data from targeted sites. The development of Nano devices using metamaterials allows Biotrek to investigate possible medical applications such as (D. Sarkar, 2019):

- monitoring and recording brain activity recording at a large scale with the precision of a single neuron
- monitoring and recording of the peripheral nervous systems
- monitoring tumours and their corresponding microenvironment
- observing treatment response
- and observing stimulus responses.

Biotrek believe the possible applications for such technology is endless, and in terms of medical treatment; possibly game changing.

MIT Comfortable Decoders - MIT MEDIA LAB

MIT's Comfortable Decoders from the MIT Media Lab researches novel approaches to create micro and nanoscale electromechanical systems with the ability to conform to or integrate closely with the chosen object of interest. Through the exploration of materials, methods of fabrication (Wicaksono, 2019) and development of physical forms, Comfortable Decoders are able to generate mechanically adaptive technologies that enhance a user's interactions with their body, environments and others.

By collecting and converting data from observations of nature and the body, the said data then informs the development of conformable Decoders various consumer electronics, biotechnology and engineering outcomes.

An example of a Comfortable Decoders project within the scope of wearable and sensing technologies includes the Miniaturized Neural System for Chronic, Local Intracerebral Drug Delivery (MiNDS). MiNDS is a miniaturised neural drug delivery system that enables dynamic adjustment (Obidin, Tasnim, & Dagdeviren, 2020) of dosage. The development of this system enables the adjustment of therapeutic drug delivery to the brain with pinpoint spatial accuracy. The device is an invasive method; taking the form of an implantable device that can be remotely controlled whilst simultaneously recording neural activity to better inform feedback control (Oran, 2019).

Synthetic Neurobiology - MIT MEDIA LAB

MIT Media Lab's Synthetic Neurobiology group develops novel nanoelectronics and computational devices as well as smart textiles and nano-materials to explore possibilities for probing, sensing and moderating capabilities for therapeutic applications relating to the body and brain (Bando, Chen, Cai, Boyden, & Gyu, 2019).

The SensorKnits project utilised the accessible and highly flexible manufacturing process of digital machine knitting to fabricate smart textile outcomes (Oran, 2019). Through the design and creation of various textile structures embedded with conductive and dielectric yarns, it was found that the resistance

MiNDS connected to two wireless micropumps (Brauer, M. S. n.d.)

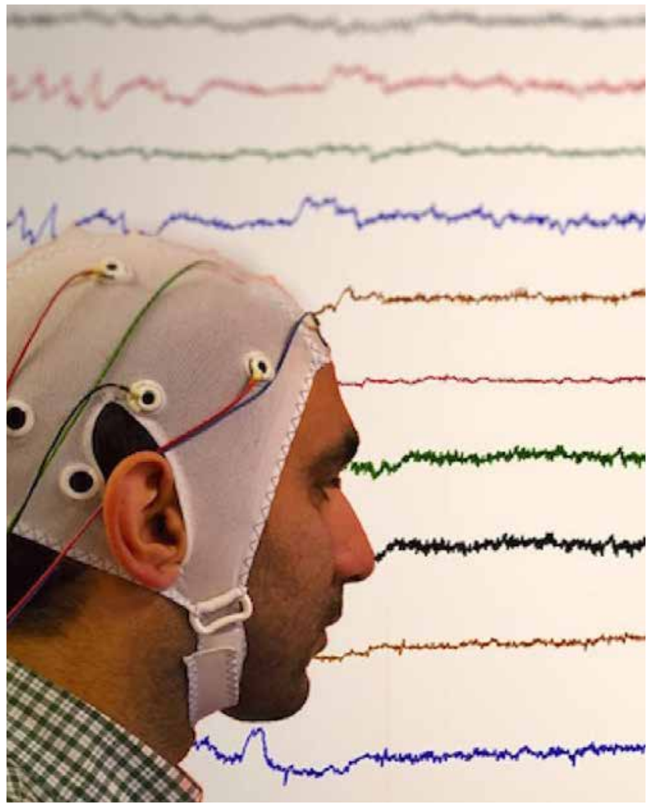
A tablecloth rheostat with magnetic balls to set the resistance (Oran, n.d.)

of the knitted fabric was able to be controlled through programming. Rather than positioning the project as further investigation into interaction design, the project explores the correlation between the knitted structure and electrical properties of a textile.

Wearable Technologies Lab - Imperial College London

Based at the Imperial College of London, the Wearable Technologies Lab specialises in monitoring technologies primarily concerned with cardiac and respiratory function within the personal healthcare space (Wearable Technologies Lab, 2019). Currently, key projects focus on epilepsy, sleep conditions and respiratory medicine with a strong attention to ergonomic design and how to best integrate these technologies into patients' lives.

In the area of respiratory function and illness, the Lab works towards developing products and methods to reduce health, financial, and social burdens to improve overall quality of life for a patient as well as speeding up the diagnosis process (Pramono, Imtiaz, & Rodriguez-Villegas, 2016). A recent outcome for the Lab includes an algorithm designed to analyse cough audio signals in



Intelligent signal processing and algorithms for health management (Wearable Technologies Lab - Imperial College London, n.d.)

children to provide automatic diagnosis of Pertussis.

The algorithm undertakes three main tasks, performing an automatic cough detection, cough classification and whooping sound detection. Throughout the testing phase, the Lab found that the algorithm was able to "diagnose all pertussis successfully from all audio recordings without any false diagnosis" (Pramono et al., 2016). There is potential for the algorithm to be used with smart devices for quick identification and early detection.

Centre for Medical Engineering Research - Dublin City University

The Centre for Medical Engineering Research at Dublin City University centres their research around the translation of engineering and materials research into viable healthcare solutions for the commercial market. Operating as a multidisciplinary practice, the Centre comprises of three main branches; materials science, biology, and engineering (Centre for Medical Engineering Research, 2019). Through research, the MEDeng Centre develops a range of products ranging including biomaterials, drug delivery systems, biomechanics, and surface engineering and coating technologies.

The Centre for Medical Engineering Research primarily focusing on medical devices and implantable technologies used to promote tissue repair and regeneration.

For example, the MEDeng Centre developed a coronary stent fabricated from poly(L-lactic acid) that resulted in illuminating the potential for a high stiffness (Blair, Dunne, Lennon, & Menary, 2018), polymeric expandable scaffold appropriate for the application of coronary stents.

KEA Wearables Lab - KEA Copenhagen School of Design & Technology

The KEA Wearables Lab heralding from the KEA Copenhagen School of Design & Technology provides access and facilities to students to provide education programs about basics in electronics and sensing technologies to create an environment where fabrication skills and conceptualisation can grow together within a collaborative space (KEA, 2019). The Lab also has connections to external businesses to produce potentially market ready products and apply research knowledge through design partnerships. The KEA Lab

Valo, a wearable compass to guide the user back to a specific location or person (Johansen, Gravesen, & Stenalt, n.d.)

has a strong presence in jewellery and textile wearable design with a focus on sustainability (KEA, 2019).

Living Lab - Melbourne University

The University of Melbourne's Living Lab centres on wearable and sensing technologies based around behavioural and healthcare applications.

The Lab developed the Smart Hospital Living Lab that creates an immersive experience for the conceptualisation and testing of practical solutions for healthcare providers through quick prototyping and iteration in situ in partnership with Industry members (The University of Melbourne, 2019).

The project focused on mobile and wearable technologies including new system architectures, wearable materials, novel sensor and machine learning techniques, in order to develop interactive systems and intelligent sensing solutions to improve hospital safety and logistics (The University of Melbourne, 2019).

Issues surrounding security and privacy, and geographical data analytics are also broached, the ultimate goal to generate a human-centred, real-world approach to creating impact within the context of hospitals and the healthcare industry.

The Pillbox was a part of the Living Lab and its outcomes, exploring the potential for the use of Near-Infrared Spectroscopy technology (NIRS) scanners for the identification of pharmaceuticals (The University of Melbourne, 2019) before being administered to patients. The product would work to minimise the financial and human costs incurred from medication mismanagement and error.

Sensor Technology Research Centre - University of Sussex

The Sensor Technology Research Centre of the University of Sussex undertakes extensive research into wearable computing and embedded intelligent systems, flexible and stretchable electronics, mobile and wireless communication, IoT and vehicular networks, electrophysiology (Prance, Watson, Prance, & Beardsmore-Rust, 2012) and the fundamentals of sensor technologies. This research facilitates further endeavour into developing wearable/IoT sensing platforms, smart textiles and considered objects to formulate holistic product and system outcomes (University of Sussex, 2019). Under the STRC banner, there are additional groups working within the wearable and sensing technology space including, flexible and stretchable electronics, wearable and embedded technologies and sensor fundamentals.

Sensors

Responsive Environments - MIT MEDIA LAB

Research from the Responsive Environments group of MIT Media Lab encompasses the development of sensor networks, energy harvesting capabilities, and power management techniques within wearable computing and medical applications. Through this research the Lab investigates human experience, perception and interactions within a number of fields.

Space Skin is a project undertaken by the Lab to develop aerospace grade electronic textiles, a material that would be able to detect hypervelocity impact and directly monitor and measure local conditions (Cherston, 2019). The material is woven, with sensory fibres embedded throughout. The resulting prototype exhibited the smart textile being woven into Teflon-coated fiberglass, which is used as the outermost skin of the International Space Station. The combination of materials and application gives the overall design the ability to both sense and protect (Cherston, 2019). In further development of the project, manufacture methods and necessary material properties for aerospace applications are to be explored in addition to the possible inclusion of secondary sensing systems to support the optimal function of the skin itself (Cherston & Paradiso, 2019).

National Centre of Sensor Research - Dublin City University (DCU)

The NCSR focuses primarily on the science behind chemical and biosensors and their respective applications. Currently, such technologies are suited to providing more accurate medical diagnoses, improving the ability of industries to monitor processes, improve energy efficiency and the state of the environment. The NCSR works across a multitude of fields, including environmental, biomedical, material innovation, and imaging. In the way of medical applications, NCSR focuses predominantly on biomolecule isolation and purification, micro instruments, sensors and systems, disease diagnosis and monitoring, and point of care applications.

An example of NCSR's work includes a project based on biomimetics, involving the manipulation of surface microstructures to inhibit the settlement or attachment of identified microorganisms for antifouling technology applications (Sullivan, McGuinness, Connor, & Regan, 2014). The concept of engineering cell surfaces enables the ability to potentially control cellular behaviour. The exploration of this concept was undertaken using cells from the crustacean Cancer pagurus, enabling the creation of model surfaces to facilitate the investigation and understanding of cell-surface interactions.

User Centred Design

Ubiquitous Health Technology Lab (UBI Lab) - University of Waterloo

The UBI Lab explores wearable and sensing technologies through the lens of human-centred design, data-driven design, and population-level health outcomes. The focus is to create outcomes that place minimal burden on the user, whilst maximising effectiveness of "zero-effort sensors and technologies" to provide reliability and strong user experience outcomes. Remote patient monitoring and data analytics form the basis for a number of UBI Lab's outcomes.

A recent project documented by UBI Lab involves the adaptation of electromagnetic radars as a means to enable remote sensing of biosignals as opposed to wearable devices that require immediate contact (Alizadeh, Shaker, Almeida, Morita, & Safavi-Naeini, 2019). This form of remote sensing was explored in order to evaluate the effectiveness of this technology when monitoring respiratory and heart rates, particularly in the context of in-home care. The technology modified and tested by the Lab showed promising result correlations as compared to baseline testing.

Design Factory Melbourne – Swinburne

Swinburne's Design Factory encompasses student body, researchers, and industry partners who together through collaboration work produce innovative solutions for forecast future scenarios (Design Factory Melbourne, 2019a).

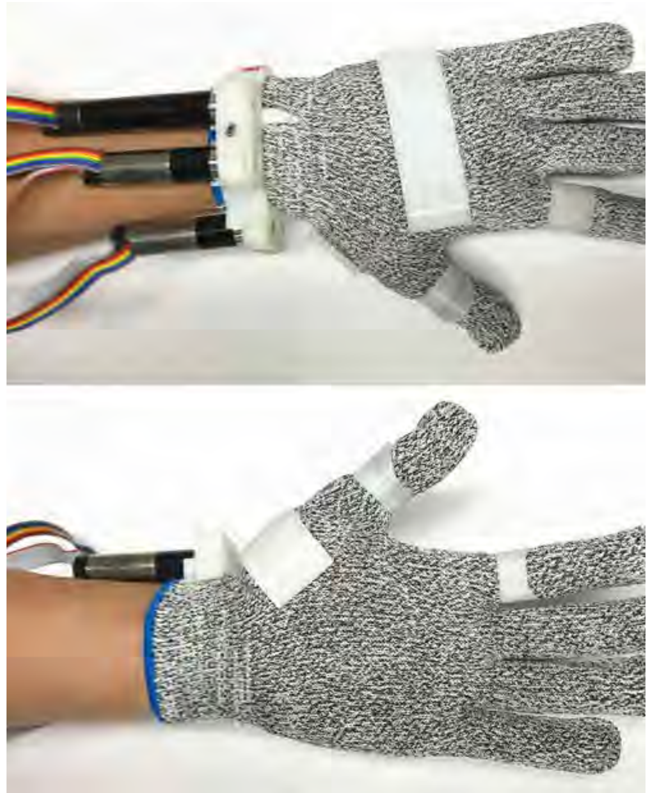
A concept prototype was generated through an industry–engaged research project called the Customer Adaptive Room Environment (CARE). Designed with hospital environments 25 years into the future, the designed space offers a user experience that improves the emotional and social aspects associated with a hospital stay (Design Factory Melbourne, 2019b). The design integrated patient programmable wall panel displays that feature circadian lighting, and an inclusion of storage and space, allowing a sense of ownership of what traditionally is an impersonal space.

Physical and Ergonomics Lab - Delft University of Technology

The Physical and Ergonomics Lab of Delft University studies the nature of human-product-interaction and therefore the physical and environmental factors at play, that ultimately influence user experience and product effectiveness. An example of this is wearables that exist within patient care scenarios.

The Designed to Fit project involved the development of an anthropometric database of children's heads and faces for the purpose of designing efficient and effective ventilation masks for children below the age of 6 years (Goto, 2019). The project

Designed to Fit Ventilation Masks
(Physical and Ergonomics Lab - TU Delft, n.d.)



Development of a Wearable Tremor Suppression Device (WTSD) (WearMe Laboratory - Western University, n.d.)

utilised 3d scanning technology to generate content for the digital database, that would enable ease of access to better inform the design of tailored ventilation products necessary for effective treatment.

WearMe Laboratory - Western University

The Wearable Mechatronics Laboratory from Western University seeks to develop novel design solutions for the rehabilitation of Musculoskeletal Disorders (MSDs).

Through extensive research, patient-centred design, and the iterative prototyping stages, the Lab endeavours to minimize weight and size of devices, improve sensing capability, and enhance human–device communication (Wearable Mechatronics Lab, 2019). Control system development is evident across a range of such projects, from wearable mechatronic braces for the upper and lower body, as well as limb monitoring devices.

The development of a wearable tremor suppression device (WTSD) was conceived by the WearMe Laboratory in 2018. The project was developed in order to provide a non-invasive solution for suffers of pathological tremors; unintentional, oscillatory movements of the body or limbs (Zhou, Jenkins, Naish, & Trejos, 2018).

The suppression device was designed to suppress upper limb tremors whilst maintaining the user's ability to move voluntarily. Alongside the device, a control algorithm was devised to maximise suppression of unwanted motion, whilst minimising its influence on voluntary motion (Zhou et al., 2018).

Nanotechnology

Querrey Simpson Institute for Bioelectronics - Northwestern University

The Querrey Simpson Institute for Bioelectronics primarily studies bio-integrated electronic systems that seamlessly integrate with living biological materials such as organs and other tissues. The ability to create devices that can link the both mechanical and biological systems offer extraordinary diagnostic, therapeutic and surgical potential within biomedical research and clinical healthcare (Querrey Simpson Institute of Bioelectronics, 2019).

The institute is prolific, generating new research and works into skin-like electronics, injectable electronics, wireless wearables, multidimensional electronic networks, as well as bioresorbable electronics.

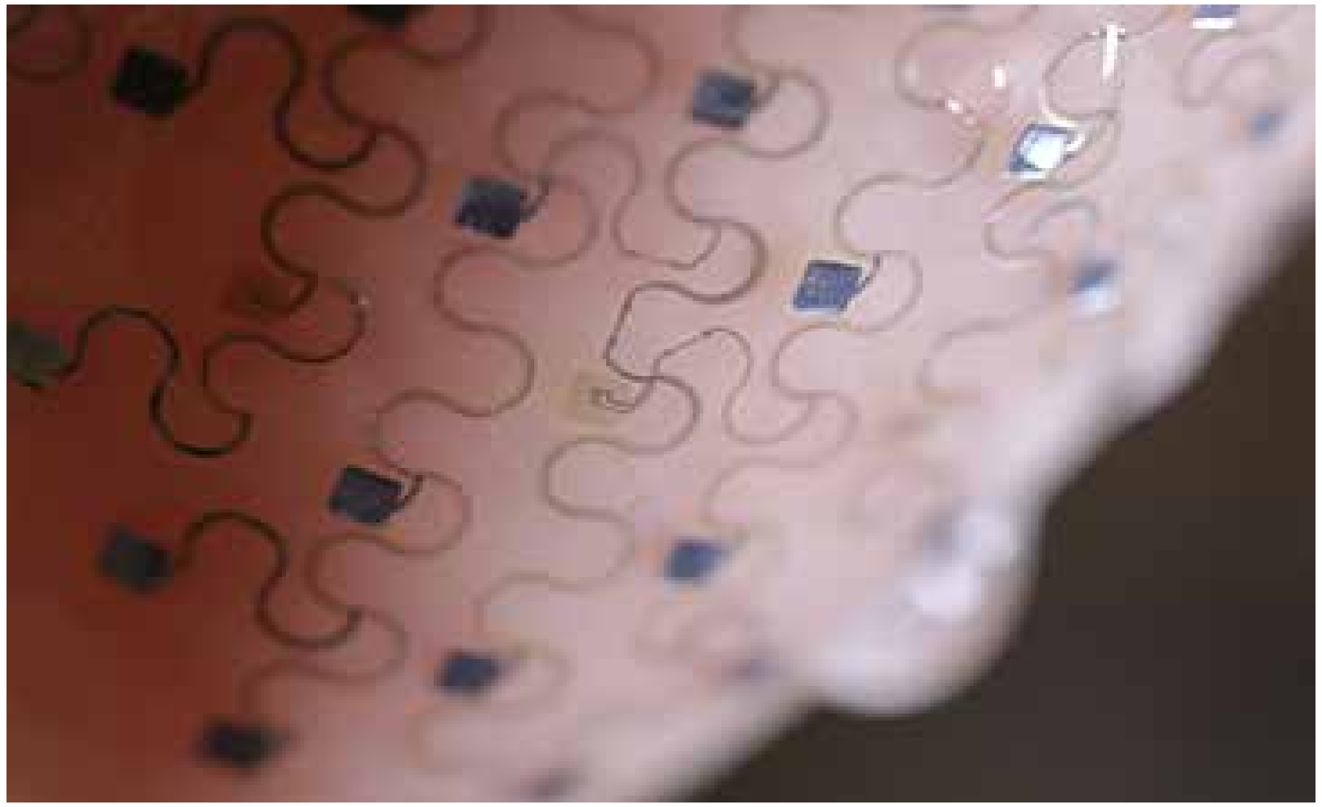
Bioresorbable electronic technologies are a developing area within the scope of sensing technologies. The emerging devices exhibit excellent biocompatibility in cell level toxicity studies and additional trials. Devices tested possessed sensing capability, wireless data transmission, power supply and actuation (Hwang et al., 2012). Bioresorbable electronics offer solutions in emergency medical treatment, recovery and rehabilitation in addition to bypassing the need for secondary surgical intervention for surgical extraction. Possible applications include temporary pacemakers, nerve and bone growth stimulators for enhanced rates of healing and intracranial sensors for monitoring users who have experienced traumatic brain injury (Lee et al., 2019).

Centre for Neuroprosthetics - École Polytechnique Fédérale de Lausanne

The Centre for Neuroprosthetics is a multidisciplinary practice that integrates engineering, physics, chemistry, computer and life sciences to develop greater understanding the relationship between biological systems and innovative technology platforms that can benefit clinical applications (EPFL, 2018).

The scope of research covered by the Centre is expansive, with major categories including (EPFL, 2018):

- Tissue engineering for therapeutic applications
- Biomedical micro-devices and image processing tools for intervention and diagnosis
- Biosensors and neuro-electrodes
- Soft bioelectronic skins and brain-machine interfaces
- Sensory and motor neuroprosthetics
- Biorobotics, biomechanics and cardiovascular modelling
- Movement and/or gait measurement and assessment
- Biotechnology for therapeutic protein production



Epidermal Skin-like Electronics
(Querrey Simpson Institute for Bioelectronics, n.d.)

A subdivision of the Centre works primarily towards assisting patients with optical disability, namely blindness. By creating and implementing novel technologies towards sight restoration, the Centre hopes to translate research and testing into viable clinical practice. In 2018, an injectable epiretinal prosthesis was developed entitled POLYRETINA with initial results showing positive translation of the device (Ferlauto et al., 2018). An additional device for optic nerve stimulation was also successfully trailed, confirming that an intraneural electrode, OpticSELINE; was able to restore sight to the blind.

AI, Machine Learning & Datafication

Affective Computing – MIT MEDIA LAB

Affective Computing from MIT Media Lab addresses machine learning and recognition, and the modelling of human emotional expression. The data collected can inform the development of new digital tools that aid in communication and management of emotional information (Zhang, Weninger, Björn, & Picard, 2019), additionally providing insight into emotional impacts on health, social interaction, and other human action such as learning, memory and behaviour.

The Hol-Deep-Sense project aims to create a holistic machine perception of human phenomena through AI technology, enabling machine to recognise emotion as well as analysing contextual information to improve recognition and response (HOL-DEEP-SENSE, 2019).

The technology would allow personal attributes such as age, gender, emotion, health status, as well as cognitive and physical states, to be recognized and factored into AI frameworks (Zhang et al., 2019).

Signal Kinetics - MIT MEDIA LAB

Similarly, to Affective Computing, the Signal Kinetics group of MIT Media Lab centre development and research around machine learning, in addition to signal processing, hardware design, network infrastructure and actuation.

An example of the groups work in relation to actuation and alternative energy sources, is the Battery-Free Subsea Internet-of-Things. The project brought about the Piezo-Acoustic Backscatter (PAB) that enables backscatter networking in underwater environments whilst enabling communication and harvesting its own energy from underwater acoustic signals (Day, 2019).

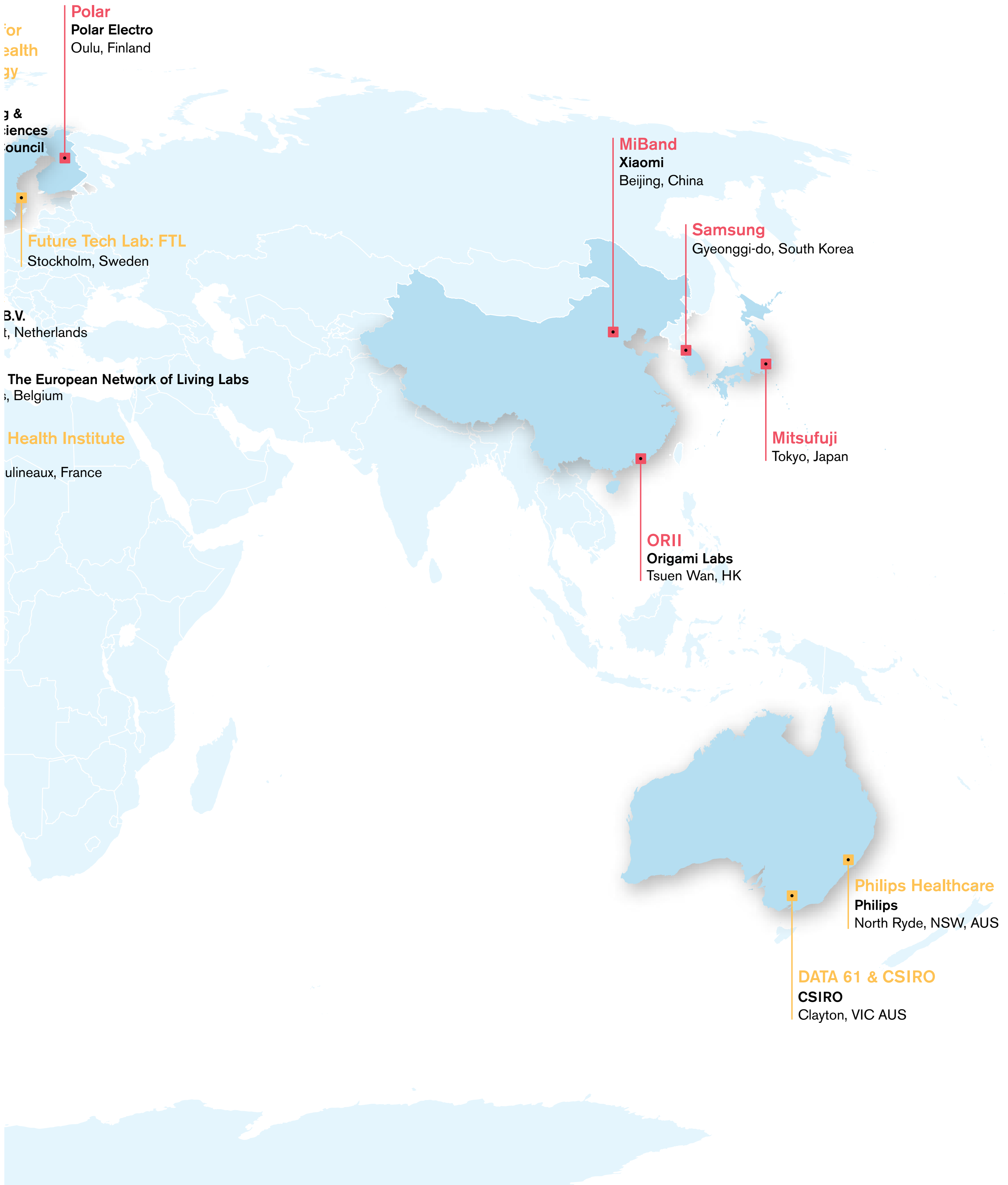
Future applications may include ocean exploration, marine life sensing, and underwater climate change monitoring.

Machine Learning and Data Analytics Lab - Friedrich-Alexander-Universität Erlangen-Nürnberg

The Machine Learning and Data Analytics Lab (MaD Lab) primarily investigates human computer interaction, machine learning, modelling and simulation, and wearable computing (Friedrich-Alexander-Universität, 2019). The Lab seeks to generate research that ultimately provides a positive impact on human wellbeing. Applications include physical performance and rehabilitation, and monitoring disease.

FallRiskPD was a project undertaken by the MaD Lab in 2018 to 2019. The project investigates novel machine learning algorithms that enable the wearable device to determine and alert a Parkinson's disease patient of fall risk using data captured by shoe integrated inertial sensors (Haji Ghassemi et al., 2019).

The sensors used create a continuous gait monitoring system, that identify specific movement or changes that occur in the PD patients to a high degree of dependability.



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Beijing, China
Samsung
Gyeonggi-do, South Korea
Mitsufuji
Tokyo, Japan
ORII
Origami Labs
Tsuen Wan, HK
Philips Healthcare
Philips
North Ryde, NSW, AUS
DATA 61 & CSIRO
CSIRO
Clayton, VIC AUS

Commercial Outcomes

Material Innovation & Fabrication

Google

In a cross collaboration between Google and clothing label Levis, Project Jacquard was the first example of a full-scale digital platform created specifically for a smart clothing product for the purpose of enabling seamless interaction with the digital world whilst navigating the day to day life (Poupyrev et al., 2016).

The garments surface itself replaces the interface of our personal digital devices such as smart phones, for example, enabling the user to accept a phone call or skip to the next song using a series of touch gestures across the garments various surfaces (Google, 2020).

Origami Labs

ORII is a Smart ring device that uses bone conduction to enable the wearer to by-pass their smartphone and operate completely screen-free. The bone conduction transducers used by ORII convert electrical signals into vibrations that are able travel directly through the bone and directly to the inner ear (Origami Group, 2020). The device has only gesture and voice controls that acts as an extension of smartphone devices.

Future Tech Lab (FTL)

Future Tech Lab (FTL) are a self-described disruptive movement of innovators bringing together fashion and science fields to create projects founded on the ideals of sustainable futures. FTL enables various practitioners to connect and therefore encourages spaces for cross collaboration and creative innovation; with a particular focus on new technologies and sustainable innovation (Future Tech Lab, 2019). Key examples of outcomes created from FTL's collaborative endeavours include textile recycling technologies and biofabricated materials such as the patented Microsilk. In collaboration with beauty brand Eighteen B ("Connecting Fashion and Science With Miroslava Duma", 2018), a biofabricated silk fibre was created bringing a revolutionary bioengineering concept to life. Based on proteins found in nature, such as collagen and elastin, the material generated can be used to form a protective, breathable barrier for the skin, in essence mimicking skin itself. There is potential for the material to

ORII Smart Ring (Origami Labs, n.d.)

become integrated into medical practice to be used to help heal wounds.

DuPont

DuPont's Research & Development Centre works across a vast array of fields, with significant development and focus in food production, apparel, electronics and alternative energy applications (DuPont, 2019). The Centre maintains in-house discovery, research, and development of all outcomes. DuPont™ Intexar™ is a notable product of DuPont's Research and Development Centre. Intexar™ is an innovative electronic ink and film device that seamlessly transforms fabric into smart clothing, given its soft and seamless design ("DuPont's Intexar Owlet Band", 2019). This innovative textile technology has the potential to deliver advances in the wearable healthcare space with possible applications in monitoring, telemetry, heat therapy, and management of respiratory disorders.

The pregnancy monitor, the Owlet Band; enables mothers to track their pregnancy and foetal health, all made possible through the implementation of Intexar™ technology.

Elitac

Elitac are another wearable innovation lab based in the Netherlands actively collaborating with various commercial partners, Elitac specialise in stretchable electronic circuitry, complimentary operating systems and a significant wealth of knowledge and expertise around agile wearable technology. Elitac also works closely with designers and research institutions to develop and generate new innovation in the integration of electronics into textiles. With its own in-house team specialising in hardware, electronics and textiles, Elitac is able to facilitate and improve and verify collaborators wearable project development and outcomes (Elitac, 2020a).

A key project generated by Elitac's lab is the Mission Navigation Belt developed in 2013 in collaboration with the Royal Netherlands Army (Elitac, 2020b). The product was designed to improve soldiers "situational awareness during complex operations in the field", by employing a series of vibration motors integrated into the belt to enable the wearer to "feel" direction.

In the context of day or night scenarios in the field, the wearer is able to follow a programmed route, and feel the direction and distance of the next waypoint through changes in vibration. This communication of information to the user is therefore discrete and highly intuitive, enabling the wearer to react immediately in critical situations without impeding physical action.

Mission Navigation Belt (Elitac, n.d.)

Similar technology was adapted to create the Sentaz system a tactile navigation system in vehicles. In this instance, the operator is able to receive navigation signals through vibration feedback in the driver's seat of the vehicle (Elitac, 2020c). The navigation is determined by third party software and then translated into a physical stimulus. The use of an intuitive vibration system would reduce the need of the driver to navigate using visual or auditory queues (Elitac, 2020c). In the context of military applications, this would effectively allow an operator's eyes and ears to be available for other tasks.

Polar

Polar focus on devices within the realm of athletic training & general fitness, the company being best known for developing the world's first wireless heart rate monitor (Blons et al., 2019). Ranging from sports training computers, to sensors used in performance monitoring, Polar provides holistic systems based on scientific enquiry into physiological and sports medicine research (Polar Global, 2020). The company conducts its research and development through its own in-house facilities in addition to maintaining relationships with a number of research institutions worldwide as well as the greater scientific community. To further encourage innovation within the industry, Polar offers co-operative research programmes to external partners to further support studies into exercise science. The research body of Polar covers a broad range of research areas including animal studies (Jorquera-Chavez, Fuentes, Dunshea, Jongman, & Warner, 2019), targeted demographic approaches (Perdomo, Balzer, Jakicic, Kline, & Gibbs, 2019), nutrition and psychological and physiological aspects that can be impacted through the implementation of wearable technologies.

Athos

The development of the Athos Training System targets professional athletes, providing a highly comprehensive method for users to collate and extract data to better inform training and physical development of athletes (MAD Apparel, 2020). Athos has developed a proprietary method to measure muscle activity that works in conjunction with motion tracking technologies embedded within the user's garments. These inbuilt cores enable real-time monitoring of the wearer's performance and technique, with data being recorded and readily analysed through a designed online platform and/or app (Lynn, Watkins, Wong, Balfany, & Feeney, 2018). The combined product and online platform aid athletes and coaches to generate highly effective and personalised physical training plans to facilitate optimum performance (Lynn et al., 2018).

Athos partners extensively with professional and collegiate football programs in the United States as well as top performance institutes such as ProActive (Los Angeles), and FastTwitch (Miami).

Athos Training System (Athos, n.d.)

L'Oréal Research & Innovation - L'oreal / La Roche-Posay

L'Oréal Research and Innovation body seeks to transform how consumers interact with the beauty market by bringing together innovative beauty products alongside devices and smart digital services.

The company is actively exploring a range of projects, delving into "flexible electronics, non-linear optical tools for in vivo imaging, tissue engineering, biophysics, synthetic biology, biochemistry, clinical biology, and new functionalized cell models" (L'Oreal Research & Innovation, 2018).

In one such project, in collaboration with La Roche-Posay, L'Oréal's research and innovation centre Open Innovation has developed sensing technology that is able to continuously measure a wearers exposure to both UVA and UVB rays in addition to pollution, pollen and humidity (McNeill, 2019). The sensor transmits the collected data and can be readily accessed via the My Skin Track UV app. Taking into consideration other key factors such as the users skin colour and type, the combined data generates personalised advice to best protect and limit negative levels of exposure.

Apple

The Apple Watch and accompanying systems include health applications for monitoring and data feedback, giving clinicians the potential to provide optimised support through more in-depth analysis of data procured from the patient.

The device offers the ability to identify and track irregular heart rhythm that can be suggestive of arterial

Apple Watch Series 4 ECG Screen (Apple, 2018)

fibrillation using photoplethysmography technology (Apple, 2020). The optical heart sensor detects the pulse wave at the wrist. This measures the beat-to-beat intervals when the user is in an active state, resting or sleeping. If the algorithm detects an irregular pattern suggestive of Arterial fibrillation, the user receives a notification along with the date, time, and in-depth record of the occurrence in the Health App (Apple, 2020).

The ECG app uses the electrical heart sensor built into the device to record the equivalent data similar to a Lead I ECG. The ECG application monitors and records any incidence of sinus rhythm, arterial fibrillation or inconclusive readings which then prompt the user to input further information about symptoms, such as rapid or pounding heartbeat, dizziness, nausea or fatigue (Apple, 2020).

The waveform, results, date and time and any other symptoms are recorded and are able to be exported via the Health App to be shared directly with a clinician (Perez et al., 2019).

The company initiated a large-scale study to Identify atrial fibrillation using the apple watch device. The study was used to determine whether smartwatch applications were able to identify atrial fibrillation during use when coupled with the optical sensors embedded in the device (Moon, 2019). In the event of a pulse notification algorithm identifying a possible atrial fibrillation, the user was notified as well as a clinician, the patient then being assessed professionally and given an ECG patch to use over a period of 7 days (Perez et al., 2019). The main objectives of the trial were to determine if the technology offered highly reliable readings in proportion to the number of participants notified of atrial fibrillation activity. In addition to data collected from the week-long trials, surveys were also conducted to fortify results.

Neue Labs

Neue Labs is based in Stockholm and offers brands, universities, and designers a platform to develop exploratory wearable technology outcomes all the way through to a market ready standard. This platform, known as Playground, provides a singular space to help companies or start-ups design and generate connected smart garments, develop associated content and services that enable customer adaptation where possible (Neue, 2020). Neue has a very strong footing in the fashion industry and is geared towards helping companies typically from this industry to overcome the innovation barrier and optimise their product for production.

The designed product and end function are fully facilitated through the capabilities of technology provided through the Neue Playground platform. An example of a Neue outcome is the F/ACT Movement (Neue, 2020), a project that explores user behaviour around garment consumption and utilisation using AI analysis and a range of sensing technologies to monitor and track garments and garment use. Potential applications relate to sustainability, development of future business models, and overall longevity.

Sensors

Microsoft

The Medical Devices Group of Microsoft are a multidisciplinary body that presents major projects surrounding wearable devices for cardiovascular health. Using novel sensors and other sensing technologies coupled with AI and Machine Learning capabilities, MDG creates ergonomic designs that operate within a holistic system to enable relevant alerts and data exchange to take place. Through the combination of signal processing and Machine Learning, long term patterns procured from the data enable the identification of actionable insights that can benefit the life of the user.

Mobility Lab

The Mobility Lab of APDM explores novel technologies that enable the scientific research community to conduct higher quality research into movement sciences. In doing so, the Mobility Lab generates technologies that can be used in performance, fitness and elite sports, as well as physical therapy, and clinical research and trials (APDM Wearable Technologies, 2019).

APDM develops and provides the market with viable commercial solutions for the quantification of human movement through the utilisation of wearable technologies for the purpose of research (Washabaugh, Kalyanaraman, Adamczyk, Claflin, & Krishnan, 2017).

Coupled with a proprietary motion analytics platform, The Mobility Lab generates wearable sensors that offer gait and balance monitoring (Mancini & Horak, 2016), kinematic inputs and continuous recording capabilities for numerous applications across a range of markets.

Gentag

Gentag provides specialised knowledge in sensing technologies, with a directive to create disposable wireless sensor technologies that are affordable and accessible to the worldwide medical community.

Gentag's efforts aim towards producing printed, flexible, and organic sensor formats that can be used for multiple applications, including NFC sensor technology, disposable NFC and biomarker patches, Lab-on-a-Chip, and nanoscale sensors (Gentag, 2020). These applications can then be extrapolated further, resulting in solutions for discharge and home monitoring kits, other forms of monitoring such as temperature, health and fitness, as well as drug delivery systems.

Valencell

An US-based company, Valencell is concerned with biometric technology and actively develops biometric sensor technology for wearables sensing

SensorLinker, a customized in-home mobile compliance and diagnostics sensor hub (Gentag, n.d.)

applications, as well as providing Benchmark sensor systems to consumer electronics manufacturers in various industries as readymade components to adapt into wearable concepts. Additionally, the Biometrics Lab affiliated with Valencell, offers testing services of prototypes through a battery of testing protocols and activity sets (Valencell, 2020). Through the analysis and validation of data captured with consideration paid to real-world scenarios, the Biometrics Lab can identify and promote improvements of products design and performance prior to going to market.

Valencell also offers the Ecosystem – a community of contract manufacturers, original design manufacturers, in addition to the Biometrics Lab, that combined; incorporates supply and manufacture alongside a certification program. Therefore, Valencell enables the generation of market ready products by providing extensive R & D services (Valencell, 2020). This action also contributes to Valencell's own research and development of technologies for the fitness and health industries, personal health applications, and military solutions.

User Centred Design

Reveal

Awake Labs implements wearable sensing technologies to aid people in understanding anxiety and thereby improving quality of day to day life. The Lab is currently working towards building a fully resolved platform that enables real-time data collection of heart rate, motion and physiological arousal, in order to provide a level of support in the care of neurological disorders such as autismThe Labs latest campaign Reveal, Empowered Care for Autism; uses a clinically validated algorithm coupled with a wearable device to enable the wearer to self-monitor anxiety by providing real-time feedback (Awake Labs, 2019), prompting the user to implement strategies to prevent further escalation. The ability for the user to self-regulate enables users to remain autonomous and work towards health outcomes in collaboration with medical practitioners.

The European Network of Living Labs

The European Network of Living Labs uses the living lab methodology, as per their name, to create collaborative environments to best resolve given design problems. The concept of a living lab utilises four main activities: co-creation, exploration, experimentation, and evaluation (Popova, 2014). Throughout these stages, designers and users alike are able to identify emerging market opportunities, behaviours and conventions surrounding a given activity.

Live scenarios can then be staged with a community of users for the purpose of experimentation and evaluation of a concept, product or service (ENoLL, 2020).

Assessment can then be made through the lens of socio-ergonomic, socio-cognitive and socio-economic criteria.

ENoLL enable networking and communication with professional communities, as well as offering learning, training and knowledge to partners surrounding best practice and legal concerns.

ECHAlliance

ECHAlliance is a not-for-profit organisation that connects communities, institutions and organisations on a global scale to bring about innovation in the field of digital health.

The organisation provides not only business and research opportunities, but also delivers insights into market sectors, latest technology trends and other information to facilitate activity across its network (ECHAlliance, 2019a). ECHAlliance aims to develop educational opportunities, to support and engage collaborative R&D in support of broad scale connected health outcomes.

ECHAlliance's ability to connect communities has led to the creation of ECHAlliance Ecosystems across the world (ECHAlliance, 2019b). These Ecosystems are regionally focused, permanent, multi-stakeholder partnerships located globally, that are working together to develop innovative solutions that improve the quality of health and wellbeing of the community, as well as the effectiveness of healthcare systems. RMIT is a current partner of the network as part of the Melbourne Ecosystem. The relationship provides significant international collaboration opportunities (Johnston, 2019).

Newmind Network for Mental Health Technology

The NewMind Network for Mental Health Technology operates as a research council, offering multidisciplinary workshops involving researchers, clinicians, charities, service users and industry partners. The Network targets mental health issues including serious forms of mental illness, mood and affective disorder, dementia, and developmental disorders (NewMind Network for Mental Health Technologies, 2020a).

Through workshops, road mapping, and proposal development through sandpit workshops, stakeholders work towards developing real world solutions in the form of human-centric systems, sensing systems, information management and data analytics (NewMind Network for Mental Health Technologies, 2020b).

The Network also provides a series of frameworks to provide a structured approach to health outcomes and ethical approaches that clearly defines core principles which guide researchers working in this field.

AI, Machine Learning & Datafication

CTRL-Labs

The CTRL-Kit from CTRL-Labs is a non-invasive neural interface platform that enables the integration of neural control into XR, productivity, robotics, and clinical research applications. The Lab has recently merged with Facebook Reality Labs, extending their potential capability with the introduction of additional researchers, developers, and engineers working in augmented and virtual reality. The Lab works towards finding new ways in which humans may relate and interact with machines through new and intuitive devices such as the CTRL-Kit (CTRL-LABS, 2019).

Launched by the creator of Microsoft Internet Explorer, Thomas Reardon, and his partners, CTRL-Labs developed a novel approach for a brain–computer interface (BCI) using their own technology (Fields, 2018).

The CTRL-Kit device detects voltage bursts that are derived from the contraction of muscle fibres in the body, and in real-time, these electrical discharges are analysed, using the data to calculate the motion and force required. A computer-generated virtual limb then initiates the very same motions (Fields, 2018).

Google

DeepMind is a multi-faceted AI system able to be implemented in health and medical diagnostic applications. Working to develop algorithms specific to targeted datasets, DeepMind has generated viable

CTRL-Kit (CTRL-Labs, n.d.)

AnatomyX
Medivis

solutions to the diagnosis of a number of medical conditions (Senior, Jumper, Hassabis, & Kohli, 2020).

An example of one such outcome is the development of an algorithm that can automatically differentiate between healthy and cancerous tissues in head and neck areas.

An extension of this line of investigation was an international evaluation of breast cancer screening using AI technologies.

The study found that the artificial intelligence (AI) system developed through DeepMind was capable of besting radiologists in breast cancer prediction by an absolute margin of 11.5% (McKinney et al., 2020). In the event of a double-reading process for diagnosis, not only did the AI system continue to demonstrate enhanced performance, but it also "reduced the workload of the second reader by 88%"(McKinney et al., 2020).

In addition to the AI system, DeepMind also developed an app called Streams, which enables communication of data and alerts to clinicians about patients at risk of acute risk injury. In 2018, DeepMind's health division and the Streams app was absorbed into Google Health (DeepMind, 2020).

Medivis

The Surgical AR platform, developed by Medivis, is a visualisation tool that can be used in situ to guide surgical navigation. The goal is to improve patient outcomes and safety through the advancement of surgical accuracy. This is made possible through the ability to create holographic overlays increase surgical precision and potentially reduce time spent in the operating room (Shieber, 2019). The AR capabilities of the platform also enable data to be viewed in a hands-free spatial environment; a tool that could aid in on the spot decision making in surgical contexts (Fornell, 2019). This also offers true depth perception, and therefore can enhance the visuospatial understanding of various scenarios.

The Surgical AR Platform integrates within any legacy infrastructure within healthcare organisations, and enables surgeons to directly sync and integrate with hospital picture archiving and communication systems (PACS).

An extension of Medivis' work includes AnatomyX; an educational VR platform that utilises augmented reality and artificial intelligence to generate surgical visualisation with potential applications in surgical planning, training and performance (Medivis, 2020).

Embodied Labs

Embodied Labs has developed a virtual reality (VR) experience to facilitate training for caregivers and medical students for care and treatment of Lewy Body Dementia (LBD), and Parkinson's Disease amongst others. The program is entitled the Dima Lab, that provides users with a library of virtual experiences simulating key problems and situations that arise in the care of older adults suffering such conditions.

The technology is shown to develop empathy and compassion in participants (Adam, 2019) and represents an integral part of treating conditions such as dementia. The Dima Lab simulates "users experience of different types of dementia-related conditions through protagonists with diverse backgrounds" (Bushak, 2019). It also enables participants to experience the physical symptoms of diseases to better understand how to manage and treat patients in real life situations (AI MED, 2018).

The technology has also been extrapolated to deal with other aspects of ageing healthcare, including end of life conversation and other prominent diseases such as Alzheimer's disease.

Embodied VR Experiences for Caregiver Training
*(*Embodied Labs. n.d.)

Philips Healthcare

Philips Healthcare works towards developing holistic system solutions for medical and clinical practice, alongside wearable and sensing technologies to provide improved health futures, compliance, and sustainable solutions for the future. Philips is currently developing cloud-based telehealth applications for home and hospital contexts, partnering with Salesforce to create a new clinical application, Philips eCareCoordinator (Philips, 2020).

The platform is defined as a "connected care application" that would enable clinicians to collaborate and monitor thousands of patients in real-time (Eddy, 2020).

In the way of devices, Philips has also developed proof of concept of a Brain Computer Interface (BCI) device that would enable ALS patients, or any person with limited muscle and speech function; to communicate and initiate commands without the use of vocalisation or physical movement (HospiMedica, 2019). The device provides users this ability "through a custom-built tablet application and wearable display interface".

DATA 61 & CSIRO

ReMoTe (Remote Mobile Tele-assistance) is hands free, wearable, technology that connects remote experts with on site operators to provide real-time assistance when problems arise. An online cardiac rehabilitation program that can improve program completion rates and patient health outcomes. Emergency Situation Awareness software.

DATA 61 represents leading data innovation in Australia, seeking to address the challenge of developing a precision health ecosystem to service individuals and the broader medical community.

Part of the CSIRO, Data 61 collaborates with government and industry partners to harness knowledge in advanced analytics, AI and Machine Learning, and 3d modelling (Data61, 2019). Through research and development, outcomes generated provide applications that address access to health-related data in real-time, and non-invasive patient outcomes.

ReMoTe (Remote Mobile Tele-assistance) is one such outcome. It is a hands free, wearable device, that connects remote experts with operators to provide real-time assistance. The ReMoTe is not designed for a singular scenario or purpose. It has the capacity to be utilised in a number of fields such as (Data61, 2019):

- offering remote medical assistance for field health workers,
- remote vocational training programs which require physical and manual skills,
- cultural programs that link experts in remote Aboriginal communities with art students,
- remote inspection of product conformance for the manufacturing industry,
- emergency response scenarios,
- remote delivery of expert services for small and medium enterprises.

ReMoTe is designed to connect an operator and "helper" via wearable computing devices that provide visual and audio links through a near-eye display. The physical gestures and instruction of the helper can be seen through the point of view of the operator, with virtual gestures visible though the display (Alem, 2011).

RMIT

Micro/Nanomedical Research Centre

The Micro/Nanomedical Research Centre at RMIT works towards solving public health problems, in particular, the availability, accessibility and affordability of point-of-care diagnostics, drug delivery and advanced medical equipment. By developing advance tools and making them accessible to health practitioners and providers, there is potential to dramatically alter public health through effective diagnosis, prognosis, and treatment.

Applied research undertaken by the Centre has led to the successful development of "integrated low-cost portable devices for drug delivery and ultrasensitive chemical detection". Such technology could be used in the detection of illicit drug use in varied scenarios (RMIT University, 2020c).

As the Centre continues its work, current studies are underway such as the exploration of acoustically-driven microfluidics for biotechnological applications, phononic and photonic nanostructures for enhanced biomolecular detection (Rezk, Manor, Friend, & Yeo, 2012), and Inhaled gene and nanomedicine for therapeutic treatments.

CAMIC : Materials & Industrial Chemistry

The Centre for Advanced Materials and Industrial Chemistry (CAMIC) investigates materials and industrial chemistry. The research Centre brings together the fields of industrial chemistry, materials chemistry, nanotechnology, catalysis and electrochemistry to facilitate the research and development of multifunctional materials, sensing technologies, and nano-biotechnology outcomes (RMIT University, 2020a). The Nanotechnology and Sensing group in CAMIC commonly focuses on multifunctional materials for chemical sensing, focusing on the development of various surface patternation (Sabri, Kandjani, Ippolito, & Bhargava, 2015). Patternation techniques are varied and can involve the deliberate arrangement of molecules at macro-scale, through etching, film deposition and electrochemical patterning processes. The resulting pattern corresponds with a particular function such as energy harvesting applications.

CMIFF : Centre for Materials Innovation and Future Fashion

The Centre for Materials Innovation and Future Fashion (CMIFF) investigates solutions for the production, design, and consumption of fashion and textiles. Ranging from textile fibres and yarns, apparel systems, and emerging textile technologies, CMIFF participates in interdisciplinary research through collaborative projects with sport, electronic engineering, aerospace engineering, product design and textile technology cohorts (RMIT University, 2020b).

From such research pathways, a multitude of applications are possible, including

Smart materials and wearable technologies, advanced materials and technologies for defence, functional apparel for sports and human performance technologies, and materials innovation to address real-world problems.

'High Risk Dressing / Critical Fashion': Opening Night. Collaborators: Professor Robyn Healy, Dr Fleur Watson, Kate Rhodes, Nella Themelios, Sibling Architecture, Studiobird, Caitlyn Parry, WOWOWA, Andre Bonnice and Ziga Testen (Titz, 2017)

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