The Royal Academy of Engineering

Neural engineering

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Biomedical engineering creates new medical technologies and systems that can greatly improve patient care and quality of life. The UK Focus for Biomedical Engineering is the Academy's forum for this increasingly important area of engineering in which the UK is taking a lead.

Introduction

Biomedical engineering is constantly expanding and extending the areas of application within healthcare. Technological developments, coupled with a stronger understanding of biological processes brought about by cutting-edge research, create new areas within biomedical engineering. Neural engineering is one such recent development.

Neural engineering, sometimes known as neuroengineering, is the discipline in which engineering skills and techniques are used to understand, repair, replace, or enhance neural systems. Neural engineers solve design problems at the interface of living neural tissue and non-living systems.

Like other areas in biomedical engineering, neural engineering draws on the expertise of a variety of disciplines such as computational and experimental neuroscience, clinical neurology, electrical engineering and signal processing. Of special note is the interface to living neural tissue, which brings together elements from robotics, cybernetics, computer engineering, neural tissue engineering, materials science and nanotechnology.

While neural engineering still has a strong research component, it has some very clear and beneficial goals. These are centred on the restoration and augmentation of human function via direct interactions between the nervous system and artificial devices, for example, restoring the ability to interact with the environment following a stroke or debilitating neural disease through interfacing technology directly with the human nervous system.

There are already real-world clinical solutions for areas such as controlling essential tremor through implants in deep-brain stimulation for Parkinson's Disease, vagal nerve stimulation for help in controlling epilepsy, and the use of cochlear implants to restore hearing in the profoundly deaf (neuroprosthetics).

The technology

Neuroprosthetics is concerned with developing neural prostheses, devices that can substitute a motor, sensory or cognitive modality that might have been damaged as a result of an injury or a disease. An example of such a device is the cochlear implant. This device substitutes the functions performed by the biological components of the ear and the cochlea, and stimulates the auditory nerves directly through an implanted device. A microphone on an external unit gathers the sound and processes it. The processed signal is then transferred to an implanted unit that stimulates the auditory nerves through a microelectrode array.

In 2009, more than 188,000 people worldwide had received cochlear implants – many of them children. The vast majority of implants take place in developed countries because of the high cost of the device, surgery and post-implantation therapy. Following recent advice by the National Institute for Health and Clinical Excellence (NICE) in the UK, a growing number of recipients have bilateral implants – one implant in each cochlea.

A second example of neuroprosthetics is deep brain stimulation (DBS), which involves the surgical implantation of a medical device called a brain pacemaker that sends electrical pulses to very specific parts of the brain. While DBS in specific brain regions has provided very good therapeutic benefits for otherwise treatment-resistant movement and affective disorders such as chronic pain and dystonia, it is in Parkinson's disease and tremor that DBS is best known.

Parkinson's disease is a neurodegenerative disease whose primary symptom is tremor. DBS does not cure Parkinson's, but it can help manage some symptoms and subsequently improve the patient's quality of life. At present, the procedure is used only for patients whose symptoms cannot be adequately controlled with medications, or in whom medications have severe side-effects. Although the underlying principles are not clear, DBS directly changes brain activity in a controlled manner, and its effects are reversible, unlike those brought about through direct surgical intervention. In fact the effects of DBS on essential tremor can be starkly seen when the DBS system is switched off – the characteristic tremor returning within moments.

Engineering's contribution

Like any other area in biomedical engineering, neural engineering is highly cross-disciplinary and requires the interaction of specialisms in engineering and in life and health sciences. Developments in the neural engineering field could not happen without training in many areas of expertise. These include: core training in electrical and electronic engineering, specialist training in signal processing and systems modelling, as well as computer engineering training in computational intelligence and machine-learning. This needs to be coupled with expertise in physiology, neuro-anatomy, neurology, elements of chemistry – as well as advanced areas such as nanotechnology.

Neural engineering relies on biomedical engineering educational programmes to produce graduates with the correct base skills to handle the unique problems associated with restoring and augmenting human function through direct interface with the nervous system.

Future work

Areas under development and nearing clinical application include the use of functional electrical stimulation to control limbs following spinal injury and neural interfacing to prosthetics to control artificial limbs. Other areas under research include ocular implants to restore sight to the visually impaired and the use of brain-computer interfacing to restore communication to those who lack the ability through stroke, severe brain disease or spinal injury.

Within neuroprosthetics, research is being carried out with the aim of predicting the onset of tremors before they occur by monitoring activity deep in the brain. The specific goal for doing this is to provide stimulation only when needed, to stop any tremors occurring before they start. This technique is similar to that being researched in the treatment of epilepsy – where the goal is to use DBS to stop debilitating epileptic seizures before they even start.

Brainstem stroke, brain or spinal cord injury and numerous other muscle wasting diseases such as amyotrophic lateral sclerosis (ALS) result in the degeneration of specific motor neurons which causes muscles to stop receiving movement commands. People suffering from these disorders ultimately lose the ability to control their muscles and to communicate while their intelligence, memory and ability to think remain intact. Therefore, a healthy brain is "locked in" a paralysed body. As the French journalist, Jean-Dominique Bauby, has shown in his memoir The Diving Bell and the Butterfly, which was composed letter by letter with 200,000 blinks of his left eyelid after suffering from a massive stroke, establishing an alternative to neuromuscular interaction is a painstakingly challenging day-to-day venture for severely impaired people.

Consequently, neural engineers have been attempting to develop systems that enable these patients to communicate with computers directly through brain activity rather than by physical means. Such systems are meant to provide new, non-muscular channels of communication – a brain computer interface (BCI) for conveying messages and commands to computers. Electroencephalography (EEG), measuring brain activity from the scalp, and related measurements are possible ways to achieve non-muscular BCI by capturing brain activity in real-time. EEG-based BCI systems require relatively simple and inexpensive equipment, should be portable and easy to set up, and should function in most real-world environments – but this is a non-trivial problem.

Conclusion

Neural engineering is an up and coming area within biomedical engineering. It addresses a wide range of debilitating illnesses and shows promise to address much more. It is an area which shows clearly the benefits of multi-disciplinary research and the continued need to fund research and development at the life-sciences interface. Continued funding in this area will help to create new businesses that exploit emerging neural engineering techniques, assessing and evaluating them and delivering them through the most appropriate means.

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