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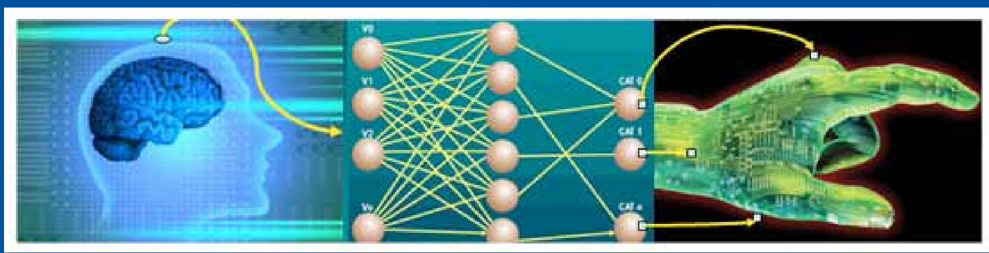
Institute

Brain Computer Interface: Neuroprosthetics and Signal Processing

The Way Forward for Australia



Gita Pendharkar

Skills Victoria (TAFE)/ISS Institute Fellowship

Fellowship funded by Skills Victoria, Department of Innovation, Industry and Regional Development, Victorian Government

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Executive Summary

The aim of this Fellowship was to enable Gita Pendharkar to gain knowledge of the educational aspects of, and to develop specific skills in, the technology used for neuroprosthetics and Brain Computer Interface (BCI). This expansion of Pendharkar's knowledge and skills will be applied in Australia, within both the medical technology industry and the tertiary education sector. In particular, it will be used to recommend short courses and program modules for introduction into Australian education programs.

Neuroprosthetics, including BCI is an important and developing area of Information and Communication Technology (ICT). Neuroprosthetics and BCI incorporate a wide number of areas: particularly processing, nervous system integration, and prosthetic device control. Research and development in this area occurs overseas, particularly in the United States of America (USA) and the Europe. A few neuroprosthetic devices are manufactured and available in Australia, such as the cochlear implant and bionic ear. However, there remains a great human need for better, more functional prosthetic devices and their control. This is due to a lack of expertise in the area of neuroprosthetic control and the associated technology, which is not yet established in Australia to the degree necessary for successful early development of the neuroprosthetics industry.

In order to address some of the issues related to the problem outlined above, the Australian context was analysed and the key areas of skill deficiency in neuroprosthetics were identified. The overseas neuroprosthetics industry was carefully studied and contacts were established. In order to order to gain a complete understanding of the ongoing developments occurring and the technology being used, Pendharkar chose to split the Fellowship travel into two segments. First, attending a Neuroprosthetics Conference in Brazil, South America, and then later visiting the Johns Hopkins University (JHU), which has one of the best Biomedical Engineering departments in the world and carries out leading research in neuroprosthetics.

The Fellow's findings and conclusions are detailed in this report. The report does not cover all the detailed technical aspects of neuroprosthetics; the emphasis is on the areas of attention required by local industry and academic leaders in order to develop the necessary expertise and experience of neuroprosthetics in Australia.

A vision to awaken Australia to the potential and benefits of neuroprosthetics enthused Pendharkar to undertake the Fellowship with great passion. As a consequence of the Fellowship, she experienced a very successful study tour to investigate a number of the issues of establishing neuroprosthetic education and industry in Australia.

The Fellow is currently working on a research project on Activity Monitoring using advanced sensors. This has many potential applications in the health care sector. One of the applications is developing *Technology Smart Homes* for the elderly, which would enable the older sectors of the community to live independently for a longer period by choosing the required electronic devices (embedded with sensors) to be used in these homes.

Based on her travels and experiences with the leading global developers of neuroprosthetics, the Fellow is convinced that it is high time for Australians to be more competent in the global market of the wider ICT applications of medical technology, and to enhance the image of Australia as a 'Technology Smart Country'.

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Abbreviations/Acronyms

AOPA	Australian Orthotic & Prosthetic Association
ASIMO	Advanced Step Innovative Mobility
BCI	Brain Computer Interface
BRI	Brain Research Institute
CCRE	Centre for Clinical Research
DBN	Dynamic Basian Network
DTF	Directed Transfer Function
ECog	Electrocortiograph
EEG	Electroencephalography
EMBC	International Conference on Engineering in Medicine and Biology
HCI	Human Computer Interface
IBT	Infinite Biomedical Technologies LLC
ICT	Information and Communications Technology
IP	Intellectual Property
ISS Institute	International Specialised Skills Institute
ISSNIP	International Conference on Intelligent Sensor, Sensor Networks and Information Processing
JHU	Johns Hopkins University
MSA	Manufacturing Skills Australia
MTAA	Medical Technology Association of Australia
NICTA	National Information and Communications Technology (ICT) Australia, Centre of Excellence
SIGFRIED	SIGnal modeling FoR Identification and Event Detection
SNR	Signal to Noise Ratio
TAFE	Technical and Further Education
UFES	Universidade Federal do Espírito Santo, Brazil
USA	United States of America

Definitions

Design

Design is problem setting and problem solving. Design is a fundamental economic and business tool. It is embedded in every aspect of commerce and industry and adds high value to any service or product—in business, government, education and training, and the community in general.[1]

ECog

Electrocortiograph is a technique where electrodes are inserted in the brain to capture the brain signals.

EEG

Electroencephalography (EEG) is a method of gathering signals from the brain. It is a non-invasive method that records activity through the scalp by monitoring and recording electrical impulses.

EVestG™

EVestG™ is a method of recording electrical signals from the vestibular system by inserting a probe in the ear canal.

Innovation

Creating and meeting new needs with new technical and design styles. (New realities of lifestyle).[2]

MATLAB®

A high-level language and interactive environment that enables computationally intensive tasks to be performed faster than with traditional programming languages such as C, C++, and Fortran.

Neuroprosthetics

A discipline related to neuroscience and biomedical engineering 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 devices is cochlear implants. They might be viewed as 'smart' or intelligent prosthetics.

Skill deficiency

A skill deficiency is where a demand for labour has not been recognised and training is unavailable in Australian education institutions. This arises where skills are acquired on-the-job, gleaned from published material or from working and/or studying overseas.[3]

There may be individuals or individual firms that have these capabilities. However, individuals in the main do not share their capabilities, but rather keep the intellectual property to themselves. Over time these individuals retire and pass away. Firms likewise come and go.

Sustainability

The ISS Institute follows the United Nations for Non-Governmental Organisations' definition on sustainability: *"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*.[4]

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[1] 'Sustainable Policies for a Dynamic Future', Carolynne Bourne AM, ISS Institute 2007.

[2] ibid.

[3] 'Directory of Opportunities. Specialised Courses with Italy. Part 1: Veneto Region', ISS Institute, 1991.

[4] http://www.unngosustainability.org/CSD_Definitions%20SD.htm

Acknowledgements

Gita Pendharkar would like to thank the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide her throughout the Fellowship program.

Awarding Body – International Specialised Skills Institute (ISS Institute)

The International Specialised Skills Institute Inc is an independent, national organisation that for over two decades has worked with Australian governments, industry and education institutions to enable individuals to gain enhanced skills and experience in traditional trades, professions and leading-edge technologies.

At the heart of the ISS Institute are our Fellows. Under the **Overseas Applied Research Fellowship Program** the Fellows travel overseas. Upon their return, they are required to pass on what they have learnt by:

1. Preparing a detailed report for distribution to government departments, industry and educational institutions.
2. Recommending improvements to accredited educational courses.
3. Delivering training activities including workshops, conferences and forums.

Over 180 Australians have received Fellowships, across many industry sectors. In addition, recognised experts from overseas conduct training activities and events. To date, 22 leaders in their field have shared their expertise in Australia.

According to Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010':

> Australia requires a highly skilled population to maintain and improve our economic position in the face of increasing global competition, and to have the skills to adapt to the introduction of new technology and rapid change.
>
> International and Australian research indicates we need a deeper level of skills than currently exists in the Australian labour market to lift productivity. We need a workforce in which more people have skills, but also multiple and higher level skills and qualifications. Deepening skills across all occupations is crucial to achieving long-term productivity growth. It also reflects the recent trend for jobs to become more complex and the consequent increased demand for higher level skills. This trend is projected to continue regardless of whether we experience strong or weak economic growth in the future. Future environmental challenges will also create demand for more sustainability related skills across a range of industries and occupations.[5]

In this context, the ISS Institute works with Fellows, industry and government to identify specific skills in Australia that require enhancing, where accredited courses are not available through Australian higher education institutions or other Registered Training Organisations. The Fellows' overseas experience sees them broadening and deepening their own professional practice, which they then share with their peers, industry and government upon their return. This is the focus of the ISS Institute's work.

For further information on our Fellows and our work see www.issinstitute.org.au.

[5] Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010', pp. 1-2 http://www.skillsaustralia.gov.au/PDFs_RTFs/WWF_strategy.pdf

Fellowship Sponsor

The Victorian Government, Skills Victoria is responsible for the administration and coordination of programs for the provision of training and further education, adult community education and employment services in Victoria and is a valued sponsor of the ISS Institute. Pendharkar would like to thank them for providing funding support for this Fellowship.

Employer Support

The Fellow specifically acknowledges the support of School of Engineering (Technical And Further Education [TAFE]), RMIT University, during the entire Fellowship candidature.

Supporters

Australia

RMIT University, Melbourne

- Meg Colasante, Academic Development Group, College of Science, Engineering and Health (College Office)
- Dinesh Kumar, Associate Professor, School of Electrical and Computer Systems Engineering
- Geoffrey Thomas, Teacher – International Trade, TAFE Business School

Victoria University, Melbourne

Rezaul Begg, Associate Professor, Biomechanics Unit

Monash Medical Centre, Victoria, Australia

Berry Rickwi, Director, Paediatric Rehabilitation

South America

Federal University of Espirito Santo, Vitoria, Brazil

Teodiano Freire Bastos, Associate Professor, Department of Electrical Engineering

North America

Johns Hopkins University, Baltimore, Maryland, USA

Nitesh Thakur, Professor, Department of Biomedical Engineering

Italy

Politecnico di Torino, Torino, Italy

Professor Robertto Merletti, Laboratory Engineering of Neuromuscular Systems

About the Fellow

Name: Gita Pendharkar

Employment

- TAFE Teacher (Electronics and Electrical), School of Engineering (TAFE), RMIT University, Melbourne

Qualifications

- PhD (Biomedical Engineering), Monash University, Melbourne, 2010
- Graduate Diploma in Industrial Education and Training, RMIT University, Melbourne, 2006
- M Eng Sci (Electronics & Electrical), Melbourne University, Melbourne, 2002
- B Eng (Electronics), Shivaji University, Kolhapur, India, 1989

Memberships

- AMIE (Associate Member of the Institute of Engineers), India
- Chartered Engineer, Member of the Charted Engineer's Society in India

Brief Biography

Gita Pendharkar has had a successful teaching career of more than 20 years. She holds a Master of Engineering Science with first class honours from the University of Melbourne, and before this gained a Bachelor of Engineering (Electronics) with first class distinction in her native India. Pendharkar has recently completed a PhD in bio-medical engineering from Monash University. She taught at the University of Melbourne and Monash University before joining RMIT University (TAFE), and has held lecturing positions in tertiary institutions in India and Zambia.

She has also worked in the electronic industry, designing Peripheral Component Interconnect (PCI) cards and maintains industry collaborations in Melbourne.

Pendharkar's chief research interests lie in developing instrumentation for remote gait monitoring using sensors such as accelerometers and analysing the gait patterns.

She is an experienced interdisciplinary research collaborator and has contributed to a wide-range of conference papers in biomedical and engineering education conferences. She has won numerous awards at RMIT and Monash University and has worked on many projects to enhance engineering education at RMIT.

Pendharkar is also a reviewer for biomedical conferences such as International Conference on Intelligent Sensor, Sensor Networks and Information Processing (ISSNIP) 2008, the International Conference on Engineering in Medicine and Biology (EMBC) 2009 and educational conferences such as Education and Information Systems, Technologies and Applications 2008, 2009.

Aims of the Fellowship Program

The aims of this Fellowship were to gain knowledge, and undertake specific skills training and education, and to develop skills in the technology used for neuroprosthetics and Brain Computer Interface (BCI). This knowledge will be used to recommend appropriate short courses and program modules for introduction into Australian education programs.

Specific Areas of Study and Development

To establish a fundamental understanding of the technology used for neuroprosthetic device control using brain signals, across a broad perspective including:

- Investigate current status of neuroprosthetics in Australia and determine new opportunities for development.
- To gain knowledge of the various signal processing techniques used for neuroprosthetic device control.
- To gain skills and knowledge in the specialised technology and algorithms used to measure and analyse signals propagating from the brain and forces to control the prosthetic device.
- To acquire skills in the various programming techniques used for the complex software interfaces for the control of the neuroprosthetics.
- To become familiar with the range of neuroprosthetic devices available for various applications such as rehabilitation, assistive technology, and health care.

Ongoing Areas for Development

- Investigate opportunities to spread the knowledge in the area of neuroprosthetics in Industry, universities and TAFEs with the support of International Specialised Skills Institute (ISS Institute), and Centre for Clinical Research (CCRE) seminars and to use the skills, knowledge and understandings gained during the Fellowship to recommend new programs for introduction into Australian TAFE colleges and universities.
- Develop strategies to build ongoing collaborations with overseas universities and industries and promote skills in the area of neuroprosthetics and BCI.
- Build and expand the network in the area of neuroprosthetics within Australian industry and training organisations.
- Use the knowledge and skills gained overseas to create a platform in Victoria to apply the skills and enhance development in the area of neuroprosthetics.

The Australian Context

Brief Description of the Industry

Background

Information and Communications Technology (ICT) is a broad area that uses software and hardware platforms for developing various applications such as education, entertainment, communications, and biomedical engineering sciences as applied to health care. Neuroprosthetics, including BCI, is an important and developing area of ICT that uses brain signals to control the prosthetic device interfaced to the body.

Development and implementation of BCI technology is multifaceted and time consuming as it involves complex hardware and software interfaces.[i] In BCI, the power of the brain is being harnessed and the implications for people with limb loss, paralysis, an inability to speak, and other disabilities are tremendous.[ii]

Recent developments in the area of neural prosthetics for assisting paralysed patients have focused on decoding intended hand trajectories from motor cortical neurons and using this signal to control external devices.[iii] Using neuroprosthetics, the brain signals can permit paralysed patients and amputees to operate computers, robots, motorised wheelchairs and even automobiles. Neuroprosthetics, and/or BCI, integrates a wide number of areas, particularly processing techniques, nervous system integration, and prosthetic device control.

Australian Context

Current Issues

A few neuroprosthetic devices are manufactured and made available in Australia, such as the cochlear implant and bionic ear. However, there remains a great human need for better, more functional prosthetic devices and their control. Such devices could then be available for use, especially for accident victims suffering amputation, and soldiers who have been severely injured.[iv]

According to the Victorian Neurotrauma Initiative report (June 2009), the cost for health care related to spinal cord and traumatic brain injury in Australia was expected to be around $10.5 billion in 2010.[iii] Additionally, the Australian Orthotic and Prosthetic Association (AOPA) is concerned that with the current prediction of a 25% increase in diabetes within in the next eight years an increasing number of amputations could crush the public hospital system, if improved practices and processes are not implemented.[vi]

With the ageing population and the increased cost in health care, the Fellow believes it can be predicted that the current medical centres in Australia will become overburdened and find it progressively hard to cope with the increasing health demands for the Australian community.

Addressing the Issue

There are various solutions to the abovementioned problems. Ensuring that improved and advanced education programs in neuroprosthetics are developed in Australia is a smart long-term solution to address one of the above issues.

In order to introduce neuroprosthetics into Australia, the Brain Research Institute (BRI), Howard Florey Institute and National Stroke Institute joined together in 2007, to form Florey Neuroscience Institute in Melbourne, Australia. Although the BRI offers courses in a similar area, the number of courses related to neuroprosthetics is very limited. As a matter of fact, Victorian universities and TAFE institutes currently do not have properly accredited programs that address neuroprosthetics or BCI.

In late 2008, a number of clinical groups throughout Australia came together under the banner of 'Bionic Vision Australia' (BVA). BVA's members include the University of New South Wales, the University of Melbourne, the Bionic Ear Institute, Centre for Eye Research Australia and the Victoria Research Laboratory of the National Information Communications Technology of Australia (NICTA). The BVA partnership brought together the necessary capabilities, expertise and technology to develop the bionic eye, including world leading experts in the fields of ophthalmology, bio-engineering, material biocompatibility, vision science, and wireless integrated circuit design.[iv]

EVestG™ is a new diagnostic tool recently developed by Monash university senior lecturer, Doctor Brian Lithgow in collaboration with Professor Jayshree Kulkarni, which will help doctors to make rapid diagnoses of the four major central nervous system disorders: depression, bipolar, schizophrenia and dementia. As recently advertised through ABC, Monash University has granted the development licence for EVestG™ to Neural Diagnostics Pty Ltd, and has already commenced the commercialisation proces.[ix]

Despite the above activities and developments, the Fellow is of the opinion that there is a lack of sufficient activity undertaken in Australia in the area of BCI and neuroprosthetic device control and that this lack has resulted in skills deficiencies. It is observed that the technological platform and the expertise in the area of neuroprosthetic control using brain signals are not yet established to the degree necessary for successful early development of the neuroprosthetic device industry.

Threats and Benefits of Obtaining Skills

Existing prosthetics technology in Australia is largely limited to providing passive devices such as knee prostheses, hip prostheses, ophthalmic prostheses, and vascular prostheses. Neuroprosthetic devices such as cochlear implants are available to very few.

While Australian universities and TAFE institutes are unable to provide accredited courses in the area of neuroprosthetics and/or BCI, there will continue to be no formal training in these areas and hence an obvious skills deficiency will not be addressed. There remains a risk of Australia falling further behind other countries in this important area of information technology.

The technology used for neuroprosthetics is advancing worldwide, and the current practices in Australia have not been able to keep up with the rapid changes in industry standards and processes in this area. If this trend continues, the technology used in the Australian biomedical industry will soon become outdated and Australia will be likely to fall further behind the world's leading technology countries, in particular the United States of America (USA) and Europe.

Embracing neuroprosthetics research and development will open up greater possibilities in the health care sector through the development and manufacture of new products to meet this market. Neuroprosthetic devices provide intelligence to passive prosthetic devices and, if the subject is trained properly to use the device, the impact could be as great as independent living and reduction of the burden on nursing homes and rehabilitation centres.

Value Chain

Neuroprosthetics have distinct advantages over traditional prosthetics, because of the powerful ability to transform the body and to integrate prosthetic devices with the human nerve system. Gaining knowledge in this powerful technology will be used to educate students in cutting-edge technology and to promote and develop public interest, as the implications of this technology for people with limb loss, paralysis, an inability to speak, and other disabilities are huge.

An exposure to this technology during the Fellowship enabled Pendharker to significantly increase her knowledge on the next generation prosthetic devices and the control technology available. This knowledge will be used to provide feedback to the interested sectors such as TAFE, universities and industry throughout Victoria and Australia.

Technological knowledge transfer is an important part of development for an individual, the Australian community and the country. Transferring the gained knowledge to others working in similar areas will ultimately benefit rehabilitation centres in Australia and help amputees and paralysed patients to be more mobile, assist them to a fuller life, and return to work if they so desire.

Through this technological knowledge transfer, the Australian neuroprosthetic industry will be in a better position to develop sustainable technology standards and practices to meet our emerging and future markets in biomedical engineering, assistive technology and health care industries.

SWOT Analysis

Strengths

Neuroprosthetics is an empowering technological application that uses cutting-edge technology in biomedical engineering and ICT. The technological concepts used for neuroprosthetics can be used for developing applications in other areas in the health care and entertainment sectors.

Neuroprosthetic devices have distinct advantages over traditional prosthetics, because of the powerful ability to transform the body and to integrate prosthetic devices with the human nervous system. It would be extremely beneficial for people with limb loss, amputees, paralysis, an inability to speak, wounded soldiers, and other disabilities.

Weaknesses

In Australia, the expertise available in the area of neuroprosthetics is currently limited as this is still an emerging area in biomedical engineering. Due to a lack of sufficient expertise, very few educational programs are offered in the area of neuroprosthetics, other than by limited offerings at institutes such as the BRI in Melbourne, Melbourne University, and NICTA in Sydney.

Opportunities

Provided the expertise soon becomes more readily available in Australia, world-class research programs could be made available to provide a technological platform to develop applications in cutting-edge technology in neuroprosthetics.

An opportunity exists to educate students at universities and at TAFE Institutes in cutting-edge technology and to promote and develop interest, particularly in electronic and industrial design/product development. A number of programs can be designed and developed in the area of neuroprosthetics for TAFE programs and universities across Australia.

Australia would then be well placed to develop sustainable technology standards and practices to meet emerging and future market demands in the biomedical engineering, assistive technology and health care industries.

Threats

If the funds provided by the Australian Government in the area of biomedical engineering remain limited for the area of neuroprosthetic research and development, this would in turn limit the educational opportunities and industry growth in the field. Hence, Australia would not be in the position to compete with the established international market in the area of neuroprosthetics due to the limited expertise and knowledge available.

Concepts for new products in neuroprosthetics may not be supported for manufacturing in Australia, and would be either ignored or taken up overseas. The longer it is delayed the more difficult it will be to catch up.

Identifying the Skills Deficiencies

Definition of Skills Deficiencies

As already established, a skill deficiency is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the-job, gleaned from published material, or from working and/or study overseas.

Identifying and Defining the Deficiencies

ICT is a broad area that uses software and hardware platforms for developing various applications for use in areas such as education, entertainment, communications, biomedical, and health care. Australia has often been at the forefront of developments in the area of scientific and commercial ICT; however, recognition of the importance of using ICT for helping humanity has until now not received the same attention or support.

Neuroprosthetics, or similarly BCI technology, is an important area of ICT which uses brain signals to control the prosthetic device interfaced to the body. Using neuroprosthetics, harnessing these brain signals can allow paralysed patients and amputees to operate computers, robots, motorised wheelchairs and perhaps even automobiles. Neuroprosthetics, and/or BCI, integrates a wide number of areas particularly signal processing, nervous system integration and prosthetic device control.

Development and implementation of BCI technology is difficult and time consuming as it involves complex hardware and software interfaces.[i] In neuroprosthetics and BCI, the power of the brain is being harnessed and the implications for people with limb loss, paralysis, an inability to speak, and other disabilities are tremendous.[ii] Rather than pure research, the emphasis of this Fellowship is concentrated toward the development, manufacture and use of neuroprosthetic devices and 'how to make them work'—that is, practical solutions.

1. Establish a fundamental understanding and knowledge of the technology used to control the neuroprosthetic device using brain signals.

- Determine the technologies used to control neuroprosthetic devices.
- Identify and analyse the interface mechanisms between the device and the brain.
- Identify the site for the device interfacing the brain with eye, ear, and muscle.

As described previously, a number of clinical groups throughout Australia came together under the banner of 'Bionic Vision Australia'.[iv] However, the technological platform and the expertise in the area of neuroprosthetic control using brain signals are not yet established in Australia.

2. Gain skills and knowledge in using the development tools used for neuroprosthetics and to acquire knowledge on various complex software programming techniques and the hardware systems involved in designing the prosthetic device and its interface to the brain.

Interfacing an external prosthetic device to the nervous system or brain involves the study of how the brain assembles and organises neurons, and how it forms a motor memory to control the prosthetic device. To study the complexity of wiring one's brain to properly control the prosthetic device is a very important factor in understanding the technology used for neuroprosthetics.

- Develop an understanding of development tools such as BCI2000 (Software) used to interface the brain to the prosthetic device.[i]
- Identify the appropriate complex software programming techniques and the hardware systems involved in designing the prosthetic device and its interface to the brain.

3. Gain the skills and knowledge necessary to interpret the electrical signals generated from the brain to provide control of prosthetic devices.

There are different methods of gathering signals from the brain. A widely used method is electroencephalography (EEG), a non-invasive method that records activity through the scalp by monitoring and recording electrical impulses. A second approach, using invasive interface devices in which electrodes are implanted directly into the brain, produces the highest quality signals.

4. Identify and understand the various signal processing techniques used to control prosthetic devices.

The signal processing involved in such a system is complex. It uses adaptive algorithms as these signals could also be rapidly adjusted by changing parameters of the task to expedite the learning that patients must do in order to use an external device. SIGnal modeling FoR Identification and Event Detection (SIGFRIED) is a signal-processing component that provides a real-time visualisation tool for evaluating complex brain signals.

5. Identify and evaluate the various next generation neuroprosthetic devices.

A skills deficiency currently exists in Australia due to the lack of sufficient action taken in the area of BCI and neuroprosthetic device control. The Honda Research Institute in Japan has taken very significant steps towards what could be an absolute revolution in human-computer interface. Honda Research has demonstrated a Brain Machine Interface (BMI) that enables a user to control an Advanced Step Innovative Mobility (ASIMO) robot using nothing more than thought.[6] A few neuroprosthetic devices are available in Australia, such as the pacemaker, mental typewriter, and cochlear implant, but there is a great human need for better, more functional prosthetic devices and their control that can be used especially by amputees, such as accident victims or soldiers who have been severely injured.[iv]

Diagrams: Medical Cost, Rehabilitation, Prosthetic Devices and Neuroprosthetic Devices related to Productivity Gains

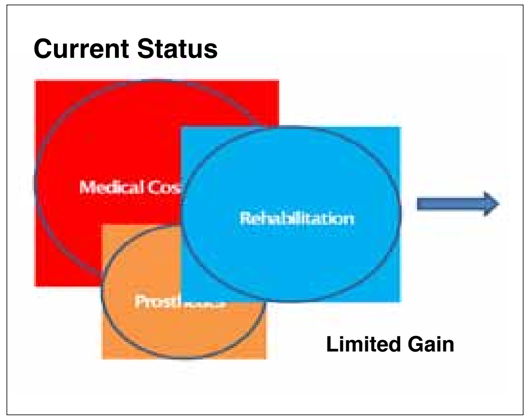

Figure 1: Limited gains, resulting from limited advanced technology application.

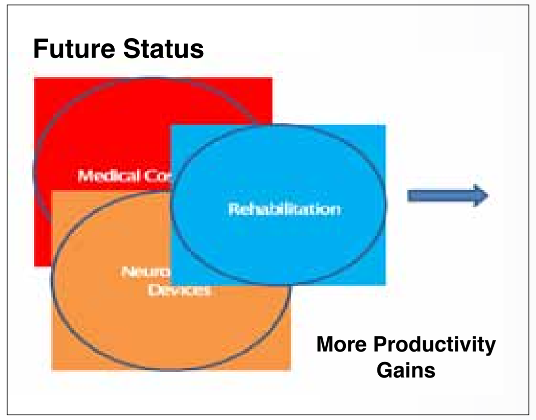

Figure 2: Greater productivity gains, resulting from investment in advanced technology application.

The first diagram (Figure 1), shows the current status of the health care system relating the medical cost, rehabilitation centres and nursing homes, and available prosthetic devices. It is observed that the current medical cost and the rehabilitation cost are higher than the prosthetic devices.

[6] http://www.gizmag.com/tag/asimo/

As a result, the small overlapping area of all three indicates the limited gain in health care industry currently available to the local community due to the limited availability of prosthetic devices. Or, it could be said that due to the limited availability of prosthetic devices, the cost of rehabilitation, nursing homes, and old age facilities are higher.

The second diagram (Figure 2), shows that if the Neuroprosthetic devices are made available along with the current prosthetic devices then even if the cost of the medical centre and rehabilitation remains the same in the coming years, we can have increased productivity gain, which is indicated by the increase in overlapping area of all three systems.

It is also obvious that if we increase the production in Neuroprosthetic devices in the coming years, the overlapping area will eventually increase signifying high productivity gains and benefits in the Australian health care system in the long term.

The Links Between Medicine, Health, Wellbeing, and Neuroprosthetic Devices

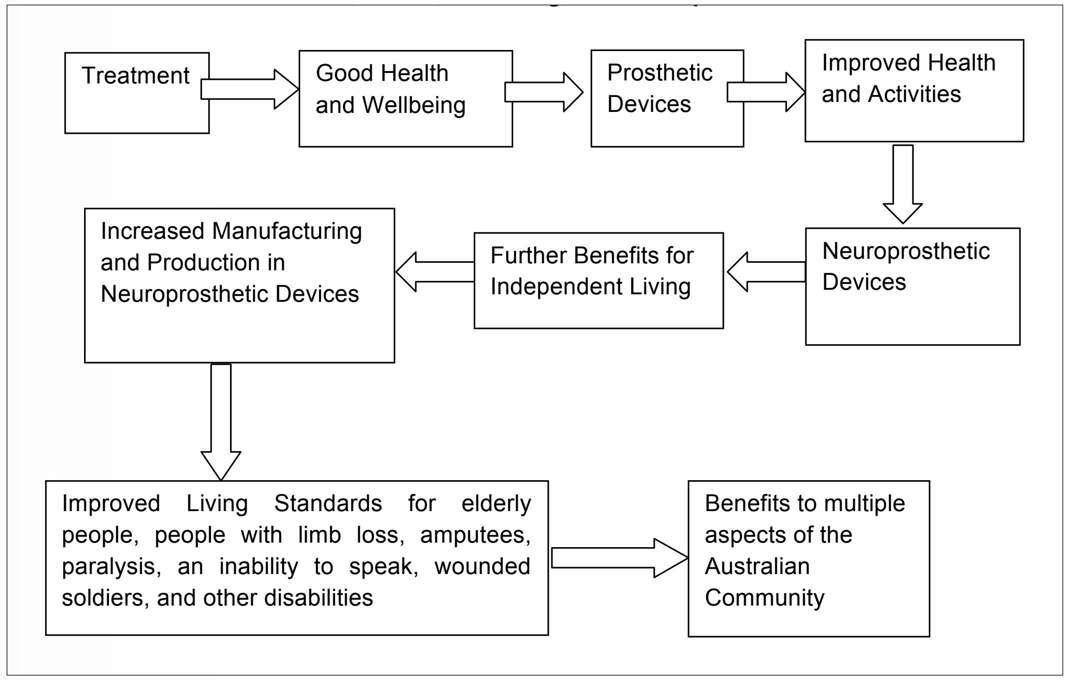

Figure 3: Flow chart of benefits/gains from investment in advanced technology

The flow chart above describes the relationship between medicine, health, wellbeing, prosthetic devices, neuroprosthetic devices, and increased manufacturing and production on neuroprosthetic devices.

The obvious current trend is that when patients with less severe issues are treated, they are most likely to recover. With critical patients who have lost a part of the body, a prosthesis normally helps them to gain some support and recovery. However, for patients who have lost total functionality of some of their body parts (or paralysis), neuroprosthetic devices offer a solution that can give them some extent of independent living. It must be realised, however, that patients need to be trained in order to successfully and effectively use a neuroprosthetic device. Depending upon the severity of the injury or loss, training a subject can be quite complex. The quicker that the knowledge and application of this technology is brought into and established in Australia, the quicker that training can be provided to the number of interested people and the greater the growth of manufacturing and production will be. This will benefit the Australian community on long-term basis.

The International Experience

Destination 1: Universidade Federal do Espírito Santo (UFES), Brazil

Location: Vitoria, Brazil

Contact: Professor Tedeos Bastos

Objectives

The main objectives of travelling to Brazil were to:

- Conduct discussions and develop international contacts with experts working in the area of neuroprosthetics or BCI at the following locations:
  – UFES
  – the annual international ISSNIP Biosignals and Biorobotics Conference 2010.
- Visit the Human Computer Interface laboratory at UFES in Vitoria, Brazil to gain an understanding of the current state-of-the-art technology.
- Present a technical paper at ISSNIP Biosignals and Biorobotics Conference 2010 in Vitoria, Brazil in January 2010.

Outcomes

UFES is considered one of the best universities in Brazil and has a large number of funded projects in the area of Human Computer Interface (HCI). The conference was held in UFES, Vitoria. The Fellow presented a technical paper, and international contacts were established during this conference in Brazil, which resulted in the commencement of valuable professional collaborations.

Figure 4: The Fellow and UFES research students

The Fellow visited the HCI laboratories at UFES and had the opportunity to discuss the recent development in HCI with some of the local postdoctorate students at the university. The local community in Vitoria, Brazil, was very friendly and had organised some sightseeing activities for the conference attendees.

The Fellow established contact and had preliminary discussions with three of the leading researchers in the world in the area of BCI during the conference. This led to her confirming an invitation to visit recognised researchers at different institutes, as mentioned below:

1. Professor Nitish Thakor, at Johns Hopkins University, Baltimore, USA
2. Professor Sri Krisnan, Ryerson University, Toronto, Canada
3. Professor Robertto Merletti, Politecnico di Torino, Italy

Destination 2: Ryerson University

Location: Toronto, Canada

Contact: Professor Sri Krisnan

Objectives

To deliver a presentation on work to date, and to initiate contacts for future collaborations.

Outcomes

Professor Sri Krishnan,[viii] who is the Interim Associate Dean (Research & Development) in the Faculty of Engineering, Architecture & Science at Ryerson University, Toronto, Canada hosted the Fellow's visit. The Fellow gave a presentation at Ryerson University, based on the research carried out at Monash University, Melbourne.

The presentation covered the use of sensor technology for accurately assessing and analysing specific medical problems associated with advanced technology sensors. The analysis of two different types of abnormal gaits, Idiopathic Toe Walking Gait and Gait in Vestibular Subjects, was discussed using sensors (accelerometers, gyroscopes). The advantages and disadvantages of using sensors and the effects on accuracy of measurement, with particular emphasis on remote monitoring and analysis of the gate were also discussed. The technology and the research findings in the Fellow's presentation were appreciated by the staff and students at Ryerson University in Toronto.

Destination 3: Johns Hopkins University (JHU)

Contact: Professor Nitish Thakor, PhD

Objectives

The main objectives of travelling to JHU were to gain an understanding of the following:

- current projects in the area of neuroprosthetics
- details of the technology used for the research in neuroprosthetics
- state-of-art commercialisation of the neuroprosthetic devices.

Outcomes

The Biomedical Engineering Department at JHU is one of the world's leading departments in the area of Biomedical Engineering.[v] What makes it so distinct and one of the best departments in the world is that it has sufficient funding available for research and development, and the department of biomedical engineering is located in the hospital and has access to all the facilities of the hospital. The running and output of this department was extensively illustrative of the importance of these two factors; without doubt the factors of importance to take back to Australia.

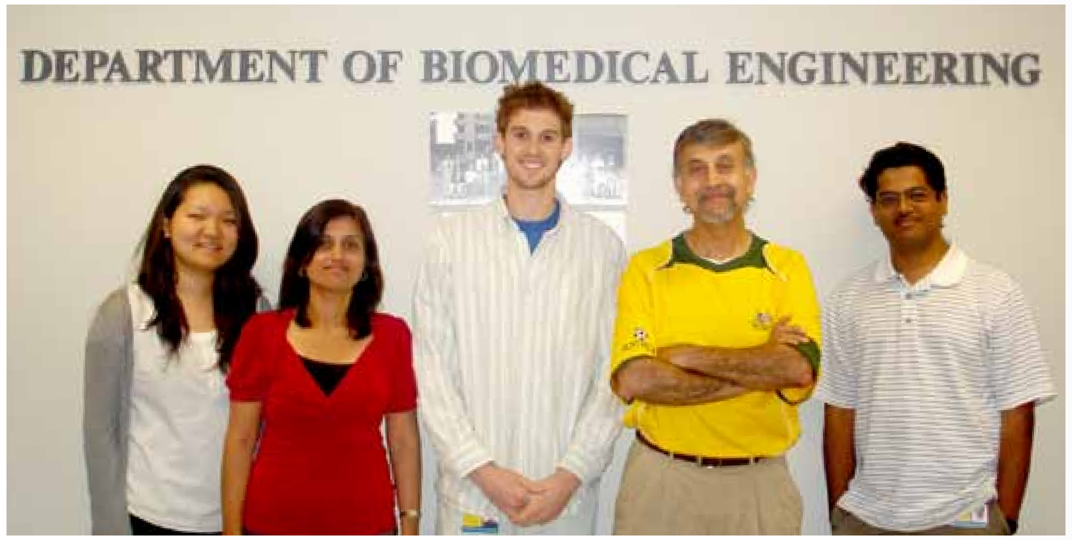

Figure 5: The Fellow with Professor Nitish Thakor and postgraduate students at JHU

Professor Nitish Thakur[vii] is a leading researcher and professor at JHU. During the stay at JHU, the Fellow had the opportunity to discuss and collaborate with the doctorate and master's students in the neuroprosthetics laboratory.

This international destination was the richest of the four destinations visited, in that it broadened the Fellow's knowledge in the skills deficiency area in multiple ways. For example, during the Fellow's visit at JHU, knowledge and skills were gained in:

- capturing brain signals
- software programming tools and techniques
- signal processing methods
- commercialisation and development of neuroprosthetics.

Information on each of these areas is detailed below.

Capturing Brain Signals

Brain signals are captured by either non-invasive techniques such as EEG or invasive techniques such as Electrocortiograph (ECog). Capturing EEG signals is done using a cap with 64 electrodes (technique available in Australia). However, to capture the ECog signals, the scalp of the brain has to be inserted with electrodes, which can be done by clinicians. The advantage of ECog signals is that they have less noise introduced and high Signal to Noise Ratio (SNR) and, hence, are easier to further analyse and process. Figure 6 shows the 64-electrode EEG cap used to extract the brain signals.

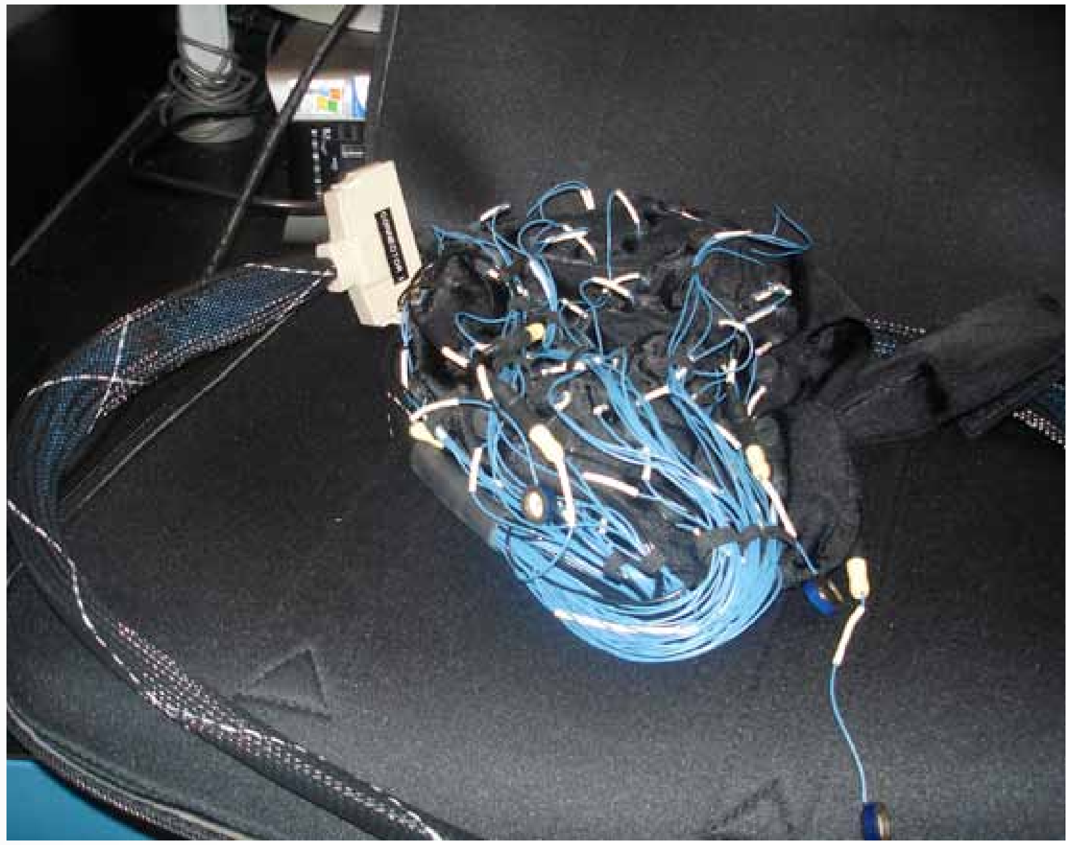

Figure 6: EEG Cap

Software Programming Tools and Techniques

Data acquisition of the brain signals can be carried out using the neuroscan toolbox in MATLAB®. The samples can be stored on the PC for further analysis. The neuroscan toolbox integrated with MATLAB® is also used to develop the algorithm for neuroprosthetics. In addition to MATLAB®, C, C++, Csharp programming languages can also used for this purpose.

Figure 7: Prosthetic Hands

Figure 8: Prosthetic hand with electrodes, showing the various connecting leads from the neuroprosthetic hand to the human brain.

Signal Processing Methods

Depending on the features to be extracted from the signals, various signals processing techniques are used such as the Kalman filter, Artificial Neural Network, Recurrent Neural Network, Linear Regression, and Linear Discremination Classifier. The Directed Transfer Function (DTF) and Dynamic Basian Network (DBN) developed at JHU are well established methods for processing the brain signals.

The photograph in Figure 7 was taken at the neuroprosthetics laboratory at JHU, and shows various neuroprosthetic hands used for human body interfaces.

Commercialisation or Development of Neuroprosthetics

There are few industries in the USA in the area of neuroprosthetics. However, it was interesting to note that some of the past master's degree students from the department of neuroengineering at JHU had started a small company called Infinite Biomedical Technologies LLC (IBT) in Baltimore to commercialise some of the neuroprosthetic devices. The company has 15 employees and runs entirely on government grants.

Destination 4: Proposed visit to Polotecnico di Torino

Location: Laboratory of Engineering of Neuromuscular Systems

Contact: Professor Robertto Merletti

Much of Professor Merletti's research and development has common aspects to the work of the contacts listed prior, and it was interesting and worthwhile to compare the work he and his colleagues are doing. However, as his location is in Italy and as Merletti concentrates on muscular function, rather than prosthetic function, it was decided after discussions between Merletti and the Fellow at the conference in Brazil that the Fellow would be better placed to concentrate on those researchers working in the specific area of neuroprosthetics.

Knowledge Transfer: Applying the Outcomes

The Fellow has discussed the outcomes of the research and development on neuroprosthetics (gained in USA) with staff members from Victoria University, Melbourne (in particular Doctor Daniel Lai) and will be presenting the work to interested people.

The Fellow presented her work at a local secondary school (Brentwood Secondary College) in April 2011. She also presented her work at Monash University in a lecture (October 2011) highlighting some of the topics covered for the course ‘Biomechanics of Human Musculoskeletal System’, course code ECE4084, offered in the 3rd year Bachelor of Engineering Program.

Similarly, workshops and presentations will be held at various Medical Centres and Gait Laboratories to emphasise the importance of neuroprosthetics.

Future seminars will be arranged at Monash University and Melbourne University to further disseminate information on neuroprosthetics (or BCI), and the Fellow will collaborate with colleagues to discuss and implement appropriate changes to existing course material.

Recommendations

Government

Currently, the Australian Government has allocated a large amount of funds for the Bionic Eye project, which is another area of neuroprosthetics. This initiative has enabled the creation of doctorate and postdoctorate positions in selected universities in Melbourne. The government should provide more funds (regularly, every year) for research and development in the area of neuroprosthetics, or BCI, for the long-term benefit of the Australian community.

Once there are sufficient funds and expertise available in this area, then the training and skills reform in the area of neuroprosthetics will be self-sustainable as shown in Figure 9. Figure 9 demonstrates the possible self-sustainable nature of the neuroprosthetic industry in Australia.

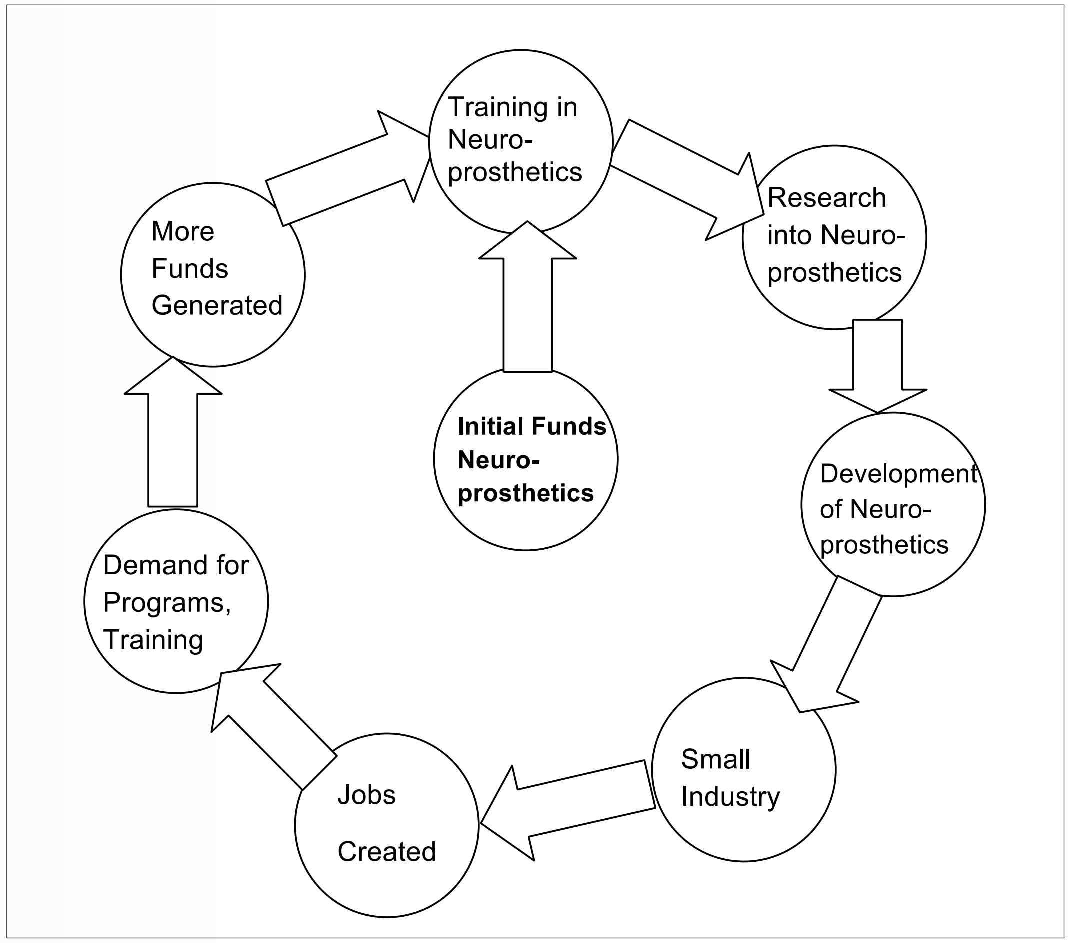

Figure 9: The possible self-sustainable nature of the neuroprosthetics industry that could be achieved

Medical Technology Association of Australia (MTAA)

Another potential funding body could be the Medical Technology Association of Australia (MTAA). This body has been funding projects in medical technology in the area of health care particularly benefiting the Australian community.[x] The Executive Vice President for Technology & Regulatory Affairs, Janet Trunzo, should be consulted to investigate the possibility of requesting further funding in the area of neuroprosthetics and BCI. Funds could be allocated over a period of time for innovative projects having commercial value in neuroprosthetics or BCI. These projects could lead to small industries in neuroprosthetics, which could further increase the job market in this area.

Manufacturing Skills Australia (MSA)

Manufacturing Skills Australia (MSA) is an organisation that addresses the skills needs of over 250,000 manufacturing businesses and other businesses in Australia. MSA is the national Industry Skills Council, owned by industry that is supported by the Australian Government to ensure that the skills needs of enterprises are being met.

MSA should take interest and provide industry intelligence and advice to Skills Australia in the area of neuroprosthetics. MSA should also actively support the development, implementation and continuous improvement of high quality training in neuroprosthetics. Proposals can be submitted to MSA regarding the current limitations in the area of neuroprosthetics.

Education and Training

Currently, Melbourne University has taken some initiative to introduce programs in brain research. Similarly, other universities need to fund similar programs in Melbourne and across Australia. University funds should be available and utilised for development and commercialisation purposes. The funds should be targeted to facilitate small industry growth from the research carried out in the universities. This will in turn create jobs due to growth in biomedical industries and also create a self-sustainable neuroprosthetics market, as shown in Figure 9. This will also foster growth in cutting-edge technology in the biomedical industry, and Australia will be competent with the other countries in ICT.

For example, at the Faculty of Engineering within the Department of Electrical and Computer Systems Engineering, of Monash University, there is a course called as Biomechanics of Human Musculoskeletal Systems (Course code ECE 4084) offered in the 3rd year of the Electrical Engineering Program. This course covers a few topics on prosthetics; however, it could be modified to have neuroprosthetics theory and practicals included in the curriculum.

Another example is the Master of Biomedical Engineering Program (Code 745BM), which is currently offered at Melbourne University. In the current course of Biomedical Engineering (Course code BMEN90015) neuroprosthetics could be included in detail.

Similarly, primary and high school students should be encouraged to take an interest in the wider aspects of ICT and particularly BCI and neuroprosthetics, that is, create an awareness of this alternate career pathway. This can be carried out by seminars, and presentations on projects in neuroprosthetics at various schools. The schools should be encouraged to visit the appropriate training centres once or twice a year. Once the school children develop an interest, there will be a demand for the courses at the university level, which will facilitate small industry growth.

How ISS Institute can be Involved

ISS Institute has the potential to utilise its many contacts to attract funding and work with Universities, TAFE and other government agencies to assist the growth in neuroprosthetics. In most cases, the lack of funding is the main obstacle that needs to be overcome. ISS Institute can facilitate opportunities for seminars and workshops with those in the industry to help disseminate information and foster understanding in the area of neuroprosthetics or BCI.

These seminars and presentations can be held at any institute/lecture hall where all the interested candidates from various institutes can be invited. Overseas experts can be invited to present at the presentations and workshops in specialised laboratories and local experts can be invited to attend.

Recommendations

Further Skill Deficiencies

The Fellow has observed that there is a further skill deficiency in the area of Physical Activity (PA) Monitoring in Australia as described below.

PA monitoring in children and adults remains an important challenge for epidemiologists, exercise scientists, clinicians, and behavioural researchers as they attempt to utilise PA in combating child-related disorders such as obesity in children and young adults. Work has primarily focused on the development of improved methods for recording and measuring the intensity of physical activity. These methods are based on direct observations, subjective surveys and recently portable activity monitors based on inertial sensors. Portable monitors using accelerometer sensors have been used since the early 1990s, with development having focused on miniaturisation and minimising the costs.

The challenges in interpreting sensor data, calibration and reliability issues, however, have been the focus of research in the last decade. Though work is still continuing in the development of models to interpret PA from sensors, field trials have already begun overseas, especially in the USA and Europe. Studies suggest that sensors such as accelerometers could objectively capture physical activities performed by their users; however, inconsistencies with calibration methods, correctly correlating sensor data against the PA and validating the techniques still remain to be solved.

Currently, the Fellow is working on a research project on Activity Monitoring and hence has developed an interest in PA monitoring and would like to attain the required skills in this area by visiting some of the overseas institutes having expertise in the field.

References

Endnotes

i http://www.prlog.org/10240565-communication-via-brain-computer-interface.html

ii http://www.oandp.com/articles/2009-02_10.asp

iii http://www.sciencemag.org/cgi/content/abstract/305/5681/258

iv Australian Vision Prostheses Group via: http://bionic.gsbme.unsw.edu.au/

v http://ww2.jhu.edu/nthakor/

vi Australian Orthotic and Prosthetic Association via: http://www.aopa.org.au/

vii http://www.bme.jhu.edu/people/primary.php?id=398

viii http://www.ee.ryerson.ca/~krishnan/

ix http://eng.monash.edu.au/news/shownews.php?year=2010&nid=56

x http://www.mtaa.org.au/pages/page320.asp