Technology and Disability 15 (2003) 57–61
IOS Press

Guest Editorial

Advances in the Control of Prosthetic Arms

The replacement of a missing hand with a functional analogue is a challenge that many engineers have responded to, with varying degrees of success. The needs of every individual are unique, but one of the challenges is to find a solution that can be sufficiently general to match the requirement of enough potential users to turn a prototype device into a commercial product. Another constraint is that the hand is a very personal part of the anatomy and is identified with action, expression, defence and personality, which makes the challenge even greater. Thus the solutions need to be as personal and particular as the users, while the basic structure is kept as general as possible, potentially diametrically opposed needs. Heretofore the restrictions imposed by manufacturing meant that any design was therefore only partly successful for any particular user, and had limited control and actuation. It is only in recent years that new technology and ideas from other industries, such as microprocessors and materials science have become truly practical in prosthetic terms and a small expansion in new prostheses has occurred. The result is that there is need to collect the best of the latest techniques and ideas in a single edition these are presented in this journal. The collection of papers attempts to capture a flavour of prosthetics at the start of the twenty first century.

The key to this wide reaching change in prosthetics is the arrival of compact and low power microprocessors. Barkhordar first connected a Southampton Hand to a microprocessor system in the mid 80's, but it wasn't until the 90's that Blatchfords produced their IP ('*Intelligent Prosthesis*'), the first, and for a time, only, commercial microprocessor controlled prosthesis. However, at the most recent Myoelectric Controls Conference at the University of New Brunswick in Canada (August 2002), there were no less than five different add-on microprocessor systems for hands and arms being offered, each having their own distinctive method of operation. The editors of this special edition felt the need to include a prosthetist's perspective on the development. Chris Lake and John Miguelez, who are leading prosthetists in the United States, were therefore invited to describe the current state of the art. As the manufacturers continue to improve apace this will rapidly become dated, but it is important for posterity that such information is recorded objectively.

The idea of controlling an artificial hand or arm using patterns of electromyographic signals from the muscles in a residual limb was proposed some time ago. Given enough patience and practice by the user they can generate the appropriate signals. The research of the SVEN team demonstrated the viability of this technique. Technological constraints meant that this method was unlikely to become a workable solution three decades ago. However recently, with the computational power available in small Digital Signal Processors (DSPs) and the development of neural computing it is now possible to create practical systems and to use contrasting techniques such as those described by Kajitani or Englehart. Beyond that, Kuiken suggests a more radical approach to the idea of electomyography, that of surgically rearranging the muscles to provide better independent control of the residual musculature.

However, electomyography is not the only technique that can be used to generate reference signals as inputs to an automatic control system. Along with the dimensional changes that occur when a muscle contracts (myokinematics), there are different ways of capturing a user's intentions and allowing them to determine the events occurring in a prosthesis. Extended Physiological Proprioception is a two way control format that has the potential for greater exploration. Notably, the group at Northwestern University have documented their latest research on this subject.

Even the idea of electric actuation as the preferred method has been (and should be) questioned. The Wilmer Group has a long reputation of elegant and innovative ideas; the latest from Delft even questions the suitability of voluntary opening or closing. Few other centres or providers (with Bob Radocy of TRS Ltd as

ISSN 1055-4181/03/$8.00

a notable exception), have considered the alternatives, Plettenberg and Herder examine the most appropriate technique. It is important for all users that we continue to do so, in order to provide that range of responses needed for each *individual* user.

Finally, the computer and the Internet also allow the servicing and inspection of prostheses to be of a different form with remote diagnostics becoming increasingly important. It has long been seen as the right direction the technology should head. Lemaire describes work in this direction.

The history of prosthetics has a number of pioneers who have opened up novel directions for research and created new ideas. The editors have been lucky enough to be placed on a path identified by two of these men, namely Professor Jim Nightingale and David Simpson. Part of our goal in recording the present and future of arm prosthetics is also to acknowledge the outstanding contribution made by these men to the subject. They represent the diversity of approaches possible, as well as typifying the best manner to address the subject; to question received wisdom, and to always try to reflect the needs of the target of this work, the prosthesis users.

Jim Nightingale

Professor Jim Nightingale left school at 16 and served an Engineering Trade Apprenticeship after which he worked in the aircraft industry for 5 years. In 1953 he was awarded a Whitworth scholarship and, at the age of 26, went to UMIST to study Electrical Engineering. His first degree was followed by the award of a Whitworth Fellowship and a PhD (1959) on Adaptive Control Systems. He lectured at UMIST until 1962 when he moved to Leicester University, becoming Reader in 1965. In 1966 he became Professor of Control Engineering at Southampton University until he retired in 1988. He then continued to teach his subject on a part-time basis until 2001.

Nightingale developed the concepts of the Southampton Hand over a thirty-year period, starting in 1959, at the University of Manchester Institute of Science and Technology. His work encompasses not only the mechanical aspects of an artificial hand but also the control philosophy. At that time EMG signals were considered a compact and promising alternative for control to mechanical signals from clumsy harnesses. However he recognised that EMG signals were noisy signals and that even smoothed, they did not have sufficient bandwidth or precision to cope with the dynamics involved in hand functions. Also, generally, only one channel of EMG could be independently controlled which limited the number of degrees of freedom a prosthetic hand could have and hence the dexterity which could be achieved by a wearer. Under Jim's guidance, new ideas for prosthetic hands were explored by a succession of PhD students. Initially, a five-fingered hand was developed by Harry DeSousa. The following year, Nightingale was awarded a grant, funded by the Science and Engineering Research Council (now EPSRC), to investigate the applications of adaptive control. One of the topics identified was to seek a hand, which had independent finger control using a single input from the user. John Baits in 1962 started to develop the concepts of hierarchical control, the philosophy of which forms the corner stone of the Southampton Hand.

Natural prehension requires the person to take cognitive decisions and is not concerned with the lower level spinal reflexes, which require complex interactions of the muscles and skeletal joints. This natural hierarchy is developed into artificial prehension where the amount of conscious action is reduced to the level of discrete decisions such as manoeuvre, hold and squeeze. These decisions can be achieved from a single EMG channel via a level detection logic circuit and, during normal operation, the switching frequencies associated with conscious commands would be well within the EMG bandwidth. The low levels involved in tracking and nulling functions are dedicated to an electronic controller and sensors. The user is then not restricted by the tasks that they wish to perform and only has to select a higher level state.

In 1963 Jim moved to the University of Leicester were he made further refinements the concept. He also worked with Bruce Kinnier Wilson, at the MRC Unit in West Hendon and he had a particular influence on this research. In 1966, Nightingale became Professor of Control Engineering at the University of Southampton, were Robert Todd started further developments of the hierarchical control. At this time the control algorithms were implemented using analogue electronics and relays. Roger Codd in 1973, improved the controller using a rule-based implementation (this method was virtually what is now known as fuzzy logic). In 1977, a need to design better mechanisms was begun by David Moore in order to reduce the hand's size. Four motors and gearboxes were used and located within the palm of the hand.

In 1983 Mohammed Barkhordar began his research on the digital control of the Moore Hand. He created sensors that combined the detection of force and slip signals in the same device, but most significantly he adapted the controller to a conventional prosthesis mechanism so that it became the first microprocessor controlled hand in clinical use. Subsequently the mechanical design was improved by Dave Whatley who dispensed with cables to drive the fingers for using solid links. Peter Kyberd then applied the latest in microcontrollers to control the latest of the four degree of freedom Southampton Hands.

A desirable feature of an arm control system is that the position of the hand is largely operated at the subconscious level and requires little or no cortical activity. Neil Storey combined the three-dimensional input from sensors mounted on a shoulder with a position control system using Cartesian co-ordinates to achieve this aim (1977). In 1982 Ian Swain investigated an eleven-degree of freedom hand/arm prosthesis using four inputs from the user (three body movements and one EMG signal). The additional information demanded by the number of degrees of freedom was provided by the constraints on elbow position, an analysis of the wrist trajectory and a variety of sensors in the hand and arm. A study of natural arm motion by David Brown a year later identified the joint velocities and torques found in an average male subject, which were used in the control of an upper limb prototype. Additional movement and control was achieved with novel transmission systems for elbow flexion and wrist joints. At the time the control of the multiple degrees of freedom was difficult to achieve with the available technology.

Professor Nightingale has made a valuable and lasting contribution to the subject of prosthetic hands. His intellect and rapid mental ability in problem solving always ensures a tight focus and he establishes a positive and uncluttered direction to research. It is a fitting tribute to the work started by Jim that the concepts of the Southampton Hand are still valid today. The research continues at Southampton with the development of mechanisms, controls and sensors while clinical work proceeds at the University of Oxford and more recently at the University of Reading.

David Simpson

David Cunningham Simpson was born in Edinburgh, Scotland in 1920. Immediately after leaving school in 1938 he joined the Territorial Army. Although demobilised in October 1938 he started an apprenticeship to a firm of Chartered Accountants but was again mobilised in August 1939 and served with the British Army until he was discharged after being wounded in March 1945.

His wounds seriously compromised the use of his right arm and affected the course of his life thereafter. In the following years he learned a great deal about the problems of people with disability, about their desire to be "normal" and be treated as normal. He learned to play one-armed golf, he drove from Edinburgh to London and back using one arm, and was generally independent. These experiences were of great importance in how he viewed his later work.

On his discharge in October 1945 he started a four years honours Physics degree and followed this by reading for a PhD. He finally gained his first paid civilian job in 1952 at 32 years of age. David married his late wife Isobel in 1946 and firmly believes to this day that, in his own words *"the strains of learning to write left-handed, the suffering of a great deal of pain and the effects of what is now called post-traumatic stress were such that I would have dropped out without the terrific support I had from the wonderful girl I married. Without her I could not have made it.*"

He started in the Wilke Surgical Research Department developing methods for monitoring patients in the operating theatre but from 1957 his involvement extended through most medical departments in Edinburgh. In 1963, at the end of a project he had been doing for the Scottish Department of Home and Health, Dr Sandy Wilson, who was secretary of their New Medical Developments Committee, approached him. He asked if Simpson would be responsible for the development of upper limb prostheses for the "thalidomide children" in Scotland. He still clearly recalls that moment, and in his own words *"of starting to say 'no' and hearing my voice say 'yes' "*.

At the end of April 1963 he went to Heidleberg to see Dr Ernst Marquardt and spent a few days with him in his clinic with the therapists and the children he was fitting with his designs. There he was able to gain a much clearer picture of the task that lay ahead over the next two years. While fitting simple devices at the Princess Margaret Rose Orthopaedic Hospital (PMR) in Edinburgh, he was able to determine on the future approach for a multi-function arm, and by 1965 the foundations of his prosthetic work were laid.

Working with 28 children from Scotland and Northern Ireland, Simpson established a continuous line of research, which is still active today. This gained international fame for both himself and The Bioengineering Centre at Princess Margaret Rose Hospital. His idea and application of Extended Physiological Proprioception (EPP) and the designs of powered limbs achieved from 1963 to 1976 remain highly influential to this day.

Simpson's gift was to recognise the simplest of facts: that the patients' controlling neurones remained intact and that they were better than anything technology could offer (then and today). In recognising that the proprioceptive sense was intact in the children's shoulders and in applying this to limb control was a major breakthrough. His concept of Extended Physiological Proprioception is so simple and obvious that it had eluded the field of prosthetics until that point. The natural extension of the body's own transducers to the control of an external device is self evident in the manner of a tennis racket or golf club. The ability to hit a static or moving ball using a combination of proprioception and visual feedback is evidence of fast data processing and closed loop control.

Simpson harnessed this and extended the degrees of freedom present in separate and repeatable movements of the shoulder girdle to individual degrees of freedom in the prosthesis. He linked control inputs to the prostheses by simple cables, effectively creating an "unbeatable" servomechanism and provided a conduit for physiologically appropriate feedforward and feedbcak signals. The end result was prosthetic multi degree of freedom control so far unsurpassed.

This remains the lasting challenge for the new millennium.

In 1976 David Simpson left to become the Executive Dean of the Faculty of Medicine at the University of Edinburgh. Subsequently, he was elected as a full member of the Royal College of Physicians of Edinburgh, a singular honour for a non-medically qualified clinician. He still lives in Edinburgh and retains a keen interest in the welfare and future of Edinburgh's bioengineering work.

The Guest Editors

Peter Kyberd

Peter Kyberd obtained a degree from Durham University in General Science in 1983. Following working for the software house CAP UK Ltd for a year he started a long association with Southampton University by taking a masters in Electronics from the Electronic Engineering department, before moving across to the Electrical Engineering Department. It was during his masters that he learned of the work on the Southampton Hand and obtained a place to study for a PhD under Jim Nightingale, (before his first retirement), then under Paul Chappell. His PhD took the fifth generation Southampton Hand and united it with the most advanced microcontroller system of the time. A mix up that ensured that he missed the one of last major Dubrovnik conferences in 1988 and so was at a local conference in Oxford, that he first met David Gow.

Following the completion of his PhD, Peter moved to the Oxford Orthopaedic Engineering Centre, at the Nuffield Orthopaedic Centre in Oxford. Here he was able to conduct clinically focussed work on the application of the principles of the Southampton Hand in prosthetics, but also in rehabilitation robotics. He has been involved in two major European prosthetics projects (MARCUS and ToMPAW), as well as other areas of rehabilitation robotics and orthopaedic engineering. He took over the long running Roentgen Stereo Photogrammetry project in Oxford, before taking up a position as a lecturer in Cybernetics at Reading University, where he maintains his links with the Nuffield. In 1999 he was chosen as one of the lecturers in a series to mark the bicentennial of the Royal Institution.

Peter currently lives in Kidlington and has been the secretary of the Kidlington Running and Athletics Club for ten years, but he runs less often and more slowly than he once did.

Paul Chappell

Paul Chappell graduated from the University of Sussex with a first-class honours degree in electronics and under the supervision of Jim Nightingale, was awarded a PhD degree in control from the University of Southampton. He joined the University of Southampton in 1984 and is a lecturer in the Electronics Systems Design Research Group in the Department of Electronics and Computer Science. While his main research interests are in Medical Engineering, particularly Prosthetics and Functional Electrical Stimulation, he has designed Power Electronic Converters for industrial applications. He has over 50 publications (Journal papers, conference proceedings, chapters in books and a patent). Paul is a Chartered Engineer, a Member of the Institution of Electrical Engineers, a Member of the Institute of Physics and Engineering in Medicine and a Member of the Institute for Learning and Teaching.

David Gow

David Gow was born in 1957 in Dumfries, attended Annan Academy and then studied mechanical engineering at the University of Edinburgh where he graduated with an honours degree in Engineering Science in 1979. He then worked in Laser Systems Engineering for Ferranti Scotland until January 1981 when he accepted a post as a research associate with the University of Edinburgh to study control systems for artificial hand prostheses. This began his association with the Bioengineering Centre at Princess Margaret Rose Orthopaedic Hospital. He took over responsibility for the department's prosthetics' research, development and service in 1986 and became assistant Director in 1991. The Bioengineering Centre became a cornerstone of a larger organisation known as Rehabilitation Engineering Services and David took over the Directorship of this in 1993.

He is currently employed by Lothian Primary Care NHS Trust and runs a department of 25 people. He is a chartered engineer, a member of the Institute of Physics and Engineering in Medicine, a member of the Institute of Healthcare Management, a member of the International Society for Prosthetics and Orthotics. He is an Honorary Fellow in the University of Edinburgh's Department of Medical Physics. He has recently obtained a Postgraduate Diploma in Healthcare Management from Queen Margaret University College.

He lives in Edinburgh with his partner Janet and follows the fortunes of Queen of the South Football club and has interests in good food, wine, music, theatre, art and sport. He is an active but slow jogger and likes taking holidays in Italy.