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Foreword
By the guest editors

I. INTRODUCTION

Prosthetics presents a challenge for engineers, they must balance user needs with practicalities. In the past the compromises made have been towards simpler devices. Recently this has begun to change, new microprocessors, powerful motors and novel batteries make it possible to conceive of different solutions. These papers give an overview of what is now possible.

Thus limb prosthetics is an exciting field were there are a large number of possibilities created by current and emerging technologies, which are beginning to filter into the field, following the upward path as technology and price allows.

II. NEW HORIZONS IN PROSTHETICS

II.1. The past

Prosthetics is an ancient art. In the past people who have lost a limb through war, accident or disease, presented a challenge for others to engineer a prosthetic replacement. For centuries few survived the trauma of amputation or infections and it was only after the development of antisepsis and anaesthesia that sufficient numbers of people survived for an industry to develop, and it was the first industrial scale war that created a market that was large enough to support the industry.

The limitations on the application of technology to prosthetics is very much based on the overwhelming need for the devices to be *practical*. No matter how elegant and advanced a solution might be it will not be adopted by users who need the device to work all the time and not be a greater hindrance that the absence is itself. Thus the specifications of a prosthesis push the technology hard in the direction of the small, the light, the strong and the cheap. A low price is a hugely important consideration in the provision of a prosthesis. The numbers who need or would use a device are sufficiently small that the economies of scale are not generally in their favour, resulting in a limited input of resources for industrial innovation. This explains the longevity of the classic prosthesis of the past: the hook and the peg leg.

Both these devices are very practical. They are strong and light and fail gracefully, allowing the user time to get home for a repair. The hook is easy to control using a harness to drive the device. It is opened or closed by the relative motions of the arm and back. The feedback channel is mostly visual and thus the control can be slow. The mechanical design allows the hook to perform the important grip forms required for the majority of manipulations. Thus it is an effective and functional device, but it is limited to a single degree of freedom. The wide range of different grip shapes and tensions created by the natural hand ensures it can adapt to a multitude of object shapes, through the use of many independent degrees of freedom. This has proven to be difficult to replicate. The natural control is hierarchical and the control of grip shape and tension is by reflex. The multiple degrees of freedom that are available in the natural hand would over-burden the user of a similar prosthesis if conventional visual control was applied. Thus the devices are limited to an easily controlled, single degree of freedom hand, with the commensurate loss in functional performance.

II.2. The present

It was for these reasons that significant changes in prosthetic technology began to take place only towards the end of the twentieth century. Initial progress was generally in the applications of new materials. The increasing importance of Information Technology only has begun to manifest itself in the recent decade. Although the first clinical experiments with a microprocessor controller for a prosthetic hand were conducted as far back as the mid 1980's in Southampton by Professor Jim Nightingale's group, the first commercial device was a microprocessor controller for the swing phase of an artificial knee by the British company, Blatchfords, a decade later. The most recent prosthetic legs now can adapt their gait to different surfaces and activities. The advantages have been perceived by the rest of the market and rival systems now exist.

More recently, microprocessors have been introduced into the commercial arm systems, and they are progressing beyond their initial application of improving stock control. Now it is possible to use the microprocessor to adjust different command styles for the prosthesis. Earlier systems were simple analogue circuits that controlled the opening and closing of the hands; they allowed little adjustment of the system except the input gain of the command signal. Now microprocessor systems allow the prosthetist to adjust the state machine that drives the hands to respond to greater or lesser signals, allowing much closer focus on the user's capabilities.

II.3. The future

There are few commercial hands with exteroceptive sensors. While from an industrial robotics perspective, it might seem natural to detect the forces a gripper is imparting on an object and thereby control the grip, the practicalities mean that the prosthetics industry is far slower in adopting them. The earliest application of microprocessors in a research prosthesis was in this category. The Southampton Hand possessed sensors in the hand to detect contact forces and the relative slipping of a held object, as well as the position of the fingers in order for the hand to perform closed loop control of the grip shape. An hierarchical controller took simple instructions from the user and adjusted the grip shape and tension in response to the target object, freeing the user to perform only a supervisory role. This work has been pursued by the editors (PHC and PJK) first in Southampton, then

Oxford, before collaboration with David Gow led to work in Edinburgh, Göteborg and now at other centres.

Pioneer by David Simpson at the Princess Margaret Rose Hospital in Edinburgh recognised that the patients' control structures remained intact and out perform artificial systems (then and today). He saw that the proprioceptive sense was intact in the shoulders of persons with reduced limbs and this sense could be applied to limb control. This was referred to as Extended Physiological Proprioception (EPP). It is the natural extension of the body's own proprioceptive feedback to the control of an external device (in the manner of a tennis racket or golf club). Simply, it is force feedforward, position feedback, so giving separate and repeatable movements of the shoulder girdle to individual degrees of freedom in the prosthesis forms an "unbeatable" servomechanism. It provides a conduit for physiologically appropriate feedforward and feedback signals. The end result was prosthetic multi degree of freedom control so far unsurpassed. This control form has been studied not only in Scotland but in America, Canada and Europe. Critically, it is still seen as a standard that other systems attempt to emulate.

However these are not the only approaches that can be adopted to solve the problem of limb loss/absence. The editors are fortunate to have secured the contributions of many of the important, leading or simply most interesting approaches that currently are being developed around the world.

Novel prosthesis mechanism and design are exemplified by three very different approaches by the teams described by Crelias, Pons and Schultz. While electrical drives might seem to have be dominant over the past 30 years both the first two teams see effective solutions coming from the more compliant or lighter actuation of pneumatics or hydraulics. Additionally each of the hands involves new ideas about the problems of hand control, with novelty stemming from new forms of myoelectric control or other means of detecting muscular intent.

One area of design that has been neglected is the kinematics of real limbs. Humans are especially good at noting deviation from the natural, so that a moving prosthesis is often easier to spot. In addition, precise knowledge of how humans use their limbs allows for a better informed design specifications. The ability to measure the use and acceptance of prosthesis is an important area of interest. Contributions from Black and Miller reflect the monitoring of the users to gauge effectiveness of arms and legs. Stavdahl et al. has developed a more sophisticated kinematic approach to that most complex joint, the wrist.

Finally, we are glad to have contributions from two people who describe two projects that were key in the clinical introduction of microprocessor systems to prostheses. Winfried Heim presents a brief introduction to microprocessors in hand systems and Saeed Zahedi details the latest intelligent knee system, showing were innovations in leg prostheses will be heading in the twenty first century.

Thus the current state of limb prosthetics is that it is an exciting field were there are a large number of possibilities created by current and emerging technologies which are beginning to filter into the field. The constraints on the industry mean that it will tend to be a few years behind the true leading edge of science, but will it continue to follow the upward path as technology and price allows.

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(Guest editors of the special issue)

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