DEVELOPMENT OF A MODULAR PROSTHETIC ARM

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INTRODUCTION

As part of an EU funded project (ToMPAW) a number of requirements for the design of an artificial arm were identified: That it should be light, reliable, functional, look natural, and be quiet in operation. To fulfil these goals and provide a systematic response to the application of a prosthesis in the field the design requires a modular approach. Modular in terms of the mechanism, the electronics and the software. The electronics and control software were developed and the choice of using a modular microprocessor system proved to be effective as they could be applied to existing devices with little specific modification. Thus a network based arm controller was fitted to arms made up from the Edinburgh Arm system with a Oxford Intelligent hand on the end. This paper outlines the controller system used and describes some clinical experience with the arms.

Given a microprocessor controller different control formats can be easily applied to the arm system. This has been effectively applied in a number of systems that are in commercial application [1], but the extent of the use is only partially what it is possible to achieve. Additionally, current arms are created from a series of units that are not part of a systematic approach to providing a single solution that can be customised to the user population so that the ToMPAW project aimed to create an arm system that fulfilled this objective.

The project began with a survey of the user population who attended the centres in Edinburgh, Göteborg and used information gathered in Oxford and Bologna in earlier surveys [2]. This was combined with a study of the opinions of the professionals in the two countries.

The design process consisted of analysing the data to create a list of requirements expressed in qualitative terms, grouped into a set of different qualities. These *qualities* and *requirements* were assembled into a list of requirements. The goal was to place a dimension to each item in the list, making it possible to understand the trade offs required in the design of the arm, following the idea of inclusive design strategies [3]. This allowed a specification to be drawn up. The result was an arm system that was modular in its mechanical and electronic systems.

CONTROL

The design of the controller took into account the requirements of modularity and reliability. This meant that there was a need to keep interconnections to a minimum (as these tend to be one of the most unreliable features of an electronic system). The arm used a network to connect a number of controller nodes together. At the top-level is the proximal node, this takes the inputs from the sensors in the socket of the prosthesis, such as EMG amplifiers, switches etc and makes the command information available to the rest of the network (Figure 1). Additionally, this proximal node can attend to any feedback units that the arm uses. Further down the arm, at each of the joints, the distal nodes reside. Each node controls only that particular joint. This means that an arm can be quickly and easily built up, or changed, from the different joints available as the prosthetist determines the user's need. Once assembled the overall controller at the proximal node can readily configured (or reconfigured) for the task.

The additional advantages of the network are that it only requires four lines to run the length of the arm irrespective of the number of active joints that are used. Thus the reliability of the arm system can be addressed and also as each joint is made independent of the action of its neighbours. So the entire arm does not fail should a particular joint break down. However the control of the arm is invisible to the operator, each distal node is built into the joint and will react to the instructions given to it by the proximal controller, so that all the user is aware of is the arm reacting to their instructions.

Network design

The network was of the fieldbus type. This solution has a number of inbuilt protection mechanisms against data corruption, and allows for graceful degradation where a fault in one processor need not affect the others. The technology selected for this project was Echelon's Lonworks network. A Lonworks network implements a full OSI seven-layer communications protocol model [4]. It is supported by Neuron microprocessor devices from Toshiba and Cypress. Each Neuron device incorporates a processor that runs the user written programs compiled from Neuron C, (a variant of C) that provides multitasking and supports the I/O features of the Neuron device.

Two further processors in the Neuron device operate the bus protocol, these are inaccessible to the programmer. They provide the reliable link between the different nodes. The allocation of Neuron devices to physical functions means that the same device handles the motor and sensors associated with each joint. This minimises the network traffic.

External communication

If arm needs to communicate with external systems. The network can be accessed via an interface card within a PC that outputs the Lonworks protocols. Additionally an external node can interface to the network via an RS232 serial link, USB or TCP/IP, depending on the application. The former are part of the set up, testing and repair of the system, by the prosthetist during set up and in the training period. The latter would allow for a degree of remote testing and diagnostics for the user at home.

PRACTICAL APPLICATION

The controller was applied in a number of systems used in the field and the laboratory. The hand controller allowed realisation of the Southampton Hand format. This is an hierarchical control of the hand where the grip shape and force are low level processes that are controlled by the microprocessor and the user simply needs to use a single command channel to control up to five degrees of freedom at the hand [5,6,7]. A single node controlled the hand. Inputs to the hand were two channels of EMG to command the hand, two to detect digit position, three to detect contact force, one for contact on the palmar surface and three to detect object slip within the grasp. Hands were fitted to individuals with losses below the elbow and who used passive, body powered or myoelectric hands.

The modularity of the electronics and control allowed the different systems to be integrated easily. The control of the two arms was very different to demonstrate the flexibility of the systems. One user employed a two-site digital input with EMG amplifiers on the forearm. The second user employing proportional two-site EMG control on the forearm (Figure 2). Both used a pull switch to switch between the different axes. Training progressed over several visits, and the adaptability of the system allowed different strategies to be tested in an effort to find the best one for the particular user.

The first user employed only switch-type input for all the joints including the two axis Oxford intelligent hand. This is entirely possible with the hand automatically switching on the slip/grip reflex and the two axes flexing as one in a similar manner to their usual proportional format.

The second user usually used a cable elbow and hand, having employed a single site EMG Steeper unit in the past. His initial ability to produce myoelectric signals from the two muscle sites was limited and he could not fully separate the two channels and there was significant co-contraction. In this case, a "winner-takes-all" strategy was created so that the signal that was smaller in size was ignored, and the larger signal was used for control. This dominance continues until both muscles are relaxed and both signals fall below pre-set thresholds.

Assessment of the device is based on a range of criteria. The users informal comments are of use in determining their general satisfaction, also directed questions based on the findings of surveys made prior to the design phase enable more precise evaluations to be made. Finally, the functional assessment will be made using a hand function assessment protocol that is based on both abstract object handling as well as simulated activities of daily living.

ALTERNATIVE CONTROL FORMATS

The addition of the localised intelligence to the arms means that other more advanced control formats can be investigated in the laboratory. The first is co-ordinated joint performance [8] (Figure 3), in this instance the end of the arm is controlled by a joystick that is operated by the shoulder residuum. The wrist moves in response to the action of the joystick, the proximal node performing the kinematic calculations [9].

This controller has been extended to include feedback to the operator in the form known as Extended Physiological Proprioception or EPP. This form of control was pioneered by David Simpson at the Princess Margaret Rose Hospital in Edinburgh [10]. He observed that the patients' control structures remained intact and out performed artificial systems. The proprioceptive sense was intact in the shoulders of persons with reduced limbs and this sense could be applied this to limb control. Extended Physiological Proprioception is the natural extension of the body's own proprioceptive feedback to the control of an external device. Simply, it is force feedforward, position feedback, so giving separate and repeatable movements of the shoulder girdle to individual degrees of freedom. It provides a conduit for physiologically appropriate feedforward and feedback signals. This form of control is currently under investigation at the Institute of Biomedical Engineering.

CONCLUSIONS

The use of a modular approach to the design and control of a prosthetic limb system allows different control formats and joint arrangements to be realised easily.

ACKNOWLEDGEMENTS

The authors wish to thank the European Union, TIDE Initiative, Leverhulme Trust, Clothworker's Foundation, Henry Smith's Trust, Sir William Coxen Trust and the Wishbone Trust for their generous support of this work.

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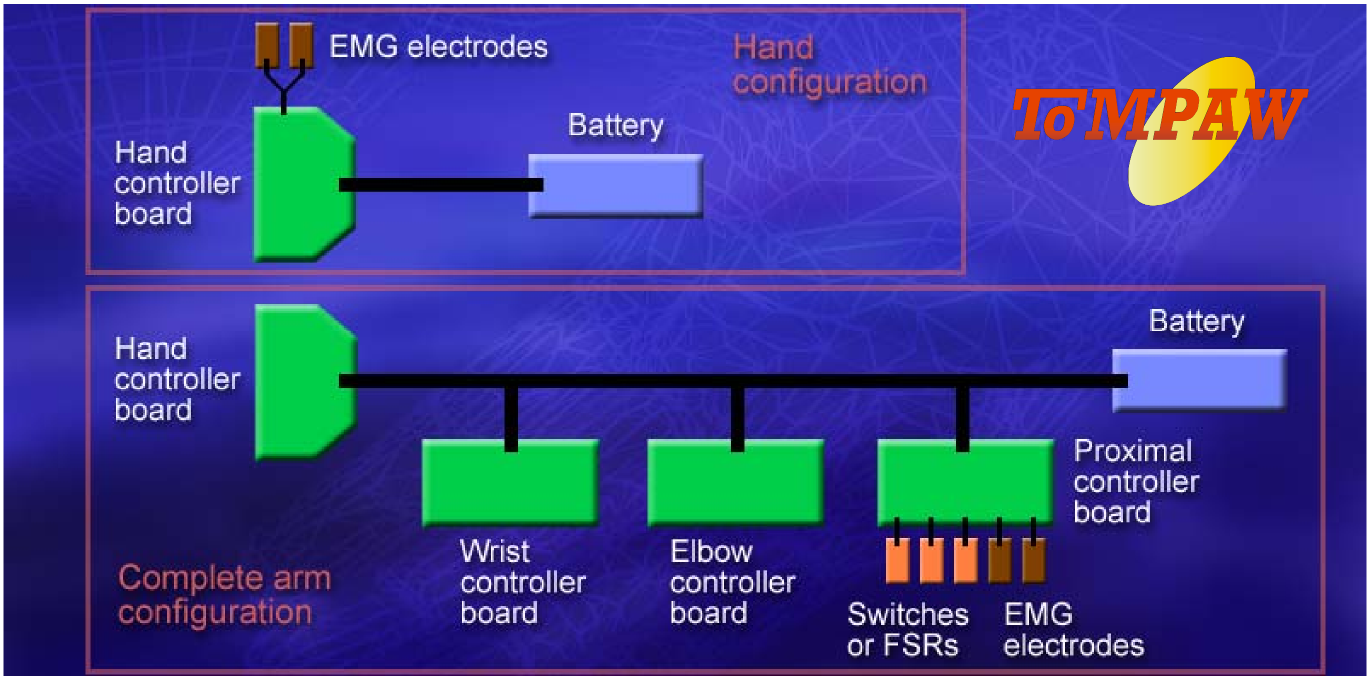

Figure 1 - Schematic of the ToMPAW systems. The modular approach allows for each arm to be customised to the users needs. Thus a hand requires only one controller which acts as the input processor and control node, which a complete arm has separate controllers for each function which reduced the number of wires passing over each joint and thus increasing the reliability of the system.

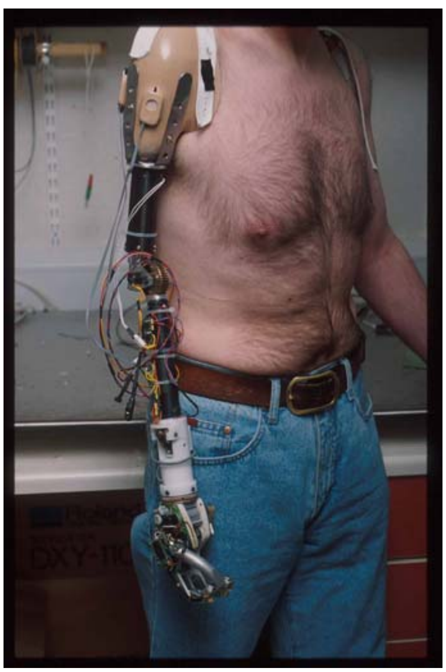

Figure 2 - Early fitting of the second ToMPAW arm system. This system includes intelligent hand, wrist and elbow. The user has a switch attached to the shoulder that allows him to change modes.

Figure 3 - Arm set up used to explore co-ordinated joint control. The able bodied volunteer controls the end point of the arm from the motions of his shoulder. The local intelligence of the arm calculates the desired position and each joint moves to them.