EXPERIENCE WITH THE INTELLIGENT HYBRID ARM SYSTEMS

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THE OXFORD/EDINBURGH HYBRID ARM

Microprocessors are increasingly used in prosthetic applications. The flexibility they provide allows new functions to be added easily, and fitting and maintenance can be simplified [1,2,3]. Prosthetic controllers are available that can be adapted to different needs through field programming, allowing the prosthetist to try different control strategies or even invent completely new ones. The process of setting up the prosthesis is made easier through the use of graphical software programming tools [4]. However, there remains a need for interoperability standards so that complete prostheses can be built up from modular components that are compatible in software terms as well as mechanically and electrically.

Small local area networks, called fieldbuses, have been in use in manufacturing applications for some years. Typically they link together items of production machinery so that they work together automatically in a coordinated sequence. More recently fieldbuses have been developed for automotive use (CAN) [5] and for "intelligent" buildings (LonWORKSTM) [6]. One element in the success of these products is that technology has progressed to the stage where the network interface can be included on the same chip as a microprocessor. This means that processing capability can be placed physically where it is needed, with the various processors or nodes connected together by a simple cable. In both these markets the fieldbus has been a tidy solution to the problem of connecting increasing numbers of devices. The systems used in vehicles - lighting, security, engine management and so forth - required ever more complicated wiring looms as new features were introduced. These were expensive to produce both in material costs and in assembly time. The CAN bus dramatically reduced the amount of cabling needed. Similarly in buildings the LonWorks bus can link all the devices of the heating and ventilating systems, so that they can operate in a co-ordinated and energy efficient way, and it can also be used in the lighting and security systems. It is also possible to connect a LonWorks bus to the internet via a suitable interface, so that a building may be remotely monitored. Both of these technologies are designed to be used in harsh environments, having good inherent immunity to noise and the capability of recovering from errors.

Many of the benefits that fieldbuses bring to these areas may also be applied with advantage to prosthetics. The ease with which new components can be added to a system facilitates a modular approach. The robustness and reliability of the prosthetic system is improved, because:

- Messages are transmitted around the system in a digital format which is resistant to electrical noise and allows for detection and correction of errors.
- The number of wires connecting components is minimised. Connections are a weak point in any electromechanical system, particularly when they run through moving joints.
- Processing is carried out at the nearest convenient physical location, so that leads from sensors and EMG electrodes can be made as short as possible. This reduces their susceptibility to noise.
• Distribution of tasks over a number of processors gives a degree of graceful degradation, where if one joint fails the remainder of the system can continue to operate. Further, the use of a standard digital bus allows simple communication with external devices, e.g. when using a PC to set up the prosthesis, or connection to the internet for remote diagnostics.

An experimental system to assess the practical merits of a fieldbus implementation for the control electronics of a prosthetic arm is described in this paper. It uses existing mechanical assemblies, namely the Oxford intelligent hand [7] and the Edinburgh arm [8], which has a powered elbow and rotating wrist. A LonWorks network was chosen as suitable microprocessors (Neuron® devices) were readily available at the time from two sources, and also because it implements a full OSI seven-layer model. Each Neuron device has two processors which are entirely dedicated to the operation of the network, and these are essentially invisible to the applications programmer. A third processor controls the applications. It runs programs that are compiled from a variant of C (Neuron C) that includes instructions to control the I/O features of the Neuron device, and supports multitasking. Thus the programmer deals only with the application and does not need to be concerned with the details of the network communications protocol.

Each Neuron device on the network acts as a local controller for the nearest joint, so that the only wires connecting joints are the network and power lines. Sensors and actuators are physically close to the relevant device. This device acts as an independent closed-loop controller, so that the amount of data that needs to be transmitted along the network is kept to a minimum. Circuit boards were made up for the Oxford hand and the Edinburgh wrist and elbow, using surface-mounted components and four-layer boards to reduce the size. The board for the hand represented an advance on the previous hand controller electronics, as the smaller size meant it could fit inside the hand envelope, instead of in the wrist space. In addition to the Neuron device it has drivers for finger, thumb and brake motors; analogue to digital converter taking signals from position and force sensors; and a signal processing circuit for slip detection. There are also inputs for EMG signals if the hand is used alone and not as part of a larger prosthesis. The boards for the wrist and elbow are similar but have motor drivers with a higher current rating, for the more powerful motors in these joints. As well as these motor controller circuits, another board was made up with a Neuron device and a fast analogue to digital converter with eight channels, referred to as a master or proximal board. It takes inputs from EMG electrodes, force sensing resistors, switches or similar input devices. In a multi-joint prosthesis it can select the joint to be controlled and send the relevant data to the joint's local controller via the network.

The arm uses the network to communicate with external systems. The LonWorks network can be connected to a PC through a transceiver which provides isolation to certified standards. A clinical support system that runs on the PC displays the EMG data graphically in real time, and allows parameters such as operating thresholds to be varied. Radio links have also been investigated, as they have the advantage that the user is not restricted by cables during setup and testing. This can be done with standard low-power transmitters and receivers which handle RS-232 serial data [9], though more advanced technologies such as Bluetooth may be used in the future.

An important power-saving feature of this system is provided by a distributed power management scheme, which relies on the ability of each Neuron device to go into a low power or “sleep” mode when the program has decided that it is not in active use. As a device cannot stay asleep indefinitely, it is woken up periodically by a “heartbeat” signal which originates from a clock in the master controller and propagates through the network to all the other Neuron devices. This mechanism is not used with a single hand - in this case it is woken by detecting activity in the EMG signals.
CASE STUDIES

The electronics boards were tested separately before proceeding to build a complete network. The Oxford hand can adopt two types of grip, precision and power. The user voluntarily opens the hand and then relaxes to allow it to close round an object. Using information from force sensors, the hand automatically adopts the appropriate grip and lightly holds the object. The user can then select a slip reflex where the grip force is automatically increased if the object starts to slip, or else voluntarily squeeze harder, or release the grip. These functions were rewritten in Neuron C to run on the new board. The new version of the Oxford hand was tested with two users.

Complete arm systems composed of hand, wrist and elbow were fitted to two users, one in Göteborg and one in Oxford (Figure 1). Control strategies were developed to suit each user during a training period that covered several visits. The flexibility of the system allowed new strategies to be set up and tested easily. The first user employed ON-OFF operation with an EMG amplifier and used a pull switch to switch between hand, wrist and elbow. The second arm user employed proportional control, also using a pull switch to switch between axes. He could produce myoelectric signals from two muscle sites, but he could not fully separate the two channels, and there was some co-contraction. In this case, a “winner-takes-all” strategy was created so that the signal that was smaller in magnitude was ignored, and the larger magnitude signal was used for control. This continued until muscles relaxed and both signals fell below pre-set thresholds.

User satisfaction is assessed through directed questions based on the findings of surveys [10] as well as the users’ informal comments. Functional assessment will be made using a hand function assessment protocol that is based on abstract object handling and simulated activities of daily living [11, 12].

Figure 1. Hybrid arm.
REFERENCES


