MICROPROCESSOR CONTROL OF A MULTI-FUNCTIONAL ARM AND HAND PROSTHESIS

I.D. SWAIN AND J.M. NIGHTINGALE

ABSTRACT

Control of a prosthetic upper limb requires the provision of two types of function. Firstly, spatial orientation of the limb through the articulation of its members. Secondly, prehension in the gripping device. The arm must offer sufficient kinematic flexibility to accurately position the wrist in space and to orientate the hand with respect to the forearm during manipulative actions. The hand must be able to hold and manoeuvre a wide range of objects within its grip in a stable manner for an extensive range of prehensive tasks. Overall the wearer should exercise supervisory control, but should not be required to have voluntary control over the detailed variations in grip force, individual joint angles, etc. So far as possible the conscious effort required to perform a task should be minimised.

To achieve these latter objectives the possibility of multi-level adaptive controllers has been investigated and reported earlier(1,2,3). Control of prehension involving 4-degrees of freedom, with six basic types of force control such as HOLD, SQUEEZE, MANOEUVRE, etc. is achieved from one EMG channel. Dynamic control of arm configuration involves 7-degrees of freedom. The use of body movements to control such a structure has been investigated, and it has been found possible to increase the effective number of control inputs by using measures of trajectory curvature as extra control for hand orientation.

An overall control scheme for the complete hand-arm prosthesis has been proposed and some trials performed(4). The complete control scheme while complex is comparatively simple to operate. The extensive logic control system associated with the many decision functions leads itself to microprocessor implementation and some work in this direction is reported.

INTRODUCTION

For a number of years, work has been undertaken at Southampton University on the development of a multi-degree of freedom prosthetic hand. Recently this has been complemented by a study of a fully articulated artificial arm. In the complete hand/arm system there are two distinct problems: Firstly, the gripping device must have adequate and stable prehension; Secondly, the arm must offer sufficient flexibility in the position and movement of the terminal gripping device. In each case the approach has involved the development of an autonomous control system requiring only limited supervisory intervention from the wearer, thus reducing his voluntary effort and any resulting fatigue.

In the hand system,(1,2,3)the wearer provides a set of basic commands labelled HOLD, SQUEEZE, RELEASE, MANOEUVRE, FLAT HAND, etc, which are obtained from a single EMG source, (Figure 1). These commands are supplemented by signals from an array of sensors on the palm of the hand relating to static and dynamic relationships between the hand and the object being gripped. These latter feedback signals.

which information can be obtainted to automatically generate the signal inputs to the wrist. These are:-

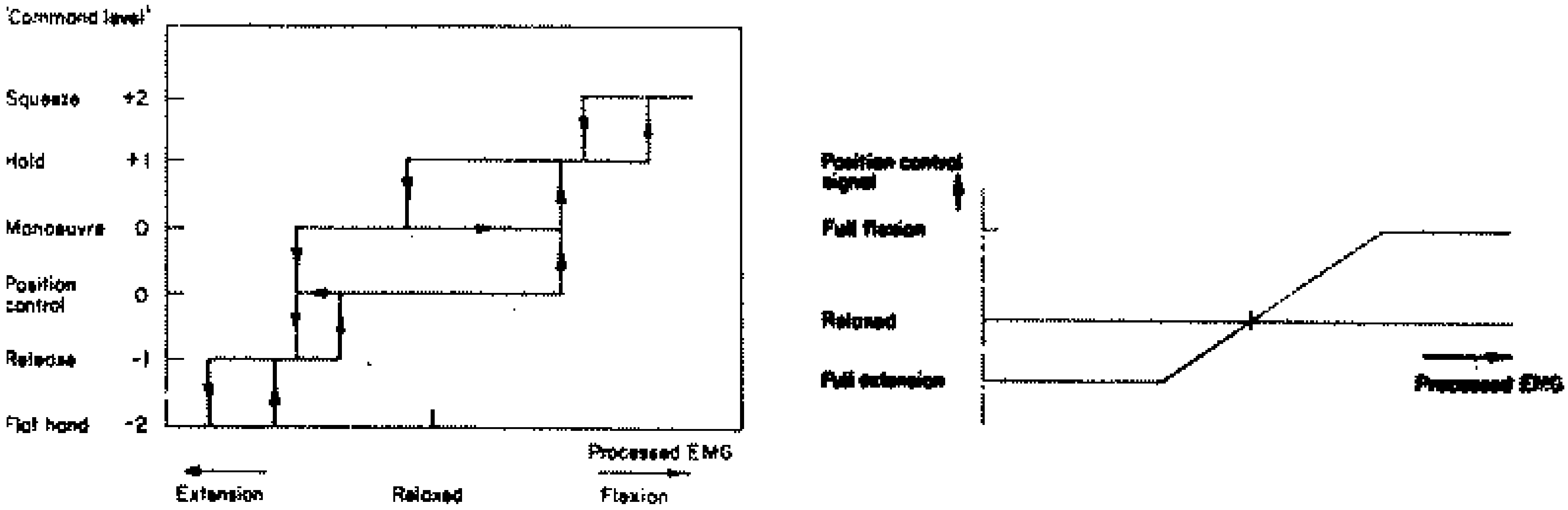

Figure 1. Command levels for the hand control system

(1) The hand/object interface, as one of the functions of hand orientation is to aid prehension.

(2) The trajectory that the hand describes in moving to an object. This will serve two functions, firstly, to enable the patient to adopt a given hand orientation before the hand reaches the object to aid prehension, and secondly, to aid manipulation of objects.

(3) The need to maintain constant hand orientations. This would enable the user to convey liquids to his mouth without spillage etc., i.e. as an inertial platform.

The first two methods are already described elsewhere: (7) and so will only be mentioned briefly here. By using information from the hand/object interface, provided by touch and slip sensors on the hand, the hand orientation can be modified in all three movements to achieve a maximum surface area of the hand in contact with the object. The path the hand takes to an object can be mapped onto two independent planes and can hence provide two input signals to drive the wrist flexion and wrist rotation. By suitable choice of these planes the two components of the trajectory can be related to the resultant movement of the wrist, thus making the control simpler for the user. The final method will be considered in slightly greater detail. There are two ways in which the human arm behaves as an inertial platform. Firstly, to maintain constant arm and hand orientation during gross movements of the trunk, and secondly, to keep the hand orientation constant while the arm is moving e.g. carrying cups of liquid.

The first of these is concerned with the complete arm rather that just hand orientation. The need for such a system is especially noticeable when the body is subjected to external forces, such as those often experienced when travelling by boat, train etc. To compensate for these external forces, the position of the body with respect to inertial space is needed. This can be detected by a 3-direction accelerometers situated on the harness and feeding into the position control circuitry of the arm.

are used for detailed control actions and so the overall system is a hierarchy in which functions are initiated at a conscious level, but are performed without conscious effort, in a manner analogous to normal human activity. Clinical trials indicate that flexibility can be achieved with very little prior training.

Similarly with the arm,(5)the approach involves an electronic controller to reduce the voluntary effort required from the wearer. Body movements were chosen as the basic source of signal since residual proprioception clearly provides a valuable feedback. These(6) signals are assumed to be related to the demanded wrist position, and control algorithms generate the required joint angles. To position the wrist in space requires four motors, therefore another input is needed to supplement the three provided by body movement. This is effectively achieved through a constraint on elbow position. In order to manoeuvre and orientate the hand relative to the forearm, three movements are used in the human system (flexion, rotation and abduction) and such a system will be considered for analysis of the complete prostheses. However, in the prototype system only two degrees of freedom were used (flexion and rotation, due to the difficulty in designing a mechanical wrist joint incorporating all three. It was also felt that if the wrist was controlled by the patient it would either make the arm too complex to control or lead to sequential operation. Therefore it is proposed that the hand orientation is automatically controlled.(4)

In order to achieve overall control a computer based system has been considered. This offers greater flexibility than a hard wired system, enableing the controller to be matched to individual patients.

This paper discusses a proposed control structure for the hand/arm prosthesis, especially the control of hand orientaion and the implimentation of this control system by means of microprocessor.

METHODS OF PROVIDING AUTOMATIC CONTROL SIGNALS

To understand fully how the control of the arm can be supplemented by automatically generated control signals, it is necessary to look at the movements of a human arm, especially those concerned with the hand orientation and arm posture. The posture of the hand and arm serve several basic functions.

(a) To aid prehension.

(b) Manipulation of objects after prehension.

(c) To enable a cup of liquid etc. to be lifted without spilling by keeping the hand orientation constant with respect to inertial space.

(d) To enable manoeuvring in confined spaces and the performance of delicate tasks.

The underlying principle governing both the hand and the arm system mentioned so far, has been to make the control of the prosthesis as simple as possible for the patient by directly relating the signal inputs to the resultant motion of the prosthetic device. By consideration of the functions of hand orientation and arm posture it is possible to extend this principle to a complete hand/arm prosthesis including three degrees of freedom at the wrist. From these functions it can be seen that there are three areas from

The second way in which the arm behaves as an inertial platform is far more closely connected with the control of hand orientation. From observations of persons eating and drinking it became apparent to the authors that abduction/adduction is the most important movement in moving food and drink to the mouth. This is especially noticeable in the case of liquids or low viscosity foods where spillage is of major concern. There are three ways in which the hand orientation can be kept constant.

(1) By a mechanical linkage; c.g. 'Anglepoise' lamp.

(2) By having three position gyroscopes in the hand.

(3) By storing the hand orientation in a computer at the time the object is grasped.

For maximum flexibility and cost effectiveness, the third method looks the most promising. This can then be used in conjunction with the gyroscope on the shoulder to refer the hand to inertial space.

THE COMPLETE HAND/ARM CONTROL SYSTEM

It has been shown that the sources of automatic control signals are dependent on the task to be undertaken. Therefore, in a complete hand/arm prosthesis all types of input would be needed for maximum flexibility. The information required concerning the type of operation being performned can be provided by the discrete level of the EMG signal in the hand control system.

For example, the hand orientation can be controlled by the hand/object interface when the hand is in the '0' state or POSITION mode. This will mean that the hand orientation and finger position can be optimised at the same time once the +1 or GRIP mode is demanded, the hand orientation can remain constant. Then, when the object is securely gripped, the hand can behave as an inertial platofrm.

A block diagram of the complete proposed system is shown in Figure 2. In this system the patient provides two types of input; three body movements to provide the control of the arm and a single EMG signal to control the hand, with additonal information being provided by the gyroscopes and the touch and slip sensors. The control of the wrist position and the tactile device is relatively straightforward and can be achieved as described earlier (Codd, 1975; Nightingale et al., 1978). The main difficulty with the control of arm posture and hand orientation is that of deciding which method of control to use at any given time. The easiest way to do this would be to consider individually the different supervisory commands the hand can be given, e.g. GRIP, SQUEEZE etc. and then to select the method of hand orientation control necessary to facilitate this. For example consider, as before, an object being picked up and moved: the trajectory method can be used before the object is grasped and then the other methods can operate to facilitate prehension and keep the hand orientation constant, even if there are external forces on the patient. This can be complemented by using other levels of the hand control signal. Firstly, if the hand is in the SQUEEZE or +2 mode, the hand orientation can be directly controlled from the shoulder to enable fine control in confined spaces etc; if the hand is in the +1 mode and an object is slipping with maximum grip force then the wrist can again be directly controlled from the shoulder.

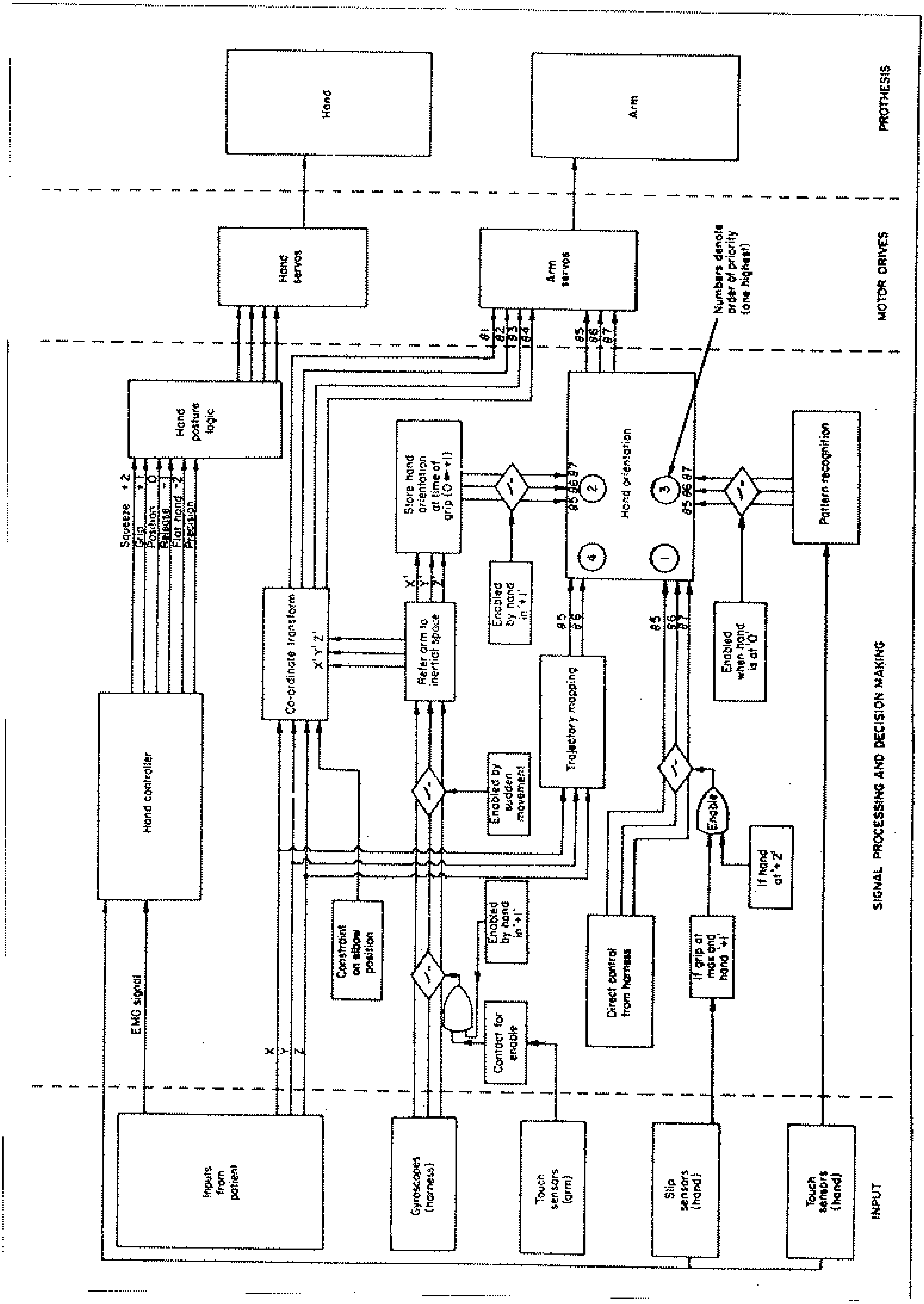

Figure 2. Complete hand/arm control system.

Another feature which can be incorporated is the use of touch sensors on the arm. This would mean that then the patient has his arm resting on a table, it behaves as an inertial platform not moving as he turns round, etc. hence reducing the possibility of knocking objects from the table.

DISCUSSION

The incorporation of all these automatic control systems necessarily menas that the complete hand/arm prosthesis will be very complex. However, having the patient in a supervisory role means that a multi-degree of freedom prosthesis, in this case with eleven degrees of freedom, can be controlled by only three body omvements and a single EMG channel, thus reducing the strain on the patient without loosing flexibility or resorting to a sequential system.

At present a new hand has just been built having four degrees of freedom and of a similar size and widtht, 500 g (approximately), to the human hand. This hand has been subjected to clinical trials and performed well (Figure 3). The patient who carried out these tests also performed the clincial trials on earlier hands and despite not having used the hand for five years was able to control it within 15 minutes.

Initially it took him 2-3 hours to achieve a useful level of control. This appears to indicate that the control system function is easily learned and remembered.

At present the hand is controlled by a hard wired controller which, although giving satisfactory performance is rather inflexible and needs care when the EMG electrodes are being attatched to the stump. The problem can be overcome by a microprocessor based control system which includes a 'learn' mode so that the controller can take account of variation in electrode position and changing skin resistance. Another advantage a microprocessor system offers is a reduction in size, enabling the electronics to be contained in the space between the stump socket and the wrist.

The arm is not a present as advanced mechanically but a prototype has been built with six degrees of freedom (not including wrist abduction). It is fitted with a dummy hand which, although it does not have any gripping fucntion, does have the same sensors as the prosthetic hand. The inputs are provided by a harness and encouraging results have been achieved using an on-line computer to control the arm. The time taken to calculate the joint angles necessary for a given demand position is 21 ms.

To date the complete system for control of hand orientation has not been implemented. However, the wrist trajectory control system has been successfully tested with inputs being provided either by the computer in the form of predetermined trajectories or by the patient via the harness. The control of hand orientation by information form hand/object interface has also been successfully tested.

The majority of problems still outstanding are of a mechanical rather than a control nature. To overcome these are to enable further evaluation of the control system proposed above a new arm of improved mechanical performance is being built. It is hoped that this arm, complete with prehensile terminal device and gyroscopes will go for clincial trials.

Figure 3. Patient buttering bread during clinical trials

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