A SIMPLE LOW COST MICROPROCESSOR CONTROLLED MEDICAL MANIPULATOE

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Introduction

The availability of microprocessors coupled with sophisticated multi-jointed arm structures gives the potential for a medical manipulator which can be of considerable benefit to the handicapped in providing self help. However, the resulting system can be extremely expensive. Whilst an instituti might be able to afford a single manipulator for a large patient population, if the device is found to be of real benefit then a patient will naturally want to have sole use of the manipulator and even sharing between two patients can result in conflict since they will tend to need the device at the same time. Whilst the mass production of small industrial robots, such as the 'Unimate Puma', has reduced the cost of sophisticated arms to the point where it is difficult to see the justification for attempting to produce special purpose complex medical manipulators, the cost still remains very high; typically, $40,000 U.S. for the 'Puma' system. An alternative approach is to design a simple medical manipulator having limited capability but the cost of which is low enough that it can be dedicated to an individual patient. However, this raises the question of whether such a simple manipulator will have enough function to justify its use at all.

The Mechanical System

As part of an undergraduate project undertaken at the University of Adelaide, South Australia, a manipulator was designed and constructed primarily to be used as a pre-programmed feeding aid (Fig 1). To avoid the need for analogue to digital converters, stepper motors were used to power the arm. Three separate motors were used to provide the equivalent of shoulder rotation, shoulder elevation and elbow flexion. The motors were supported together on a base board and power transmitted using worm gears and a pair of 4-bar links, using aluminium alloy tubing,to form the framework. In this way the relatively heavy motors do not need to be moved on the arm. The power transmission system is sufficiently rigid that it can move a reasonable load without too much backlash and yet does not require extreme accuracy of manufacture which would make costs prohibitive. Balance springs were attached to each arm segment to compensate for the dead weight of the arm. Since it was anticipated that relatively low forces would be needed, the stepper motor stall force was limited so that the force supplied by the manipulator tip was sufficiently small that it would not be dangerous even if the patient's face were in the way. Similarly the stepper motor cycle time was deliberately extended to ensure the patient had plenty of time to avoid the trajectory of the manipulator tip. The end of the manipulator was adapted to allow various devices in holders, such as a shallow bowl spoon or felt tip marker pen, to be clipped in position.

The Microcomputer System

An Intel SDK-85 kit, based on the 8 bit Intel 8085 processor chip, was used for the development of the central program. The basic system consists of 256 bytes of RAM and 2k of ROM containing the monitor program. The system was further expanded by an additional 256 bytes of RAM and 2k of EPROM. The stepper control was achieved by software generated pulses, rather than hard-wired controllers, in order to minimise costs. Control was achieved using 2 bytes of 8 bits in which the top 5 bits were used to select either one, or a combination, of motors together with a direction of rotation. The lower 11 bits were used to define any one of 1600 possible steps.

A limitation of this type of system, which has no direct position measurement, is that unless the complete sequence of motions returns the arm to exactly the start position and no steps are lost, the error will increase cumulatively when the motion is repeated. This could be overcome by including microswitches on the arm connected to interrupt lines which signal the location at the end of the cycle. However, in this instance, a lower cost expediency was adopted in which the arm was returned to the beginning of the cycle, or group of cycles, and several additional motor pulses were applied to ensure that the arm was driven hard against the mechanical end stops.

In execution mode the memory code is fetched and deciphered into 2 parts. The highest 5 bits, specifying the combination of motors, is used to generate a jump to the appropriate subroutine call sequence. The return address is first pushed onto the stack and the subroutine then performed with appropriate delays to regulate the stepping speeds of the motors.

The arm can be 'taught' a number of sequences either by loading an appropriate program from paper tape or, more usually, by using the keyboard in a 'learn' mode. Here a sequence of keys are pressed corresponding to particular end point motions and the arm then moves in that direction until the vector interrupt is pressed whereupon the motor execution subroutine ceases bringing the arm to rest. The motor combination code and number of steps moved are then loaded into memory and the processor then awaits the next keyboard instruction. In this way the 'learn' mode can be used to guide the arm through a sequence of movements. This can be replayed, either one cycle at a time or repetitively, until a further key is pressed. The whole program can be burnt into EPROM for permanent retention. In this way a program of a sequence of motor motions and delays can be set up so that a task such as feeding can be replayed by pressing a single keyboard button.

Preliminary Trials

Since the arm was to have a preliminary trial at the Adelaide Childrens' Hospital and be used by Cerebral Palsy patients, it was thought that the standard pocket calculator style of keyboard was too small for these children to hit the correct keys. A much larger keyboard, containing a smaller subset of keys, was made up in a style that the children had used for controlling T.V. games and electric typewriters, (Fig 2). In order to have some check on the patient utilisation time during the trial, a simple mechanical counter was connected to the shoulder elevation mechanism so that it could be tripped each time the shoulder returned to its base position. A number of vacuum formed food trays were also made up with a narrow shape that permitted easy removal of the food using a spoon and which did not result in too much food being left in the tray. For the feeding cycle, the EPROM was programmed to allow one of the feeding programs to be selected having similar movements but different delay times to change the speed of operation. The sequence of motions programmed was for the spoon to first move forward and down into the food tray to scoop up food. The spoon then continued to move forward to the end of the tray and then lift up so the food was free of the tray. Excess food was shaken from the spoon by moving the spoon to the middle of the tray and shaking it forward and back to allow any drips of food to fall back into the tray. The food was then moved forward and up to present the spoon at a location convenient to the patient's mouth. After taking the food into the mouth a second key was pressed which returned the arm to a base position to initiate the next cycle. The patient, an 8 year old cerebral palsy boy with poor hand control, was able to operate the keyboard quite adequately, selecting the desired feeding program and then initiating each cycle with the correct key. Provided food was cut up into reasonably small pieces and the tray placed at an appropriate position on the table, the patient could feed himself at his leisure. Not only did this release the nursing staff during much of the time for feeding, but it allowed the patient to take his time eating without feeling that he was keeping someone waiting.

A further program stored on the EPROM was used for drawing. A felt tip pen was clipped to the end of the arm and a sheet of drawing paper pinned to a vertical board. After initiating the drawing program, which swung the pen to the middle of the paper, the pen could be moved in uniform short step lengths in any direction in 45° increments. Thus pressing, say, a key at '3 o'clock' on the board resulted in the pen moving horizontally to the right. A further key allowed a pen up/pen down command. Whilst the drawings initially lacked artistic skill, the patient much enjoyed the whole activity and particularly appreciated having a 'hard copy' output! (Fig 3). Other routines, such as page turning for books, have also been stored on EPROM.

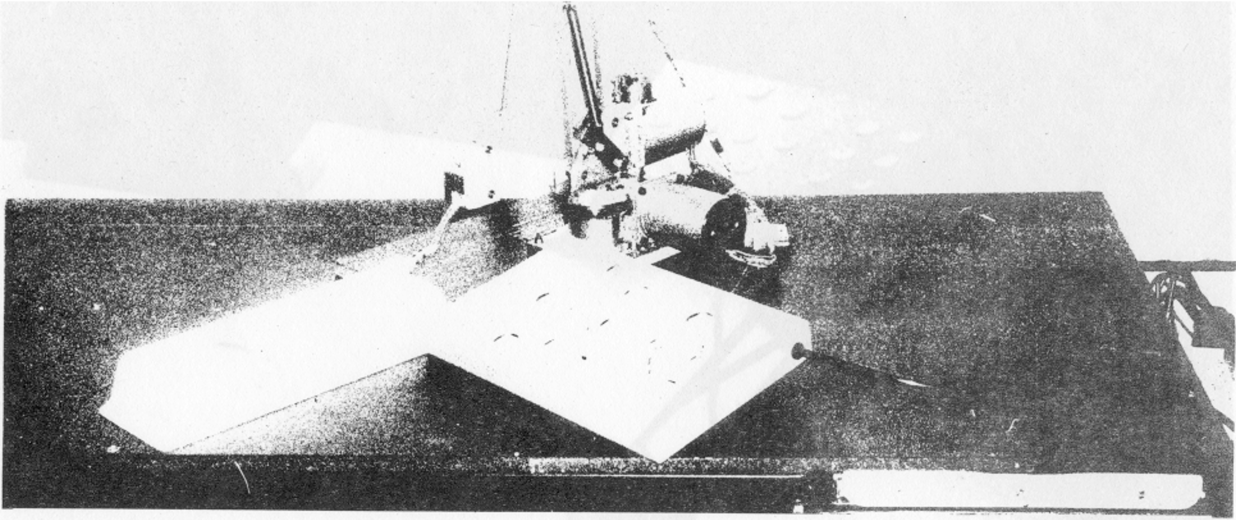
Conclusions

It is difficult in this type of preliminary trial to divorce the child's enthusiam for a sophisticated new toy from an appreciation of a useful aid. However, after a period of some weeks, the patient was still using the arm regularly and it was felt by the resident Occupational Therapists that it had been of direct benefit in giving some sense of ability to have personal control of the environment. The patient expressed a desire to retain personal use of the manipulator. The further addition of a standard electric powered hook on the end of the manipulator could widen the activities that are possible with this simple type of structure but nevertheless the number of tasks that are possible will remain very limited. The structure itself costs around $450 U.S. and the expanded microprocessor about $500. Whilst the cost of microprocessors is falling rapidly, it is probable that the cost of mechanical components will rise slightly. Reducing the number of motors would leave the arm with little utility and so there is no hope of cost saving there. The microprocessor, however, could be further utilised by linking into a personal environmental control system for turning on T.V., lights, etc.

At an approximate cost of $950 it would not be unreasonable for the manipulator to be dedicated to a patient's single use. The degree of practical self help with such a simple machine is however limited. However, it is felt that the psychological advantages of being able to have even this small degree of control over the physical environment are immense and justify the utilisation of simple, low cost, medical manipulators.

Captions

Fig 1	Overall view of microprocessor controlled manipulator with keyboard - arm retracted.
Fig 2	View of manipulator with arm extended.
Fig 3	The manipulator in use as a feeding aid.
Fig 4	The manipulator arranged as a drawing aid.



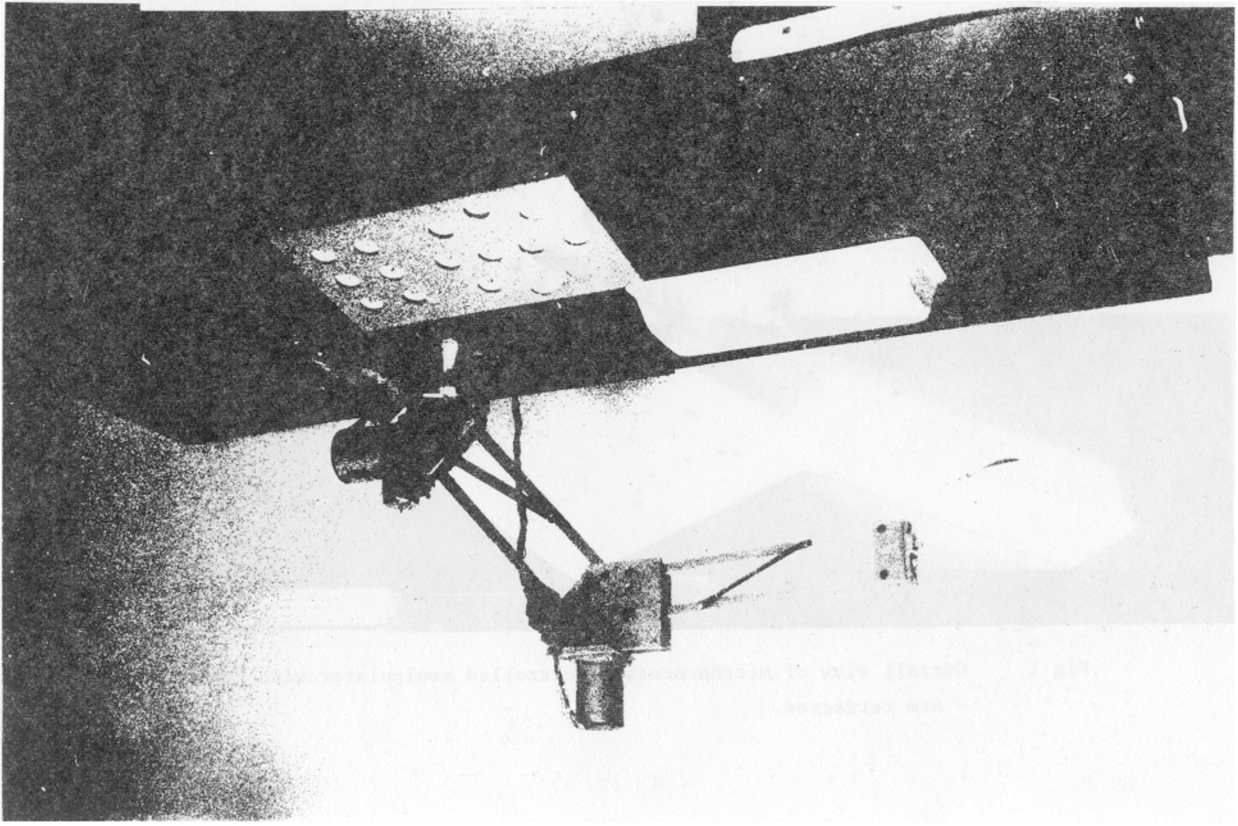
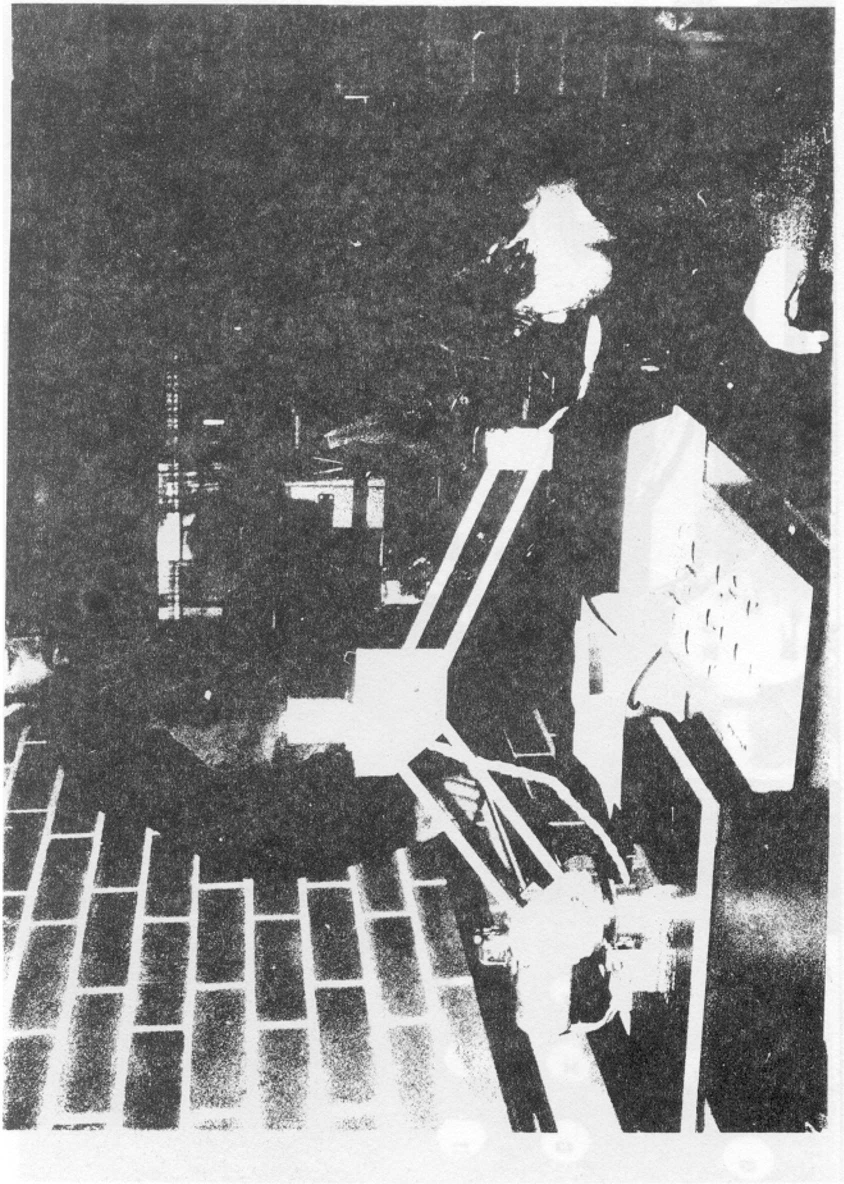


Fig 1. Overall view of microprocessor controlled manipulator with arm retracted.



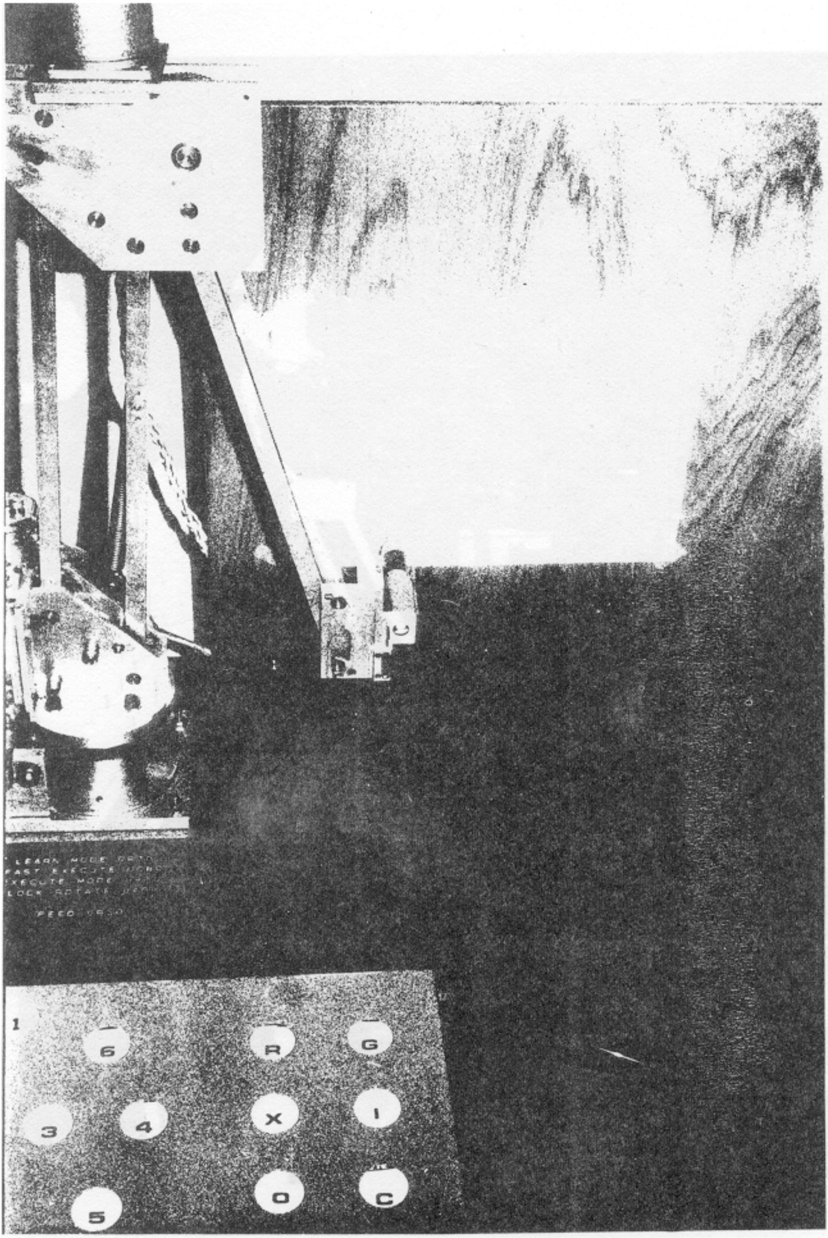


Fig 4 The manipulator arranged as a drawing aid.