A FUNCTIONAL CLOSED-LOOP STAND/SIT SYSTEM FOR MID-LOW THORACIC PARAPLEGICS

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ABSTRACT

The use of Functional Electrical Stimulation (FES) to enable paraplegics to stand is not new or indeed difficult to undertake under laboratory conditions. However, there are substantial problems to overcome before such a system can be used routinely by patients without professional supervision. First, the orthosis must be capable of automatically responding to changes in the posture and muscular condition of the paraplegic. Secondly, the system must be quick and easy to use in a variety of locations, otherwise it will not provide any increase in function. Finally, it must be inexpensive enough to be available to many paraplegics. The primary aim of our work is to provide such a system to enable mid to low thoracic paraplegics to stand on demand in the community. The system comprises of a microprocessor controlled stimulator implementing a three term controller, knee angle is measured as the feedback term to achieve closed-loop control. A folding standing frame replaces the arm rests of the wheelchair to provide support. Three complete systems are being successfully used in the community and it is planned to fit a further 19 soon, as part of a Department of Health funded programme.

INTRODUCTION

Laboratory open-loop standing of mid-thoracic paraplegics is a relatively simple operation to perform [1,2]. However, most research groups would contend that to be functional, an electrical orthosis would have to automatically compensate for changes in patient posture, electrode position and muscle condition [3,4]. Many research centres are therefore concentrating on the development of closed-loop stimulation systems. However, because the aim of such work have been to achieve long standing times, usually more than of one hour, the resulting orthoses are at present limited to the laboratory. Although this work is of importance, the result is that few practical systems are in daily use. It has been the objective of this research to design a system, with the minimum number of patient attachments, which when combined with a suitable mechanical support could provide functional standing for up to 10 minutes and then safely allow the patient to sit [5]. This paper discusses the design of a simple portable closed-loop quadriceps muscle stimulation system which uses knee angle as the feedback, which when combined with a wheelchair standing frame can safely restore standing and sitting functional to mid-low thoracic paraplegics.

EQUIPMENT DESIGN

The present system can be split into 4 components:

a. The Stand/sit Stimulator,
b. The Stand/sit Controller Software,
c. Knee Sensors,
d. The Standing Frame,

a. Stand/sit Stimulator

The original stimulator described in [5] was a 2 channel microprocessor based design which allowed amplitude control only (although the frequency and pulse width could be adjusted via internal potentiometers) and which used switched-mode power supply techniques to efficiently generate the stimulus. The design offered no practical means of data logging or of remote computer control. The latest design uses the same power output circuitry, but is a 4 channel machine allowing frequency and pulse width to be controlled in addition to amplitude. With the on board RS232 circuitry it also allows two way serial communication up to 19200 Baud. As for the original design extensive analogue and digital input/output is incorporated for use in closed-loop stimulation systems.

To accommodate the wide range of exercise regimes encountered a multi-position switch on the front panel allows for 1 of 10 pre-programmed stimulation sequences to be selected. The size of the unit is approximately 173 mm x 154 mm x 54 mm. The weight, including the internal nickel cadmium batteries, is approximately 1 kg.

b. Stand/sit Controller Software

A sampled data rule based PID controller is used to effect and maintain standing. Sitting is achieved in an open-loop fashion by slowly reducing the stimulus amplitude. For standing the frequency and pulse width are fixed in the range 15-25 Hz and 300-500 μsec. More details on the original rationale behind this are given in [5].

For the basic system the controller attempts to move the knees linearly from the seated position to knee "lock", in a time defined to suit individual paraplegics. Once standing the controller then attempts to keep the knees in a certain angle band centred on this "lock" position.

To allow for movements and misalignments in the knee sensor, an auto calibration routine is used to determine the initial "lock" angle. To achieve this the control loop attempts to move the knees to a hyper-extended position in the stand up phase. At the end of this, samples are taken of the knee angles. These are then averaged to give the desired "lock" angles.

Other rules govern the loop parameters used in the two phases of the stand, the maximum and minimum allowed stimulation values, and in laboratory work the change in the stimulation frequency.

To maximise the safety of the system, standing is prevented until satisfactory checks have been made of the state of charge of the batteries, and the correct operation of the stand and sit switches and the knee angle sensors.

c. Knee Sensors

Precision servo potentiometers mounted on aluminium struts, which are in turn attached to leather thigh and calf cuffs, are used to measure knee angle. This design is reasonably unobtrusive. The high linearity and output smoothness of the servo allows angle measurements down to 1 degree, although error calculations of the whole system result in a worst case error of 4 degrees.

d. Standing Frame

It is necessary to provide some kind of balance aid/support for the paraplegic. This can be achieved by the use of a rolator or parallel bars. However, in order for the system to be functional, such support must be portable and require the minimum of assembly.

A frame has been designed which will fit a standard National Health Service wheelchair [6]. Essentially, this consists of two foldable "walking sticks" attached to a mechanism which mounts in the front arm rest socket and, by use of an over centre clamp, on the backrest pillar.

This design allows for changes in patient height and terrain, and because the patient load is transferred through the "walking sticks" no large forces are applied to the wheelchair itself.

The stand and sit switches used by the controller are mounted in the handles of the standing frame. Phono sockets at the other end of the handles enable connection to the stimulator.

CLINICAL TRIALS

To date 3 patients who have successfully completed the retraining programme, [7], have been supplied with standing systems. 2 of these had the original 2 channel stand/sit stimulator, the remaining 1 has the new 4 channel device. After demonstrating their competence with the system in the laboratory, all of the patients have used the system in their home environment. Other than minor problems with lead breakages, which have largely been overcome by a change in wire type, there have been no technical difficulties with the equipment.

Although still at an early stage in this aspect of the work the indications are that to maximise the usage of the system it will be necessary to redesign the frame to allow it to be used on lightweight wheelchairs, and that the wiring harness associated with the knee sensors and stimulating leads needs simplifying. However, other than the problems of fine tuning, the actual stand/sit algorithm has been well received.

SUMMARY

A portable closed-loop standing has been described which can enable certain mid-low thoracic paraplegics to stand on demand in the community for up to 10 minutes. 3 paraplegics have successfully used the system at home and a further 19 are planned. The feedback that has been received so far is that to maximise usage changes may be necessary to the standing frame, and the method of interconnecting the components of the system.

Acknowledgements: The authors gratefully acknowledge the time and assistance given by the patients to this research. They would also like to thank Mr R Nash and Mr M Davy, for the design and development of the standing frame, and B. Fox of the Department of Physiotherapy, Odstock Hospital for help with this work.

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