DESIGN OF AN EXOSKELETAL ARM FOR USE IN LONG TERM STROKE REHABILITATION

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Abstract

This paper describes an ongoing project to develop a system for assisting upper limb rehabilitation of stroke sufferers. The device is designed to support the weight of the arm whilst carrying out a range of activities of daily living specified by physiotherapists and occupational therapists. The system will be able to provide data on task performance on disc for periodic assessment of treatment and for research.

Introduction

Stroke is the single most common cause of disability in this country with four percent of NHS costs associated with rehabilitating and caring for people who have suffered strokes [1]. The six weeks or so of physiotherapy received by patients in hospital following a stroke is mainly aimed at improving lower limb function in order to regain as much mobility as possible and, because of the one-to-one nature of physiotherapy, long term treatment is out of the question. Clearly the degree of function which may be regained by individuals is highly variable but there is evidence of major improvements in cases receiving long term therapy even after starting some years post-stroke [2].

This paper describes an ongoing design project at Loughborough University to develop a machine to enable a patient to perform activities essential to rehabilitation of the upper limb. The machine would be used on a regular basis in the home to carry out a range of appropriate exercise regimes under the direction of professional clinicians. For this to be achieved, performance parameters will be recorded on disc and the data used at intervals for assessment and review of the treatment programme.

Such a machine will have two purposes; firstly to enable individual stroke sufferers to work towards achieving their full potential and secondly to provide research data on stroke rehabilitation over extended periods. The system does not purport to be a robot physiotherapist but is intended to assist in the carrying out of a range of exercise and treatment regimes and simultaneously to provide the capability for detailed monitoring.

Design Rationale

The aim of this work is to create a system which can fully support the weight of the arm whilst performing a range of activities. Early work led quickly to the conclusion that devices for assisting or monitoring the motion of a single joint would have little value due to the importance of synergistic movement patterns in physiotherapy. This research therefore is aimed at developing devices which can support the arm whilst allowing sufficient degrees of freedom (DOF) and range of movement (ROM) to allow activities of daily living (ADL) to be performed in a natural way.

Existing devices such as the OB Help Arm [3] are useful but are inherently limited in the range of ADL tasks for which they can be used. Robotics technology incorporating gravity compensation algorithms may be transferred from the nuclear and offshore oil industries, but the cost of such systems is high. A low cost approach appropriate to the needs of the Health Service is required but which may draw on technologies from other fields.

An initial investigation carried out as an MSc project resulted in a simple two DOF arm support moving in a horizontal plane allowing movements of the shoulder and elbow. This provided a simple and effective means of overcoming gravitational loads and was useful in testing reactions of both professionals and patients and to elicit information on problems. The ideas generated considerable interest in the potential of such devices for long term therapy and monitoring, and also highlighted the task limitations inherent in a 2 DOF system. The importance of synergistic movements and particularly the need to carry out a range of ADL tasks including reaching the face and head confirmed the necessity for a multiple degree-of-freedom system with large ROM in all joints.

Design Development

The next stage considered the configuration of an exoskeletal device to enable shoulder, elbow and forearm rotation movements. Leaving wrist and hand functions to be considered later, a five DOF exoskeletal system concept was proposed as having the minimum functional capability for carrying out ADL tasks. A proximal-to-distal approach to development was then adopted. Since the shoulder is a highly mobile joint it was considered essential to investigate shoulder movement before addressing the elbow and lower arm functions.

A two-axis test rig was set up to investigate whether the human shoulder could be approximated to a static ball joint for tasks which do not require hyper-extension (forward stretch) of the shoulder. In testing it was found that tasks such as lifting a cup from a table to the lips produced almost no forward movement of the shoulder but vertical displacements ranging from 8 to 20 mm were observed in all cases. As a result of these tests it was decided to use the centre of the shoulder ball joint as the origin for the five DOF design and to carry out initial tests with the shoulder joint statically mounted. Ultimately an active shoulder mounting would be developed to follow the motion of the patient's shoulder.

The remaining three movements were provided by two rotation units and an elbow pivot joint. One rotation unit surrounds the upper arm to enable humeral rotation and another surrounds the forearm to allow pronation/supination. The elbow comprises a simple pin joint for the current series of tests. The working principle of the design requires that the machine joint axes are concurrent with the approximated human joint axes in order to eliminate relative movement at the points of contact between skin and machine. A prototype, adjustable for 2.5th to 97.5th percentiles, was built to assess the kinematic functionality of the concept. For the initial trials the subject's arm was located within the upper and lower arm rotation units using curved wooden pads with screw adjustment.

Test Results

The prototype, just completed, has been tested on eight subjects, all healthy individuals of varying sizes. The tests were based on ADL tasks including picking up a cup and drinking, buckling a belt, brushing hair and cleaning teeth. The main criteron for assessment was the relative movement between the attachment pads and the human arm, success being regarded as the achievement of no detectable sliding or shear strain at the arm contact areas.

It was found that the system worked well for all subjects tested provided that the joint axes were well aligned with the human arm joints. Goniometric measurements with the arm in place are straightforward since the joint angles of the machine correspond directly with the subject's arm. The major problems encountered centre around the difficulty of maintaining elbow pivot axis alignment over a period of time due to the arm attachment pads rotating around the upper arm. The shaped woden pads fitted to the test rig provide insufficient friction and compliance and a new system comprising inflatable pads is expected to provide a significant improvement.

In addition to the above trials the device has been used to elicit feedback from a number of physiotherapists and researchers in stroke rehabilitation. The response has been very positive with the potential for assisting, monitoring and recording task performance over an extended period being perceived as a worthwhile objective.

Further Development

The issue of effective and safe arm location is an important area to be addressed, particularly in terms of friction and contact pressure. The duration of treatment periods will be a significant factor.

Means of supporting the weight of the human and mechanical arms fall into two categories; passive counterbalancing and active systems. Full passive counterbalancing is possible but spatial problems need to be solved if the ROM is not to be restricted. Also inertia effects must be minimised. Active (i.e. powered) systems introduce a number of serious safety issues and have the disadvantage of high cost. The problems of passive counterbalancing are currently being given priority since success would provide the basis of an intrinsically safe and low cost system.

Conclusions

A five degree-of-freedom system has been found to be the minimum for carrying out the ADL tasks important in stroke rehabilitation.

The design has been validated by tests which show that the configuration interfaces well with the human arm. A static shoulder assembly works satisfactorily for healthy individuals but motion compensation may be required when used by stroke sufferers. Addition of goniometric measurement sensors is straightforward.

The response from physiotherapists and occupational therapists to the potential of the system has been very positive. The project is now progressing to the next stage of full gravity compensation.

References

[1] Department of Health and Social Security report, "Cost to the NHS", 1990

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