Can Iterative Learning Control (ILC) mediated by Functional Electrical Stimulation (FES) be used in the re-education of upper limb function post stroke?

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Abstract

Patients with post-stroke hemiplegia may have impaired upper limb function related to motor control, weakness and spasticity. Evidence has shown that robotic therapy or Functional Electrical Stimulation can improve impairment levels and possibly function. To date there has been limited research into possible benefits gained by combining the two techniques. This is also true of the application of Iterative Learning Control to problems that are not concerned with industrial processes. The aim of this project is to test the feasibility of re-educating upper limb movement post stroke, using ILC mediated by FES using a robot.

In the initial phase of this project, models have been created using data from eight neurologically intact subjects. Muscle activity was recorded using surface electromyography in a cross sectional observation study during which participants undertook tracking tasks using nine different trajectories, with their forearm constrained in a two dimensional plane by a robot. Kinematic and kinetic data was then collected, used to produce a dynamic model for each subject and to derive iterative learning control laws. These algorithms were applied to adjust the level and timing of electrical stimulation, to achieve accurate arm tracking using the robot over the course of six iterations.

1 Introduction

Following stroke many patients have a complex and varied pattern of motor and functional impairment in the hemiplegic upper extremity.
Systematic reviews of the robot therapy literature for the upper limb suggest that robot aided therapy improves motor control of the proximal upper limb and may improve functional outcomes [1-3]. There is also a body of clinical evidence to support the use of FES to improve motor control [4]. However there is little research that has combined these two fields.

It is known that when stimulation is associated with the person's intention to move the effect is enhanced [5]. However, until now, techniques have not allowed feedback which could be used to adjust stimulation parameters and provide more precise feedback. This research seeks to address these issues, using a robot and ILC mediated by FES. ILC has its origins in the control of processes that repetitively perform a task with a view to improving accuracy from trial to trial by using information from previous executions of the task. The classic example is the area of trajectory following in industrial robot applications, but can it be usefully applied to neurological rehabilitation?

To answer this question, a study is in progress in which ILC will be used to control FES applied to appropriate muscles of stroke patients, to enable them to accurately track a number of reaching trajectories. Following repeated accurate tracking the stimulation will be reduced, to encourage optimal voluntary contribution to the task; ensuring that the patient is always working at the limit of their ability.

Phase 1 of this project comprises tests conducted with unimpaired subjects to produce a model of their voluntary tracking ability and to test the ability of ILC to correct tracking error via stimulation.

The model uses normal activation sequences and kinematic characteristics recorded during gravity eliminated reaching tasks. The ILC controller then utilises the model to govern the stimulation applied, in order to eliminate error during tasks in which unimpaired subjects provide no active movement. Furthermore, the model will also be used to inform when to apply stimulation in stroke patients (although effects due to impairments such as spasticity will be taken in account) and will be used as a tool with which to analyse their results.

2 Methods

As a major purpose of phase one is to provide a normative data set, in order to identify which muscles to stimulate in phase two, only normal healthy adults were chosen to participate. During the second phase, the technique will be applied to a small sample of stroke patients.

2.1 Participants

Eight neurological normal participants aged fifty years and over were recruited as representative of stroke patients. Participants gave written informed consent, and ethical approval (S05-12/1) was granted.

2.2 Interventions

Visit 1 – Identification of normal muscle activation patterns during different trajectories: EMG electrodes were attached to the participant's triceps, biceps, anterior deltoid, upper, middle and lower trapezius and pectoralis using a standard procedure [6]. They were then seated in front of the robot at a height which allowed normal shoulder positioning, and restraining seat belts were used to limit trunk movement. Their arm was placed in the robot arm holder which had a Perspex layer over the grip with a central target area marked with a cross wire. An overhead projector displayed an image of an elliptical trajectory with a moving red dot. The participant then attempted to follow nine different trajectories (in three different directions, at three different lengths, speeds and resistances). Each trajectory was calculated depending on the subject's maximum reach capability and biometrics, an example is shown in Figure 1.

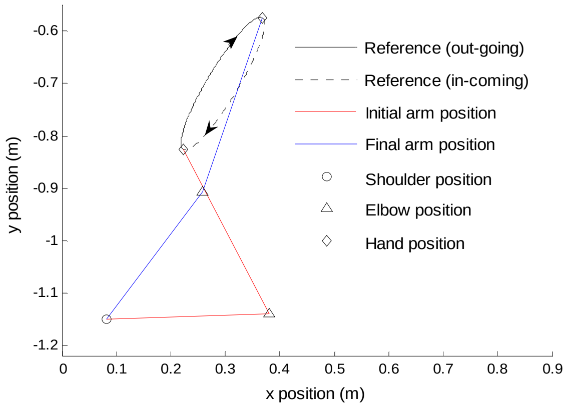

Figure 1: Arm position and reference trajectory.

Visit 2 – Modelling and application of ILC: Participants were positioned as in Visit 1, and were asked to relax. To provide data for the dynamic model, the arm was moved by the robot in different directions at varying speeds. The maximum comfortable level of stimulation was then identified and used as an upper limit. The sequence of movements was then repeated whilst using stimulation (asymmetric, biphasic, 40Hz fixed amplitude variable pulse width 0-300µs with a resolution of 1µs) to identify parameters in a model of the triceps muscle. Finally, the subject was again asked to relax their arm and to shut their eyes, so they did not anticipate movement. Iterative learning control mediated by ES was then used to control the movement of their arm over six iterations of selected trajectories. During these, the action of the robotic arm was firstly to make the movement feel 'natural' to the subject. Secondly, to provide a minimal level of assistance to ensure the task was achievable, yet allow the stimulation to drive its completion (the robot provided an assistive torque about the shoulder only when stimulation produced a torque about the elbow).

3 Results

The robot was designed and constructed at the University of Southampton [7].

3.1 EMG data during gravity eliminated reaching tasks.

EMG data was bandpass filtered (Butterworth 10-500Hz), full wave rectified, smoothed (moving average 0.1s window) and normalised to maximum voluntary isometric contraction data. For each reaching task the mean data for all subjects was calculated and then integrated to produce a cumulative plot showing the relative activations of each muscle (Figure 2 shows a plot for one of the nine tasks).

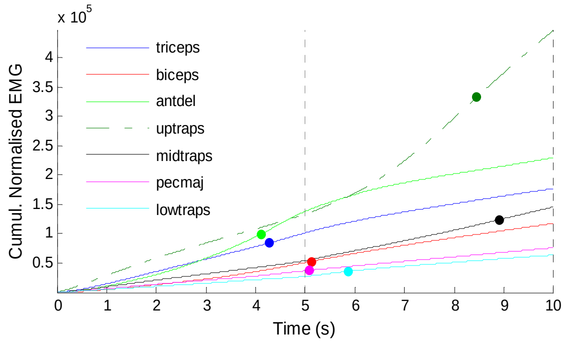

Figure 2: Cumulative normalised EMG during one reach and return task ('•' at peak rate).

3.2 Tracking error data during gravity eliminated reaching tasks.

The mean tracking error over each trajectory for all subjects was calculated using:

i) Voluntary movement (without stimulation, performed three times)

ii) ILC mediated by FES (without voluntary movement, performed six times)

Mean error values for each case are shown in Figures 3 and 4 respectively. FES was not tolerated by one subject and could not generate sufficient force in two others, so these are absent from Figure 4.

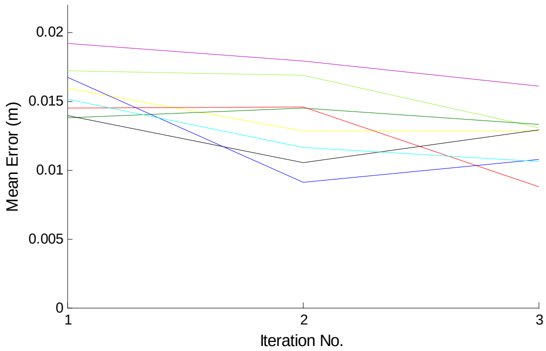

Figure 3: Mean error against iteration number using no stimulation.

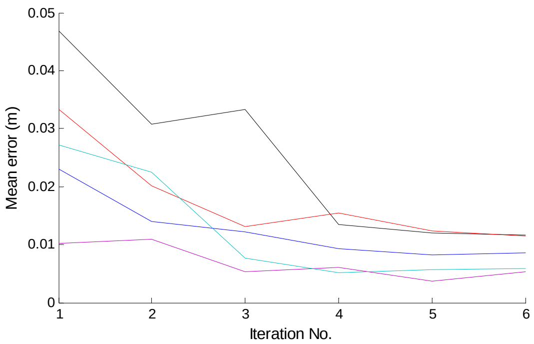

Figure 4: Mean error against iteration number using ILC mediated by FES.

4 Discussion and Conclusions

The gradient of the cumulative normalised EMG graph represents the rate of increase of EMG activity. The '•' symbol indicates the centre of the 2 second interval in which the muscle was most active. The end point amplitude of each muscle corresponds with its total contribution to the completion of the task. Cumulative EMG graphs have been drawn for each trajectory to enable a simple characterisation to be constructed of muscle activation patterns in unimpaired subjects.

Iterative Learning Control mediated by FES has been applied to enable unimpaired subjects, contributing no voluntary movement, to track trajectories; the accuracy achieved within six iterations is comparable with voluntary movement without stimulation.

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Acknowledgements

This work is supported by the Engineering and Physical Science Research Council (EPSRC), grant no. EP/C51873X/1.