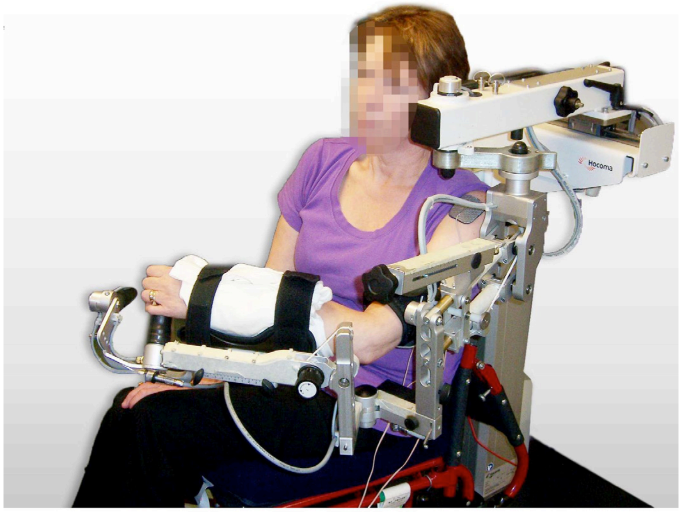
Control in Stroke Rehabilitation

Stroke is the foremost cause of disability in developed countries. Less than 15 percent of patients with upper-limb impairment following stroke regain full function, which restricts their ability to perform everyday reaching and grasping tasks. Functional electrical stimulation (FES) used to assist stroke patients in moving their impaired limbs has been shown to increase upper-limb function; however, the benefits of FES are greatest when combined with maximal voluntary effort from the patient to perform the movement. This presents a control problem: to provide the right amount of FES to assist with movement while also encouraging maximal voluntary effort.



An upper-limb rehabilitation system has been developed at the University of Southampton that uses iterative learning control (ILC), FES, and robotic support. Significant improvement in patient arm movement has been realized.

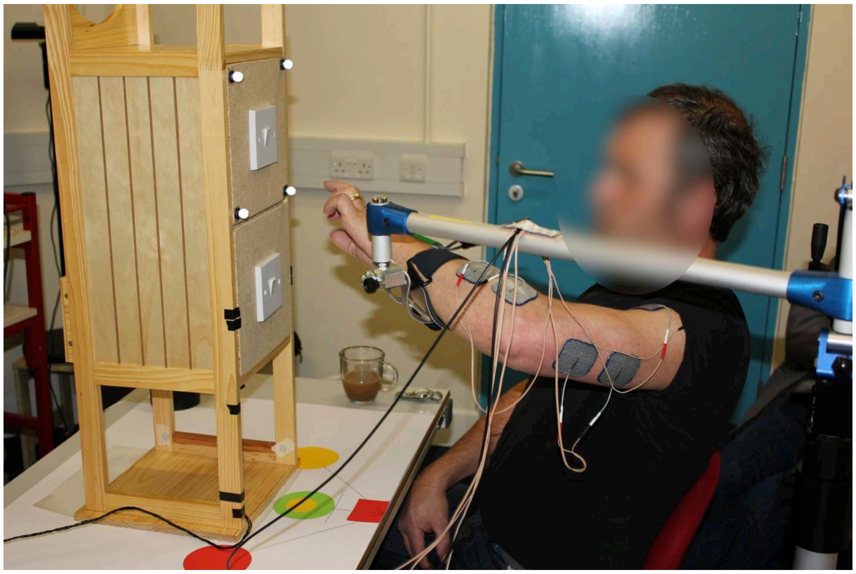
Development of Upper-Limb Rehabilitation Systems

This development was the outcome of three main research programs:

- ***Planar reaching:*** Initial proof-of-concept experiments incorporated movement in one plane and stimulated one muscle group (triceps) to control movement around the elbow joint. Patients tracked a moving trajectory with their hand while FES was applied to assist with the movement. Following each trial, ILC updated the FES signal for the subsequent trial. Results showed improvements in tracking accuracy during the sessions.

- ***3-D virtual reality:*** Following the successful proof of concept, the system was extended to movements in 3-D space using a virtual reality tracking task. Patients' arms were supported by an Armeo robotic support (Hocoma, Switzerland), with FES applied to the triceps and anterior deltoid muscle groups to control movement around the elbow and shoulder joints. An experimental trial demonstrated the system's effectiveness, with improvements shown in tracking accuracy and in Fugl-Meyer clinical assessment scores. See the figure at top right.

- ***Functional reach and grasp:*** The most recent system advances the work to include control of the hand and wrist during functional tasks. ILC-controlled FES is now also applied to the extensors of the wrist and hand to assist with picking up and manipulating real-world objects. Minimal robotic support is provided by a spring system (SaeboMAS, USA), and patient tracking is achieved using Microsoft Kinect. A recent study reported improvements in patients' performances of functional tasks and clinical scores (Fugl-Meyer and ARAT). See figure at right.



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Relearning of Functional Tasks

Rehabilitation Tasks

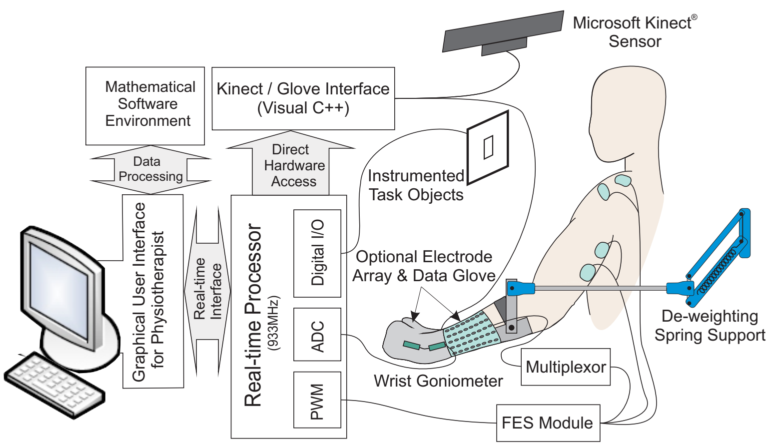
The current system incorporates common tasks of daily living, utilizing instrumented objects associated with daily life. The tasks currently performed include closing a drawer, pressing light switches, picking up and repositioning a drink, and stabilizing objects to assist the unaffected arm. Spasticity in stroke patients often restricts flexion of the shoulder, extension of the elbow, and extension of the wrist and fingers. Therefore, the anterior deltoid, triceps, and wrist and hand extensor muscles were selected for stimulation.

Control Approach

A simplified dynamic model of the arm-support system incorporates a biomechanical description of the human arm and a representation of the spring support (see below right). A proportional-integral-derivative (PID) controller is currently used in this system in parallel with phase-lead ILC, based on joint angle reference signals from unimpaired movement. The repetitive performance of the rehabilitation tasks used in this system make it an ideal application for ILC to control the FES signals for each muscle group. Performance error from each trial is used by the ILC to update the FES control parameters of the subsequent trial in an attempt to reduce error. This approach reduces the stimulation following successful performance, increasing the effectiveness of rehabilitation by requiring maximal patient effort.

Clinical Improvements

Reaching the clinical trial stage is often difficult in rehabilitation engineering. The FES-ILC technology has reached this stage, and initial clinical trials involving 15 chronic stroke patients over six-week periods have shown significant improvements in clinical assessments of arm movement across all patients.

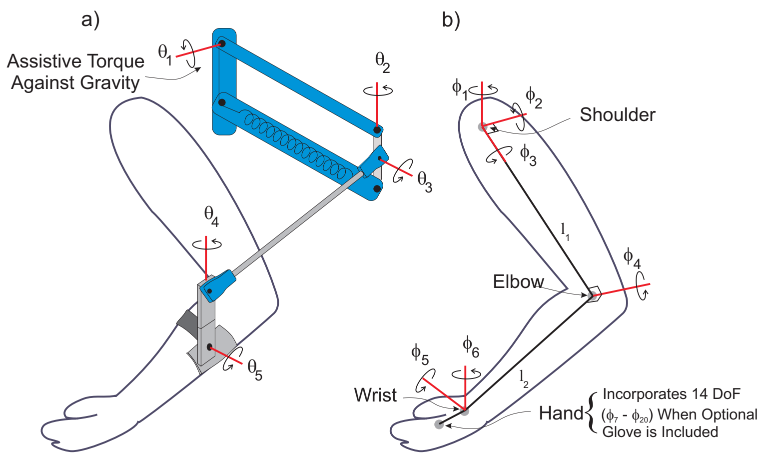


Left: Architecture of the current system, incorporating ILC and real-time controlled FES applied to each muscle group

Below: (a) Kinematic model of the spring support, and (b) anthropomorphic arm used in the control model

Future Directions

- Incorporate patient-customized models of movement within control design
- Reduce size and cost of system hardware for use within patients' homes
- Develop greater selection of functional tasks that can be incorporated, utilizing instrumented "real-world" objects
- Undertake a large-scale clinical trial through national stroke units



For more information: C.T. Freeman, et al., Iterative learning control of FES applied to the upper extremity for rehabilitation, Control Engineering Practice, vol. 17, no. 3, pp. 368-381, 2009; K.L. Meadmore, et al., Functional electrical stimulation mediated by iterative learning control and 3D robotics reduces motor impairment in chronic stroke, J NeuroEng Rehabil, vol. 9, no. 32, 2012; T.A. Exell, et al., Goal orientated stroke rehabilitation utilizing electrical stimulation, iterative learning and Microsoft Kinect, in IEEE International Conference on Rehabilitation Robotics, Seattle, WA, 2013.