ADAPTIVE ITERATIVE LEARNING CONTROL FOR ROBOTIC-ASSISTED UPPER LIMB STROKE REHABILITATION

FENGMIN LE, CHRIS T. FREEMAN IVAN MARKOVSKY AND ERIC ROGERS, *

Abstract. The percentage of people in England who are over 65 will increase from 16% in 2003 to 23% in 2030 and the cost of stroke care in Europe is predicted to rise by 30% between 1991 and 2010. Consequently there is an ever increasing burden on health care and rehabilitation resources and if the capacity of health services is to meet future demand novel approaches to rehabilitation are required. Enabling rehabilitation outside the hospital, supported by mobile technology, could lead to: reduced cost, increased intensity of therapy and shift the emphasis of responsibility for good health from the healthcare professional to the patient.

A stroke is usually caused when a blood clot blocks a blood vessel in the brain. It acts like a dam stopping the blood reaching the brain downstream. As a result some of the connecting nerve fibres die and the person suffers partial paralysis on one side of the body, this is called hemiplegia. These fibres cannot re-grow, but the brain has spare capacity and new connections can be made. In fact the brain is continually and rapidly changing as we learn new skills; new connections are formed and redundant ones disappear.

When people re-learn skills after a stroke they go through the same process as you do when you learn to play tennis, but they have a problem because they can hardly move at all so they cannot practise, which means they don't get feedback. Muscles can be made to work by Electrical Stimulation (ES). Electrical impulses travel along the nerves in much the same way as the electrical impulses from your brain. If stimulation is carefully controlled, a useful movement can be made. This works better if the person is attempting the movement themselves; we therefore need to combine a person's own effort with just enough extra electrical stimulation to achieve the movement.

Rehabilitation robots are powered or mechanically supporting devices that enable a person with limited physical ability to practise tasks. Such practice and the resulting sensory feedback is known to be associated with cortical changes that can bring about recovery of useful movement. Measuring devices on the robots allow for objective measurement and evaluation of patients' performance. Studies have also shown increased motivation to actively participate in training exercises.

Recent work [1] has used Iterative Learning Control (ILC) to control the ES by incorporating data from previous trials of the task and taking account of the voluntary effort made by the patient. The workstation involved used a robotic arm to constrain the arm to move in the horizontal plane and create the effect that the subject is moving a simple point mass with damping. Moreover, the control signal is an electrical pulse applied as a pulse width modulated signal and hence a model of the response of a human muscle to ES must be constructed together with response of the human arm. To be of use for stroke patients the final system must be safe to use and supported by clinical trials and if the patient is improving with each attempt his/her voluntary effort should be increasing and that due to the FES decreasing. Clinical trials [2] showed these features for the case of reaching out in the 2D plane, for example to a cup, where there this human response is required in approximately 50% of daily living tasks.

Modeling of the response of electrically stimulated muscle is by system identification In particular, the Hammerstein model is an empirical representation of the response of human muscle to ES that consists of a static nonlinearity representing muscle fiber recruitment, followed by a linear dynamic model that converts the stimulation applied into a torque. The structure has the form

$$\tau(u(t), \phi, \dot{\phi}) = h(u, t) \times F_m(\phi, \dot{\phi}) \tag{0.1}$$

where the term $h(u,t)$ is a Hammerstein structure incorporating a static non-linearity, $h_{IRC}(u)$, representing the isometric recruitment curve, that is, the static-gain relation between the stimulus activation level (u) cascaded with linear activation dynamics, $h_{LAD}(t)$. The term $F_m(\phi, \dot{\phi})$ models the multiplicative effect of the joint angle and joint angular velocity on the active torque (τ) developed by the muscle.

The results in [1] and [2] and the related cited references in these publications, has generated many areas for further research where progress would greatly aid the onward development of this approach towards use by rehabilitation professionals. This paper reports more recent results where adaptive ILC algorithms have been investigated, starting with trial-dependent adaptive ILC where the update rule is trial dependent and not updated during the trial. Gradient and Newton-based ILC in this setting will also be analyzed.

* Electronics and Computer Science , University of Southampton, Southampton SO17 1BJ, UK (etar@ecs.soton.ac.uk).

Key words. system identification, robotics, adaptive iterative learning control

AMS subject classifications. 93B30, 93C40

REFERENCES

[1] C. T. Freeman, E. Rogers, A.-M Hughes, J. H. Burridge, and K. L. Meadmore, *Iterative learning control in healthcare: electrical stimulation and robotic-assisted upper-limb stroke rehabilitation*, IEEE Control Systems Magazine, 32(1) (2012), pp. 18–43.

[2] A.-M Hughes, C. T. Freeman, J. H. Burridge, P. H. Chappell, P. L. Lewin, and E. Rogers, *Feasibility of iterative learning control mediated by functional electrical simulation for reaching after stroke*, Neurorehabilitation and Neural Repair, 23(6) (2009), pp. 559–568.