LOGGING THERAPY SESSION DATA VIA AN UPPER LIMB FES REHABILITATION SYSTEM

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Abstract: *This paper reports on an approach to capturing real-time therapy session data using an upper limb functional electrical stimulation (FES) system to support our understanding of its usability in clinical environments and to record therapy delivered. The recently developed advanced FES system, FES-UPP, which is allowed clinicians to quickly and easily set up controllers to deliver FES-support for patient-specific upper limb functional task practice. One stroke patient participant carried out 7 therapy sessions in clinical environments. Some example information has been summarized from the logged data and shows a noticeable increase in the efficiency of therapy delivery with using FES-UPP system.*

Keywords: *Upper limb, Rehabilitation, Functional electrical stimulation, Therapy session data*

Introduction

FES technology is showing promise as a tool to promote upper limb recovery following a stroke [1, 2]. However, the small number of commercial FES systems are insufficiently flexible to support the varied, yet challenging functional task practice that the literature suggests may be needed to promote motor re-learning. For example, most systems provide a small number of stimulation channels, with some systems are restricted by design to stimulation of the particular body anatomy. To address this problem, the University of Salford and Odstock Medical have developed an advanced FES system, FES-UPP, which allows clinicians to quickly and easily set up controllers to deliver FES-support for patient-specific upper limb functional task practice.

Hochstenbach-Waelen and Seelen [3] report the low uptake of rehabilitation technologies for the upper limb in routine clinical practice and summarized in their paper the potential factors that may be behind this finding. Of particular note, any rehabilitation technology should be quick and easy to setup. Therefore, techniques to capture the usability of our new system were required. Further, the ability to capture data on the therapy delivered (as opposed to simple therapy contact time, which is often reported as a proxy measure of therapy input) would be of great value in future clinical studies of the new system.

Previously, we used direct observation of an earlier prototype of the FES-UPP system [4] but this approach is time consuming and always required input from the researchers and/or therapists. Here we describe the design and implementation of a system to log data reflecting use of the FES-UPP system. We illustrate its application with data collected as part of a clinical evaluation of the system in three clinical settings.

Methods

Design of the FES-UPP system

The FES-UPP system has been reported in detail by Sun et al. [5, 6]. In summary, the FES-UPP system consists of a 5-channel stimulator running an FES finite state machine (FSM) controller, the FES-UPP software installed on a tablet PC, body-worn sensors and an instrumented object. The FSM controller represents a functional task as a sequence of movement phases. The output for each phase implements the stimulation to one or more muscles. Progression between movement phases is governed by the therapist-defined rules, which may be based on data from body-worn sensors, the instrumented object, button pressing signals, or clock time for timeout. The instrumented object detects when a patient grasps, releases, or replaces the object onto a surface.

The FES-UPP software guides clinicians through the setup of a FSM for a given patient and task. The software concept is to break the setup of a FSM for a particular upper limb functional task into five stages:

1) Create, modify and select tasks;
2) Don electrodes and sensors, and initial channel setup;
3) Set up stimulation parameters for each phase and capture manual transitions data;
4) Set up transition conditions; and
5) Set up task instructions and feedback.

Once the five stages have been completed for each of the selected tasks, the therapy session manager guides the patient in repeated attempts at the task(s). In addition, it also provides feedback on task performance to the patient and clinician.

Design of the therapy session data logging

The FES-UPP software on the tablet logs data in a set of automatically created patient-specific files for each therapy session. The data and directory structures are shown below.

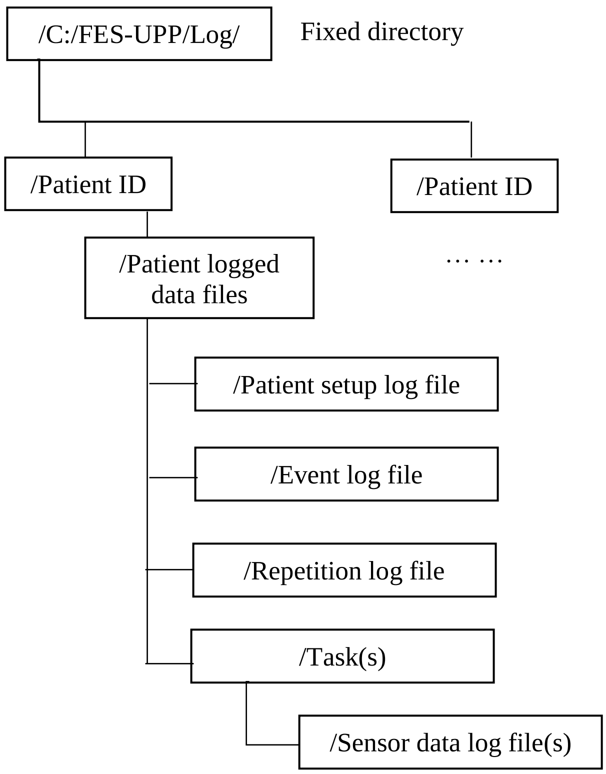

Figure **1**: Directory design

The patient logged data files include patient setup file for each functional task, key interaction events between the therapist and software, information corresponding to each repetition of task and Quaternion angle data from sensor used for tracking body segment movement (see Fig. 1 and Tab. 1).

Table 1: Patient logged data files.

Item	**Ext**	**Number of files**	**Example file name**
Patient setup log file	.xml	1	Z04_03-02-2017_13.00.xml
Event log file	.txt	1	Event log.txt
Repetition log file	.txt	1	Repetition log.txt
Sensor data log file (s)	.txt	/	Rep 1.txt

Patient logged data files

The ***Patient setup log file*** contains the core setup information, including FSM parameters (e.g. number of movement phases, phase name(s), muscles to be stimulated during each phase), stimulation parameters that defined stimulation profiles (targets, ramp time, delay time and motor threshold), and transition rules etc. The ***Patient setup log file*** could be reloaded from the tablet hard drive for use in a new therapy session.

The ***Event log file*** contains the key software interaction events that occurred during the FES-UPP session. The timestamped and logged events include when the user logged on/off the software, and entered different setup stages and session manager.

The ***Repetition log file*** contains information corresponding to each repetition of a task included the task name, repetition number, time spent in each movement phase, reason(s) for leaving each movement phase, and whether a repetition was successful. A successful repetition was deemed to have occurred when the FSM had progressed through each movement phase and returned to the neutral phase.

A ***Sensor data log file*** was automatically created for each repetition of a task while in therapy session manager. It logs the continuous quaternion data from those sensors assigned to a body segment and associates the data with a movement phase number and computer time.

The software uses "appointment date and time" to name a unique directory for each therapy session.

Experiment demonstration

To illustrate the application of the approach, below we report on case study data gathered as part of a clinical evaluation of the system. Following ethical approval (REC ref 16/YH/0258), the study aimed to evaluate the system in three different clinical settings. In each case, the system was used by trained therapists without on-site technical support. In this paper we report on use of the system in very early post-stroke rehabilitation (less than 1 week) with 1 participant who had severely impaired upper-limbs. The patient participant was treated by three therapists using the FES-UPP system during 7 therapy sessions, spread over approximately 4 weeks.

Table 2: Therapist participants

Therapist participants	**PT[1]**	**OT[2]**	**TA[3]**
Clinical experience on treating stroke patients (years)	6	15	1
FES experience	Yes, lower limb only	No	No
No of session completed	2	2	3

[1]PT = physiotherapist;

[2]OT = occupational therapist;

[3]TA = rehabilitation therapy assistant;

One PT, an OT and a TA, none of whom had prior clinical experience of upper limb FES treated the patient participant reported here (see Tab. 2). All three therapists completed a two-day training session to learn how to use the FES-UPP system and to follow the study protocol. A clinical manual and on-line training materials for the system were available to the therapists during the study.

In each therapy session, the participant was asked to carry out one or two functional tasks assisted by electrical stimulation . The tasks were imported by the therapist from a standard hand-arm activity library in the FES-UPP setup software.

Table 3: The therapy session information for patient participant.

Therapy No	Performed task(s)	Total Reps No	Success rate[1] (%)	Total practicing time (mins)	Total therapy time (mins)	Efficiency[2] (%)
1	Reach to Target	8	100%	2.2	35.8	6.1
2	Sweeping coins	10	40%	3.8	50.2	7.6
3	Reach to Target	7	85.7%	2.8	48.7	5.7
4	Reach to Target	7	71.4%	9.9	76	15.1
	Sweeping coins	3	100%	1.6		
5	Sweeping coins	67	100%	23.8	50.3	47.3
6	Sweeping coins	56	98.2%	14.1	34.6	40.8
7	Sweeping coins	98	100%	19.4	25.8	75.2
Mean		36.6	96.1	11.1	45.9	24.2

[1]Successful rate (for a task) = (number of successful repetitions of this task/ the total number of attempts at the task)×100%;

[2]Efficiency (for a session) = (total practicing time of this session/ total therapy time at the session)×100%

Results

Two different functional tasks, tailored to suit the impairment level of this particular stroke participant were set up across the 7 therapy sessions (see Tab. 3). The two tasks were “Reach to target” and “Sweep coins”. On one occasion, the participant managed to complete two functional tasks.

All 7 therapy session data were successfully logged. Some example outcomes were extracted from the patient logged data files, and summarized in Tab. 3 and Fig. 2. They include the performed tasks, total repetition number of each task, success rate, total practicing time, total therapy time, the efficiency in each therapy session and the therapist-defined rules. The total practice time was extracted from the ***Repetition log file*** and defined as the sum of time period when the FSM had progressed through each movement phase and returned to the neutral phase in the session manager. The total therapy time of a session was extracted from the ***Event log file*** and defined as follow:

Total therapy time = Software log off time –log on time

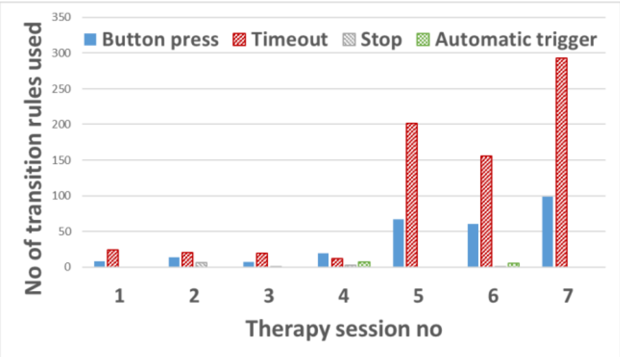

Figure **2**: Transition rules used for the participant

Fig. 2 illustrates the type of therapist-defined rules used in movement phase transitions for each task within each session. In all cases, therapists used a single rule. The automatic trigger defines a transition between two successive phases, based on data from body-worn sensors or the instrumented object.

Discussion

In this paper, we have reported an approach to recording real-time therapy session data each time the FES-UPP system was used. Redundant information was logged for each therapy session. Useful outcomes have been extracted from the patient logged data files. On average, the participant achieved 36.6 repetitions within 11.1 minutes practice time per session across the study. The participant achieved a very high success rate (96.1%) Part of the reason for this was that all three therapists almost always chose to use simple transition rules, such as timeout or a button press (Fig. 2). It will be interesting to explore whether, as therapists gain confidence in the use of the FES-UPP they will exploit the opportunity to use motion sensor or object-based rules, which offer greater potential for patient engagement in the practiced activity. Tab. 3 illustrated a significant increase in the efficiency delivered in the last three therapy sessions. The number of repetitions and amount of practice time during the last three sessions increased, while the total therapy session time decreased. The outcomes extracted from the patient logged data files demonstrated the potential of FES-UPP system to be used in busy clinical environments.

Conclusions

In this paper, we reported the design and implementation of an approach to log real-time therapy session data reflecting use of the recently developed FES-UPP system. The FES-UPP system has potential to allow therapists to efficiently deliver high intensity, high repetition task orientated upper limb therapy in a clinical setting. Therapists with little or no FES experience and without any programming skills could use FES-UPP system to set up a range of functional activities on severe early-stage stroke patients. One stroke patient participant carried out 7 therapy sessions in clinical environments. Redundant information was logged for each therapy session to support our understanding of its usability in clinical environments and to record therapy delivered. Some example information has been summarized from the logged data and shows a noticeable increase in the efficiency of therapy delivery with using FES-UPP system.

Nevertheless, future work to extract more information from the redundant logged data files is still required. The logged data files has potential to provide the feedback about the patient performance to the therapists during each therapy session.

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