

SMART project: application of emerging information and communication technology to home-based rehabilitation for stroke patients

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ABSTRACT

The SMART project, entitled 'SMART rehabilitation: technological applications for use in the home with stroke patients', is funded under the EQUAL (extend quality of life) initiative of the UK Engineering and Physical Sciences Research Council (EPSRC). The project aims to examine the scope, effectiveness and appropriateness of systems to support home-based rehabilitation for older people and their carers. In this paper, we describe the design and development of a low-cost home-based rehabilitation system. Through the project we have involved end users in the design process and this model can be applied to the design of other healthcare related systems.

1. INTRODUCTION

In the UK, stroke is the most significant cause of adult disability. Reports (DoH, 2000) showed that six months after stroke, 49% of patients need help with bathing, 31% of patients need help with dressing and 33% of patients need help with feeding. Research suggests that intensive and repetitive training may be necessary to modify neural organization (Miltner et al 1999, Rossini et al 2003). However, in the UK, inpatient rehabilitation length of stay for patients with stroke is decreasing, with limited outpatient rehabilitation. Therefore, there is a need to develop a low-cost, accessible, home-based rehabilitation system.

The SMART project, entitled 'SMART rehabilitation: technological applications for use in the home with stroke patients', is funded under the EQUAL (extend quality of life) initiative of the UK Engineering and Physical Sciences Research Council (EPSRC). The project aims to examine the scope, effectiveness and appropriateness of systems to support home-based rehabilitation for older people and their carers (www.shu.ac.uk/research/hsc/smart). The SMART consortium consists of one NHS Trust, four universities and one voluntary organisation, namely Royal National Hospital for Rheumatic Diseases, University of Bath, Sheffield Hallam University, University of Essex, University of Ulster and The Stroke Association.

The rest of this paper is organised as follows. Section 2 introduces the SMART rehabilitation system currently under development. In Section 3, the user involvement design strategy is presented. The motion tracking unit is detailed in Section 4 and the ICT decision platform is presented in Section 5 respectively. In Section 6, outcome measurements are described. Finally, a brief summary of the system usability and some discussion on the SMART system are presented in Section 7.

2. SYSTEM OVERVIEW

The SMART rehabilitation system employs an ambulatory monitoring system linked to an ICT decision support platform that provides therapeutic instruction, supports the rehabilitation process and monitors the

effectiveness of rehabilitation interventions upon patient function. Information relating to this process is fed back to patients, their carers or health care professionals.

The system consists of three components; (i) motion tracking unit (ii) base station unit (iii) web-server unit (Figure 1).

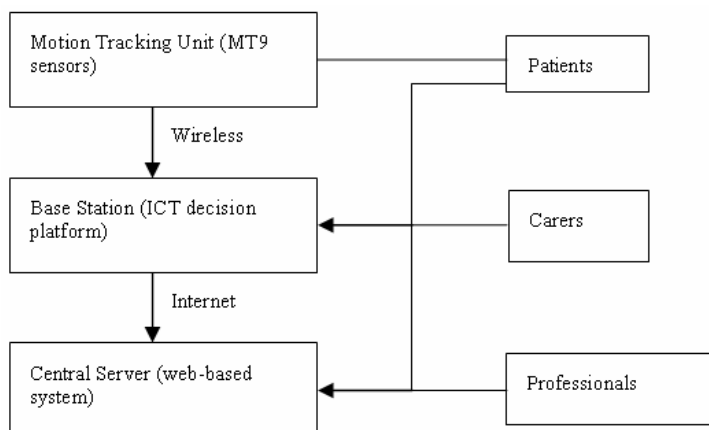


Figure 1. System Architecture.

The motion tracking unit (Zhou et al 2004) consists of two MT9 inertial sensors (Xsens Dynamics Technologies, Netherlands) which are attached to the patient's arm to track the movement during activities such as drinking or reaching. The MT9s record the movement information (positions and angles) of three joints, i.e. wrist, elbow and shoulder. The information is then sent wirelessly to the base station (Media PC) via a digital data box called "XBus" (placed on the waist) for further processing by the ICT decision platform (Figure 2). The ICT platform will display the movement in a 3 dimensional (3D) environment at the base station; analyse the data; store the data and upload the data to central server. Healthcare professionals can assess and monitor movements remotely via the internet by accessing the central server, ultimately to provide comments over the web-based system (Zheng et al 2005b). The ICT platform will provide these comments as feedback to the patients and their carers alongside other more detailed analysis.

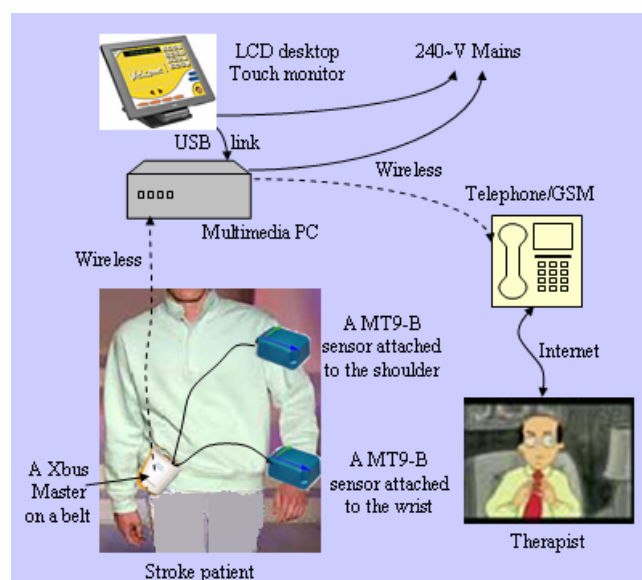


Figure 2. Illustration of Smart Rehabilitation System.

3. USER INVOLVEMENT IN DESIGN

Early in the project the project focus groups were held with patients and healthcare professionals to ensure that proposed technical solutions, methodology and outputs were acceptable. A number of key principles were identified with their help during the focus group process:

- It is an aid to therapy, not a stand-alone therapy.
- It is not specific to any one model of therapy
- It is a generic device applicable to a variety of rehabilitation aims for upper and lower limb
- No two people who have had a stroke are the same: there must be flexibility in all elements of the device.
- The device must be as simple as possible to use, and adaptable to individual needs. Stroke patients have complex impairments often incorporating cognitive difficulties such as problems with perception, attention, information processing, language and memory.
- The device should provide accurate feedback on performance.

In the later stages of the project we recruited a group of expert users to provide specific feedback on key aspects of the system such as user interface, type of feedback and computer interface. This data was collected by qualitative researchers, summarised and fed back to the engineering teams. Table 1 summarises some of the key factors that were identified.

Table 1. Key points for designers: how the individual interacts with the device.

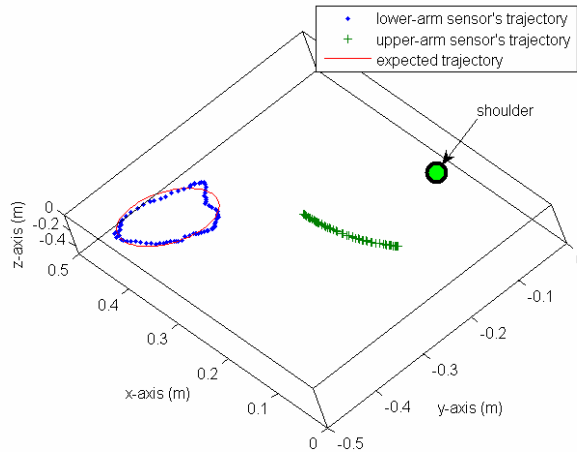
	Implications for design	
Points of interaction		
The sensor (attached to the body)	Ease of application (e.g. one handed, poor fine motor skills, cognitive impairments.) Size of sensor (weight, cumbersomeness) accuracy and repeatability of sensor placement	Independence of use
The device	Ease of use (e.g. size of buttons, colour codes, information delivery) Instructions for use: (on/off, charging, positioning etc) Capacity to set an individual programme (nb fatigue) comfort and wearability for user adaptability for different users - 'one size fits all'	Simplicity of design
The feedback mechanism/s		
Real Time (Knowledge of Performance)	- Choice of methods (auditory, visual, written, storable and retrievable) -Simplicity of information display	Instructions – Different methods / clarity / simplicity Targets, possible to set Accuracy of results
Results for User (Knowledge of Results)	- Choice of methods (auditory, visual, written, storable and retrievable) Feedback presented positively Simplicity of information display	
Results for Therapist (Knowledge of Results)	Visual, written, storable and retrievable records	

4. MOTION TRACKING UNIT

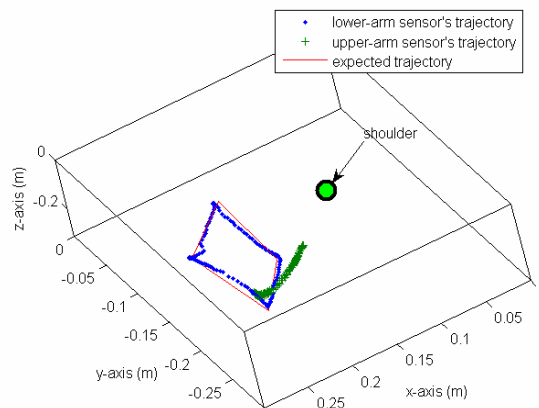
The tracking unit utilises sensor fusion and optimisation techniques and is implemented using Visual C++, based on a Media PC with a VIA Nehemiah/1.2GHz CPU. The Bluetooth wireless feature allows the subject to carry out motion exercises freely.

In order to determine the position of the upper limb, inertial measurements corresponding to human arm movements are continuously generated. A kinematics model is applied to locate the wrist and elbow joints in the global frame. The displacements of the shoulder joint are computed from accelerations of the sensor adjacent to the elbow joint using a Lagrange function with an equality-constrained optimisation method.

The proposed algorithm was validated by tracking a circular motion (radius: 0.1 m) and a square motion (rectangle 0.2×0.14 m²), drawn on a table. A subject sit still in a chair with the motion patterns placed on the desk in front of him (the lengths of two segments of the arm are 0.26 and 0.24 m respectively). The two MT9 sensors were attached to the middle position of the upper arm and the wrist joint of the lower arm, respectively. During the experiments the subject allowed the MT9 sensor attached to his wrist joint to move along the path of each shape on the desk surface. The data was generated continuously for 40 seconds with a sampling rate of 25 Hz. The errors were defined as the Euclidean distance between the measurements by the MT9 system and the designed trajectories. Means and standard deviations are calculated from these errors (Figure 3).



(a) Mean position estimation of the two sensors in circular motion. Mean errors = 0.017 ± 0.013 m.



(b) Mean position estimation of the two sensors in square motion. Mean errors = 0.011 ± 0.008 m.

Figure 3. Motion trajectories of the two sensors using the proposed motion detector.

5. ICT DECISION PLATFORM

The ICT platform consists primarily of five modules: database, sensor interface, decision support, communication and a feedback module.

- The database module stores the personal information, individualised questionnaires to check the patient can safely complete the exercises, rehabilitation history (prior movement data) and the comments/instructions from healthcare professionals;
- The interface module provides tools and menus to access system functions. We have included a facility to allow individual patient to select their own preferences regarding the presentation of the interface, such as colour, font size and feedback style. Users interact with the system using a LCD touch screen monitor.
- The decision support module will analyse the data and provide key outcome variables relating to physical performance (such as length of reach, elbow angle), while the communication module manages the transfer of information with the central server;

- The feedback module is the core module, which provides different types of information to patients, namely 3D movement information, comments/instructions, and analysis results in the following formats: text; 3D visualisation; tabular and graph.

The visualisation feedback displays and replays the movement of rehabilitation exercises to users in a 3D environment. To improve the realism, 3D rendering is applied to a virtual head and arm based on the movement data collected by the tracking unit. In order to provide a reference for patients, stored target movement templates are available which can be overlaid or mirrored on the screen to help the patient replicate the best movement. Figure 4 shows two types of methods used in presenting the 3D information, one displays exercise movement and the target template movement in two separate windows; and the other displays them in the same window with the template movement as a ghost layer. Through preference settings, users are able to choose either mode. This is a novel feature of the interface design, which provides a visualisation that is easy for users to understand, rather than biomechanical stick diagrams. The target movement template is personalised and adaptive. The first target template can be the patient's first movement, after that, it could be the best past movement that the patient has carried out. The decision on which template to use will be made by the therapist based on the change in outcome measurements.

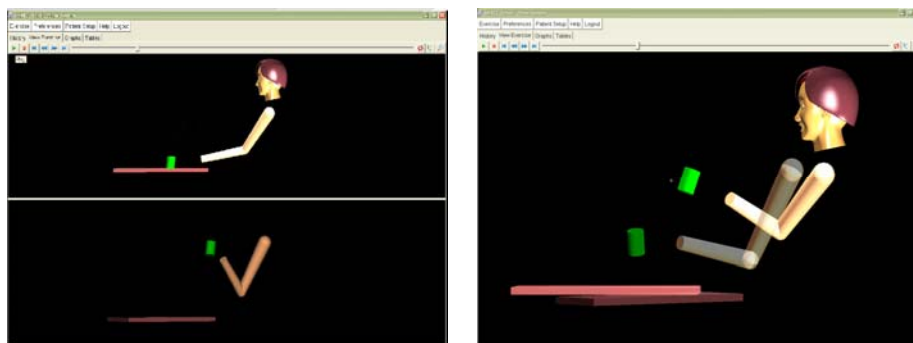


Figure 4. Screen shot of 3D rendering.

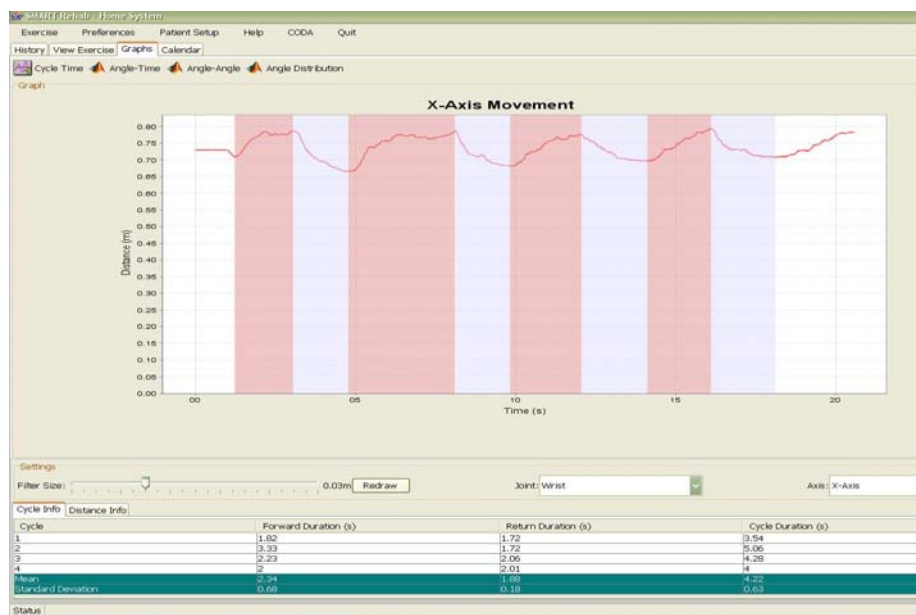


Figure 5. Screen shot of cycle time measurement

Measurements of variables are shown in graphs. Figure 5 shows the measurement of cycle time for a reaching movement. The forward duration and return duration of each cycle is calculated and shown. Users can select to view the movement and measurement results of each joint. Mean and standard deviation is calculated for each exercise. Similarly, rotation rate and other variables can be measured and displayed using graphs and/or tables. These variables will be used to monitor and assess the rehabilitation procedure, and can be used to modify the rehabilitation setting and system setting, such as the selection of target exercise template.

6. OUTCOME MEASUREMENTS

It is important that the system provides outcomes that are clinically relevant to the restoration of functional activities. A range of measurements were identified by the therapy user group and quantified by comparing age matched normative data to stroke data, collected using a commercially available 3D video motion analysis system (CODA Charnwood Dynamics, Rothley, UK).

Work is underway to validate the performance of the MT9 motion sensors against this system prior to evaluation in a home environment and to optimise the user interface following feedback from the expert user group and naïve users attending local Stroke Clubs. We are also evaluating a range of quantitative outcome measures that might be used to provide feedback on the progress of the rehabilitation.

7. SUMMARY AND DISCUSSION

This work shows that current information and communication technologies can be applied to stroke rehabilitation. It is important that the engineering teams involve users at the start of the system design and then to get feedback at regular intervals. Once prototypes have been developed these should also be evaluated by naïve users, since expert users may have become familiar with operation of the system. This process requires input for a multidisciplinary team that includes therapists, ergonomists and researchers familiar with qualitative research. We have also benefited from support provided by industrial partners and input from a Professional Design Team. The research demonstrates that it is feasible to apply the emerging motion sensor technology and information and communication technology (ICT), to develop a low-cost home-based system that could be used to support post stroke rehabilitation.

Acknowledgements: We would like to thank all the patients and carers who have given time to the project. We would also like to thank the support from Design Futures Sheffield, Xsens, Charnwood Dynamics Ltd. and The Stroke Association.

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