

**The SMART project: Application of emerging information
and communication technology (ICT) to home-based
rehabilitation for stroke patients**

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1. Introduction

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 (<http://hsc.shu.ac.uk/smart/>). In this paper, we describe the design and development of a low-cost home-based rehabilitation system and demonstrate [1] that it is feasible to apply the emerging motion sensor, information and communication technology (ICT), to develop such a system in which the needs of users are fully considered [2].

2. System overview

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

The motion tracking unit [3] consists of two MT9 inertial sensors (Xsens Dynamics Technologies, Netherlands) which are placed on patient's limb 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 [4]. The ICT platform will provide these comments as feedback to the patients and their carers alongside other more detailed analysis.

3. User involvement in design

Early in the project we held focus groups with patients and health professions to ensure that proposed technical solutions methodology and outputs were acceptable. They help us identify a number of key Principles:

- 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.
- 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 provides 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, summarized and feedback to the engineering teams. Table 1 summarises some of the key factors that were identified.

4. Motion Tracking Unit

The tracking unit utilizes sensor fusion and optimisation techniques and is implemented on Visual C++, based on a Media PC with a VIA Nehemiah/1.2GHz CPU. The 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 kinematic 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 $0.2 \times 0.14 \text{ m}^2$), 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).

5. ICT decision platform

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

- The database module stores patient's personal information, individualised questionnaires to check the safety of completing the exercises, patient's rehabilitation history (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 preference presentation of the interface, such as colour, font size and feedback style;
- 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 movement templates are available which can be overlaid or mirrored on the screen to help the patient replicate the best movement. **Error! Reference source not found.**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 an easy understanding visualisation to users rather than complicated biomechanical stick diagrams.

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.

Work is underway to validate the performance of the MT9 motion sensors against this system prior to clinical evaluation. We are currently evaluating a range of quantitative outcome measures that might be used to provide feedback to users, carers and health professionals on the progress of the rehabilitation.

7. Summary and discussion

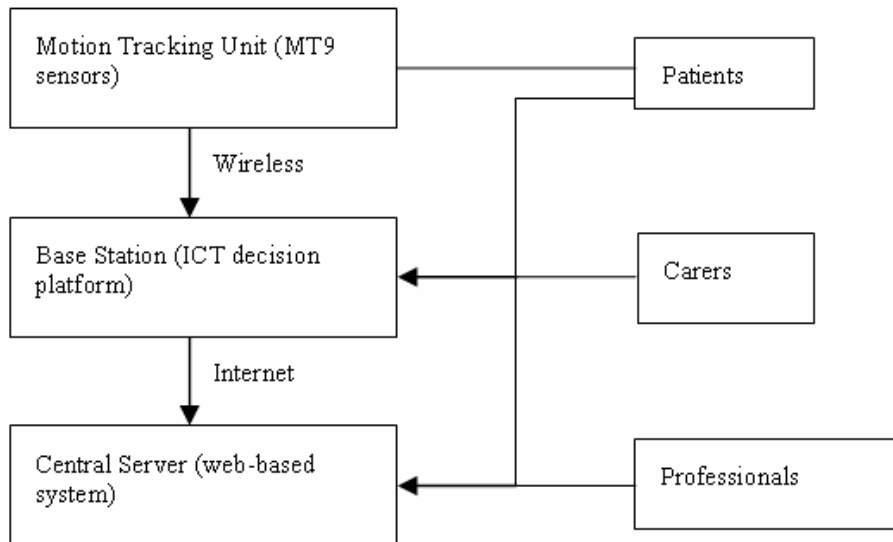
Our research shows that current information and communication technologies can be applied to stroke rehabilitation. It is important to involve users in the system design to ensure that the equipment will be suitable for use in the home environment and provide information that will support post stroke rehabilitation process.

References

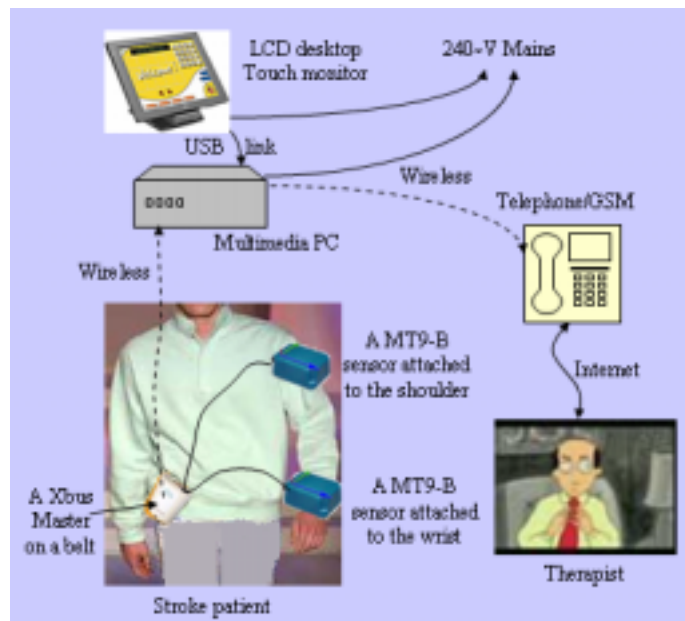
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Figures:

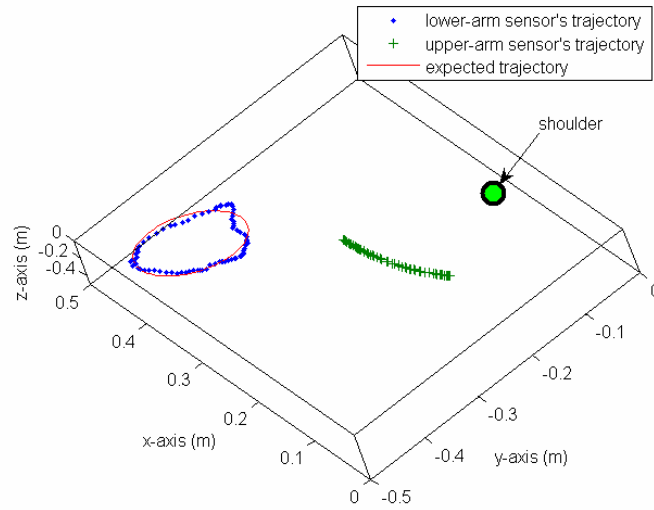
1. **Figure 1 Architecture of the SMART rehabilitation system**



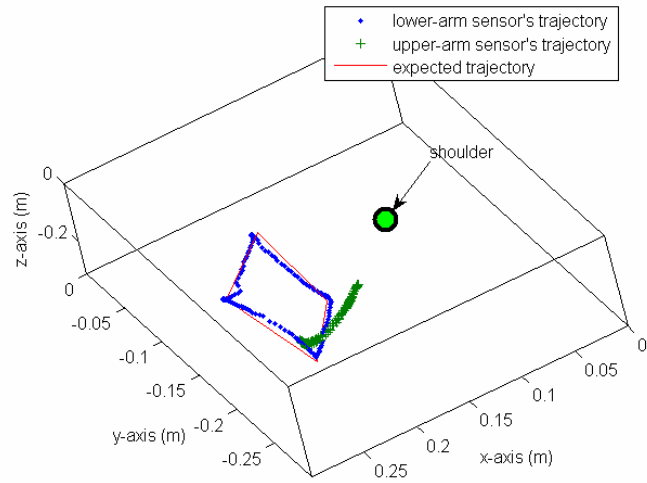
2. **Figure 2 Illustration of the SMART rehabilitation system**



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

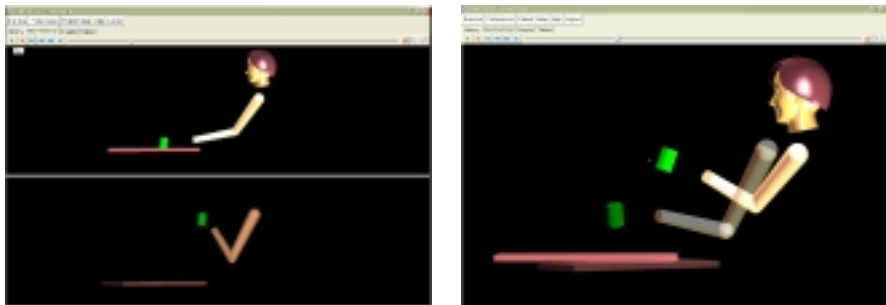


(a) Mean position estimation of the two sensors in circular motion. Mean errors = 0.017 ± 0.013 m.



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

4. Figure 4 Screen shot of 3D rendering



Tables

1. 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	