2009 IEEE 11th International Conference on Rehabilitation Robotics
Kyoto International Conference Center, Japan, June 23-26, 2009

Developing a User Interface for the iPAM Stroke Rehabilitation System

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***Abstract*—The increasing population of older people is leading to growing healthcare demands. Stroke is the commonest cause of severe disability in developed countries leaving one third of patients with long term disability. Rehabilitation is the cornerstone of recovery. Lack of rehabilitation manpower resources can limit recovery of limb function. However, technology can assist rehabilitation staff to deliver greater intensity of treatment. Robotic systems such as the iPAM robot can provide semi-automated arm exercises for people with complex impairments leading to loss of functional arm movement. Feedback to the patient about their performance, usability of the exercise "workspace" and motivating exercises are key aspects of the successful deployment of robotic systems within routine clinical use. We describe the development of the patient interface for the iPAM robotic system. Central to this development is user involvement (with rehabilitation professionals and people with stroke). Using user centred design methods which included use of questionnaires and one to one discussions, the user interface was changed from a simple screen showing a stick figure of the arm to a 3D scene with simplified indicators and feedback screens, providing feedback about performance and feedback about the quality of the movement. Patients were positive about the changes to the user interface, confirming that the feedback screens were clear, useful and motivating. The user interface can further be improved by adding more feedback about the quality of the movement.**

Manuscript received February 7, 2009. This work was supported by the UK National Institute for Health Research New and Emerging Applications of Technologies funding scheme (NIHR NEAT E027).

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I. Introduction

Over the last decades improvements in healthcare have led to an increase in life expectancy. However, this has also led to greater healthcare demands. One of these demands is therapy treatment after stroke. A stroke occurs when the blood supply to the brain is interrupted or when a blood vessel in the brain bursts [1]. This causes brain damage and in some cases leads to death. A person who survives a stroke often shows symptoms such as numbness and weakness of limbs as well as difficulty with walking, balance and coordination. In the UK, approximately 150,000 people suffer a stroke each year [2] of whom, up to 85% are left with some form of arm paresis [3] with a quarter of these reporting difficulty using their arm five years post-stroke [4]. Conventional treatments for arm impairments aim to enable patients to relearn motor skills lost due to the stroke by facilitating guided functional movements and posture control. Important aspects of skill acquisition are the intensities of appropriate practice and appropriate feedback. Rehabilitation robotics can assist clinicians to deliver higher intensities of practice. A key aspect of the potential usability of robotic technologies in rehabilitation is the user interface, which facilitates interaction between the stroke patient and the robotic system during the treatment session.

Fig. 1. The two iPAM robots are attached to a patient's arm

This paper presents data on how information gained from a user centred design process improved the user interface for a specific rehabilitation device, called iPAM; the intelligent pneumatic arm movement robotic system. This device was developed at the University of Leeds in collaboration with Leeds Teaching Hospitals NHS Trust, Leeds Primary Care Trust and NHS Grampian to "provide responsive safe coordinated assistance of upper arm and forearm to facilitate interactive rehabilitation treatment for people with arm paresis after stroke" [5]. iPAM consists of two robots, one for the upper and one for the lower arm attachments, that help patients move their arm to target positions (Fig. 1). The therapist can prescribe an exercise movement by moving the robot arms. The iPAM system will store the criterion movement and target positions. The robots can then guide the patient's arm to these target positions when the patient is exercising while sensing the effort made by the patients and altering the assistance provided.

The iPAM robotic system is linked to a computer screen that is the user interface for the task, a visual representation of the patient's arm and the targets the patient has to aim for. Fig. 2 shows how the user interface looked at the start of this project. A specifically designed user interface allows the patient to identify the exercise that needs to be undertaken and provides information about their performance. In this research a virtual representation of the work space, a 3D virtual space with an arm and a target, is used. Patients have to reach out their arm to the position set by the therapist, in order to touch the virtual target with the virtual arm. The previously used user interface, as shown in Fig. 2, had limitations in that the robot state indicator (shown on the right hand of the screen and used to inform the patient when exercises are about to be performed) was overly complicated, the colours did not address issues of vision impairment and the representation of the arm did not clearly distinguish the shoulder and hand position. We present the methods used to improve the user interface of the iPAM robot system which resulted in adding feedback and simplifying the indicators on the screen. Results concerning patient improvement are not discussed here as the focus lies on user interface development and patient experience.

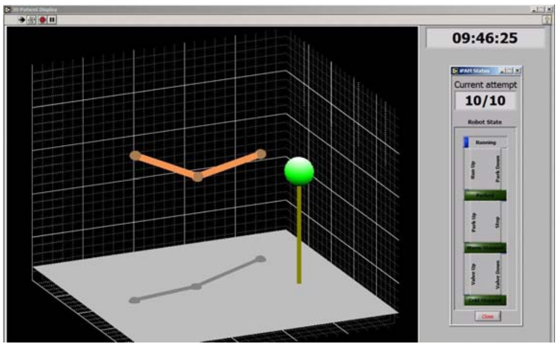

Fig. 2. Initial prototype iPAM user interface

Most research into rehabilitation robotics has not discussed user involvement in interface development (e.g. [6-11]). It is critical that end users are involved throughout device development to avoid poor usability that is difficult to remedy once the system is commercialised. For rehabilitation robotics user involvement is especially important because it is likely that patients will be using the robotic systems with little involvement of a therapist. In order for rehabilitation treatments to be effective, people need to be motivated to actively participate in their treatment; the computer generated environment in which they undertake the robot assisted exercise needs to be motivating. We therefore tried to ensure that potential users of this robotic device would find the new/adapted elements in the user interface motivating (helpful/encouraging). This research had four stages, starting with mock-ups and developing three user interface versions. This enabled us to interactively receive users' opinions regarding the changes in interface elements throughout the development of the user interface.

In addition making feedback comprehensible for the end user is essential [12]. Feedback is most effective when it is presented in various modalities. Feedback can be given as *knowledge of results* or *knowledge of performance* [13]. *Knowledge of results* feedback concerns the results of the action, e.g. whether the goal was reached, and *knowledge of performance* feedback is about the whole process, e.g. whether the movement itself was correct. Furthermore the feedback can be given as *prescriptive* (internal focus) or *descriptive* (external focus) feedback. The evidence published indicates that feedback needs to be personalised to the individual needs, but there is no evidence that one type is significantly better than another [14-15]. To develop an appropriate feedback system we experimented with the modalities and timing (e.g. after every attempt, to enable the user to change their behaviour) of *knowledge of results* feedback and then with *knowledge of performance* feedback.

II. Research Methodology

A. iPAM assisted exercise

This research project spanned two patient trials. Each treatment program consisted of approximately twenty iPAM assisted exercise sessions per patient. A typical session started with a start-up exercise followed by an assessment exercise, several active exercises and ending with another assessment exercise. The start-up exercise enabled the patient to get familiar with the robot and with the virtual representation of the arm on the computer screen. Patients had to relax their arm and let the robot move it in a circle (prescribed by the therapist). After three attempts on the start-up exercise, the first assessment exercise was started.

The assessment exercise consisted of two attempts on a short reach and a far reach. On the short reach the time taken to reach the target was used as a performance measure and on the far reach the distance the patient was able to move towards this target was used. Each person undertook 30 to 40 minutes of active iPAM assisted arm exercises per treatment session. These were prescribed movements that correspond to exercises the physiotherapist would facilitate the patient to achieve during a routine clinical treatment sessions.

B. User Interface Development Process

For the design of the user interface mock-ups were constructed of possible layouts and colours that could be used for the user interface as well as a mock-up for performance feedback. These mock-ups were presented at a user group meeting with five stroke patients (and partners), physiotherapists, psychologists and engineers. Information gathered from these initial discussions was used to develop the prototype user interface (version 1).

All user interface versions were constructed using LabVIEW (v8.2.1 by National Instruments) and evaluated through questionnaires; results of the questionnaires were used for the development of the next user interfaces. The first user interface was used during the first patient trial of the iPAM system. This interface was evaluated after the participants had completed five out of the twenty treatment sessions. After ten sessions the second user interface was used and it was evaluated at the end of this first patient trial. The third user interface was used at the start of the second patient trial and evaluated after three sessions were given.

C. Patient Questionnaires

The first and second questionnaires were given to the patients from the first patient trial, and the third questionnaire to patients from the second patient trial. In the first trial, eight people participated (aged 41-70 years and 1 to 12 years post-stroke). Four patients had right hemiparesis and four had left hemiparesis; five patients were men and three women. The second patient group also contained eight participants. They were aged 44 to 81, between 4 months and 4 years post-stroke, of which there were 7 men and 1 woman. A wide range of patients was chosen to verify that all potential users would be able to work with iPAM.

The first questionnaire contained questions about elements in the user interface such as the representation of the virtual arm and the feedback screens. As the same group of patients received the second questionnaire, this questionnaire contained questions about new or adapted elements of the user interface only. Seven of the eight patients completed this second questionnaire. The third questionnaire was handed out during the second patient trial and was a merge of the first and second questionnaires to encompass all elements in the user interface. Six of the eight participants filled out this questionnaire.

III. User Interface Development

This section discusses the different user interfaces together with the results from the corresponding questionnaires; the results from the questionnaires led to design considerations for later user interface versions.

A. User Interface Version 1

Figure 3 shows the first new user interface version. The target colour changed from black to pink to green as the patient got closer to the target. These colours were tested with a colour blindness simulator to make sure that colour blind people would be able to distinguish these colours. Whereas the previous user interface (Fig. 2) contained an attempt indicator, current time and a robot state indicator, the new user interface (Fig. 3) does not show current time but only contains an attempt indicator and a robot assistance indicator.

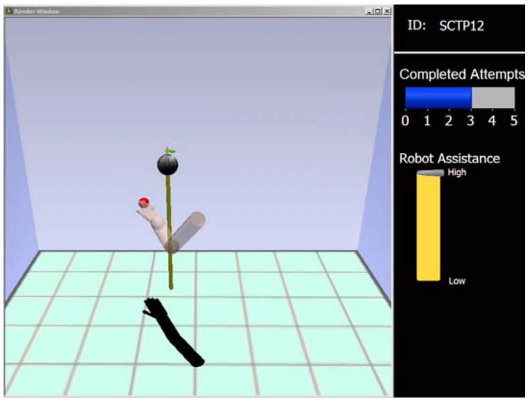

Fig. 3. User Interface Version 1

Other new elements that were implemented in this first adapted user interface version were a "Get Ready" screen, "Please Wait" screen, assessment feedback and attempt feedback. The "Get Ready" screens were implemented to replace the robot status indicator that was previously used to show when a patient could start a new attempt. A "Please Wait" screen was used after the start-up exercises.

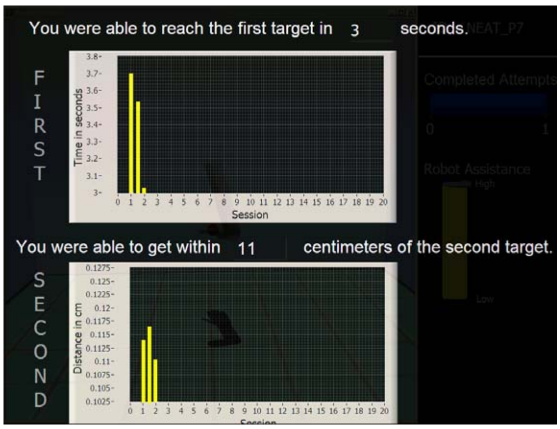

Fig. 4. Knowledge of performance feedback for User Interface version1

Fig. 4 shows one form of the *knowledge of results* feedback. The two graphs on this screen show the accomplishments of the patient on the two outcomes ("time" for nearest target, "distance" for far target). If there are improvements, they can be seen through a downwards trend in these histograms. Fig. 5 also shows *knowledge of results* feedback, displayed after active exercises, otherwise referred to as attempt feedback. This screen displays the percentage of targets that were fully hit, and a visual representation of the achievements. Fig. 5 shows that the patient was able to both fully hit and nearly hit the target twice.

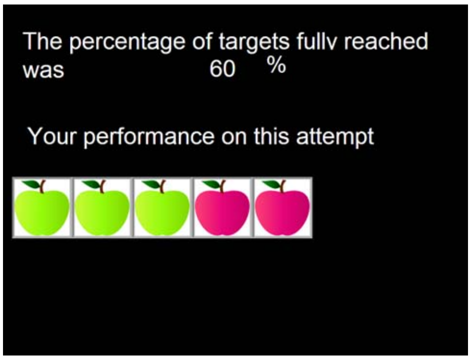

Fig. 5. Attempt feedback

1) *User Interface Questionnaire 1 Results*

Results from the first user interface questionnaire showed that overall patients were very positive about the user interface (full questionnaires and answers are to extensive to include here and can be found in [17]). Seven patients indicated that the attempt feedback after the active exercises was clear and motivating. The feedback after the assessment exercise was not as well received; three patients gave a neutral answer on the question if the assessment feedback was clear and one patient thought the information unclear; they thought it would be better to get high instead of low values if performance was good. The questionnaire feedback also indicated that further developments in viewing the scene from different angles, seeing the robot assistance level, and further feedback were needed. Two patients indicated that they had difficulty navigating in the 3D space. These requests and comments were taken into account during the development of the second user interface.

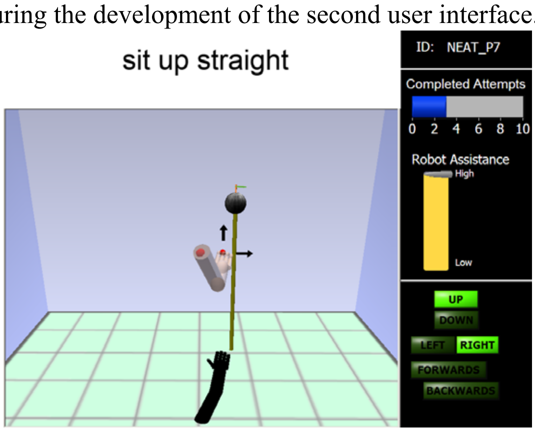

Fig. 6. User Interface Version 2

B. *User Interface Version 2*

Fig. 6 shows the second user interface version. In addition to the elements already introduced, this interface contained a text area, to enable the therapist to leave messages, and direction indicators. These direction indicators consisted of arrows around the hand and shadow as well as indicators on the bottom right side of the screen that show the patient how to move in the 3D space. If one of the directions (forward/backward, left/right, up/down) was correct, the specific arrow would disappear and the indicator would turn off.

Fig. 7. Assessment feedback for User Interface 2

Fig. 7 shows the second generation *knowledge of results* feedback screen for the assessment exercise. Based on patients' comments from the previous questionnaire it was revised to improve readability of the graphs by indicating that low values are better than high values and by using different colours for start and end of the session and spacing in between sessions. It was considered to switch the values so that better scores would be higher values in the graphs, e.g. by subtracting them from a maximum value, but because there was not a standard maximum for distance or time and because doing so would prevent future automatic scaling of the graph, which is very useful for patients whose values only differ slightly, it was decided to leave it as is and instead give indications that lower values are better instead.

Fig. 8. Exercise and Session Feedback

Apart from adapting this already existing feedback, two new feedback screens were introduced in this second user interface: exercise and session feedback (Fig. 8). The exercise feedback was shown after an exercise ended, e.g. after 10 attempts, and was a summary of the attempt feedback screens, providing the patient feedback on performance within a single exercise. The session feedback was shown at the end of the treatment session and showed the totals of targets and attempts and the achieved colours of the apples the patient reached towards during the current and previous session. This layout of the feedback enabled comparison between the previous and current session's performance.

1) User Interface Questionnaire 2 Results

Results of the second questionnaire showed positive responses to the adaptations. Six patients found that the new arrows were clear, but one patient mentioned that the arrows were difficult to see when they got in line with the pole or the arm, due to the 2D computer screen showing a 3D exercise scene. However, all patients agreed that the arrows helped them to aim for the apple. The direction indicators however were not used by all patients. All patients thought that the second generation assessment feedback was clear and improved compared to the previous version. All patients found the exercise and session feedback clear, while four out of the seven patients also found it motivating. Again further feedback was requested which was used as the aim for the third user interface.

C. User Interface Version 3

The final user interface included revisions to the screens already described. In the first and second questionnaires patients indicated the need for feedback about the quality of arm movement in addition to feedback about how many times the task was achieved. Therefore the user interface was revised to include such *knowledge of performance* feedback. Initially both a 2D and 3D representation of the arm were constructed, that replayed the movement the patient had made in relation to the prescribed movement. However, the feedback using representations of the arm movement after exercises was not useful to the patients (some of who had visual impairments) as they were unable to appreciate the quality characteristics of the movement due to lack of clarity of computer generated arm movement representations. To address this issue it was approached from the perspective of a physiotherapist and the type of commands a physiotherapist treating a patient might give to improve quality of voluntary arm movement, were used.

In order to provide feedback on quality of movement, data on extent of unwanted shoulder abduction (degrees), shoulder elevation (millimetres) and shoulder protraction (millimetres) was used to define the feedback given (Fig. 9). Together they provided information necessary to determine how far the patient's arm movement during active iPAM assisted exercise differed from the exercise trajectories prescribed by the treating physiotherapist. Because the different feedback measures have different units, they were classified into classes ranging from 'awful' to 'best' performance using four trial-based thresholds per measure. Afterwards these classifications were compared to determine which measure the patient performed worst on and corresponding feedback was shown, e.g. if the patient's shoulder protraction was classified as awful and all others as average a message such as "Sit up straight" would be shown.

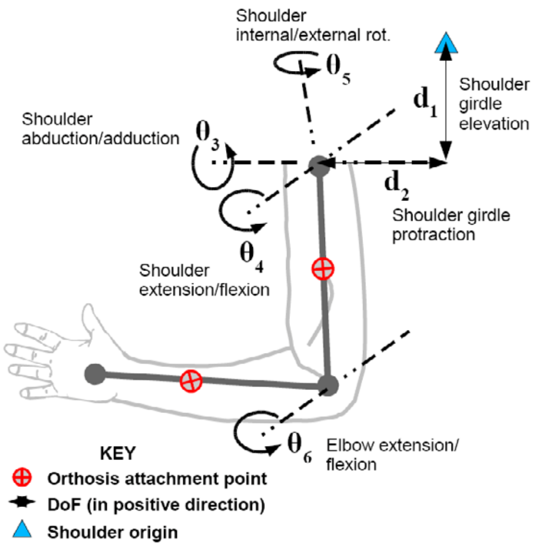

Fig. 9. Shoulder abduction, elevation and protraction [16]

The *knowledge of performance* feedback was given as a message similar to what a physiotherapist would say to a patient during normal therapy practice, as an addition to the attempt feedback, see Fig. 10. A physiotherapist constructed three sentences she might use during therapy for each type of error and these were integrated into the system. This *quality of movement* feedback was also linked up to the top text area, to remind the user during an exercise what to pay attention to.

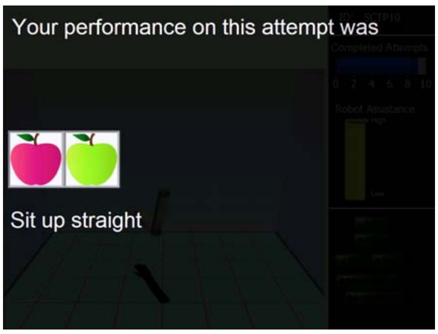

Fig. 10. Attempt Feedback with Quality of Movement Feedback ("Sit up straight")

To make sure that feedback would only be shown if necessary, a threshold sensitivity mechanism was implemented that allowed the therapist to change the sensitivity to a specific measure. By moving a slider up or down, the therapist could increase/decrease the values of the aforementioned thresholds that determine how a measure is classified. This could for example be used when a patient is not able to move in the prescribed way and the therapist wants the patient to focus on something else. A sensitivity feedback mechanism could also prevent patients from becoming irritated by getting the same message repeatedly.

1) User Interface Questionnaire 3 Results

The third questionnaire, although handed out to a different group of patients, also showed positive reactions from patients regarding among other things the arm representation, attempt indicator, robot assistance level and arrows. As opposed to the second questionnaire responses, patients indicated that they thought the direction indicators were clear (6/6), helped them aim for the apple (6/6) and that they used them often (5/6). The feedback screens were also received well; all patients thought the performance feedback, exercise feedback and session feedback were clear and motivating.

Several additional issues were mentioned; some patients complained that the text-to-speech voice was irritating, that quality of movement feedback was shown too often, and that the text on the screen was not displayed long enough. These issues can be solved in the next user interface, by prerecording text instead of using a computer-generated voice, adding an irritation-prevention mechanism and performing a trial session to determine individual preferences.

IV. Conclusions And Future Work

A. Conclusions

This project bridges the gap between users' needs and health technology developments driven by the research community. Three user interfaces were iteratively developed in interaction with the intended end users, and evaluated during two patient trials using questionnaires. Eventually four feedback screens were used (attempt feedback, assessment feedback, exercise feedback and sessions feedback), all showing *knowledge of results* feedback and the attempt feedback including *knowledge of performance* feedback.

During this research project, the user interface of the iPAM robotic system has been improved by changing the information display and adding feedback screens. Involving end users plays a key role in improving the computer generated exercise workspace and introducing or changing modes of feedback. In addition to visual feedback, simple auditory feedback was used but some patients found this distracting. In the final version, feedback was by default given both visually and auditory, but the auditory feedback could be turned off based on user preference. Further developments in the computer generated visualisation of the person's arm are however needed, e.g. to prevent problems with object occlusion due to the 2D display of the 3D scene. Overall, this project has shown how a user interface can successfully be developed by maximising user involvement.

Acknowledgment

We are grateful to people with stroke in Yorkshire who have helped us to develop and test this system and the Erasmus programme, Groningen University Fund and the UK National Health Service under the New and Emerging Applications of Technologies funding scheme for the funding of this research.

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