A Tool to Address Movement Quality Outcomes of Post-Stroke Patients

Vincent Crocher, Justin Fong, Marlena Klaic, Denny Oetomo and Ying Tan

***Abstract*— A new neuro-rehabilitation system is proposed to address the movement quality of post-stroke patients. The system is designed to be used concurrently with existing upper-extremity virtual rehabilitation devices, and to aide correction of compensatory trunk and shoulder movements. A 3D sensor is utilised to estimate the movement of the shoulder, and an auditory cue is given to the patient when the system estimates that a compensatory movement has been made. The results of preliminary trials of this system on a single patient are presented.**

I. INTRODUCTION

Compensatory movements are often observed in post-stroke patients, in which limited mobility of certain body parts is augmented with unnatural movement of another. A classic example of this is seen in reaching movements of the upper extremities, during which post-stroke patients often lean with their torso to reduce the distance they are required to reach, even if this action may normally be comfortably completed without leaning. This is considered a poor quality movement.

Concurrently, many new robotic and virtual rehabilitation (VR) systems dedicated to recovering movement through neuro-rehabilitation have been developed over the past decades [1], [2], [3]. These devices are seen to be of particular interest due to their potential to reduce the work load on clinicians; their potential to be used to employ new rehabilitation strategies; and their contribution to a patient's motivation levels within a therapy session. Some of these systems are now used in clinics such as the Able-Reach from Im-Able.nz, the ReJoyce from Rehabtronics, the ArmeoSpring from Hocoma or the InMotion ARM from Interactive Motion Technologies. However, they often do not address the problem of movement quality. Only some exoskeletons, such as the passive ArmeoSpring or the active ArmeoPower, are capable of interacting with the whole limb at the joint level. However, even with these devices, the interactive games do not usually take into account the way the movement is achieved and instead present only high level goals. Often, these goals are related only to the hand trajectory of the patient, and thus this is the only feedback presented to the patient. Information about the limb movement, such as trunk, shoulder or elbow is neglected. This can lead to poor movement quality due to the reinforcement or development of undesirable compensatory movement patterns commonly seen in post-stroke patients.

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In contrast to this, in a systematic review of the studies where extrinsic feedback is provided to post-stroke patients in a rehabilitation process [4], the authors, state that "there is evidence to conclude that extrinsic feedback is useful for implicit motor learning in stroke survivors". More precisely they differentiate between feedback related to a task completion and thus provided at the end of the task, called KR (for Knowledge of Result) feedback, and feedback based on the way the movement is performed — i.e. the movement quality — and that can thus be provided real-time, during the movement itself. According to their review, the latter type of feedback, Knowledge of Performance (KP), is the most commonly used and appears to be the most suitable and efficient in a rehabilitation process. Moreover, there are indications that the treatment of pathological synergies and compensatory strategies in post-stroke patients is also important [5], [6], [7]. Following these two ideas, in [8] the author has shown that during a classical rehabilitation therapy when patients are asked to reach and manipulate different objects, the use of an external audio feedback related to the trunk displacements, such as 'lean against the back of the chair', was more beneficial than a restriction of the trunk movements using a harness.

In this paper we introduce a low-cost system to facilitate rehabilitation, focusing on reducing trunk and shoulder compensatory movements — it aims to provide feedback to the patient in order to improve the quality of his or her movements. The system is based on a 3D sensor (Kinect from Microsoft, Redmond, USA) and is intended to be used in conjunction with classical robotics or virtual rehabilitation devices. The system and the feedback computations are described in section II and a first preliminary study is presented in section III.

II. SYSTEM DESCRIPTION

A. Overview

The system aims to provide feedback based on the tracking of the shoulder movements, which are observed at the acromion. These movements are mostly due to the trunk movements and to acromioclavicular and sternocalvicular joint rotations — it is assumed that the glenohumeral joint rotations have no effect on the acromion position. In order to track these movements, the system uses a Kinect sensor and an image processing algorithm able to detect the 3d positions of two coloured plastic markers. The use of a Kinect sensor and simple plastic markers ensures a very low-cost and simple system which constitutes one of the main advantages of VR systems.

The subject is thus equipped with one or two markers, secured on his/her shoulder(s) while he or she is undergoing rehabilitation therapy. C++ Software is used to capture a colour image (*rgb*) and a depth image (*depth*)from the Kinect. This data is then processed in real time to identify the positions and speeds of the markers in 3D space. The software finally computes a feedback input value (i) according to this position or speed and translates it into a vocal cue through a speaker placed behind the subject.

A general schematic of the system is given in Fig. 1, and Fig. 2 shows a subject using the system.

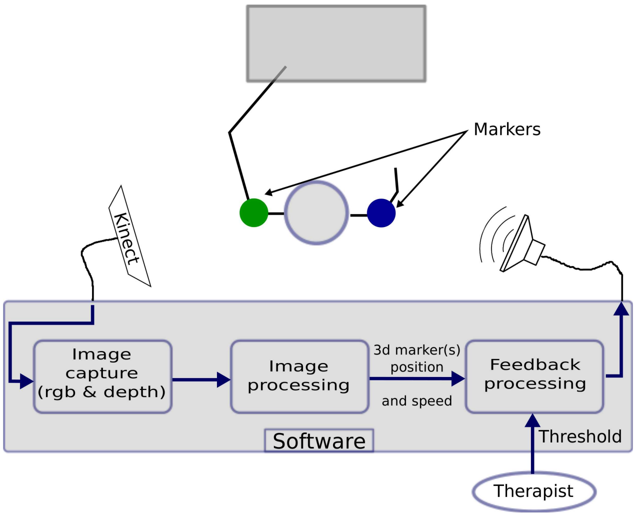

Figure 1: System overview.

Figure 2: Subject using the system. The feedback is computed and provided by the laptop, whereas a separate VR game is run on the desktop computer.

B. Feedback Computations

The system provides feedback during the movement itself, related to the quality of movement, inferred through the quantity of shoulder movements. The feedback is intermittent, active only when a given threshold is exceeded, and is provided as a vocal cue.

To address different types of pathologies, two different ways of computing the feedback — i.e. the input value i — are proposed. In the first mode, denoted *speed based feedback*, the input value is the current speed of the shoulder whereas in a second mode, *postural feedback*, the input value is computed relative to the patient static trunk posture.

1) speed based feedback computation: In the first mode, the input value i corresponds to a filtered measure of the instantaneous speed of the marker, computed as:

$$\begin{aligned} i(t) &= \dot{X}(t) \\ &\simeq \frac{\sqrt{(x(\text{t})-x(\text{t-5}))^2+(y(\text{t})-y(\text{t-5}))^2+(z(\text{t})-z(\text{t-5}))^2}}{5\times\Delta t} \end{aligned} \quad (1)$$

where $X(t) = \begin{bmatrix} x(t) \\ y(t) \\ z(t) \end{bmatrix}$ is the position of the marker on the impaired shoulder and Δt the time step of the system. The time step is approximatively 60 ms which corresponds to a frequency of 17 Hz, sufficient to capture slow human movements occurring at approximately 1 Hz. In order to filter the positioning noise, the speed is computed over five time steps, which correspond to approximately 300 ms, as described in equation 1.

2) Postural feedback computation: In the second mode, an input value is calculated proportional to the difference between the current posture and an optimal reference posture.

Specifically, unit vectors are constructed from the position of the first shoulder to the second shoulder. The first vector, $\vec{S}ref$, is calculated when the subject is in the optimal reference posture, during an initial calibration stage. During the operation of the system, the second vector, $\vec{S}$ is calculated at each time instant in real time. The input value is then calculated as the sum of the angle between these two vectors in the (XY) plane (γ), and the (XZ) plane ψ). Fig. 3 shows the construction of the vector, and the angles in each plane.

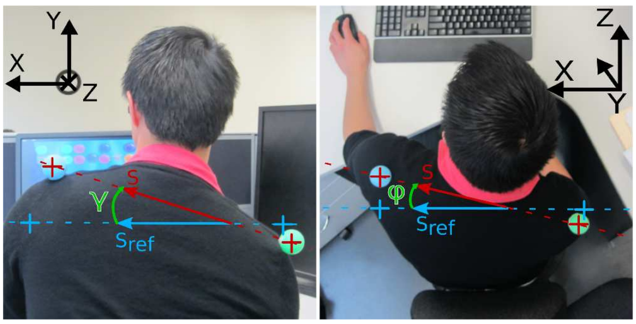

Figure 3: Subject using the system in the *postural feedback* mode with the $\vec{S}_{ref}$ and $\vec{S}$ vectors, the two angles γ and ψ and the global frame. Back and top views.

The angles γ and ψ can be seen as approximations of the rotations around the central point of the C7 vertebra, in the coronal plane and transverse plane respectively.

C. Feedback Provision

For both modes, the feedback is an auditory cue in the form of a voice pronouncing the word "Shoulder". This feedback explicitly reminds the subject to correct his/her shoulder movements. The audio medium has been chosen in order to be complimentary to the classical visual feedback provided by classical virtual rehabilitation games. Indeed, the proposed system aims to be complementary to existing devices which mainly focus on hand movements.

The feedback is provided depending on the input value (i), calculated at each time instant, and a threshold value ($i_{Threshold}$). The feedback (f) is provided each time the input value exceeds the threshold value.

The threshold value ($i_{Threshold}$) can be either manually or automatically set. When set manually, a therapist observes the motion of the patient, and sets the threshold at the value at which he or she believes requires correction. Alternatively, an automatic adaptation of the threshold value ($i_{Threshold}$) can be used instead of manual tuning. With this automatic tuning, the threshold is computed such that no feedback is provided ($f = 0$) 97% of the time, suggesting that 97% of the time, the subject's movement is considered normal and does not require correction. The 97% value was determined experimentally through an identification based on the threshold values chosen by a therapist. The use of this adaptive method also provides a degree of personalised rehabilitation — the patient is consistently challenged at their own level without the need for constant supervision and monitoring by a therapist.

III. EXPERIMENTS

A. Method

In order to validate the usability of the proposed system in a rehabilitation context, preliminary trials have been conducted at the Royal Melbourne Hospital. The system has been tested over nine sessions — three sessions a week — with one chronic stroke patient involved in a virtual rehabilitation protocol.

The patient used the Able-Reach (from Im-Able.nz, Lower Hutt, New Zealand) system together with the proposed shoulder tracking system. The Able-Reach offers different games dedicated to upper-limb rehabilitation that the patient controls using a mouse like device, which supports the entire forearm, over a table (see Fig. 4).

Figure 4: A subject using the Able-Reach and wearing a shoulder marker.

Each one-hour session consisted of several playing "blocks" of duration 5 to 8 minutes — depending on the game. A 5 minute rest was offered to the patient between each block and the program (game choice, difficulty level, duration) was constantly adapted by the therapist to the patients current motor capacity, motivation and needs.

Four different games were trialled: (a) Apples, (b) Targets, (c) Mosquitoes and (d) Butterflies. These games can be classified into two categories according to the task to be performed. The first two ((a) and (b)) require slow and controlled movements with precise starting points and targets. In contrast, the second two ((c) and (d)) consist of tasks requiring quicker and continuous movements with no precise targets or desired direction of movements.

In addition to the Able-Reach, the patient was equipped with the shoulder tracking system with *speed based feedback*. The shoulder of his impaired limb was thus equipped with a coloured marker and the position and speed calculated in real-time. The auditory feedback was activated each time the patient moved the shoulder with a speed higher than the threshold. During the first three sessions the threshold value was tuned by the therapist for each game and for the last four sessions, the threshold was automatically tuned by the system in order to be activated only 3% of the time (see Section II-C). In order to observe the immediate effect of the feedback on the patient behaviour, the feedback provision was turned off randomly during one block in several sessions.

During each session the shoulder movements, the feedback input value — i.e. the shoulder speed —, the feedback threshold and the Able-Reach game data were recorded.

B. Results and Discussion

In order to observe the evolution of the patient's shoulder speed over the different sessions, the speed values have been averaged for each session.

1) Game types: Since the games proposed by the Able-Reach system are of two different types, this computation has been done separately in each session according to the game played in the different session blocks. Fig. 5 presents the average speed of the patient's shoulder movements for the different sessions while he was playing either the games (a) and (b) or (c) and (d).

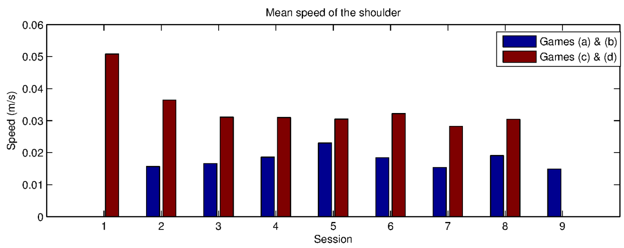

Figure 5: Mean shoulder speed for each session for the two different game types and for each session. Note that games (a) and (b) and games (c) and (d) were not played int the first and last sessions respectively.

In every session, a difference in the speed was observed between the two game types. This suggests that the patient was using more compensatory shoulder movements in games (c) and (d), which is coherent with the requested task: quicker and less controlled movements. The clear difference in the shoulder movements observed by the proposed system also confirm the sufficient sensibility of the proposed system to track such compensatory strategies.

2) Shoulder movements evolution: According to results presented on Fig. 5, no clear evolution or global trends can be observed over the different sessions on the averaged speed value, meaning that the patient does not seem to reduce his amount of shoulder movements over the therapy. Nevertheless, observing the differences in Fig. 6 in between the blocks when the feedback was activated and when the it was not activated shows that an immediate effect of the feedback exists after several sessions and that he patient can properly respond to the feedback, when provided, after some training.

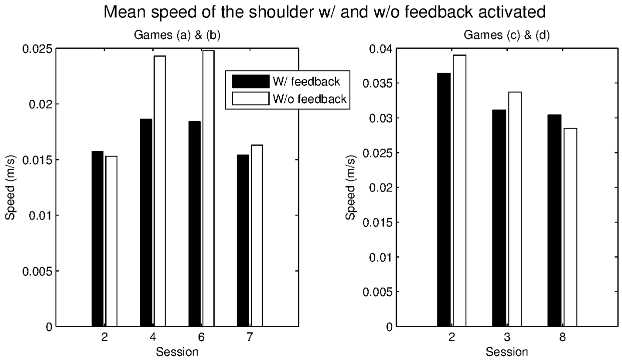

Figure 6: Differences of the mean shoulder speed with and without feedback activated for the two different game types.

3) *Hand trajectories:* Analysing the cursor trajectories — directly related to the patient's hand trajectories — recorded by the Able-Reach system in the games (a) and (b) allow us to display the evolution of the trajectories' smoothness. These have been computed as the Spectral Arc Length (SAL) smoothness value, and the mean speed of the cursor during these movements as shown in Fig. 7. The SAL value is introduced in [9] and is a measure of smoothness based on the Fast Fourier Transform (FFT) coefficients of the speed profile.

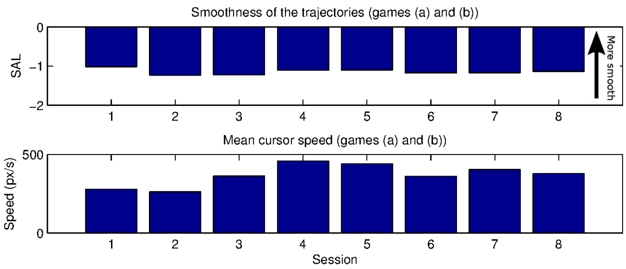

Figure 7: Spectral Arc Length smoothness coefficient (higher means smoother) of the trajectories and mean cursor speed, for games (a) and (b) during each session.

From these values, no particular evolution or correlation between smoothness and shoulder speed can be observed at this point. The patient's potential progress is thus not observable through these variables — smoothness and mean speed — at this stage. More sessions are needed to confirm or infirm this assumption.

IV. CONCLUSION

In this paper a new system aimed at addressing movement quality is proposed to complement existing rehabilitation systems. The system provides auditory feedback based on the inference of compensatory movements through the shoulder. Preliminary experiments with one subject demonstrate the usability of the system in a clinical context, as the patient appears to respond to the auditory feedback. However, these trials do not yet provide an indication of the effectiveness of the system to limit compensatory movement and improve patients' quality of movement. Nevertheless, this can certainly be explained by the absence of formal training to teach the patient how to correct his/her movement when the feedback is provided. In order to further investigate the potential efficiency of such kind of systems, further experiments with more subjects and a proper training session will be conducted in the future.

Since VR systems are becoming more prominent in clinical settings, and may soon arrive in patients' homes to be operated without a therapist supervision, it is obvious it will be important to:

- ensure that these devices can be used correctly by the patients on their own, with correct movements;
- ensure that these devices do not only reinforce patients compensatory strategies and pathological movement synergies but really provide a ”true” recovery.

Systems such as the one proposed can be used to address these points.

V. ACKNOWLEDGEMENT

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