Mixed Reality as a Means to Strengthen Post-stroke Rehabilitation

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Abstract. Purpose of this paper is to present a mixed reality system (MRS) for rehabilitation of the upper limb after stroke. Aim of the system is to increase the amount of training using the fun factor as driver. While the acceptance of such a system can be assessed with patients, true clinical validity can be assessed only through a long randomized clinical trial. However, a first important impression of usefulness can be based on therapists' expertise. For this reason before testing the MRS with patients we carried a study with therapists involving the rehabilitation staff of a French hospital. Three sessions, one using the Wii System with a commercial game, another using an ad hoc developed game on a PC, and another using a mixed reality version of the same game were held. In synthesis results have shown the MR system is regarded to be useful for a larger number of patients, in particular the ones in the more acute phase after stroke.

Keywords: Mixed reality, Post stroke rehabilitation, Serious Games.

1 Introduction

Each year in the United States alone approximately 795.000 people are affected by stroke [3]. In France there are around 150.000 strokes each year [17], and similar trends are evident all around the industrialized world. Being the third cause of mortality and the first one of handicap in adults, we can say that stroke is one of the main health problems in our era [20]. A stroke can cause significant disabilities, such as paralysis, language difficulties, and cognitive impairment. These disabilities strongly affect the quality of daily life for survivors both from the behavioral and physical point of view. Concerning this latter point, several researchers on the field have shown that important variables in relearning motor skills and in changing the underlying neural architecture after a stroke are the quantity, duration, and intensity of training sessions (for more information see e.g. [10]).

In this paper we propose a mixed reality system (MRS) for rehabilitation of the upper limb after stroke. Aim of the system is to increase intensity and number of training session using the fun factor as driver. However while the fun factor can be assessed with patients, clinical validity can be assessed only through long clinical training sessions and/or based on therapists expertise. So, before testing the MRS with patients, we carried a study with therapists in order to understand the potential and the

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benefits of mixed reality for rehabilitation purposes. The study involved the rehabilitation staff of a French hospital. Three sessions, one using the Wii System with a commercial game, another using an ad hoc developed game on a PC, and another using a mixed reality version of the same game were held.

Before describing the pilot study in detail in the following subsections we will describe in more depth what a stroke is and what its consequences are, and why a 'virtual' approach could be useful for this kind of rehabilitation.

2 Describing Stroke

A Cerebral Vascular Accident (CVA) or simply ‘stroke’ is traditionally defined by the World Health Organization as “a neurological deficit of cerebrovascular cause that persists beyond 24 hours or is interrupted by death within 24 hours” [20]. A stroke induces a loss of brain functions due to disturbance in blood supply to the brain, resulting in altered sensori-motor and/or cognitive functioning. The most striking motor impairment is the loss of motion control on the contra-lesional side. Cognitively one can think of language disturbance, attention troubles and hemi neglect, whereby the contra-lesional side of the body and of the environment is completely neglected.

Because of this, stroke sufferers are often unable to independently perform day-to-day activities such as bathing, dressing and eating, inducing a loss of autonomy and a decrease in quality of life [20]. Stroke is a highly heterogeneous syndrome. The specific abilities that will be affected by stroke depend on the location, type and size of the lesion. Each patient is characterized by a specific combination of deficits [11]. Therefore, stroke rehabilitation programs are strongly personalized and not generic. They are adapted to a particular patient, to regain as much function as possible.

The most important gain of function takes place within the first six months after stroke. In most countries, due to high costs, only 6/8 weeks of rehabilitation are executed under the direct supervision of an expert (i.e. in the hospital or rehabilitation centre). In addition, therapy focusing on mobility (recovery of leg function) is the primary concern within these first weeks, so that recovery of arm function is conducted mainly at home [19].

Important in relearning motor skills and in changing the underlying neural architecture are the quantity, duration and intensity of training sessions (see for example [14][9]). To experience significant recovery, stroke patients must then perform a substantial number of daily exercises. Unfortunately, typical rehabilitation sessions with therapists include a relatively small number of motions [8] due to the low duration of personal rehabilitation sessions. Home training can increase the amount of executed movements. However, while this is often prescribed, only 31% of the patients actually perform the recommended exercises [16]. This raises the problem of selecting a home-based rehabilitation technology that both can help and motivate patients to perform their therapeutic exercises to ameliorate their recovery after stroke.

3 Motivations: Advantages of 'Virtual Rehabilitation'

The challenge for post stroke rehabilitation is then to create exercises able to decrease the monotony of hundreds of repeated motions. In order to overcome this challenge, different kinds of 'non traditional' therapies have been proposed.

For example, the possibility of using 'virtual' rehabilitation has been the subject of experiments by several authors (such as [13][7]). Although most of the studies on this topic are linked to the study of virtual reality environments recent works have focused on the use of videogames and consoles for rehabilitation (such as [2][5]).

We can summarize the results of these studies as follows:

1. *Personalization*: Virtual rehabilitation technologies create an environment in which the intensity of feedback and training can be manipulated to create the most appropriate, individualized motor learning paradigm [7].
2. *Interactivity:* Virtual rehabilitation exercises can be made to be engaging so that the patient feels immersed in the virtual world. This is extremely important in terms of patient motivation [12], which in turn, is one of the key factors for recovery.
3. *Feedback:* Interactive feedback can contribute to motivation. By providing visual and auditory rewards such as displaying gratifying messages in real time, patients are motivated to exercise [4][6].
4. *Tracking:* The evolution of the patient's performances can be easily stored, analysed and accessed by therapists [7][12].
5. *Telerehabilitation*: Virtual rehabilitation can stimulate the patient using a variety of rehabilitation exercises at a low cost. In addition cheaper personal equipment (pc-based for example) could eventually allow rehabilitation stations to be placed in locations other than the rehabilitation centre, such as patient's home.

On the other hand, Virtual Rehabilitation does raise significant challenges before its widespread adoption such as:

- Clinical acceptance, which relies on proved medical efficacy.
- Therapist's attitude towards the technology (e.g. the therapist fears that technology could replace therapists and the like).
- Patient's attitude towards the technology (e.g. the patient may not consider a game to be 'real' rehabilitation).
- Ethical and regulation challenges linked to the kind of technology used.

In the rest of this paper we will describe: (i) the mixed reality system and the game we designed for the experiment, (ii) the experiment held and its results, (iii) some consideration on future improvements on the system.

4 The Mixed Reality System

In this section we describe a mixed reality system (MRS) conceived for post stroke rehabilitation purposes. In general a mixed reality environment aims to merge real and virtual worlds to create a new context of interaction where both physical and digital objects co-exist and interact consistently in real time. The mixed reality system we conceived and developed for this study is composed of three main subsystems: (i) the gaming subsystem responsible for managing the game application; (ii) the motion

capture subsystem responsible for tracking patient's movement; and (iii) the display subsystem responsible for displaying the virtual game environment in a physical environment.

The gaming subsystem follows a client-server pattern: the mechanics of the game are implemented at the server level. The game server translates this input into game events that are used to compute the next state of the game according to the game mechanics. Once the new state of the game has been computed, update events are sent to the game client(s) to update their local copies of game objects, which in turn update the graphical environment. The game client fulfils the following functions: (i) receiving patient's movement events from the motion capture system; (ii) forwarding these events to the game server; (iii) receiving events from the game server to update game object state; and finally (iv) generating the game's output in terms of 3D scenes and sounds.

The motion capture subsystem is responsible for tracking the patient's hand and to communicate these movements to the game client. The motion capture system is composed of three components:

1) An IR emitter: this is an active sensor built using a simple infrared (IR) emitter that is attached on the patient's hand using a Velcro strap. This basic device is very cheap (less than 1 euro) and convenient to use even with patients that suffer from spasticity.
2) An IR camera: To track the IR emitter a Nintendo Wiimote was used as an IR camera. The Nintendo Wiimote is an affordable device (less than 30 euros) that has been used in many open source projects. Consequently, a plethora of open source libraries now offer the use of Wiimote as pointing device.
3) A processing software: the role of this component is to translate Wiimote events into mouse events so that the IR emitter and IR camera are considered as a standard pointing device from the operating system's point of view.

T*he display subsystem:* Within a mixed reality context it is necessary to display game objects directly in the physical world. Thanks to a new generation of mini video projectors, namely pico projectors, it is possible to display the game on a flat surface almost anywhere. Within the context of this experiment, the pico projector is attached to a support to display the game onto a standard table. Pico projectors are affordable (less than 200 euros), lightweight (less that 300g), and easy to use by simply plugging a VGA cable into a computer. However, they are limited in terms of brightness (the one that was used in this experiment was less than 30 lumens). This constraint has to be taken into account when building the game's graphical environment by selecting colours and contrasts to compensate for this limitation.

The overall system is presented in Figure 1. The patient holds on his hand the IR emitter device and sits in front of the table (a) to play the exercise. The IR camera (c) and pico projector (d) are placed on the top of a support (b). A laptop computer is used to run the game client and to establish a Bluetooth connection with the WiiMote.

The ad hoc developed games: The MR system described above is able to support different types of therapeutic games, conceived ad hoc to train different types of movements. A module of the game server allows developers to integrate different types of adaptation for every game, offering a personalized gaming experience for each patient.

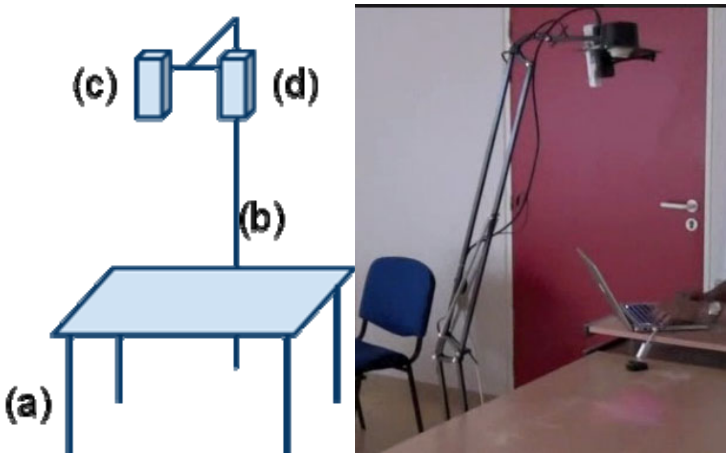

Fig. 1. The overall system

5 Therapists Opinion and Virtual Rehabilitation Systems

A great majority of systems created for virtual rehabilitation purposes tests patient's acceptance and do not test in a systematic way therapists' opinions about the system (interesting exceptions are [1], [18]). On the contrary we are convinced that only a therapist can assess the rehabilitation value of a system. In fact, from a previous pilot study we held with 4 patients affected by stroke emerged clearly that the patient is not able to measure the impact of the system on her/his rehabilitation session/program. In that pilot study patients tested a game with a graphical tablet, a mouse and the mixed reality system described above. While we will not enter in detail here, we can summarize results as follow. Firstly patients were not able to differentiate the difficulty of using the system from the difficulty of executing the movement, strongly impaired by the stroke. Secondly, the clinical eye of the therapist, who assisted the sessions, was able to observe for which patient the exercise was more difficult or when the patient had to put all efforts to move his hand (and thus was concentrating on his hand and not on the screen and the like). For this reason we decided that before testing the system with patients, it is really important to assess potential benefits with the therapists.

5.1 The Experiment Protocol

As said in the introduction aim of the experiment described in this paper was to compare the use of an in-house designed Mixed Reality System (MRS) with two alternative tools through an empirical investigation. The two alternative tools were a classical PC system, and the Wii system. In order to compare acceptance level of these systems (in Shackel terms, see [15]) we decided to assess perceived utility, usability, likeability (affective evaluation) of the three systems.

Participants: The mixed reality system described above has been tested on 17 members of the medical staff of a rehabilitation department of a French hospital. 3 occupational therapists, 9 physiotherapist, 3 students in physiotherapy and 2 general practitioners participated in the study. Participants had an average of 15 years of experience.

The experiment: The experiment was composed of different sessions, each one testing a different 'form of potential therapy' (the Wii console with the Wiimote, computer and mouse, mixed reality with captor). The game on the computer and the one on the mixed reality system were identical. This was done in order to show that games and hardware system could be independent. The virtual rehabilitation game developed for this experiment was conceived to train upper limb 2D movements (i.e. movements on a plan without need to lift the arm). The gameplay stages a maize plantation and crows trying to steal maize. Aim of the game is to chase away all the crows; aim of the exercise is to train free movements. For each session therapists were let free to play with the system, but they were asked to keep in mind that they were playing the patient's role. Each session took 10 minutes. After the last session a questionnaire was conducted. Order of sessions was randomized.

The Questionnaire: The survey was conceptually divided into two parts. Results are expressed as a note on a four level scale, "4" being the best note and "1" being the lower one (Likert scale). The first part addressed the different hardware systems while the second one the games. In the first part, several questions addressed the usability of the different systems from the patient's point of view. Another group of questions addressed the perceived utility of the system for therapy. Finally, a last question compared usability of the three devices. In the second part of the survey, a set of questions addressed the different games utility for therapy, and the fun perception of each game. Each question asked also to motivate the rating.

6 Results and Discussion

As said previously, the first set of questions was related to the system and did not concern the games.

The first question asked the therapists if they thought that patients **will be able** (from a physical point of view) to work with the three systems (considered as a whole). MR rated a means of 3,8(±0,4); PC rated 3,1(±0,9), the Wii system rated 2,9(±0,9). Another question addressed the **devices** used with the three systems (the Wiimote, the mouse, the led captor). The u**sability** for a patient of the IR Led rated a means of 3,3(±1,2), the mouse 2,2(±1,2), the Wiimote 2,4(±1,4).

To motivate these ratings the therapists wrote in synthesis that to be manipulated the Wiimote requires a set of motor skills that patients do not necessarily have regained. Most patients have also coordination problems. For those patients it will be difficult to support or release buttons on the controller in time. In addition, having to press a lever can generate spasticity or synkinesia (i.e. uncontrolled movements). While the subject of spasticity was raised by all the therapists (for both, the mouse and the Wiimote) several of them underlined that the Wiimote could be interesting in order to re-educate grasping.

On the other hand, in the therapists' words, the MR system is easy to understand and requires no cognitive effort by the patients. Finally, the sensor on the hand seems to me more suited for a larger number of patients.

Almost all the questionnaire in the end commented that the two systems (MR and Wii) could complement each other following the patient recovery. While the mixed reality system can be used in a more acute phase, the Wiimote becomes an interesting device for patients who have recovered better (remembering that not all the patients will attain this phase).

The therapists were then asked if they thought that working with the different systems could be **useful** for the patients. The MR rated 3,8(±0,4), The PC rated 3,1(±1,1) and the Wii rated 3,5(±0,6).

As for the usability questions, both, the Wii and the MR have their advantages. The mixed reality system allows for coordination and proprioception (i.e. the sense of the relative position of neighbouring parts of the body). In fact, the patient must try to move her/his limb in coordination with other parts of his/her body to reach a target. The MR allows also for a better hand-eye coordination, as the hand moves within the game. In fact in both, the PC case and the Wii case, the patients have to look at another place (the screen) in order to perform the task. This kind of task requires an additional difficulty for patients in the first rehabilitation phase. Comments on PC usage are also related to limitations about screen dimension. On the other hand the Wii uses more planes in the space respect to our MR version which is more useful for joints. Finally, both allow the therapist to work with larger amplitudes than the traditional PC.

The second set of questions was related to games. The first question addressed the **usefulness of the** ad-hoc **game** with respect to the commercial Wii game. As perceived utility the ad hoc game rated 3,6(±0,6) while the Wii game rated 2,9 (±1,0). On the other hand the perceived fun of the ad hoc game was 3,0(±1,0) while the Wii game rated 3,6 (±0,5). This is an indicator of two elements. While there is a need to create ad-hoc games for stroke rehabilitation, they need to be real games with the fun factor and not only simply exercises. Also in this case there are different needs in different parts of the rehabilitation. In fact, more complex games require patients with no cognitive or attention difficulties.

The final question comparing the utility for therapy of the three systems had the following results: MR rated 3,6(±0,7), PC 2,9 (±1,1) and the Wii 3,2(±0,7).

In this question one of the therapists stated clearly that the MR system is more suitable for patients in rehabilitation even if commercial games seem more fun.

To summarize, the Mixed Reality System has a higher potential to be useful for a huge number of patients. In fact, the most underlined problem with PC and Wii for rehabilitation - the use of a hand held device - becomes one of potentiality of mixed reality. In addition, the mixed reality system uses objects from the natural environment as an interface to the computer. This intuitive way of interaction simplifies the communication between man and machine, especially for unpractised users. Finally, a MR system can be used by several persons because it is not restricted to one screen or one keyboard.

7 Conclusion and Future Works

Objective of this paper was to evaluate a mixed reality system (MRS) for rehabilitation of the upper limb after stroke. Because it is the goal of therapists to guide the stroke patients through their rehabilitation, we are convinced that the therapists are the most suited to understand the potential utility of a tool for rehabilitation.

For this reason a study has been conducted in a rehabilitation department of a French hospital in order to understand the potential and benefits of mixed reality. The study involved physiotherapists and occupational therapists of the same hospital. Three sessions, one using the Wii System with a commercial game, another using an ad hoc developed game on a PC, and another using a mixed reality version of the same game were held. In synthesis results have shown the MRS is seen as useful for a huger number of patients, in particular the ones with more acute diseases. Therapists found value also in the Wiimote for patients with a good recovery to exercise grasping while they found no interest in the use of a PC system.

Remarks on the MR and the Wii systems underlined the necessity of objects manipulation to recover grasping. However this is a limitation of the above described prototype not a mixed reality limitation.

While the MR presented in this paper did not use objects and was conceived to work in a 2D space we are currently working on another prototype adding physical objects manipulation. This second prototype will also take into account a user profile using agents to create a personalized rehabilitation experience. In fact the most innovative and interesting part of this kind of rehabilitation tools is the mix of adaptive aspect combined with the ease of use of the same tool. Further prototypes will extend objects manipulation in the 3D space. This way the interaction with virtual objects can be done in the same way as the interaction with real objects without removing the personalization part. The adaptation algorithm can in fact place targets in the best place to push the patients to work exactly the area in need. In addition both hands can be used for interaction because the user does not have to hold a device. Several objects could be then being manipulated at once enabling bimanual therapy.

Finally, the last prototype we will develop will implement collaboration between several users in order to understand if a collaborative therapy is possible.

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