Augmented Reality for Rehabilitation Using Multimodal Feedback

João Vieira
Técnico Lisboa / University of Lisbon
Portugal
felixvieira@tecnico.ulisboa.pt

Maurício Sousa
INESC-ID
Técnico Lisboa / University of Lisbon
Portugal
antonio.sousa@ist.utl.pt

Artur Arsénio
Universidade da Beira Interior
Portugal
arturarsenio@di.ubi.pt

Joaquim Jorge
INESC-ID
Técnico Lisboa / University of Lisbon
Portugal
jaj@inesc-id.pt

ABSTRACT

It is usual for a patient to continue performing exercises outside of the clinic and without any therapist's supervision, after being exempted from in-clinic physical therapy. While performing unsupervised exercises, it is desirable for the patient to receive similar feedback as otherwise provided by a physical therapist, to maintain an accurate execution of the rehabilitation tasks. To address this problem, several approaches have been proposed using multimodal feedback for rehabilitation. Unfortunately, the test subjects frequently reported difficulty in completely understanding the feedback given to them, therefore failing to correctly execute the given movement. In this work, we present SleeveAR, a novel approach to address multimodal feedback strategies, and evaluate which different combinations are more suitable to successfully guide a subject through an exercise prescribed by a physical therapist. Therefore we expect this work will contribute to facilitate the rehabilitation process.

CCS Concepts

•**Human-centered computing** → **Gestural input;** *Mixed / augmented reality;*

Keywords

Rehabilitation, Augmented Reality, Multimodal Interfaces

1. INTRODUCTION

Even though physical therapy holds a great part of a rehabilitation process, the individual effort from the patient also holds great responsibility in its own recovery. The patient must be ready to learn about his condition and how to perform the therapeutic exercises prescribed without the need for professional supervision.

It is hard for the patient, alone and without significant body awareness, to perform correctly the exercises. Without real-time feedback, the patient may end up hurting himself. This feedback is usually given by a professional, but without their presence, it would be desirable for people to receive similar feedback from other sources, in order to maintain a certain quality in the task execution.

Augmented Reality (AR) could be a possible solution to overpass the lack of clear feedback sources when no physical therapist is present. It holds great potential in the field of rehabilitation. In addition, there are already a variety of tools available to help with the development process of Augmented Reality applications that interact with the body [2]. If combined with a carefully designed form of feedback for the patient, AR can be of great use in the rehabilitation of a person [4]. The whole idea is to give more information to a person in a way that it can make the assigned task easier. Usually, this feedback is given by a therapist while enduring physical therapy, which can be of a visual form (the therapist demonstrating what to do), auditory (the therapist giving orders) or physical (the therapist applying physical force). For unsupervised exercises, a different approach must be followed on the types of feedback used, making sure that the goals are still achieved and the patient performs correctly. By using multimodal feedback, we can take advantage of senses, while providing more information without overloading just one sense (e.g., just using visual cues on a screen can become overwhelming for a patient). A system like the one described is called a *multimodal feedback system*, which, by definition, uses various sensory inputs and outputs to achieve the desired task.

Studies have already shown that the usage of augmented reality feedback enhances the motor learning of an individual [4]. Aiming to a home rehabilitation process without the presence of a therapist, the feedback has the responsibility of guiding the patient and correcting him throughout his tasks. By experimenting on the several forms of feedback

REHAB '15, October 01-02, 2015, Lisbon, Portugal

DOI: http://dx.doi.org/10.1145/2838944.2838954

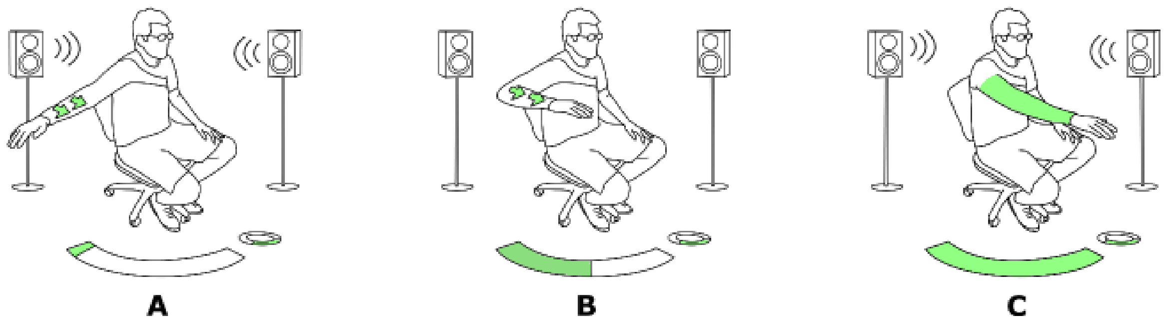

Figure 1: Patient following feedback given to execute a simple movement: A) The initial phase, combining audio and visual cues. B) Floor projected visuals follow the patient's movement in real-time. C) A completed exercise also triggers audio feedback.

that can be used on a patient, we want to evaluate which combinations can be useful to specific tasks and how can they complement each other in a way that it creates a clear set of instructions for the patient.

In this work, we introduce *SleeveAR*, a platform that combines multiple sources of awareness feedback to aid and guide during rehabilitation exercises. In the end, we want to be able to determine the most appropriate feedback combinations to successfully guide a person through a given movement. Hence, the aim is to contribute to future augmented reality feedback applications that might need to interact with a user in the clearest possible way.

2. RELATED WORK

The physical therapist role is fundamental to plan what exercises a patient must execute and to make sure they are correctly executed. Since the patient is not always able to execute the exercises alone, or even move without an external help, the therapist can intervene during the session and adapt his approach according to the patient's needs[4]. Again, whenever the rehabilitation exercises are done at home, without the therapist presence, the patient might perform incorrect movements to avoid pain[6] or might not even be able to move at all.

To help with this unsupervised rehabilitation work, several solutions have appeared as an alternative to the classic paper or video instructions. Using modern technologies and leveraging on an increasing offer in reliable tracking devices, a large diversity of applications are being developed that aim to solve some of the difficulties in unsupervised rehabilitation [3, 1]. Using light-projectors for augmented reality has enabled the creation of very interesting applications. Through techniques of projection mapping, it became possible to turn any irregular surface into a projection screen.

This kind of technique can benefit fields that rely on guiding feedback by being able to focus projection on a body part for example, just as it is necessary in rehabilitation systems. But for it to be useful, the projection mapping should be interactive and be influenced by what is currently happening with its projection target.

LightGuide [5], explored the use of projection mapping in a innovative way. The projection was made onto the user, using his hand as a projection screen. Real-time visual cues were projected onto the user's hand in order to guide him through the desired movement. By projecting the information in the body part being moved, the user could keep a high level of concentration without being distracted by external factors.

To apply real-time projection mapping onto a moving body part, its position must be known at all time to make sure the light projector is illuminating the correct position. Motion tracking devices enable such active approach allowing tracking of the person's actions and movement.

LightGuide [5] does not rely on interactive mirrors or screens to apply its visual feedback. By using a depth-sensor camera and a light projector, they were able to project information on the user's hand. This system was able to guide the hand through a defined movement by projecting visual cues. All the information projected on the hand was being updated in real-time influenced by the current position given by the tracking device.

The visual cues varied according to the desired direction of the movement. If the current movement only required back and forward motion, only one dimension was being used. Therefore, the visual cue would only inform the user where to move his hand in the z axis through a arrow pointing to the correct position. Two dimensional movements would combine the first visual cue by virtually painting the remaining of the hand with a color pattern. The portion of the hand closer to the desired position, would be painted with a different color than the remaining portion. They concluded that by using LightGuide, most of the users could better execute a certain movement than if they were following video instructions.

3. SleeveAR

SleeveAR aims further beyond the accomplishments LightGuide was able to make. As described in the previous section, Lightguide only focused on projecting information on top of the hand. Not only does this leave a small room for movement variety, but also the amount of possible information given can be quite reduced. By increasing the projection area throughout the whole arm and by combining other feedback sources (such as sound and vibration), we can drastically improve a user's awareness while an movement is being executed. Not only that, but if it was possible for the movement being replicated to be originated by another person, we could achieve much more realistic and useful guidance. With SleeveAR virtual content can be projected onto different surfaces, and even, onto people's own limbs, to provide, in real-time, for a more immersive experience.

Our vision consists on two main concepts. Firstly, the precise recording of the exercise being demonstrated by a personal therapist. And secondly, the ability to properly guide another person, the rehabilitation subject, during the execution of the pre-recorded exercise. While, at the same time, provide awareness of the rehabilitation exercise progress to insure the correctness of the patient's movements. With SleeveAR, a therapist can demonstrate the prescribed exercises and make sure his patient will perform them correctly without the requirement of his close supervision.

In the SleeveAR system, the exercise being performed needs to be recorded beforehand, which, in this case, should be a health professional. Hereafter, as depicted in Figure 1, the patient follows all provided feedback to replicate the prerecorded movement step-by-step, without ever seeing the exercise executed before. The current position of the subject's arm is being constantly tracked in order to always provide real-time feedback based on how he should move it from that point. Visual feedback is achieved by projecting light onto his full arm and surroundings. The projection on the arm will enable us to guide a subject through translations and rotations, using different kinds of visual cues to different situations. As for the projection on the subject's surrounding will serve the purpose of providing other useful information not directly connected to the movement itself. In Figure 1 we can observe a progress bar being projected on the floor. This bar not only provides the subject an understanding of how far in the exercise he is at the moment, but also helps the subject visualize the angle of movement he should be doing. Audio and haptic feedback can help inform the subject about specific information, without making him loose his focus on the visual feedback. The haptic feedback is used to quickly notify the subject of any vital information about the current state of the exercise. Awareness of erroneous movements is achieved mainly by the employment of vibration cues into the patient's arm. Furthermore, for the purpose of timing, auditory feedback provide the subject with information regarding when to start or stop the exercise by using recognizable audio cues which represent those same actions.

4. PROTOTYPE

The SleeveAR prototype, relies on several already existing devices. In some cases, we had different approaches available, which made us evaluate which ones would benefit the most for each of the described feedback sources. For the SleeveAR system to be reliable, the body tracking quality was a key factor in the whole implementation. Not only there is the need to record movements with great precision and save all the data in files to be later accessed. It was also necessary for the second phase of implementation, where another subject would be tracked in real-time and his movement compared to the one previously recorded.

Even though Microsoft's Kinect[1] has proven to be a great tracking tool for several studies we analyzed, it seriously lacked the accuracy and reliability needed. Even with a completely still arm, we could observe a noticeable flickering

[1]http://www.xbox.com/xboxone/kinect

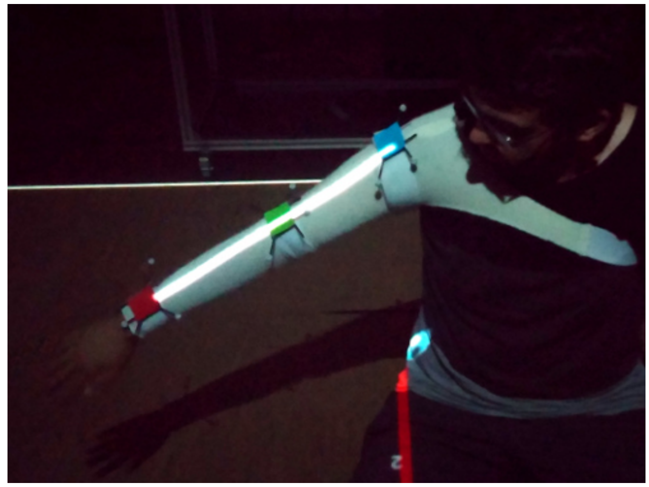

Figure 2: Sleeve responsible for holding the tracking equipment.

Figure 3: Real-time visual feedback being given.

on the values which represented the arm position. Another problem with using Kinect was the fact that the joints coordinates given were always influenced by where the tracking device was placed in the room. Since we required a static and stable coordinate system, a better alternative was used, the OptiTrack Motion Capture system [2].

To provide the visual feedback, a commodity projector was placed on the laboratory's ceiling, pointing downwards. Our main challenge here was to understand how the projected information would hit the right spots on the surface of a person's limbs. For this to be possible, a series of coordinates transformation had to be applied to the tracking information received by our devices. For haptic feedback, we had two possible options. The first one, the smartwatch Pebble, did not have a compatible SDK to use on our project. On the contrary, MYO[3] a wireless bracelet, already provides all

[2]https://www.naturalpoint.com/optitrack/
[3]https://www.thalmic.com/myo/

the necessary hardware devices to provide a multiple range of vibrations in a easy and simple way by via wireless communication.

Finally, to provide audio, a set of speakers was placed around the laboratory. In this case, we can also provide 3D sound in the future, even though our main focus is the visual feedback.

5. CONCLUSION AND FUTURE WORK

Augmented reality with multimodal feedback for rehabilitation is expected to provide a patient with improved sources and correction when executing exercises outside of a clinic. This would be preferred, as opposed to exercising with no feedback where there is no way of correcting the execution. The state of the art presents several solutions to provide guidance during movement's execution, some already applying multimodal feedback. However, there is still room for improvement, and much research is needed to determine the optimal combination of different feedback sources Projecting light on top of the limbs to guide a subject through a movement had some promising results with Lightguide, still it is difficult for patients to accurately replicate the rehabilitation exercise prescribed.

We have introduced SleeveAR, which brings multimodal feedback and guidance to therapeutic and rehabilitation exercises. Not only to precisely guide people in how to perform, but also, to provide simple and clear awareness of the exactitude or the incorrectness of the required actions, using visual, audio and haptic cues. With SleeveAR, we will be able to formally assess the feedback combinations suitable for guiding a patient while solving some of the perception problems and also contribute with different feedback techniques in addition to the ones observed in the state of the art. Furthermore, we are planning to execute several tests with people, mainly to compare the results of a subject replicating a movement by only looking at a video and by using SleeveAR as a guidance tool. Also, it is our intention to include health professionals as test subjects, so that through their opinions validate the therapeutic attributes of our approach.

We consider that it is both possible and interesting, as future work, to add multitude of projected surfaces (walls, furniture, or even the ceiling) to determine their impact on the people performance and awareness during a rehabilitation session.

Acknowledgments

The work presented in this paper was partially supported by the Portuguese Foundation for Science and Technology (FCT) with reference UID/ CEC/ 50021/ 2013, and through projects CEDAR (PTDC/ EIA-EIA/ 116070/ 009) and TECTON3D (PTDC/ EEI-SII/ 3154/ 2012).

6. REFERENCES

[1] N. A. Borghese, R. Mainetti, M. Pirovano, and P. L. Lanzi. An intelligent game engine for the at-home rehabilitation of stroke patients. *2013 IEEE 2nd International Conference on Serious Games and Applications for Health (SeGAH)*, pages 1–8, May 2013.

[2] A. D. Gama, T. Chaves, L. Figueiredo, and V. Teichrieb. Guidance and Movement Correction Based on Therapeutics Movements for Motor Rehabilitation Support Systems. *2012 14th Symposium on Virtual and Augmented Reality*, pages 191–200, May 2012.

[3] N. Kitsunezaki, E. Adachi, T. Masuda, and J.-i. Mizusawa. KINECT applications for the physical rehabilitation. *2013 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, pages 294–299, May 2013.

[4] R. Sigrist, G. Rauter, R. Riener, and P. Wolf. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic bulletin & review*, 20(1):21–53, Feb. 2013.

[5] R. Sodhi, H. Benko, and A. Wilson. LightGuide: projected visualizations for hand movement guidance. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2012.

[6] R. Tang, A. Tang, X.-d. Y. Scott, and J. Jorge. Physio @ Home : Exploring visual guidance and feedback techniques for physiotherapy exercises. 2015.