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An approach to physical rehabilitation using state-of-the-art virtual reality and motion tracking technologies

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Abstract

This paper explores an approach to physical rehabilitation using state-of-the-art technologies in virtual reality and motion tracking; in particular, Oculus Rift DK2 (released in July, 2014) and Intel RealSense (released in November, 2014) are used. A game is developed which requires from the patient to perform an established set of abduction and adduction arm movements to achieve rotator cuff rehabilitation after injury. While conduct of clinical trials is outside the scope of this work, experts in physical rehabilitation working in the medical field have carried out a preliminary evaluation, showing encouraging results.

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Keywords: physical rehabilitation; virtual reality; oculus rift; motion tracking; intel realsense.

1. Introduction

In the recent years, videogames technologies are rapidly evolving by changing the way users interact with the game. Some of these technologies, which are shifting the gaming paradigm, are motion tracking and virtual reality.

Motion trackers started to appear in the gaming industry in the early-2000s, with products such as the EyeToy for PlayStation. Later in the decade, there was an important growth in the number of games where the user required a more dedicated interaction with the console rather than just pressing buttons in a controller, such as moving their

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bodies in certain ways to achieve goals. Some of the most common devices in charge of recording and tracking the user movements were the WiiMote, Wii MotionPlus and Wii Balance Board from Nintendo, Kinect from Microsoft and the PlayStation Move and Eye from Sony. All these devices use different technologies to achieve a similar goal, by means of video cameras, depth sensors, accelerometers, gyroscopes, pressure sensors, etc. Sometimes, games involving motion tracking are called active games, and the fact of playing these is often referred as *exergaming*, and to the date several research studies have been conducted to explore the advantages of this practice.[1-7]

Regarding virtual reality, it is actually an old concept, as the term goes back to the 1980s and the concept and the technology existed years before.[8] However, recent technologies achieving a satisfactory degree of virtual reality are now starting to become mainstream,[9] as devices such as Oculus Rift are generating great expectations and its price is now affordable for many users. Also, there is increasing interest from the academic community in this area, as it can be seen in the organization of recent special sessions such as the one from IEEE based on this topic.[10] Moreover, there are a broad and diverse number of fields besides gaming where virtual reality can be applied, such as education or military training among many others. However, one of the sectors where the application of virtual reality becomes more promising is health, as medical experts and students have been using virtual reality for performing simulations of surgery interventions,[12] and in recent years this sector is incorporating virtual reality devices for patients.

This paper presents an approach to physical rehabilitation of the rotator cuff using motion tracking and virtual reality technologies, by means of a videogame that explains the patient the movements he must perform and tracks these movements to check that they are carried out properly, maintaining a score system to provide feedback to the patient. The main objectives are (1) to develop a proof of concept of the integration of these technologies in the health field and (2) to test whether a videogame-based immersive system could accelerate the patient recovery. The devices used for this work are the virtual reality glasses Oculus Rift DK2, released in July 2014 and shown in figure 1a; and the motion-tracking device Intel RealSense, which was released in November 2014 and can be seen in figure 1b. Both are state-of-the-art devices, which are only available for developers at the moment of writing this paper.

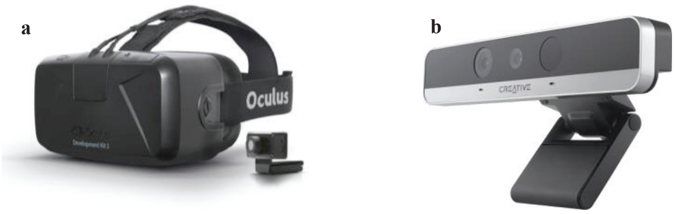

Fig. 1. (a) Oculus Rift DK2[13]; (b) Intel RealSense[14].

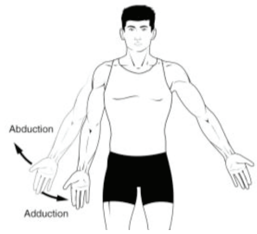

Fig. 2. Abduction and adduction movements[16].

This paper is structured as follows: section 2 presents some medical background which is required to understand how physical rehabilitation can be achieved while section 3 studies related work. Later, section 4 describes the prototype developed in this work, and the results of a preliminary evaluation carried out by experts are presented in section 5. Finally, section 6 presents some conclusive remarks and describes research work left for the future.

2. Medical background

Physical rehabilitation of a patient involves on one side specific treatment of the affected area by a medical expert and on the other requires kinesiotherapy, i.e., the performance of certain exercises to recover mobility lost after injury. While these exercises do not always require expert supervision, it is often helpful, as many patients tend to perform incorrect movements or postures during exercises, which may decrease their effectiveness or even turn harmful for the rehabilitation purposes. This section explores the movements considered for the prototype developed for this work, and also explains the additional advantage of using virtual reality for developing proprioception.

2.1. Rehabilitation movements

In this work, physical rehabilitation is bounded to the rotator cuff of the right shoulder. Works on physiology of the joints define six main movements to achieve complete rehabilitation[15] in this area: abduction, adduction, flexion, extension, internal rotation and external rotation. The game developed in this work focuses on the first two of them:

- Abduction is a movement of the upper limb away of the trunk, and takes place in the frontal axis. Abduction has a joint range starting at 0 and ending at 180 degrees: in the former case, the arm rests on the trunk side while in the latter the arm lies vertically over the trunk. When the movement reaches 90 degrees, the arm lies horizontal under the base of the neck and perpendicular to the trunk. Figure 2 illustrates this movement. The joints involved in this movement are the shoulder joint and the scapulothoracic, each to a certain extent depending on the phase of the movement. The muscles involved in this movement are the deltoid, the supraspinatus and the pectoralis major.
- Adduction in this work is considered starting in the position of abduction (this is also called relative adduction), and the movement consists in "undoing" the previous abduction by having a joint range starting at 180 and ending at 0 degrees. Figure 2 illustrates the adduction movement. The muscles involved in this movement are the latissimus dorsi, the pectoralis major and the subscapularis.

2.2. Development of proprioception

Proprioception is the ability to sense the position of the muscles, and the relative position among contiguous body parts. In the game developed for this paper, the sight is blocked when the patient wear the virtual reality glasses, so he is unable to see himself moving his upper trunk. This hardens some tasks such as motion coordination, automatic body responses and awareness of self-position across the space. As a result, extra effort must be done by other sensors, which according to experts[17,18] might accelerate the treatment and increase its effectiveness.

3. Related work

Academic interest in applying new technologies in the medical field has significantly increased in the recent years. This section explores related work where technologies such as virtual reality or motion tracking are used for medical applications, including physical rehabilitation.

The application of virtual reality to the fields of rehabilitation and therapy has been examined for many years, and a decade ago it was growing significantly. This fact led to the publication of a SWOT analysis of this topic[19], which revealed it to be a promising area for the coming years. Some recent works reveal some applications of virtual reality to physical rehabilitation such as the use of Oculus Rift glasses during occupational therapy in child patients with burn wounds to reduce the pain of the treatment[20].

Moreover, as exposed in the previous section, an important advantage of virtual reality is that it can be used to enhance the development of proprioception, which at the same time can have additional advantages. The concept of presence and consciousness in virtual reality systems was explored in the early- and mid-2000s.[21,22] Medical applications for this principle have been explored in the recent years with research works involving reducing phantom limb pain,[23,24] acquiring functional skills in patients with cerebral palsy,[25] achieving upper limb rehabilitation of stroke patients[26] and improving balance and postural stability in patients with diabetic peripheral neuropathy.[27] Also, the application of virtual reality in neuroscience has been recently explored.[28]

Regarding motion tracking, medical applications were explored in the academy soon after the first devices appeared, as soon as in the 1980s.[29] By far, the most common device within this research field is Microsoft Kinect, which has been used for a variety of applications including assessment of postural control,[30] evaluation of foot posture,[31] identifying anterior cruciate ligament injury risk[32] and again for in-clinic and in-home physical rehabilitation[33,34] and for enhancing mobility and reducing the risk of falling with gait tracking.[35] Besides Kinect, Leap Motion has also been used for hand rehabilitation,[36] and specific devices such as smart gloves have been developed for improving hand and upper extremity function.[37] The use of other motion-tracking tools for physical rehabilitation has also been surveyed,[38] and in cases as preventing cognitive decline results better than with traditional exercise have been achieved.[39]

Finally, the combination of motion tracking and virtual reality for physical rehabilitation has also been explored.[40] It should be noted that some works use the term "virtual reality" to refer to any device that can capture the patient's movements and include them in a virtual environment. In this paper, the term "virtual reality" is referred explicitly to immersive 3D virtual reality such as that attained using 3D glasses.

4. Development of the proposal

A first prototype is developed using Unity3D in order to achieve physical rehabilitation of a patient's rotator cuff of the right shoulder. For this early version, only the abduction and adduction movements are considered, and the recognition of the remaining movements required for attaining full rehabilitation (flexion, extension, internal rotation and external rotation) are left for future work. To motivate the execution of the exercises the prototype consists on a soccer game, and the patient takes the role of the goalkeeper. The game analyzes the patient's posture and infers the position of the upper trunk joints, i.e. the shoulder, the elbow and the hand. The patient increases his score only if the movement is performed correctly, which requires the trunk to be straight and perpendicular to the ground, the arm to be completely extended and to stop the ball.

The rehabilitation session can be either supervised or autonomous. In the supervised version, a physiotherapist can decide when the ball is shot and its height over the ground. A faster shoot frequency will require faster movements to be performed by the patient and a big difference in the height between consecutive shoots will require a wider angle in the adduction or abduction movement. On the other hand, the autonomous session starts with low frequency shoots and small angles between shoots and increases or decreases the difficulty level based on the score.

To enhance the effect of proprioception, the patient can only see his own hand, but not the rest of the skeleton, as it can be seen in figure 3a. This will require an extra effort on his side to keep the arm completely extended and the trunk straight, to perform the movements correctly, thus increasing the effectiveness and efficiency of the treatment.

For the game to run properly, the physical setup shown in figure 3b must be used. The motion-tracking device must be vertically aligned with the shoulders and front-facing the patient. The distance between the patient and the device must be in the range from 0.8 to 1.2 meters, as otherwise some movements might not be captured.

a

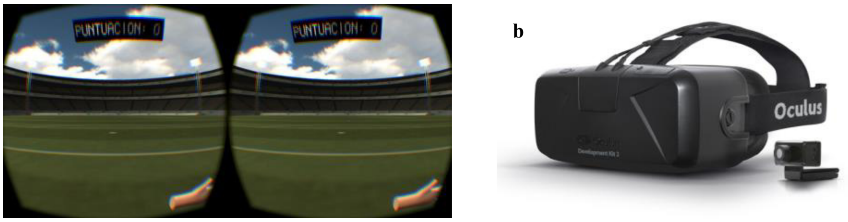

Fig. 3. (a) Game scenario as seen by the patient (each screen is projected to an eye by Oculus Rift glasses, producing a 3D effect in the brain by the effect of stereopsis. (b) Physical layout of the environment describing the relative position of the patient and the Intel RealSense device.

5. Preliminary evaluation

Medical evaluation of the product developed in this paper by means of clinical trials requires special procedures to be fulfilled and thus lies beyond the scope of this work.

Nevertheless, while real patients have not been subjected to clinical experimentation, four experts working in the field of physiotherapy have tested the product. In their opinion, the movements performed by the patient would correspond to those required by a treatment of active kinesiotherapy, and performing shoulder abduction of over 90 degrees would achieve an increase of the shoulder joint mobility, which would in any case depend on the patient and the injury severity. Also, they also expect an increase in the muscle tone and strength, as all movements are performed against gravity.

None of the experts suffered from dizziness, nausea or other sickness while wearing the virtual reality glasses, but they agree on the fact that some patients may experiment those symptoms. They all think that the animations are fluid (the game is running at a minimum rate of 30 frames per second).

Finally, they have pointed out that an average assisted kinesiotherapy for a patient with shoulder injury takes about 20 minutes, and engaging in the soccer game could allow them to complete the exercises on their own. However, they agree on the fact that at least the first session must be supervised by a physiotherapist to check that the patient is performing the right movements, and the supervised session mode has proven successful for that purpose. One expert stated that the system should have a feature to limit the exercises time, to prevent patients from performing the movements during too much time, thus reducing the effectiveness of the treatment.

During the evaluation, experts showed interest and expectation in the developed proof of concept, and they agreed on the fact that virtual reality and motion tracking are promising technologies to be applied to physical rehabilitation. Moreover, they suggested improvements and extensions to the project, described in the next section.

6. Conclusions and future work

This paper have presented a new approach to physical rehabilitation of the right shoulder's rotator cuff which combines immersive virtual reality using Oculus Rift DK2 goggles and motion tracking using Intel RealSense. These devices were both released in the second half of 2014, so they can be considered state-of-the-art technologies in their respective fields.

A soccer game has been developed where the patient takes the role of the goalkeeper, and has to stop the balls that are shot with certain frequency and height (angle), in order to perform shoulder adduction and abduction movements. The motion-tracking device performs tracking of the position of the upper body skeleton and the game increases the patient's score if the movement is performed correctly (in which case, the ball will be stopped).

As the patient wears the virtual reality glasses, he is unable to see his surrounding environment, which is replaced by a virtual soccer field. Also, the patient is only able to see the position of his hand, but not the rest of his body, neither his arm. This enhances the effects of proprioception, as the patient must perform an extra effort to carry out the required movements in the right way, keeping the trunk straight and the arm completely extended.

Finally, four experts tried and evaluated the game, concluding that it shows promising results for the sake of shoulder rehabilitation, pointing out that an expert should supervise at least the first session.

The objectives stated before are accomplished to a certain degree: (1) a system integrating immersive virtual reality and motion tracking and serving as a proof-of-concept for physical rehabilitation has been effectively developed and (2) the evaluation with medical experts show that it can potentially enhance the process of physical rehabilitation and accelerate recovery, while this fact is not strictly validated through clinical trials, but rather supported by evidence in the literature and by experts' knowledge.

The prototype developed in this paper only recognizes adduction and abduction movements of the right shoulder, and recognizing the remaining movements required for full rehabilitation as well as supporting rehabilitation of other muscles and joints (from both the upper and lower trunk) is left as future work.

Also, experts have suggested during the evaluation to introduce new games in order to increase engagement of the patient with the system, so that the patient does not get bored while exercising. Moreover, a social approach where patients could share their scores could also be positive, but its effects should be studied with further detail.

Finally, a more exhaustive evaluation of the system conducting clinical trials is required to effectively prove that physical rehabilitation treatment and effectiveness is improved.

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