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A Tele-Rehabilitation Platform for Shoulder Motor Function Recovery Using Serious Games and an Azure Kinect Device

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Abstract. Background: Tele-rehabilitation is gaining importance due to the increasing need for objectiveness in the evaluation of patients with impaired motor functions. Low-cost marker-less motion capture systems are becoming key enabling technologies as support in the treatment of musculoskeletal diseases. Objectives: The goal of this work is to investigate the use of the Microsoft Azure Kinect device to develop a tele-rehabilitation platform for shoulder motor function recovery. The platform comprehends a set of serious games, which are fundamental to increase the patients' engagement in shoulder rehabilitation. Methods: Starting from a set of functionalities identified together with the medical personnel of an Italian hospital, the Azure Kinect device has been used as motion capture system to interact with the serious games. Mobile applications for patients and physicians have been developed to manage the rehabilitation process. Results: The solution has been tested by the involved medical personnel. It has been considered interesting and promising. Further improvements in the design of the virtual environment of the serious games are required. Conclusion: The presented platform is a starting point to develop a complete IT solution for the daily shoulder rehabilitation.

Keywords. Telerehabilitation, Shoulder rehabilitation, Virtual reality exposure therapy, Rehabilitation research.

1. Introduction

Musculoskeletal disorders (MSDs) are injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs, caused by multiple factors in various parts of the body. They can limit the general daily activities in the long term [1]. MSDs accounted for more than 30% of all injury and illness cases in the late years among full-time workers, especially in certain occupational sectors and industries dealing with high and repetitive physical efforts. Among the MSDs, the shoulder district is the most affected. Despite the continuous improvements in the work environment safety measures, the annual prevalence of shoulder musculoskeletal disorders among adults is 2.4% and the incidence is 1.5%. They represent approximately 20% of all disability payments for musculoskeletal disorders, with significant economic impact [2].

Shoulder disorders cause pain and functional loss. After an injury or a surgery, an exercise conditioning program can help the patient to return to daily activities and enjoy

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a more active, healthy lifestyle [3]. The two main goals of shoulder rehabilitation are strengthening and improving flexibility of muscles to restore the physiological range of motion [4]. In traditional shoulder rehabilitation, the patient performs exercises with the help of a physiotherapist within a rehabilitation center. However, there are two main drawbacks with the conventional approach. The former is the lack of an objective evaluation of gradual patient's improvements since it is based on an observational assessment of the physiotherapist. The latter is the poor adherence of the patient, due to the repetitive nature of the therapy that may become tedious for whom is not accustomed to exercise.

In the last few years, tele-rehabilitation applications have been increased, thanks to the development of new IT technologies and of more advanced devices [5]. They allow the physician to remotely evaluate the patient's performances. Both healthcare structures and patients can benefit from telerehabilitation because it leads to a reduction of hospitalization rates and the prevention of readmissions, the early discharge from rehabilitation units, the reduction of costs, time, and the improvement of health outcomes and quality of life [5].

Gamification in rehabilitation is a strategy of telemedicine that can potentially address motivation and increase the patients' compliance, due to its interactive nature. [6]. In the meanwhile, tele-rehabilitation based on serious game can also offer guidance and feedback regarding the task, since it gives the possibility to automatically extract useful information from patient's movements during the exercise [7], [8].

Usually, the serious games exploit motion capture (Mocap) systems as devices to interact with the virtual environment. A Mocap system can automatically track patient's body and generate a virtual skeleton that follows the performed movements. The animated skeleton makes available a set of kinematic data (i.e., positions and orientations of each virtual articulation) that can be used to assess the rehabilitation exercises. Marker-less mocap systems is composed by low-cost devices that exploits either RGB cameras or RGB-D sensors to track a human body and generate the associated virtual skeleton. Many sensors for marker-less mocap systems have been designed for entrainment and gaming with few attentions to their integration with other IT, which are very important for the design of a telerehabilitation platform (e.g., easily interface with game engines and software interfaces for data exchanging with web or mobile applications). The last generation of Microsoft RGB-D device, i.e., the Azure Kinect, has been designed for research and development and a set of software interfaces are already available to explore its use for tele-rehabilitation.

In such a context, this research work investigates the development of a tele-rehabilitation platform for shoulder motor function recovery based on the use of a Microsoft Azure Kinect device and consumer technology. Firstly, a scientific background about tele-rehabilitation is introduced, then method and tools for the development of the platform are explained. Finally, results and conclusions are discussed.

2. Scientific Background

Serious games have been intensively developed for general health and specific disease management [9]. The gaming scenario, which motivates patients, and the user acceptability play a significant role in promoting their employment in clinical practice.

Moreover, the user safety aspect needs particular attention to avoid new clinical complications for patients.

Several instruments are used for the evaluation of the range of motion, starting from simple tools as the universal goniometer to the Mocap systems. Wearable inertial-based Mocap systems and optical Mocap systems are available on the market, to map, monitor and acquire human body movements in real time. They integrate multiple IMUs that provide detailed information regarding the movement of the patient, without suffering from occlusion among different body parts. However, the scientific community still faces challenges related to their extensive validation in real-life contexts. It is correlated to the low level of usability for people who do not have good IT skills and to the excessive cost to get a complete human body tracking [10].

Among the optical Mocap systems, the marker-less solutions are the most used for tele-rehabilitation and allow the estimation of human postures without markers. Even if marker-less mocap technology is not as accurate as the inertial Mocap systems, their low-cost and ease of use allow a wide application for tele-rehabilitation solutions [10]. The most used sensors for a marker-less acquisition are the RGB-D cameras. In the last decade the most used RGB-D device has been the Microsoft Kinect v2: his better accuracy and the easy integration with game engines as Unity and Unreal Engine encouraged researchers to use this device in the rehabilitation field. Unfortunately, Microsoft stopped the production of Kinect v2 in 2017 and thus, new tele-rehabilitation solutions must be designed by considering other solutions. In the last 5 years, Mocap system based on convolutional neural networks applied to videos and pictures are able to estimate huma poses human body movements, such as OpenPose and PoseNet [11]. However, several research works evaluated the accuracy of this new systems not enough for the assessment of rehabilitation exercises [12],[13].

In 2019, Microsoft launched the Azure Kinect, which exploits the RGB-D functionalities combined with artificial intelligence algorithms to allow a better identification of the 3D skeleton joints than the Kinect v2 device. Therefore, tracked movements and their related features can be much more representative of actions, and thus, more discriminative to assess the correctness of a rehabilitation exercise [9]. Few studies demonstrated the use of Azure Kinect for biomedical applications. In particular, the use of an Azure Kinect as Mocap system for a tele-rehabilitation platform for shoulder motor skills recovery should be investigated.

When the patient performs his rehabilitation at home, a direct communication must be maintained between medical personnel and patients by using consumer IT. Utilization of smartphones, tablets and laptops based on mobile and web applications have rapidly grown also in the healthcare sector. The use of mobile devices was already pervasive in 2012, with almost 90% of healthcare professionals using them in the workplace. Currently, mobile apps are a useful tool for supporting patients in their healthcare needs. People can easily use smart devices, which allow the rapid and simple interaction among patients, physicians and healthcare structures [14].

Considering the specific context of the tele-rehabilitation for the shoulder, S. Jiang et al. [15] and other research works [16-18] have demonstrated how the telerehabilitation following total arthroplasty and upper limb intervention are similar or even superior in comparison with conventional rehabilitation.

The aim of this work is the development of a dedicated tele-rehabilitation platform for shoulder motor function recovery using consumer technologies for mobile apps and the new Azure Kinect device as motion capture system. Both patients and physicians can have advantages: the patient is more involved thanks to the stimulating rehabilitation exercises; the physician has the possibility to schedule the rehabilitation activities and to monitor patient's status over time.

3. Method and tools

The development of a reliable and applicable solution requires a medical point of view. To this extent, a discussion with experts in the treatment of shoulder MSDs of an Italian hospital has been crucial to understand the boundaries of the project and to have more insights.

3.1. Software architecture

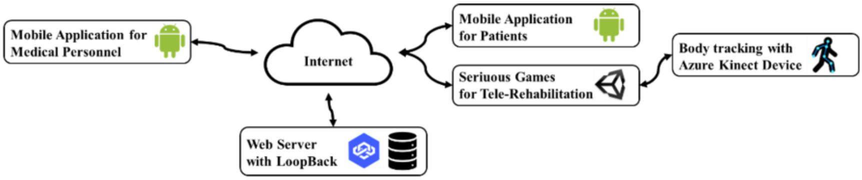


Figure 1. The software development architecture of the tele-rehabilitation platform

Figure 1 depicts the software architecture of the developed solution. The platform can be subdivided in three main parts: (i) a set of serious games through which the patient can perform rehabilitation exercises using the Azure Kinect device; (ii) a web server with a database where data are stored and (iii) two mobile apps, one for the patient, where he/she can see the scheduled activities on a monthly calendar, and the other one for the physician, where he/she can schedule daily activities and have a direct feedback on the quality of the performed exercises.

The serious games have been developed in Unity. The developed software modules allow the definition of (i) the game logic of the serious games, (ii) the integration of the Azure Kinect device [18] to interact with the virtual environment and (iii) the analysis of motion captured data to automatically assess the correctness of each performed rehabilitation exercise.

Android Studio has been chosen for the creation of mobile applications. Finally, the data exchange among all the applications has been made possible with the use of MySQL DBMS and Loopback [19]. The former allows the design of the database; the latter provides the automatic REST API generation to get data from the web server.

3.2. Development of the serious games

The serious games have been developed in a unique virtual platform with a starting menu that displays (i) the access to a virtual environment to record the movements of the healthy contralateral used as references to assess the patient's performances, (ii) the rehabilitation exercises scheduled by the physician for the current day and (iii) the description of the goals of each available serious game and the relative tutorials.

Starting from the discussion with the medical personnel, three rehabilitation exercises have been considered: shoulder abduction, flexion, and the external rotation of the upper arm. The movements performed with the healthy contralateral shoulder are used as references to evaluate the correctness of the same movements performed with the injured shoulder. A virtual avatar helps patients to correctly record the three movements using the healthy shoulder. This task requires the presence of the physician to ensure the correct recording of the reference movements.

A specific software module has been developed in Unity to record the reference movements and compare them with the movements performed with the injured shoulder during the use of the serious games. Three measurements are computed and used for the comparison: the maximum value of the angle measured during each specific movement (Figure 2), the time and the velocity of execution. The correctness of the movement is defined as an integer score between -5 to 5. The score “0” represents the optimal performance, which is the reference movement performed by the contralateral arm. A negative score means a rehabilitation exercise performed with a maximum angle and a velocity lower than the reference movement. A positive score is relative to a movement done too fast and with a maximum angle higher than the reference value.

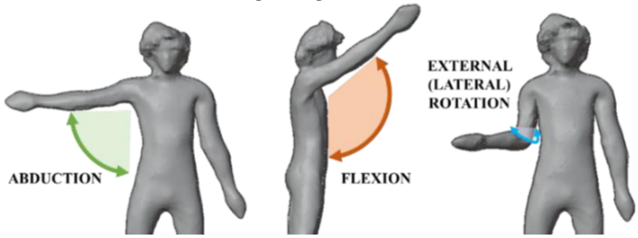


Figure 2. Rehabilitation exercises: the highlighted angles are used to assess if the rehabilitation exercises are correctly done.

For each exercise, the platform makes available a specific serious game (Figure 3). In Figure 3(a), the airplane is directly moved with the abduction movement performed by the patient. When the patient raises the arm from the initial standing position the airplane moves upwards accordingly. Vice versa, when the patient performs the opposite movement to close the repetition, the airplane moves downward.

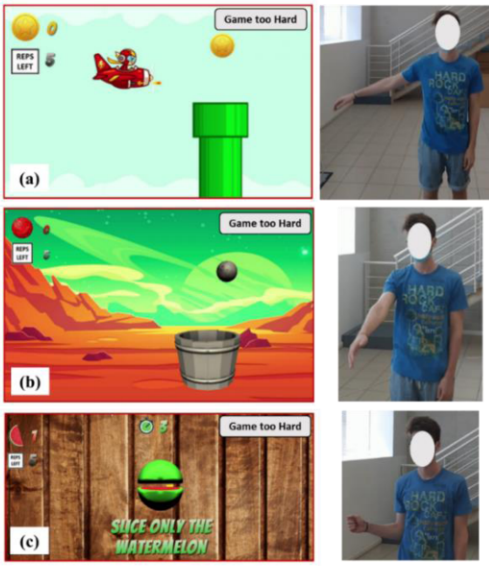


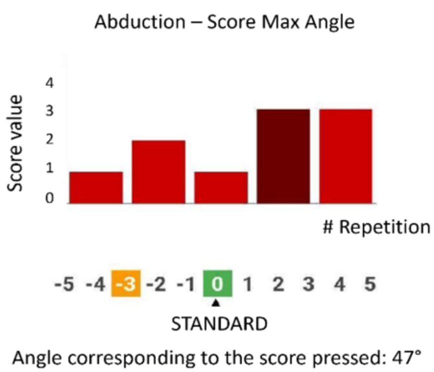
Figure 3. The serious games for the three rehabilitation exercises: the arm abduction (a), the arm flexion (b) and the arm external rotation (c).

In Figure 3(b), the ball is associated to the flexion movement. The goal is to drop the ball into the bucket positioned below. When the patient raises the arm from the initial standing position, the ball, which is sliding from left to right and vice versa, moves downwards accordingly. In Figure 3(c), the slicer is linked to the external rotation movement. The goal is to cut the fruit only if it is a watermelon. When the patient performs a lateral movement of the forearm from the initial standing position, the slicer moves from right to left of the scene and cuts the fruit spawned in the scene.

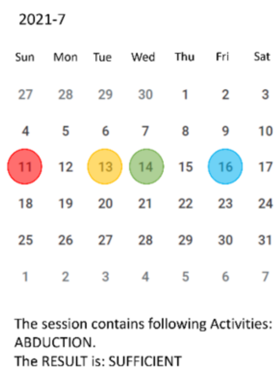
The patients' movements are tracked using the Microsoft Azure Kinect device, which requires an NVidia graphic card to exploits its 3D body tracking algorithms. Among the available 32 virtual joints, only those relative to the upper body (i.e., from the pelvis up to the head) have been considered: hip, shoulder, elbow, wrist, and head.

3.3. Development of the mobile applications

Two mobile applications have been developed respectively for patients and medical personnel. The mobile app for physicians makes available the list of patients to which the rehabilitation process must be scheduled. For each patient, the physicians can schedule a set of weekly sessions of rehabilitation by means of a calendar: the physician can choose which exercise the patient has to perform and the level of difficulty of each serious game. An interface reports the data relative to the automatic evaluation of the rehabilitation sessions already performed by each patient. Figure 4(a) shows the results of each specific exercise during a rehabilitation session: the score between -5 and 5, the maximum angle reached for each performance and the time of execution.



(a)



(b)

Figure 4 – Physician's app (a): session results for a specific patient. Patient's app (b): a calendar with the planned rehabilitation sessions.

The mobile application for patients is composed by a calendar with the rehabilitation activities scheduled by the medical personnel. Figure 4(b) shows the calendar visible in the patient's app. Several colors represent the stage of a rehabilitation session to do (i.e., the blue circle), done correctly (i.e., the green circle), done partially (i.e., the red circle) or the today date (i.e., the yellow circle). The calendar also offers the possibility to check the level of correctness of the performed exercises.

To handle the great amount of data coming from both the serious games and the mobile applications, the designed database allows storing data and information, which can be retrieved by both mobile applications and serious games using a set of REST API generated with Loopback 4.0.

4. Discussion

The prototype of the platform has been tested by ten healthy people. The testers have been requested to play with the serious games by performing the defined rehabilitation exercises both in correct way and wrong way to emulate the pathological condition. The platform and the mobile applications have been evaluated even by the medical personnel. Two orthopedic surgeons and a physiotherapist, specialized in the treatment of shoulder, have been involved in this research work. The serious game has been installed on a personal computer with a GPU NVidia GeForce RTX 2060, which has a cost of 375 Euros. The mobile applications have been installed on two different tablets Samsung Galaxy Tab A.

All the involved testers have correctly performed the requested task. The automatic analysis of motion captured data and the assessment of the correctness of the exercise has mirrored the healthy and the simulated pathological conditions for all the testers.

The obtained results are promising since the platform allows an objective evaluation of the patient's gradual improvements. Moreover, the presence of simple and entertaining game interfaces enhances the patient's engagement in the daily home-based rehabilitation. The use of tablets, smartphones, and the Microsoft Azure Kinect device is coherent with the requirement to be a low-cost solution easy to be used. A limitation is relative to the use of a laptop with an Nvidia graphic card that usually has a higher cost compared with the traditional PCs. Concerning the serious games platform, some effort could be applied in the future to design a better-looking avatar for the recording of the reference movements. Furthermore, real-time feedback about the correctness of the performed exercises could be added.

Physician's and patient's mobile applications are functional, and the interaction is quite intuitive. The physician can remotely visualize the main parameters (i.e., time of performance and angles) in specific bar charts. In this way, he/she can directly intervene if low scores due to a bad execution of the rehabilitation program are identified. Finally, the medical personnel have proposed the integration of sensorized elastic bands, to be able to measure the muscle strength while performing the exercises.

5. Conclusions

The research work presents a web platform for the rehabilitation of injured shoulders based on the use of a Microsoft Azure Kinect device as marker-less mocap system, serious games and mobile applications for both patients and medical personnel. The solution aims to introduce the last generation of the RGB-D Kinect device as tool for telerehabilitation. The gamification of the exercises allows to increase the motivation of the patient to be adherent to the therapy, with the aim to obtain the best outcome possible in terms of recovery of the motor functions, reducing the convalescence time. The solution has been designed and tested by a group of physicians and physiotherapists of an Italian hospital. The involved medical personnel have considered the solutions very promising even if some improvements should be done in the design of the virtual environment of the serious games. Technological limitations have been highlighted relative to the use of a dedicated graphic card to guarantee the correct use of the Azure Kinect device which increase the cost of the IT needed for the rehabilitation at home.

In the upcoming years, thanks to the continuous improvements in technological devices, as well as in the technological skills of the population, telerehabilitation platforms might become a dominant choice for supporting physicians and patients in rehabilitation activities.

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