KiReS: A Kinect-based telerehabilitation system

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***Abstract*—The goal of this paper is to show the main features of KiReS, a telerehabilitation system based on Kinect for Windows, that offers, for both, users and physiotherapists some specific elements that make it more friendly to them. From the point of view of users, they can see in two 3D avatars how an exercise must be executed and how they execute it respectively. This feature can help them improve exercises performance. Moreover during the rehabilitation session they will always see an informative list that shows the exercises to be done in the session. From the point of view of physiotherapists the system allows them on the one hand, to define customized rehabilitation therapies. That can be done by defining different exercises that combine pre-defined movements. Moreover, they can add tests oriented to specific illnesses so that users themselves evaluate their physical state. On the other hand, they can create new exercises just performing those exercises in front of the system and recording them. Those features, not fully supported by already existing telerehabilitation systems, provide an added value that is well valued by both groups. Moreover, a prototype of KiReS is in operation, and allowed us to test its suitability from the point of view of real time performance as well as from the point of view of usability.**

Keywords—Kinect, Telemedicine, Telerehabilitation, Virtual therapy.

I. INTRODUCTION

The aging population and the people higher survival to diseases and traumas that leave physical sequels are challenging aspects in the context of an efficient health management. In this scenario telerehabilitation systems that support remote physiotherapy sessions can help save healthcare costs while improving also the quality of life of people. Telerehabilitation should not be seen as a technology itself, but as the use of new technologies to improve and optimize both, rehabilitation services and users outcomes. Several studies have shown that virtual interaction can be as effective as traditional treatments, and even more, the use of systems with motion capture can increase the intensity of rehabilitation and the fun of the user [1, 2].

Nevertheless we can see that the type of virtual interaction that users have is not equal in all cases. So, we can find systems that make use of wearable devices [3-5]. Other proposals advocate that users do not wear devices but they only use them [6, 7]. Finally, with the aim of facilitating even more the interaction of users appears another trend that advocates the use of Kinect, a motion capture device that tracks user movements without any physical contact. Among the proposals that follow that trend we can distinguish those that use Kinect Xbox version [8-10] and those that use Kinect for Windows, a version that was launched in February 2012. In this last case, the proposals that can be found are mainly commercial products such as [11-13] which do not show many technical details concerning their internal behavior and are oriented to specific pathologies.

In this paper we present KiReS (Kinect Rehabilitation System), a system with which we advocate for a video tracking solution without markers that allows users to control and interact with the system through an interface that can recognize movements, voice commands and objects. We believe that non-invasive solutions are most welcome by the users. Moreover, our proposal presents the following main novel contributions with respect to other proposals. From the point of view of users, KiReS provides a natural form of interaction through two avatars. Those animated characters are able to attract the user's attention. Looking at one avatar the user can see the exercise he must make and looking at the other he can see how he is doing it. This feature can help him to correct the performing of the exercise when he does not make it properly. Furthermore, the postures that constitute an exercise are visualized at the top of the interface, so the user can figure out how much remains to finish the exercise. Last, KiReS provides also to the user the possibility of review summaries of exercises already made by him. From the point of view of physiotherapists, KiReS allows them to define customized exercises for the users, using for that, pre-defined postures and movements already stored in the system; to create new exercises just by performing them in front of the system and recording them; and to add a test or a visual analogue scale in order to have not only objective information from the exercise execution but also subjective information directly from the user. Moreover, physiotherapists can also analyze data recorded of the users in order to redefine the therapy for those users or to discover situations that present problems for many users. Finally, we want to mention that KiReS considers a broad spectrum of types of exercises as opposed to the majority of proposals that consider fixed exercises to specific physical pathologies; and that we have tested it's suitability in a real scenario.

As a summary, we can say that our goal is, as in some previous works, to try to exploit the potential of Kinect for Windows, a non-wearable device, in the area of telerehabilitation because it is a non-invasive and easy-to-use solution for user interaction. Moreover, in the development of KiReS we have put a special emphasis on achieving that KiReS motivates the user, incorporating a friendly interface that includes motivational features. The use of avatars in

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telerehabilitation systems is highly desirable, successful rehabilitation depends largely on the patient's motivation and compliance with therapy. Also the contributions we have described are oriented to obtain a novel system that outcomes the limitations we have identified in other proposals.

The rest of the paper is organized as follows: In section 2 we describe the overall architecture of the system. In section 3 we provide details on the features provided for the user and in section 4 details on the features provided for the physiotherapist. In section 5 we present briefly some results obtained when operating with KiReS. And finally, in section 6 we present our conclusions.

II. AN OVERVIEW OF KIRES

KiReS is a telerehabilitation system that offers the users and the physiotherapists innovative features by using Kinect as interaction device. The architecture of KiReS is divided into modules and follows a client-server approach. We give in the following a brief overview of the main (communication and database access modules, although they exist in the system, are not described nor shown in Fig. 1). Moreover, it is distinguished between the client of the user and the client of the physiotherapist. Both have the same modules but the functionality supported by its respective interface module is different. User's interaction with the system is done only through Kinect while the physiotherapist can interact with keyboard and mouse and also with Kinect.

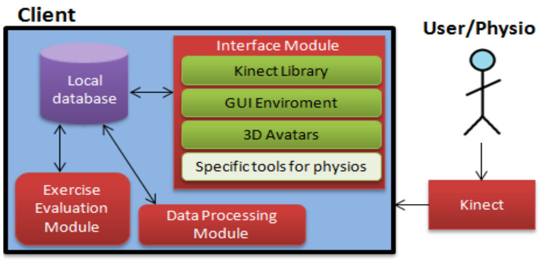

Fig. 1 System architecture

A. *Exercise Evaluation Module*

This module evaluates performed exercises and sets if they have been properly executed by comparing the results obtained with the expected data.

In rehabilitation therapies, exercises are defined using tables. These tables indicate the members of the body that should be exercised and which movements should be performed. The definition of the exercises in our system is based on this way of working, in order to develop a methodology as close as possible to that followed by physiotherapists in traditional therapies. Exercises consist of a series of movements and these movements are composed of an initial posture, one or more trajectories and a final posture. The postures indicate the beginning and the end of a movement, and the trajectories of the joints indicate the movement itself.

We have developed an exercise recognition algorithm that analyses user movements in three stages, one for each element (initial posture, final posture and the trajectories of the most relevant joints).

B. *Data Proccessing Module*

This module handles received data from Kinect and creates a descriptor of the user's posture. The skeleton data that Kinect provides is the base of the descriptor. In this skeleton structure each node is a joint of the body. There are a total of 20 joints described by points with 3 coordinates width, height and depth (see Fig. 2). The data received by Kinect about all joints are processed to obtain three types of measures: angles between joints, angles between limbs and, relative positions in the Z axis. With all these measures we define a descriptor of 30 features that gives information about the relative position in 3D and angles formed by the different members of the body (please see in [14] the features of the descriptor).

Fig. 2 Joints of Kinect skeleton

C. *Interface Module*

As mentioned before, the features of the interfaces designed for users and physiotherapists are different. We show them in section III and IV respectively. However, in both cases, interfaces have been developed using Unity 4 for the 3D environment and all the scripts that control the behavior of the interface were developed in C#. The avatars and the rest of the 3D models were modeled in 3Ds Max and exported to Unity.

Kinect drivers are not directly compatible with Unity, for this reason, an open source dll library has been used for interaction. This library provides basic functionality for Kinect in Unity.

III. KIRES FOR USERS

When displaying the exercises, the interface has to be attractive enough to encourage users to participate in therapy but also simple and clear. The interface module handles the structure and functionality of the provided GUI (Graphical User Interface) and of 3D avatars that show the user how to execute the exercise and the actual execution respectively. Other elements could be incorporated to the interface in order to provide comments and tips for the user.

A. *Exercise execution*

The interface for exercises execution handles two avatars (see Fig. 3). The one on the left shows to the user the exercise he/she has to execute. This avatar can show the posture that the user has to perform (the initial posture of the next movement) or it can show the movement the user has to do. The avatar on the right follows the user and shows the ongoing posture he/she is performing.

The avatar on the left acts as a guide for the user showing the exercise he/she has to do. In the meantime the exercise recognition algorithm analyzes user's posture and movements and updates the avatar on the right and the boxes below to give information.

As Fig. 3 shows, this interface has also in the low part four informative boxes that give specific information to the user. A series is the list of exercises to be done on a session and the repetitions is the number of times an exercise has to be done in each series. The boxes in the first line show the number of series left and the number of repetitions left for the actual exercise respectively. When the user has done all the series of the session the session is finished.

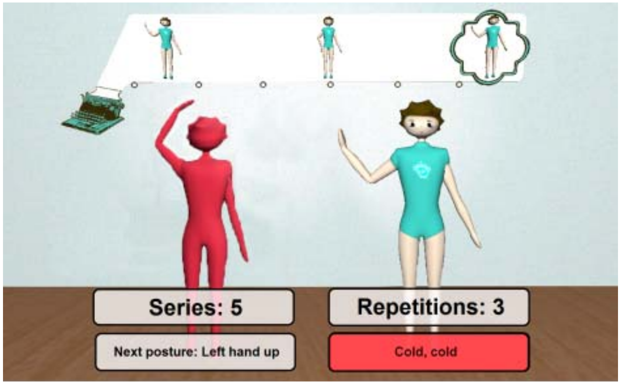

Fig. 3 Performing an exercise of a series

In the second line there are two more boxes. The box on the left shows the name of the next posture the user has to reach. And the one on the right shows the "state" of the actual movement in real time. This box is continuously updated by the exercise recognition algorithm and it displays the info with five different messages:

- "Execute the movement": When the user has reached the initial position and has to execute the movement
- "Execute posture": When the user is very far from reaching the next posture.
- "Cold, cold" (Red box): When the user is about to reach the posture.
- "You're close" (Yellow box): When the user is very close to the posture.
- "Correct!!" (Green box): When the posture is correct.

The avatars and the informative boxes provide feedback to the user. This way the system guides the user in his/her therapy, but also provides a game-like immersive experience that motivates and makes the therapy more enjoyable.

On the top there is a ribbon that shows the exercise as the list of postures that have to be reached in a session. This ribbon is updated as the user completes exercises to show in every moment how many are left.

IV. KIRES FOR THE PHYSIOTHERAPIST

The therapy management tool is specific for the physiotherapist interface. On the one hand, it handles aspects concerning the development of therapies and, on the other hand, it facilitates the task of associating auto tests to therapies. In the following subsections we explain briefly those two aspects.

A. Therapy management

When a physiotherapist needs to define a therapy for a user he can use predefined exercises or he can define new ones. In the first case, those exercises had also been defined previously; for that reason, we focus on the task of managing postures, movements and exercises respectively. New postures and movements are added performing them in front of Kinect, after that can be assigned to the new exercises. The interface provides the assistance to create exercises step by step, this way we guarantee that the exercise structure is respected and our recognition algorithm is able to evaluate them.

1) Posture management

Posture definition requires fulfilling a simple form giving a name to identify it. A posture is the simplest element of an exercise and therefore necessary for the definition of any other structure.

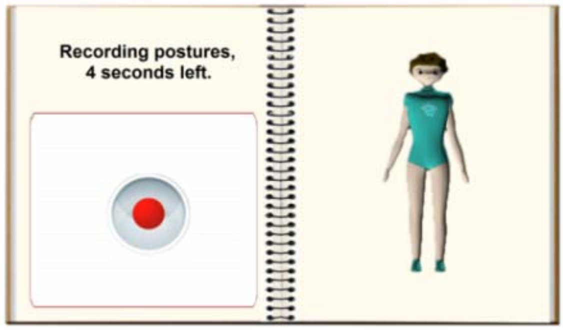

Fig. 4 Posture recording

The physiotherapist performs the posture in front of the system and records it (see Fig. 4). Then, a recording player tools allows him/her to select frame by frame which postures to store from the recording. When storing postures, the posture recognition algorithm analyzes them in order to guarantee that they are similar enough. This way the possibility of adding completely different postures with the same name is avoided. For the best recognition accuracy it's convenient to store at least 6 different examples of a posture.

2) Movement management

Movement definition requires assigning at least a name to identify the movement and select the initial and final posture that the movement will have. Once both postures are selected, the system analyzes them. The relevant joints, that best represent the transition from initial posture to final posture, are selected from the posture descriptors. These joints will be recorded and stored to characterize the movement in the next phase.

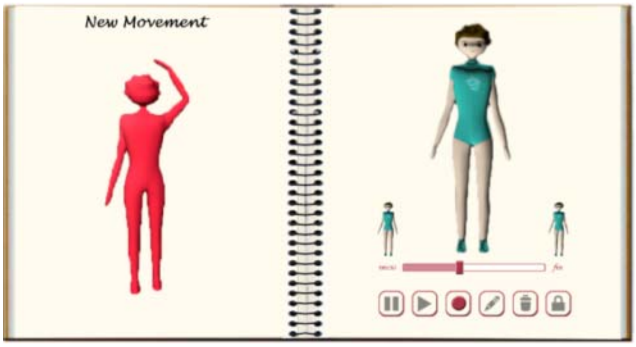

Fig. 5 Movement recording

Movement recording makes use of the same features as posture recording. In this case the physiotherapist selects the movement he/she wants to record and the system shows an interface like Fig. 5. In this interface two avatars are shown. The one on the right is controlled by the therapist. The one on the left shows the therapist the posture he/she must reach. The posture recognition algorithms checks when the therapist makes both the initial and final posture. In the meantime the trajectory of the relevant joints is recorded. After reaching the final posture the recording player tool is available and the therapist can visualize the movement and decide whether to store it or not. It is recommended to perform and record at least 4 times the same movement.

3) *Exercise management*

Exercise definition is made by assigning movements to an exercise. A simple exercise can be made with just one movement but complex exercises are defined as a combination of basic movements, creating a sequence of movements where the final posture of a movement matches the initial posture of the next one.

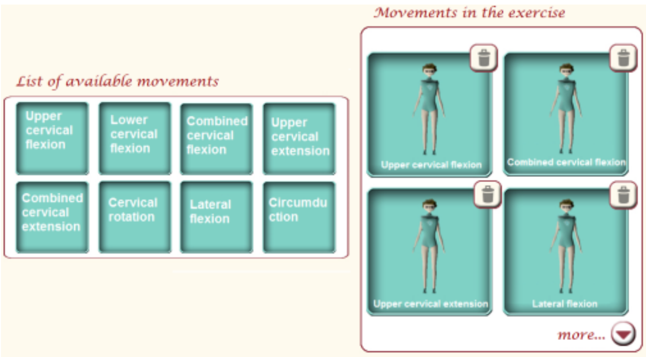

Fig. 6 Exercise definition

The exercise creation interface allows the therapist to define the composition of an exercise. It shows a form to fulfill data of the exercises and two lists (see Fig. 6). The top list contains the movements assigned to that exercise and the bottom list contains the available movements to add. When selecting a movement the system checks if the final posture of the previous movements matches the initial of the new one. If they match the movement is added to the exercise. This is the last step to define a new exercise. Once this is done the exercise will be stored in the system and will be available to add them to a therapy session.

B. *Tests management*

Performance evaluation is an important factor in therapy. Our proposal includes the option of adding two types of subjective evaluation tests, auto tests and visual analogue scale. Users may answer after their session these tests in order to have not only objective information from the exercise execution but also subjective information directly from the user.

1) *Auto tests*

The auto test interface is oriented to create, manage and evaluate auto tests. These auto tests include questions about different aspect of user's daily life and the possible answers are valued differently depending on their severity. We developed an auto test management interface, in order to include these tests in the system. With this tool, the therapist defines the questions of the test and the possible answers with their punctuation. Once the test is defined, the therapist can assign it to a therapy, so that, the user will have to answer the test before ending a session. Test results are automatically generated according to specifications once the user has answered the questions.

For each physical alteration a specific auto test can be defined to accurately measure user's state. Thus, the system lets the therapists add subjective user evaluation to the automatic evaluation of our algorithm.

2) *Visual analogue scale (VAS) for pain*

Another evaluation tool used in physiotherapy that we have incorporated to our system is VAS. The visual analogue scale is a technique used to measure subjective phenomena like pain. It is a self-reporting device consisting of a line of predetermined length that separates extreme boundaries of the phenomenon being measured.

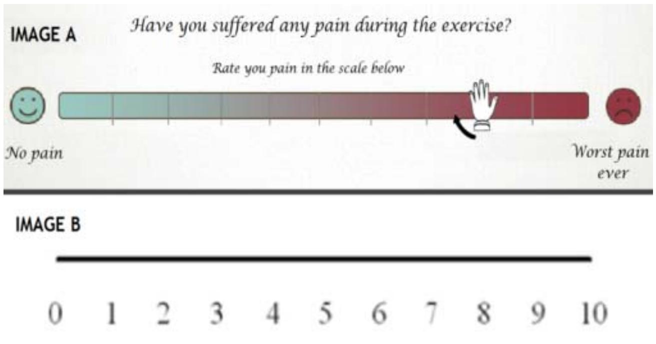

Fig. 7 VAS example

The user sees the image A, on which he/she marks a point on the line between the absence of pain and the worst pain you can imagine. That point is projected on a sliding scale scored from 0 to 10 (image B) that the user will not see (This value may be rounded). Like in auto tests the system lets the therapist to decide when he/she wants to add the pain test with VAS.

V. Some Performance Results

Since we have developed a functional prototype we made some performance tests in order to analyze the suitability of the system. Using the specific algorithm that we developed for exercise recognition with Kinect, we made some performance tests to measure recognition accuracy and execution time. We have created, with the supervision of physiotherapists, some test and train datasets to evaluate the performance of the algorithms. In the recording of the datasets five volunteers took part. These datasets contain on the one hand, body postures (45 in the train set and 4500 in the test set) and, on the other hand, recordings of rehabilitation exercises (32 recordings in the train set and 48 in the test set). We achieved a 91% accuracy in posture recognition, an 88% accuracy detecting correct exercise executions and a 94% accuracy detecting wrong exercise executions. The previous results are close to those reported in [15] (85% accuracy) or in [16] (91.2% accuracy). Although it is difficult to make an accurate comparison, because the first [15], uses a different device to track movement, and the second [16], is oriented to complex pose comparison in 3D motion data. We cannot compare results with other systems that use Kinect [8-13] because they do not provide performance results. During the tests we also established a threshold value for posture recognition. This parameter is adjustable, therapist could change it to make the system more strict identifying body postures depending on the stage of the therapy.

Considering that user feedback is a key point for a successful rehabilitation, the recognition algorithm should be able to process Kinect data in real time. So we checked whether the algorithm was able to process the data without delays in the system. We found that our algorithm could process more than 20000 postures per frame, which in practice guaranties no perceptible delays (for more details see [17]).

VI. Conclusions

This paper presents the main features of KiReS, a Kinect for Windows based telerehabilitation system. This system is oriented to take advantage of the innovative interaction capabilities of Kinect in order to offer new functionalities for the users but also for the physiotherapists. The different modules of KiReS provide a wide spectrum of functionalities standing out: posture, movement and exercise efficient management; user interaction via Kinect; exercise recognition and evaluation capabilities; and a user friendly interface with 3D avatars.

In order to develop the system and characterize postures, movements and exercises we have worked jointly with physiotherapists. In contrast to other approaches, KiReS is adaptable to different physical treatments. It can be loaded with exercises for a wide variety of physical alterations, giving physiotherapists the opportunity to add themselves new exercises according to their own criteria. We also think that assessment based on scientific methods (combining automatic evaluation with user auto tests) is a point of difference of our proposal.

Additionally the system allows the recording of a great amount of patients' data: exercise executions, therapy evaluations, results of the tests, in summary, the recovery evolution of the users. We believe that these data can be a great source of knowledge for the physiotherapists. That is why in future research we expect to develop a data mining and an automatic therapy planning module to exploit all these data.

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