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MIRA –UPPER LIMB REHABILITATION SYSTEM USING MICROSOFT KINECT

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Abstract. In the current context of profound involvement of technology in different areas of science, our research approaches the medical field, aiming to help the physical recovery process of people having a temporary handicap at the upper limb.

The result of our research is a software application called MIRA (Medical Interactive Recovery Assistant) that uses the Microsoft Kinect sensor, which, having an RGB camera, an IR camera and a depth sensor, makes possible the detection of the arm and its movement relative to the body. The application comes in the help of doctors, who receive important statistics and data about the performance of the patients during the exercises and games. Furthermore, receiving accurate data about the moves, the patients do not need to be supervised by a medical professional at all times, as the correctness of the exercises are verified automatically.

1. Introduction

In the last decades, medicine has improved its therapeutic procedures and techniques, making use of numerous modern approaches that are given by the exponential development in technology and other sciences. Being well known that the physical health is strongly related to the mental condition of the patients, to their motivation and engagement in fighting the illness they have to face with, a lot of studies have focused on how to improve their moral, by bringing fun or interesting elements in the recovery treatment.

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In this context, occupational therapy is known to promote health by enabling people to perform meaningful and purposeful occupations like enjoying life, being socially and economically productive, being involved in community or group activities [2]. In this area, the use of Video-Games together with Virtual and Augmented Reality is more and more acknowledged by recent studies, not only as an occupational therapy framework basis, but also in physical therapy and rehabilitation, for both adults and children with movement problems having neurological or trauma causes.

Regarding these, our solution MIRA (Medical Interactive Recovery Assistant) proposes to assist and augment the physical recovery process of patients with movement disabilities (at the upper limb) caused by neurological, orthopedic and rheumatoid problems, by the use of interactive applications and games that monitor the patients' movement and engage them in performing the exercises recommended for recovery. This is something that many researchers have recently tried to achieve using different devices and sensors for patients' movements detection, like the Wii-mote, but the innovation we bring is given by the use of a latest generation sensor , the Microsoft Kinect, which tracks the human motion without requiring any devices attached to the body. Even more, the application provides meaningfull feedback, like statistical data about the patients' movement, which can be used by the doctor as an evaluation of the patients' state and improvement.

This way, it is supposed to improve the recovery process, shortening the period (it is known that physical exercises reduce the recovery time with 50% to 70%) and saving time and money for the medical institutions, while being attractive, engaging and adaptive to the patients' needs.

The next section describes comparatively the results obtained by similar studies and applications, such as Wii-hab. Section three contains a list of used technologies and a detailed presentation of Kinect: its capabilities, possible improvements and extensions. Also, the features provided by the open SDK used for programming Kinect will be presented here. The solution and its functionality will be explained in the fourth section: what does MIRA offer, how does it work in practice, the exercises mapped till now for the upper limb and the games created on this basis, how the data about the movements are collected and interpreted, which were the main challenges and which are the possibilities for future extension. Last, will be presented the evaluation results made on the patients at the Rehabilitation Hospital of Cluj-Napoca and the conclusions and future perspectives regarding the development of MIRA.

2. Related work

The use of virtual reality in medicine is under a continuous study for the past years, starting with simulation environments for practicing surgery and other medical interventions, continuing with diagnosing from 3D data mapping of human body and ending with psychological and physical rehabilitation therapies. Therefore, MIRA was inspired by many ideas already seen in existing application and studies.

Regarding this area of study, we know that the recovery of patients is usually a lengthy process that requires professional supervision. From our perspective, the best improvement would be a device that monitors the patients' movement and progress, while providing visual feedback during the rehabilitation exercises.

This was achieved by other studies, through games that use sensors for collecting data about the patients movement, having an adaptive difficulty for every patient and a winning rate of 80%, in order to keep the patient engaged in making exercises and avoid getting him or her bored because of always winning or frustrated because of low performance. Some good examples of such systems and studies, mainly as an aid to recovery therapies of stroke patients, are the ones designed by RIVERS Lab, using the Glove and other external devices for input in Virtual Reality applications [4], by VividGroups Gesture Xtreme Virtual Reality using the PlayStation II EyeToy [5] and a very interesting system using Webcam based Augmented Reality applications [7]. The clinic Northern Arm & Hand Center for Upper Limb Rehabilitation in Duluth, Minessota, uses VR games in this kind of therapy as they wanted to create a relaxed and family-oriented environment for the patients, and noticed that many patients over-exercise because they enjoy so much playing, and forget about their condition, fastening the recovery [9]. A Canadian study managed to measure the percentage of improvement in case of a VR and Video Games based therapy in Stroke Rehabilitation in comparison with classical recreational routine therapy, on a number of twenty stroke survivors; after two weeks the results in terms of improvement measured on different tasks were with 30% more advanced in the case of th patients that used games during the therapy [8].

A very similar application to ours is Wii-hab, based on the Wii-fit system, that uses the Wii-remote for movement detection to implement a system on exercises for limb recovery in different types of injuries (the system is functioning, but still in development, exploring its potential) [?]. The difference is in that they use existent games which are likely to require adaptations to the limitations of the patients with disabilities, and their target is much wider, including a large spectrum of therapeutic procedure, while MIRA is specialized on physical rehabilitation and adapts to the patient's limited range of motion (of the upper limb).

In this context, this system would be the first one that is created specifically to assist the recovery process of patients in an interactive and fun way, not just using existing games, but creating them so that any patient would enjoy playing while recovering, making use of a last hour wireless device, the Kinect.

3. Microsoft Kinect

3.1. **Motion Sensor.** "Microsoft Kinect (Figure 1) is based on a software technology developed internally by Rare, a subsidiary of Microsoft Game Studios owned by Microsoft, and on range camera technology by Israeli developer PrimeSense, which interprets 3D scene information from a continuously-projected infrared structured light." [1] This system employs a variant of image-based 3D reconstruction, which actually means that it is very convenient for every person, as it is wireless, requires no devices attached to the body, and permits total freedom in movement.

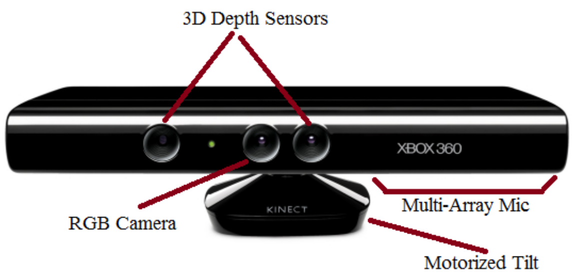

Figure 1. Microsoft Kinect for Xbox 360 [1]

Physically, the Kinect sensor "is a horizontal bar connected to a small base with a motorized pivot and is designed to be positioned lengthwise above or below the video display. The device features an RGB camera, depth sensor and multi-array microphone running proprietary software,which provide full-body 3D motion capture, facial recognition and voice recognition capabilities.[...] The depth sensor consists of an infrared laser projector combined with a monochrome CMOS sensor, which captures video data in 3D under any ambient light conditions. The sensing range of the depth sensor is adjustable, and the Kinect software is capable of automatically calibrating the sensor based on game-play and the player's physical environment, accommodating for the presence of furniture or other obstacles." [**?**]

The most interesting thing is that Kinect offers the possibility of "simultaneously tracking up to six people, including two active players for motion analysis with a feature extraction of 20 joints per player" [1], the number of people the device can detect being limited only by how many will fit in the field-of-view of the camera.

3.2. **Programming Kinect using the OpenNI library.** MIRA was initially created using the OpenNI SDK with the NITE library and the PrimeSense drivers that provide the possibility of programming in many languages, and on different platforms. The one used here, on Windows OS, in C# (Visual Studio 2010), provides us with the possibility of detecting gestures (hand wave, hand click), the entire human body, or partially, after recognizing a pose body position similar in shape to the Greek letter "ψ"(psi) as presented in Figure 2. The wave gesture detection is used also for the hand position detection, that can be tracked during the application or game, after this pose position was detected. If the hand tracking is lost for a short period, the simple gesture of raising the hand will help quickly recognizing it, and it will start being tracked again. [3]

The human body recognition and body parts tracking is done in several steps. First, a movement with the whole body in front of the sensor will signal that a person is there and it will wait for the pose detection. When the "ψ" position is identified (standing straight, with hands up, forming a right angle at the elbow and between the trunk and forearm) it starts the calibration process: the joints positions are calculated. When this is completed, all the user's motions and body parts are tracked: head, neck, hand, elbow, shoulder, knee, etc. It is possible to make the calibration detect the entire body (which requires standing up), or only for certain regions: the upper part (which can be done even sitting down), or only head and hands. In case the tracking of one or more joints is lost, reassuming the "ψ" position will quickly solve the

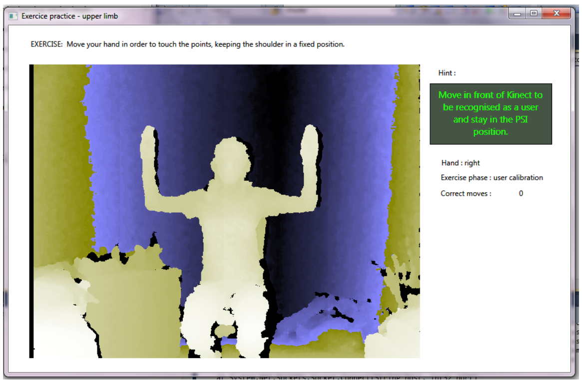

FIGURE 2. The "ψ" position of the body, while sitting on a chair. The depth map is visualized from white to yellow (near) and from light to dark blue (far).

problem. The best part is that many users can be tracked at once, at least two or three, even if they overlap and move in front of the camera.

4. The idea of MIRA

4.1. **What is MIRA.** Knowing these new tendencies in medicine, MIRA, as we designed it, should build an appropriate framework for the fulfillment of the medicine's new objectives. It is a system composed of interactive applications and games based on external sensors, created specifically to assist the patients during rehabilitation therapy.

The applications and games are created such that they require the same moves as in the case of a medical exercise, while monitoring the movements of the patient, in order to evaluate the correctness of the exercises (example in Figure 3), to adapt to the patients possibility of movement and to provide a statistical feedback about its performance and improvement. This way, the presence of the specialized medical staff is not required at all times, as the movements are correctly supervised, and this kind of therapy could replace a large amount of classical exercises.

By providing a good visual and audio feedback, these applications and games are very engaging and motivating for patients, being powerful stimuli to overcome their limits and to regain reflexes and dexterity. Moreover, the games are conceived such that the winning rate is about 80%, in order to keep the patient motivated to play and not frustrated by too much losing or bored

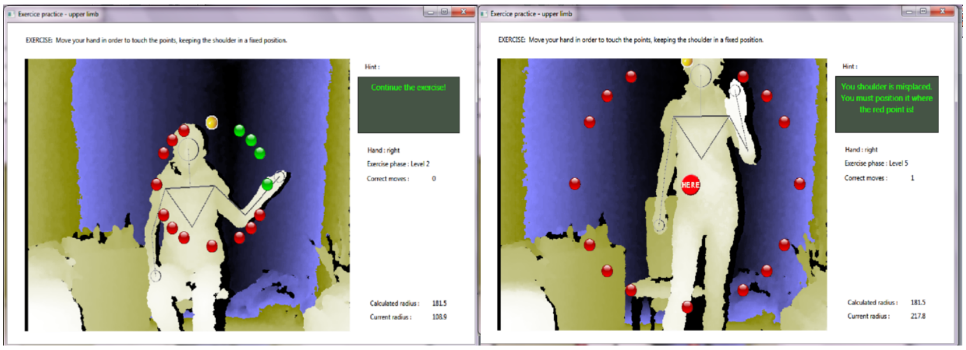

FIGURE 3. Patient performing rotation exercise for the shoulder in a correct manner (left) and trying to cheat, raised up from the chair (right the red point specifies that the shoulder should be placed there).

by too much winning. The applications perform the calibration, registering the range movement (the basis, calculated for each patient) and then sets the target range 10% higher during the exercises, in order to push the patient towards improvement.

Initially, for monitoring the patients' movement, we used an accelerometer, because it was very good for detecting the arm moves in four directions, and approximating the acceleration of the movement , while being attached to the patients' hand. The idea was to create a system that could be used with any device that contained an accelerometer, like a Wii-mote, a smart phone and so on, in order to keep extra costs low and increase its range of applicability for any kind of person. Despite this, it had different flows: for more complex motions, something more sophisticated was needed to monitor the movement, to prevent cheating and to be able to monitor even patients that are able to do only small limited movement, with a very small acceleration. This required the integration with some other sensors that would have increased the costs very much and lead us far from the main idea of making it universal and adaptive to other existing devices.

But looking at the latest technology products, the Microsoft Kinect was a single sensor providing a complete feedback with respect to what was needed: detects the human body with its components and joints, providing feedback about its position in a 3D space. It is wireless, requires no other devices attached on the human body, does not depend on light, magnetism or other sensible environment factors, because it is based on a web-cam, an infrared-cam and a depth sensor that complete each other in detecting 3D objects.

Another feature that brings efficiency is that it can be used at the hospital, with two patients at once, or at home for those who have a Kinect sensor. The feedback obtained is relevant in all cases and can serve the medical staff to decide the next step of the therapy.

4.2. **The system architecture.** MIRA consists of a Desktop interface application for the therapist, that manages the list of patients and their data, and a series of applications and games mapped on different types of exercises. What we are interested in here is the second part, mainly the interaction between the application and patient during the exercises, provided by the Kinect sensor.

The existent applications can be split into several categories, considering their functionality : applications for user calibration, applications for learning, performing and correcting typical exercises and moves, and games mapped on the same type of exercises. The first two types of applications consist of gradual exercises and moves, destined for beginners, to get used to the system and to performing exercises with MIRA. The last category brings a large diversity of games that keep the patient engaged in a range of moves adapted to the patient's possibility of movement, using the values calculated in the previous exercises.

The applications can also be categorized by the recognition gesture that needs to be done by the patient : the "ψ" pose position, for advanced patients that can raise their hands up, or the wave hand gesture for the patients that are able to perform only limited movements.

From a technical point of view, the applications' visual feedback is based on either virtual or augmented reality, in all types of applications and games developed in C# using WPF, Silverlight and OpenTK.

The types of exercises and games currently implemented by MRA include the basic movements of the arm: extension and flexion of the shoulder and elbow, rotation of the shoulder, dexterity and reflexes of the entire hand, detailed finger motion. Every application has an option for remote monitoring, that would be ready to be activated and used after setting it up in a large medical system.

4.3. **The conceptual model on which exercises are based.** The current implemented exercises were recommanded and validated by medical specialists and constitute the basics of the rehabilitation therapy of the upper limb. For typical exercises, the patients have to perform the calibration phase, after which they have to touch with their hand (more eaxctly with the hand of their body represented virtually in the application, as tracked by the sensor) some points on the screen, according to the type of exercises (shoulder flexion-extension, rotation and left-right movement, elbow flexion-extension). In the calibration phase, the system computes the user's body dimentions and adjusts the position of the points that mark the wanted movement according to his or her particularities. The exercises are progressively; this means that they start in a simple way and as the level of the exercises increases, the points are placed such that the movement of the hand that should touch them becomes wider and more complex (for example, in a rotation movement, the points are situated in a small circle, and as the level increases, the circle becomes wider till it requires a completely stretched hand). In case of the games (Figure 4 presents some examples), the same principle is valid, but instead of points there are different funny elements, as butterflies, and more complex movements (for example use of fingers in the puzzle game). Also, the system verifies the correct position of the body relative to the initial calibration position, in terms of distance, correct position of the shoulder or elbow relative to the Kinect sensor and to the hand during the exercise. If such a mistake is detected, the user is announced and can not continue the exercise, unless the exercise is done correctly. Of course, a small percentage of error is admitted, easily adjustable according to the disability of the patients, knowing that they might not be capable of a perfect performance at the beginning.

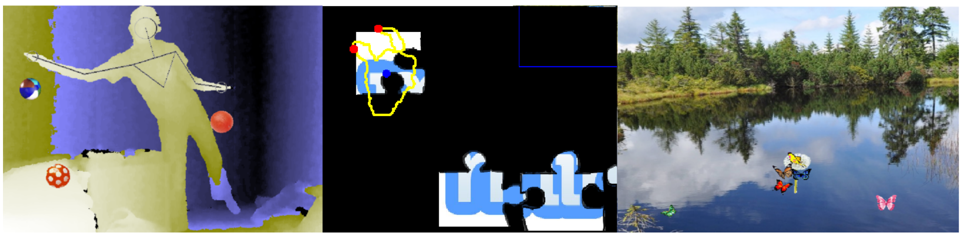

FIGURE 4. Other games and exercises: BeatBalls, Puzzle, Butterfly

The importance of this system is that it implements specific exercises and games, that match the specific requirements of the patients that need rehabilitation therapy. As it is very flexible at the software level, it is the most convenient for rehabilitation centers, as it requires a unique device at a low price with a lot of utilities, always extensible in a short time. This way, when a particular new case appears, it is easy to implement something adapted to it, without requiring the construction of a new device that would suit the specific need of the patient. As a result, the patients can perform the correct exercises in a fun way, fastening their recovery also because of the increased moral, the exercises adapted perfectly to them in matters of difficulty and fun factor, and because they can perform the exercises any time, regardless of the availability of a therapist.

5. Evaluation of MIRA

The application had great success among the patients that can recover even at home, by playing, and also among medical professionals that gain more time. Testing done on patients at the Rehabilitation Hospital in Cluj-Napoca proved that the applications and games engage the patients in the physical rehabilitation therapy very intensely, and motivates them to perform the exercises while fully capturing their attention. As a result, the improvements were very soon noticed in terms of physical mobility and reflexes, but also in what concerns the mental state of the patients.

The main study subject was a 30 year old male, recovering from shoulder fracture. At first, he was not able to make the "ψ" position, so we skipped to the simpler games that require a wave gesture for the detection of the hand. These games made him very interested, and being concentrated on winning, his hand was making wider moves than usually, pushing himself to something more. He is still recovering, but he seems motivated by MIRA and quickly improving. He is still not yet able to make the "ψ" position, which keeps him from performing many of exercises that would fit him better and help him more, so it would be necessary to create an improved calibration that permits the pose detection in some other position that is easier to perform by a person with a shoulder movement disability.

6. Conclusions and future perspectives

MIRA seems to have achieved its purpose in making the recovery process of the upper limb more efficient and pleasant by using applications and games based on external sensors (mainly the Microsoft Kinect), but future improvements are required in order to make it usable by rehabilitation centers and even at home, personally. The medical advisors in the project suggest that it should be extended to support other disabilities as well, a wider scale of exercises and games, a more complex interpretation of the incoming data about the pacients' motions, and to offer the possibility for phyicians to create easily new exercises and games using a specially designed framework. Also a different pose detection needs to be implemented, to increase the adaptability of the system to any kind of disability that could benefit from it, but this is easity implemented with the official Microsoft Kinect SDK that has been released in the meantime and, of course, now it is considered for the future implementation of MIRA applications.

But the most important scientific contribution of this system is the fact that it manages to offer a new way of using technology in the benefit of medical health. Moreover, based on similar existing system that proved to be useful, it takes the best of each, creating something with a great potential that is recognised both by specialised medical therapists and by researchers in this field of technology, which agree that even if the classical therapies and the physicist's guidance during the exercises is very important, in many cases when they are not possible or productive, this system would be able supplement or even replace these in a very efficient manner.

7. Acknowledgements

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