The Mobile RehApp™: an AR-based mobile game for ankle sprain rehabilitation

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***Abstract*—People struggle to recover from injuries due to the lack of commitment to their rehabilitation exercises as they are often boring. Recent approaches that involve the use of interactive video games have shown positive results in exercising as users engage in physical activity while playing a game. For example Nintendo Wii and Microsoft Kinect based games have shown to be effective in the treatment of post stroke patients. Yet, there are not tools in the market that offer portable rehabilitation exercises in the form of interactive games. The work presented in this paper focuses on the development of the Mobile RehApp™, an augmented reality based application for mobile devices designed for therapeutic support that aims to assist physiotherapists and patients on ankle sprain rehabilitation.**

Keywords—augmented reality, mobile augmented reality, ankle sprain rehabilitation, exergames, mobile games, serious games for health, gamification, games for rehabilitation, lower limbs.

I. INTRODUCTION

Physical exercise has shown to be one of the most effective ways to improve well-being and quality of life. Working out is becoming a must in the modern society not only because of the health improvement benefits but also as a means to rehabilitate from injuries [1-3]. Similarly, passive and active exercises are beneficial for the development of muscles, tissues and a strong skeletal structure [4]. More importantly, regular physical activity has shown to dramatically reduce the risk of diseases such as diabetes, high blood pressure and stroke [3].

There are however some risks inherent in the practicing of a sport that could lead to suffering injuries such as contusions, sprains or even fractures [1-3]. In a comprehensive study conducted by the School of Medicine at the University of Rochester, Football was shown to be the most common sport of injury with 1185 out of 4551 cases of injuries surveyed over a 7 year period [5]. This is 12 times the number of injuries seen in the next most common sport of injury, which is basketball with 126 cases. More importantly, it was found that the most common areas injured were the knee and ankle, where sprains and strains were shown to be the most common injury with 949 cases for males and 194 for females. These injuries can become problematic and recurrent if not treated correctly [3].

Despite the fact that physical rehabilitation can help to recover from injuries, it can also be tedious and boring. This is mainly attributed to the exercises not appealing to most patients, and the inconvenience of having to keep their health constantly monitored and reassessed through periodical visits to the specialist. More importantly the inappropriate execution of the prescribed exercises may affect negatively the rehabilitation process.

One of the ways through which this can be improved is the use of technology that provides appropriate visual feedback allowing the patient to perform the exercises adequately [6]. For instance, the work of to Shull et al [7], use visual clues to provide accurate biomechanical feedback on user's performance during gait retaining therapy. Similarly, the use of virtual reality technology in lower limbs rehabilitation showed positive results in delivering training exercises as well as measuring the effectiveness of the treatment [8].

These new rehabilitation technologies can bring new aspects and elements on diagnosis and treatment in order to cooperate with other disciplines and enhance the benefits for the parties [9]. However to facilitate this type of feedback, specialized equipment and trained personnel are often required, hence limiting its use in a laboratory or clinical settings [6].

In this paper we describe the development of the Mobile RehApp™, a game application for mobile devices that aims to assist physiotherapists and patients on ankle sprain rehabilitation in a portable and cost-efficient manner. The Mobile RehaApp uses Mobile Augmented Reality (MAR) to deliver range of motion (ROM) exercises as well as monitor the user's performance in a form of a game. The rest of the paper is structured as follows: Section 2 presents a brief summary of related work in the field of augmented reality applications for health and rehabilitation. In Section 3, the methodology of this study is presented. Section 4 describes the design process and the aspects that were considered throughout the development process. Finally, the discussion and conclusions can be found in Section 5 and 6.

II. RELATED WORK

Augmented Reality (AR) and Mobile Augmented Reality (MAR) are fast growing technologies that are being applied to different fields including, business, marketing and gamming. It can be described as an augmented virtualization of the real world or environment by over imposing computer-generated inputs such as graphics, video, sound and GPS information. AR and MAR technologies are being adopted and used for a whole

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range of innovative applications, moving from the IT industry and diversifying its approaches into businesses, gaming, among others.

In the area of rehabilitation and physiotherapy, AR has also gained much interest. For instance Alamri et al. [10] used AR-based game to develop a rehabilitation system that aims to minimize the need of therapist supervision during post-stroke rehabilitation. This system delivers interactive exercises though the use of two guided games and three unguided ones. In the guided games, a set of predefined scenarios are presented and the user is required to complete them. The game ends when the last step is completed. In the unguided setting, a patient plays against a computer controlled opponent. The winner of the game is determined by the player who achieves the maximum score. Every game was mindfully designed to enhance the motor function capability of the patient hand whilst monitoring the user's performance. This feature reduces the complexity in the rehabilitation process as it eliminates one of the main limitations of such systems, that is the ability to continuously evaluate patient's performance. The lack of a reliable measurement of the patient's performance can affect negatively the therapist's decision making ability in his/her treatment. This feature makes this system potentially useful in a clinical setting as it allows for an enhanced treatment plan for the patient.

In the work done by Zhang, et al [11], a low cost rehabilitation system for hand motion was built based on AR technology. In this system the interaction is achieved through the use of a custom-made data-glove that is being monitored by a web camera attached to a computer. Through the use of flex sensors, the data-glove can detect the bending angles of the fingers. In addition to this, a virtual piano game was developed to train the dexterity of the fingers. The virtual piano is ideal for patients suffering from muscle weakness, as the virtual keys do not require considerable muscle strength in the fingers to press the keys. One of the problems with this approach is that the use of the glove still imposes an obstacle on the degree of freedom and the portability of the system.

In the work done by Ranky et al [12], an augmented reality cycling kit was built as a tool for training and exercising. This system consists of a TV set, a computer and a set of sensors installed on a stationary bicycle. The sensors monitor physiological and biomechanical parameters of participants while immersed in a virtual reality simulation. Also a set of hydraulic pressure sensors and pedals were attached to the cycle to monitor lower extremity kinetics and kinematics. Measurements taken by systems are transferred to the practitioner's screen where they can be amplified before entering the virtual environment. This feature enables the practitioner to personalize the delivery of the exercises, whoever, the practitioner is still required to devote the time to monitor the patient.

In summary, all these approaches indicate a huge potential for AR-based systems specifically designed for rehabilitation purposes. AR technology is growing and reaching diverse fields at a fast pace and the gamification of a well-known process such as rehabilitation could be advantageous and beneficial not only for the professionals in the field but also for patients by making the process and applications more attractive and appealing for the user. However, there is still a gap in the literature about AR applications developed for lower limb rehabilitation.

The work presented in this paper utilizes Mobile Augmented Reality technology to deliver rehabilitation exercises that aim to assist on ankle sprain recovery. MAR technology is used to track markers located on the feet of the user and translates their movement into interactive elements of a mobile game application without the need of using a game controller or additional sensors to operate. This feature makes this system ideal for mobile ankle rehabilitation not only because it is portable and cost-effective but also because it increases adherence to therapy, and provides the patient with real-time feedback on the prescribed exercises.

Furthermore, the proposed system incorporates mechanisms that can potentially collect health performance parameters and transfer these data over the Internet via a cloud based system. These results can then be accessed remotely by the user, or physiotherapist, and could potentially close the gap between practitioners and patients. The following section sets out the methodology used for the conception of this system and the most relevant aspects that were considered through the design process.

III. METHODOLOGY

In order to develop an understanding of the requirements for MAR-based rehabilitation tool, the technology was initially explored in order to assess its capabilities and limitations. The resulting criteria was determined according to the following challenging technical aspects of MAR technology: (1) Power consumption: MAR systems require considerable amounts of computation, calculation, storing and matching [13]; (2) Light sensibility and depth perception in indoor and outdoor areas [14]. (3) Inability to measure force and pressure [15].

A literature review on existing exercises for ankle sprain rehabilitation was conducted. The review was aligned to the technical specifications with the purpose of identifying a set of exercises that can be performed with MAR technology.

A number of exercises that could be performed without utilizing expensive equipment were found; however, most of them were not suitable to be used with Mobile AR technology. The majority were discarded due to the need of using external objects such as a board like in the case of balance recovery, or an immovable object in the case of strength training exercises. The presence of a third person or the clinician was another factor that hindered the autonomous delivery of the exercises through MAR technology. Table 1 gives an overview of the identified exercises and the reasons for non-selection.

TABLE I. GROUPS OF EXERCISES INVESTIGATED AND THEIR LIMITATIONS TO BE USED WITH CURRENT MOBILE AR TECHNOLOGY. ADAPTED FROM [16]

Category	Exercise	Limitation
Balance Recovery	Wobble Board	Requires a board in which the user stands and keeps from falling
ROM (Range of Motion)	Passive range of motion	Requires the clinician to apply light pressure
	Achilles tendon stretch non weight bearing	Requires the use of a towel to provide resistance
	Achilles tendon stretch weight bearing	Depth detection issues may cause inaccurate measurements
Strength Training	Plantar flexion	Required either an immovable object, rubber tubing, weights, or the clinician to provide resistance
	Dorsiflexion	
	Inversion	
	Eversion	
	Toe curls and marble pick-ups	
	Top raises, heel wals, toe walks	

On spite of the above limitations, the researchers found a set of exercise that could to be easily adapted in the MAR-based application and converted into an interactive game. These are listed and described below

A. The Alphabets

In this exercise the patient is required to be seated with the edge of the heel on the floor. He/she is tasked to draw the entire alphabet one letter at the time by moving the injured ankle and using the great toe as the 'pen' (See Figure 1). It is recommended to complete two sets of (A-Z), two or three times a day [17].

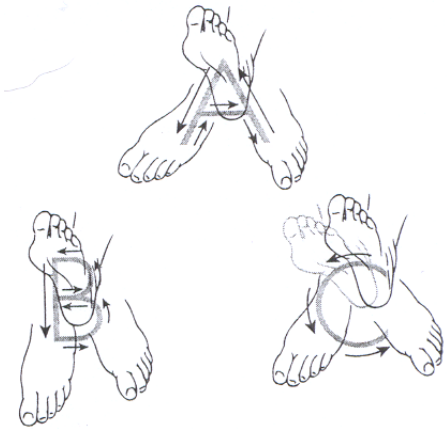

Fig. 1. The Alphabets, extracted from [18].

B. Windshield Wiper

In this exercise the patient is asked to sit with the foot flat on the floor and facing straight ahead. Then, he/she is instructed to rotate the affected foot to mimic a windshield wiper blade (see Figure 2). In other words, to pivot the foot outward and touch the inside edge of the foot to the floor, then rotate it inward and touch the outside of the foot to the floor. It's recommended to complete two sets of 10 to 15 repetitions, two or three times a day.

Fig. 2. Windshield Wiper, extracted from [17].

IV. THE MOBILE REHAPP™

The Mobile RehApp™ is an Augmented Reality-based application for mobile devices that delivers range of motion exercises to assist the ankle sprain rehabilitation process. This system consists of 3 mini mobile games that were built using as a basis the exercises found in the literature. In order to interact with this system, the patient is encouraged to be seated with the injured foot flat on the floor. A custom-made AR marker is then place on the foot enabling for the Mobile RehApp™ to track its movements. The game is then run on a mobile device such as an Android tablet or iPad that must point to the foot with the marker (See Figure 3). Shortly after, a game menu presenting three games is shown on the screen. These games are described below.

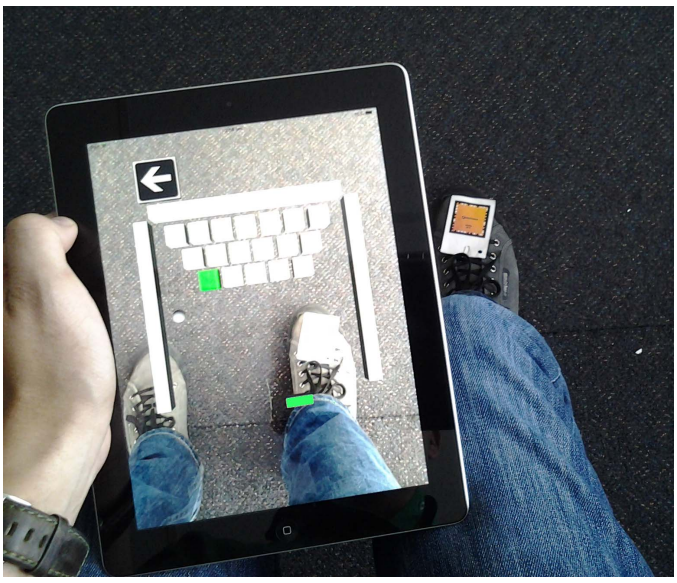

Fig. 3. Interaction with the Mobile RehApp™. The player is seated with the edge of the heel on the floor whilst holding a mobile device with his/her hands.

A. *The ABC*

This mini game was adapted from the 'alphabets' exercise, one of the Range of Motion (ROM) exercises in which the user is encouraged to move the injured ankle in multiple planes of motion by drawing the alphabet in uppercase. In this mini game, a letter from the alphabet is shown in the screen and the user is required to draw it using the AR marker as a 'pen'. Once the foot with the marker is placed in front of the mobile device's camera, a virtual image is over imposed on the marker indicating that system is currently tracking the user's feet (see Figure 4). As the user moves his/her feet drawing the letter that is being presented, parts of the letter are turning green and then disappearing indicating the completion of the exercise.

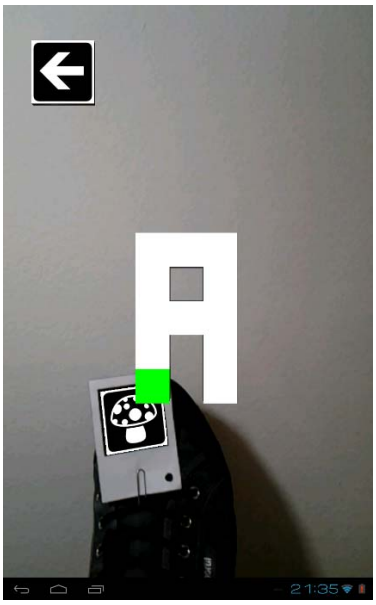

Fig. 4. The Alphabets running on an Android Tablet. The virtual 'mushroom' indicates that the system is tracking the movements of the player's foot.

In addition to the tailored alphabet game just described, two more mini games were developed around the idea of mimicking a windshield blade movement [17]. In order to make this exercise more appealing to the user, two classic arcade games were implemented. These are:

B. *The AR-kanoid*

Based on the Atari's Arkanoid game, the player controls a paddle that prevents a ball from falling from the playing field. The main objective of the game is to bounce the ball against a number of bricks making them disappear. When all the bricks have disappeared, the player can move to a higher level where another pattern of bricks is presented. In our game, the paddle is controlled by the AR marker placed on the injured foot. In other words, the Mobile RehApp™ will translate the lateral movements performed with the foot and use them as input for the game. The paddle will turn green when the player's foot is placed in front of the device indicating that the marker is being tracked (see Figure 5).

Fig. 5. AR-kanoid running on the iPad. The paddle turns green indicating that the AR marker on the foot is being tracked.

C. *MARS Invaders*

Based on the Atari's Space Invaders game, MARS Invaders is a 2D shooting game in which the user controls a laser cannon that can move horizontally across the bottom of the screen. The aim is to fire at descending 'Martians' in order to defeat them. These Martians move horizontally (back and forth) across the screen as they move towards the player's cannon. While descending, Martians will also try to destroy the player's cannon by firing at it. In our system the player's cannon is controlled by the users foot's movement. Similarly to the AR-kanoid game, the Mobile RehApp™ tracks the marker's position and translate lateral movements into the game in real-time. The player's cannon will turn green as soon as the AR marker is detected. A 'fire' button is also displayed on the screen to allow the player to shoot at the Martians by tapping on the device's screen (See Fig 6).

Fig. 6. MARS Invaders running on the iPad

Following a review of guidelines for building interactive games with health purposes, the following aspects were considered throughout the design process:

A. *Meaningful Play:*

The goal of a successful game design is the creation of a meaningful play experience in which the user is not only fully immersed in the game but also his/her actions are consistently associated with the game's outcomes [19]. This interaction must be intuitive allowing the player to learn the task easily in order to take control of the game. Similarly, the provision of appropriate feedback enables the player to measure his/her own performance within the game helping him/her to concentrate on achieving the game goals. For the purpose of the Mobile RehApp™ these goals are not only to entertain the player but to engage the user into the needed repetitive exercises in order to rehabilitate the injured ankle. Furthermore, the system was designed to allow for the collection of the foot's movement information in order to provide accurate feedback in real-time and support the proper execution of the exercises.

B. *Challenge:*

When playing with a new game for the very first time, the challenge is to appropriately meet the player's ability and familiarity with the game [20]. As the user plays with the game he/she develops new skills making necessary the presentation of new challenges and higher difficulty levels in order to keep the player engaged. However, if the difficulty levels are too high either because of their lack of ability or poor feedback, players can easily become frustrated and quit the game [19]. Consequently, the difficultly of the three mini games was adjusted according to the potential users difficulty to perform quick movements due to the ankle injury. Similarly, the difficulty of the mini games is increasing gradually enabling the player to get familiarized with the activities and develop the range of motion and skills needed to move through the higher levels.

Finally, a comparative review of the available gaming technology was carried out in order to select a suitable developing platform to implement this AR-based system. Unity 3d and the Vuforia Augmented Reality Development Kit (SDK) were chosen for the following reasons:

- Easy integration of the game development engine and the AR plugin allowing the development of fast-prototypes that were used as a proof-of-concept.
- Wider deployment of the game for Andriod and iOS mobile devices for trial purposes, making the prototype exposed and available to a larger audience.

V. DISCUSSION

Physiotherapy is moving away from big machinery and moving towards using a more portable and practical devices and software's in order to achieve better diagnosis and treatment. The Mobile RehApp™ aims to fill the existing gap in the rehabilitation industry of portable and autonomous tools for exercising lower limbs. A set of exercises available in the literature were shown to be easily adapted and translated into the application. However, exercises that involve the measurement of force and plantar pressure and/or required the use of bands could not be adapted in the system due to the inability of MAR technology to measure force and pressure. Nevertheless, the Mobile RehApp™ has the potential to provide the physiotherapist with current and historical data of the patient's performance to enable practitioners to make informed decisions in the patient's treatment. More importantly, the Mobile RehApp™ hast the potential to be used as a cost-effective and portable ankle rehabilitation tool that could increase compliance to physiotherapeutic prescribed exercises through the fun factor and engagement inherent to video games. Nevertheless, further research is still required to determine whether the system is useful for clinical practice.

VI. CONCLUSIONS AND FUTURE WORK

This paper describes a system that uses Mobile Augmented Reality (MAR) to deliver range of motion training exercises to people suffering from an ankle sprain. The game-based system builds on MAR's features to allow continuous real time tracking and provisioning of feedback. This implementation enhances the user interaction as no game controllers or sensors are required for operation making the game intuitive and easy to use. More importantly, this implementation has the potential to be used as a means to provide home-based therapy increasing levels of motivation and adherence to rehabilitation. The continuation of this work includes the development and integration of a cloud-based system where user's performance information can be stored and accessed remotely. This cloud-based feature aims to help to close the gap between practitioners and patients. The next stage of this study will involve a series of studies in which the feasibility and responsiveness of the system will be evaluated.

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