AUGMENTED REALITY GAME BASED MULTI-USAGE REHABILITATION THERAPIST FOR STROKE PATIENTS

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Abstract- For the surviving stroke patients that are affected physically and mentally, they are required rehabilitation after the stroke. Rehabilitation can be quite expensive on the patient and their families. The augmented reality rehabilitation gaming system aims to decrease the dependency on supervised therapy. This paper presents two augmented reality games. The games focus on rehabilitating stroke patients affected with upper limb disabilities. The games simulate current physical therapy techniques in an interactive augmented environment. The benefits of using a gaming platform are to provide the user with increased motivation, as well as a cost effective rehabilitation solution. The games can be used with or without a hand held roller-ball device, which can change the movement and focus of the exercise.

Index terms*:* Augmented Reality (AR), Stroke Rehabilitation, Virtual Reality, Upper Extremity, Mixed Reality

I. INTRODUCTION

The two main parts related to the work of this paper is the Stroke and the Augmented Reality (AR) components. Stroke affects the activities of daily living (ADL) of their survivors and requires stroke rehabilitation exercises that focus on improving the limb function. While AR aims at augmenting the perception of reality through modification via a virtual environment. AR has been used in the medical field with applications such as retraining rehabilitation..

a. Stroke

Stroke is a type of cerebrovascular disease that can be simply described as a 'brain attack'. When oxygen is unable to be delivered to the brain, that area of the brain can experience devastating motor, sensory or intellectual dysfunction [1] thus causing a stroke. For the surviving patients, the effects can be physically, mentally and financially devastating. The symptoms of stroke vary greatly between patients and depend on the location of the stroke in the brain as well as how much of the brain was affected.

The most damaging resulting disability could arguably be the loss of motor control, where patients can experience loss of control of a limb (hemiparesis) or paralysis on the whole of one side of their body (hemiplegia). The ability to perform everyday activities is greatly affected and depending on which part of the brain is damaged, certain abilities will be lost.

Performing repetitive exercises help the patient to regain function in disabled limbs so that they can perform activities of daily living independently. Exercises can be used to relearn fine motor skills, strengthen mobility and increase range of motion.

The emphasis on task specific training is important because research has shown that simulating practical movements with goals achieves better success than through repetition alone.

Once improvements have been made and the patient begins to regain function, it is essential that activities of daily living (ADL) be addressed so that the patient can independently function in their community. They range from personal tasks such as showering, toileting, dressing and eating to domestic and community related tasks such home maintenance and driving. ADL can be improved using occupational therapy that focuses on patient's strengths to encourage full participation in activities that they want to partake [2]. Studies have shown that therapy time for exercising upper limbs ranged from 30 to 90 minutes per day, 3 to 5 days a week, and lasted from 5 to 20 weeks. [10]

Eng & Harris [11] have developed a stroke rehabilitation exercise program that focuses on improving arm and hand function. The program is called the Graded Repetitive Arm Supplementary Program (GRASP) and aims at providing practical and cost effective therapy, something that the augmented reality games proposed in this paper hopes to achieve.

The program involves a variety of exercises such as:

- Range of motion exercises
- Strengthening exercises
- Weight bearing exercises
- Functional tasks
- Fine motor skills

One of the ranges of motion exercises includes 'The Twist' as shown in Fig. 1.

Figure 1. The twist exercise [11]

The shoulder muscles are essential for proper arm movement and so the 'Arm to the front' and Arm to the side' exercises are particularly useful as shown in Fig. 2.

Figure 2. arm to the side/front exercise [11]

The aim of this program is to provide the patient with a procedure that they can follow at home so that a) they can practice as much as they like, thus increasing their chance of better results and b) it provides a cost effective solution without expensive hospital bills. Eng & Harris [11] have found that their exercise program has improved patients test scores in outcome measure tests such as the Wolf Motor Function Test and the Fugl-Meyer Upper Extremity Assessment. The emphasis is on 'homework' therapy since their research has found that an additional 20 hours of therapy can provide significant benefits. However it is important to note that results are dependent on other factors such as age and the location and size of the stroke in the brain.

Rehabilitation can be quite expensive on the patient and their families with the costs being estimated at around $5 billion for 2012 in Australia [3]. Intensive therapy is preferred however this requires constant supervision from a health professional, which is expensive to maintain over a long period of time. Unfortunately, the more intensive the treatment, the more chance to full recovery and thus leaving disabled stroke patients in a tough financial predicament.

The need for cost effective treatment can be answered with concepts explored in this paper. The Augmented Reality gaming system proposed will aim to decrease the dependency on supervised therapy as the patient will be able to continue unsupervised rehabilitation at their home. The foundation of stroke rehabilitation is to improve their capabilities to perform Activities of Daily Living (ADL) [4]. This is achieved through repetition and practice, and so with unlimited access to our proposed gaming system, patients have the opportunity to progress through their recovery much faster. Not only does this reduce the costs of seeing a therapist, but also increase the patient's motivation to continue on with their rehabilitation as the game environment can detract from the monotony of stroke recovery. The Augmented Reality game will be designed so that the objectives will mimic ADL, which adds a practical element to the treatment, which can be beneficial to the patient as they are not just learning exercise movements, but they are re-learning to perform movements with goals, similar to daily activities [5].

b. Augmented Reality

Virtual Reality applications can be extended to create applications that combine the environment from the real world with digital information. In short, augmenting the perception of one's reality through alteration of the sensory-motor bond with a virtual environment [6].

There are three main core components required to create an augmented reality experience:

1. Sensors
2. Processor
3. Display

Sensors are used to gather information from the real physical world. The most common sensor used is a camera that classified under computer vision area. The camera is used to look into the real world and the computer software determines the cameras location with respect to the environment. The uses of visual cues are used to help with this process and these visual cues are called fiducial markers or fiducial symbols. The relative location and orientation of the camera compared to the marker is useful in displaying computer graphics in a particular point of view [7].

Tracking objects involve not only the location, but also the orientation. This is why the markers such as the one in shown in Fig. 3 should be asymmetrical in design, so that the computer software can easily determine the orientation. Therefore, the true position of an object is calculated using the

six degrees of freedom. This includes finding the location against the X, Y and Z axis, as well as calculating the pitch, yaw and roll of the object [7].

Figure 3. Fiducial Marker example

Research is developing fast in the area of natural feature tracking (NFT). This is where 'natural' features such as many real world objects are used as trackers, eliminating the need of using fiducial markers. This would create a more intuitive and natural augmented reality experience and is undoubtedly the future of augmented reality applications [7].

All augmented reality applications require a processor to process the digital information received from the real world, apply any appropriate calculations and prepare the information to be displayed. The processor must be capable to perform the calculations in real time. Any lags in the augmented reality application will hinder the experience. A frame rate of at least 15 frames per second is recommended for smooth motion [7].

Displays are the last core component involved in augmented reality applications. For visual purposes, displays include computer monitors and TV screens. However augmented reality is not limited to visual experiences, thus an example of an audio display would be headphones or speakers [7].

One of the main challenges that augmented reality applications face is the ability to recoginise and track markers, whether they be fiducial or natural, in less than ideal conditions. Poor conditions are inevitable outside of a lab environment and one of the biggest issues in the real world is uneven lighting. Poor lighting conditions can make the makers unrecognizable and potentially be mistaken for another marker [12].

Potential issues with using AR in the medical field include retraining medical staff and users with new tools and procedures. Training may be expensive and time-consuming depending on the technical extent of the application [8].

An Augmented Reality game will provide a platform in which patients can practice various upper limb movements in an interactive environment in order to restore independent movement in their upper limb extremities. Ultimately, this gaming system will be used to supplement other current rehabilitation techniques.

Augmented Reality is not prominently present in the medical industry, but we believe it has the potential to create an engaging environment for patients to simulate normal practical activities for motoric, cognitive, social rehab and recovering purposes. Stroke can have a devastating impact on a patient and the cost of recovery is a significant factor. Implementing an Augmented Reality gaming system can provide a cost effective solution as it reduces the need for supervised therapy.

II. REHABILITATION GAMES

There are two rehabilitation games proposed in this paper that will be further explained below. These games have been implemented using the coding language Actionscript 3.0 and was developed using Adobe Flash CS5 and Adobe Flash builder 4.7. We have incorporated the use of an augmented reality framework called FLARManager in order to access various libraries to assist with video capture and pattern object tracking. A simple PC webcam is required to capture the live feed of reality, in which the Actionscript code will then overlay virtual objects to create an augmented reality for the user. The purpose of these games is to present the user with a simple yet engaging way of rehabilitation exercise. The game scenario aims to remove the mundane nature of repetitive exercise and increase motivation so that continued use is sustained, thus increasing the chances of fast recovery.

With both these games, there is an option to play the games using a handheld roller-ball device. This device will drastically change the way the games are played, and thus focusing on different movements and muscles. By not using the device, the games will be played with the webcam facing the user, which is shown in Fig. 4. This will allow the arm movements to performed in free space, using gravity as a resistance. However when using the roller-ball device, the games will be played with the webcam placed above the user facing the table as shown in Fig. 5. This will allow the arm movements to be performed on the table in front of user.

Figure 4. Gameplay without the roller-ball device

Figure 5. Gameplay using the roller-ball device on the desk

The roller-ball device also works the hand muscles through palmar abduction and finger flexion as the patient tries to grip the hand device. It further adds extra stimuli to the hand so that the patient can get used to the feeling of holding something while reaching. This stimulus allows the patient to develop their sensory discrimination, dynamaesthesia and kinaesthesia as well as the appreciation of counter pressure of the fingertips [5].

As the games involve the patient to sit down at a table, while in this position, the patient can further train their controlled posture and balance. With their hands on the table, their position is seen as a 'useful' resting position. Leaning forward to reach over the table will cause the patient to transfer weight forward over their heels, which can help train, the lower limbs as well [9]. This 'useful' position allows further opportunities to train their trunk rotation movement. Thus, the augmented reality games have essentially turned this resting position into an exercise position, which allows for good rehab by providing the patient with self-care exercises.

a. Mole Attack Game

This game is based off the popular arcade game 'Whac-A-Mole', in which the player uses a rubber hammer to hit toy moles that randomly pop up from the playing table. However in this rehabilitation game, the moles appear in a sequenced order in order to focus on, and reap the benefits of repetitive movement. As shown in Fig. 6, there are 4 moles/hit targets spread out to each corner of the screen. The AR maker will control a 2D image of a hammer.

A mole will pop up from its molehill and remain there until the hammer touches it, indicating a hit. Once a hit occurs, the mole will go down and the next mole will appear. This cycle continues until the game is stopped. The sequence in which the mole appears is illustrated in Fig. 7. After molehill number 4, it continues back to number 1 and so on. This creates somewhat of an X shaped movement.

Figure 6. Mole Attack game main layout

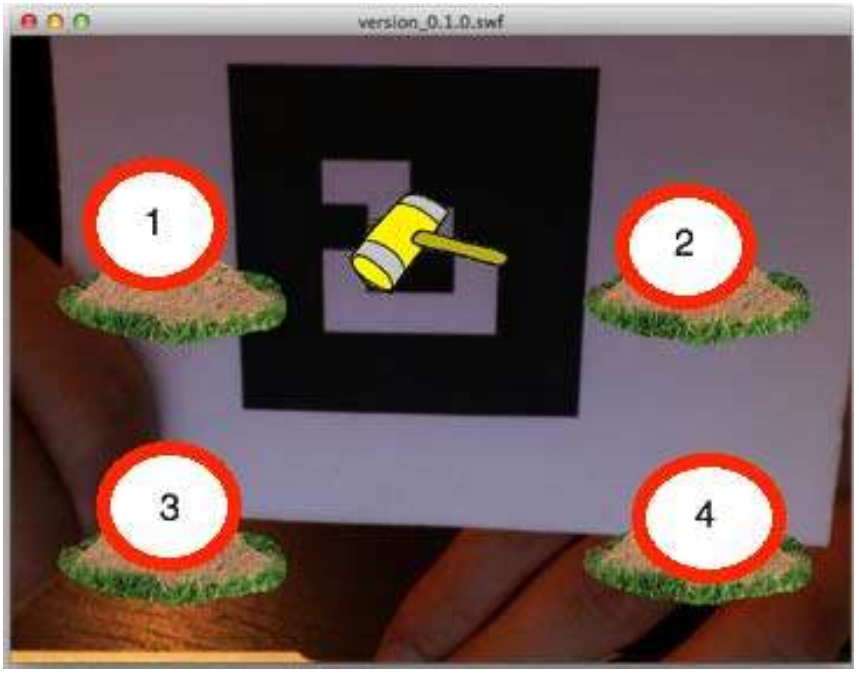

Figure 7. Mole Attack game sequence

When using the roller-ball device with this game, a lot of elbow extension and flexion will be worked on. However without the device, the focus will be on shoulder abduction and shoulder forward flexion. These are some of the essential components for major function of the arm [5].

The game also attempts to recreate activities of daily living (ADL) such as reaching for items and moving them around. The idea is to create a playing space that maximises the distance between each target i.e. the molehill. Thus, 4 molehills are used and placed in each corner of the screen. The distance between the molehills allows the user to stretch and reach for each target, thereby experiencing great movement. The distance of the webcam in relation to the AR marker can be adjusted to determine how much movement is required, thus increasing or decreasing the difficulty of the exercise.

b. Colour Ball Game

This game requires the user to hit a coloured ball to the side with the same colour using the paddle that appears on the AR marker. Basically a red ball will come from the red side, a blue ball from the blue side and a green ball from the green side. The layout is shown in Fig. 8.

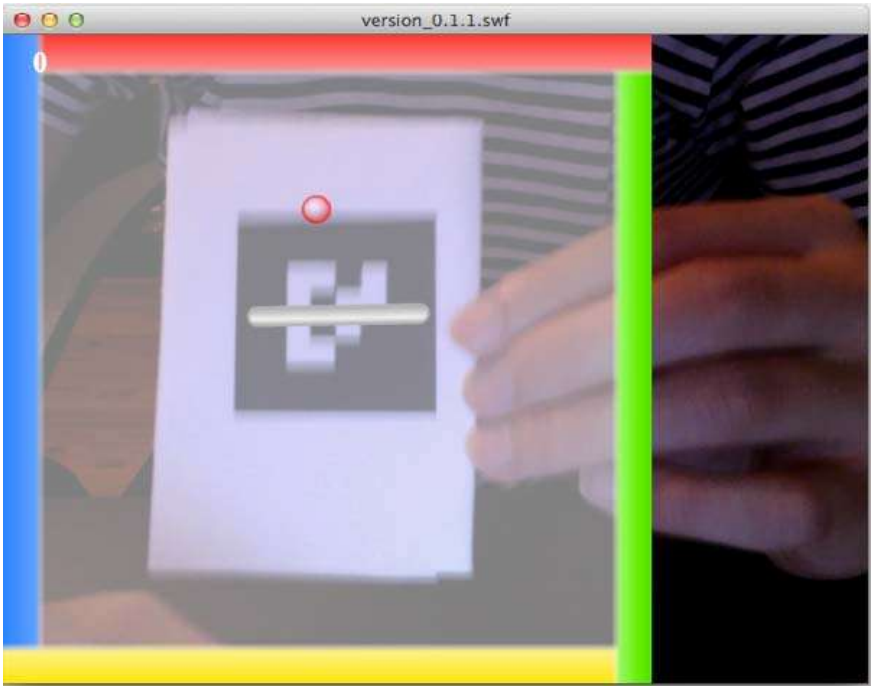

Figure 8. Colour Ball game layout

The balls will be generated in a set sequence to focus on specific repetitive movements. A ball will be generated one at a time and continue to be generated from the same side until the user hits the ball into the correct side. The orders in which the balls are generated are: Red, Blue, Red, Green then repeats. Whenever the user correctly hits a ball, a score in the top left corner is incremented. A wrong hit does not decrease the score.

When using the roller-ball device for this game, the main focus will be on hand muscles through radial deviation as well as working on shoulder medial and lateral rotation. However without the device, the focus will be on the forearm muscles through supination & pronation. Regardless of the device, there will also be some shoulder abduction and flexion involved.

The game also attempts to recreate activities of daily living (ADL), specifically simulating the motion of turning objects, such as a doorknob, when the roller-device is not being used. It breaks down the turning motion of the hand and forearm through supination and pronation movements. The movement of the ball also allows the user to develop their hand eye coordination, which can be diminished after the onset of a stroke.

III. USABILITY STUDY

In order to study the effectiveness of these games as a motivational rehabilitation tool, we have asked 4 volunteers to take part in a usability study. This involved surveying the volunteers to give feedback immediately after playing both games. All volunteers are healthy subjects of both sexes ranging from 22 to 47 years of age. Since none of the volunteers are stroke victims, we have developed a questionnaire. The questions used in the usability study were influenced from other research papers and focused on a users' initial reaction to the game so it can be refined, as can be noticed in Table 1. We would provide brief instructions to each volunteer on how to play each game, and then allowed them to play it independently with our supervision.

All volunteers easily followed the games instructions, and the gameplay was said to be familiar and intuitive. The Mole Attack game ranked as the most popular game with two volunteers claiming it was enjoyable and would play the game again. Both games produced a sense of accomplishment, shown in Fig. 9, with one subject claiming that the scoring system on the Colour Ball game increased her motivation to play. Two of the older volunteers were fascinated

by the augmented reality environment, in which they felt satisfaction when progressing through the gameplay. All members were able to understand how these games are focusing on specific muscles and movements so that they can be applied for therapeutic applications.

The responses given for the games were positive in terms of usability. One of the main advantages of using and augmented reality gaming system for rehabilitation is the increased motivation provided by the interactive game play. This claim was supported by consistent comments from the healthy test subjects.

The most common negative feedback given from the volunteers was that the gameplay wasn't smooth. More specifically, the marker object tends to flicker, which made the game unresponsive at times. Also, when the games are played without the roller-ball device i.e. playing the game with the arm in the air, the volunteers complained that their arm was getting fatigued after prolonged game play.

With the colour ball game, two subjects felt that the speed at which the ball travelling was too slow and made the game boring. However, the design choice for this is due to the fact that real stroke victims will need much more time to react to visual cues.

Below is the list of questions that answered by each volunteer immediately after they played each game. Each question is ranked on a scale of 1 (strongly disagree) to 5 (strongly agree).

The user was also asked to give any general comments or feedback.

1. I am familiar with AR technology and systems
2. I felt the game was intuitive and enjoyable
3. I was able to play the game correctly
4. I would play this game again
5. I felt pain/discomfort during the game
6. I can recognise the exercise application of the game

Table 1. Usability Questionnaire

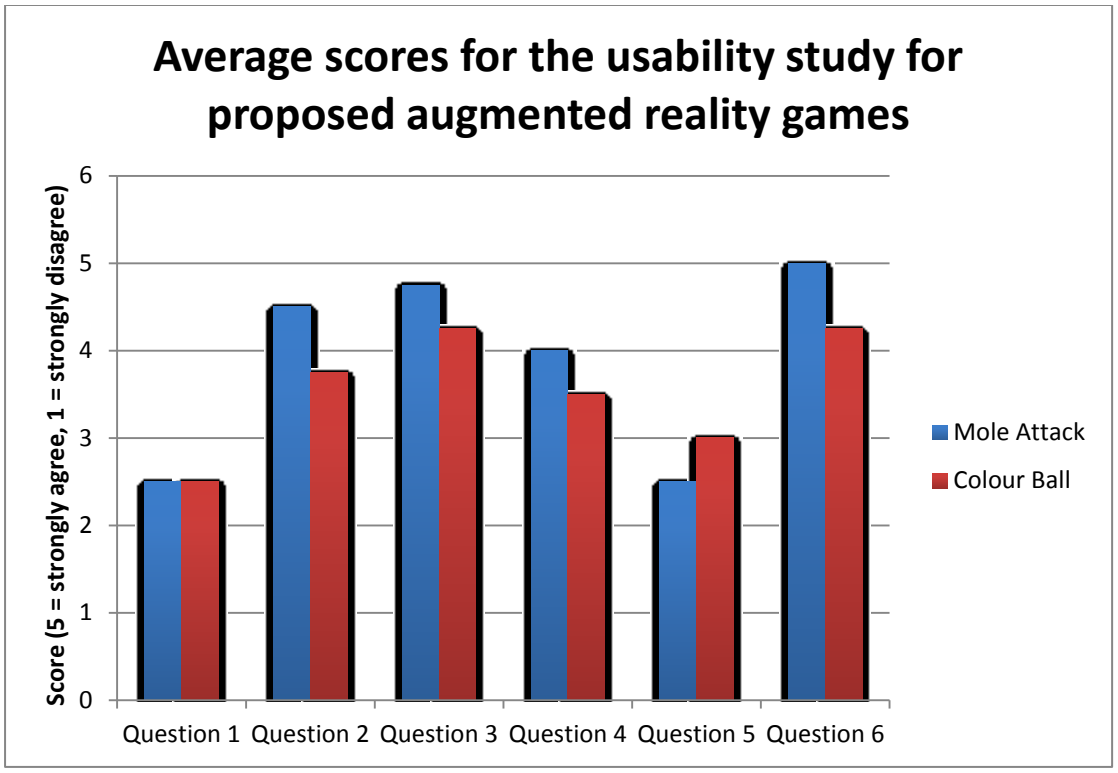

Figure 9. Results for the usability study

VI. CONCLUSIONS AND FUTURE WORK

In this paper, two augmented reality based games have been presented. They have been specifically modified to focus on specific upper limb movements for the purpose of stroke rehabilitation. The games have been developed using libraries from the FLARManager framework. The games can be easily accessed using a PC with Flash installed and a simple webcam. The optional use of a hand held roller-ball device allows each game to focus on different movements and muscles, thus increasing the effectiveness of the games. These games aim to improve the user's participation by presenting an interactive way of rehabilitation.

As simple as these games are in design, they still capture the proposed idea that stroke rehabilitation can be enhanced using augmented reality games. The games have been modified to force the user to perform specific movements that are strongly linked with current physical therapy techniques.

The marker tracking capabilities of the FLARManager have proved to not be very robust as the marker tends to flicker at times, thus not providing smooth gameplay. The marker would successfully activate 70% of the time. Future work can involve the use of other augmented reality libraries in order to find the most robust object tracking process to provide smooth gameplay in a variety of lighting conditions. Also, since these games are in 2D, it would be interesting to explore the possibility of working with 3D models to further add depth and interactivity to the gameplay. The future work will include a stroke patients test.

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