# A Mobile Augmented Reality Framework for Post-stroke Patient Rehabilitation

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**Abstract.** In this paper, we put forward a novel framework based on mobile augmented reality (AR) to enhance the post stroke patients participation in the rehabilitation process. The exercises performed in the rehabilitation centers are monotonous and thus requires maximum effort and time from both the patients and the occupational therapists. We propose to combine these tedious activities with the interactive mobile augmented reality technologies. We call this framework Cogni-Care. In this paper, we introduce the underlying architecture of the system that eases the work of the stakeholders involved in the process of stroke recovery. We also present two exercises to improve the fine motor skills, AR-Ball exercise and AR-Maze exercise, as examples and perform the initial usability study.

## 1 Introduction

Paralysis of one side of the body is called Hemiplegia and is caused by injury or disease to the brain motor centers [5]. Hemiplegia most commonly occurs in brain stroke. Depending on the severity and location of the lesion, brain strokes can cause a variety of locomotor disorders. Spinal cord injury, example Brown-Sequard syndrome, diseases affecting the brain, or severe brain injury are the other causes of hemiplegia. Symptoms other than weakness include decreased movement control, spasticity and decreased endurance [6]. Premature babies show much higher incidence of hemiplegia than full term babies. There is also a high incidence of hemiplegia during pregnancy and experts believe that this may be related to either a traumatic delivery, use of forceps or some event which causes brain injury. Trauma, bleeding, brain infections and cancers are the most common causes of hemiplegia in adults [6]. Uncontrolled diabetes, hypertension or smokers have a higher chance of occurrence of stroke [7]. Facial palsy is a condition where weakness on one side of the face may occur and is caused by viral infection, cancer or stroke [6].

In many of the instances the cause for hemiplegia is not known, but it appears that the brain is deprived of oxygen and this result in the death of neurons. Hemiplegia is diagnosed by clinical examination and investigation by a health professional, such as a physiotherapist or doctor. Radiological studies like a CT scan or magnetic resonance imaging of the brain should be used to confirm injury in the brain and spinal cord, but alone cannot be used to identify movement disorders [6].

Rehabilitation is the most important treatment of patients having hemiplegia. The main aim of rehabilitation in hemiplegic patients is to regain maximum function and improvement of quality of life. Improvement in the quality of life is achieved by both physical and occupational therapies [14]. Most of the rehabilitation activities are carried out in the rehabilitation centres located in hospitals. Stroke patients with restricted physical mobility will have problems in getting access to such facilities. In addition, these rehabilitation methods need a lot of equipments and man power in the form of trained therapists [15]. The studies carried out in [9] and [1] have shown that for effective motor rehabilitation the important factors are duration, capacity and intensity of the exercise sessions. But, with the lack of proper equipments and qualified therapists, efficient treatment of the stroke patients is challenging. These activities concentrate on the patients motor functionality and hence are repetitive, trivial and boring. For example, moving the hand back and forth frequently. This causes the patients to quickly lose interest in the rehabilitation process. Therefore, for a successful post-stroke recovery the patients have to be motivated to perform these exercises [15]. In this paper, we propose a novel framework that uses mobile augmented reality to make these activities motivating and entertaining.

### 1.1 Related Work

Rehabilitation applications are specifically designed to recover certain handicapped functions of the individuals with disabilities. In the past two decades, a lot of research has been conducted making use of computer applications to help brain stroke patients recover basic motor skills. In this paper we focus on augmented reality and hence we will discuss the state-of-the-art research that has been carried out in augmented and virtual reality domain.

In the study conducted by G.Burdea [15], the author shows that virtual reality (VR) rehabilitation systems can make the dull occupational therapy exercises interesting and entertaining. In the virtual reality system the patients are exposed to pre-programmed tasks designed under the guidance of the occupational therapist. To keep up the patients engaged in these computer generated exercises, audio-visual motivational messages are triggered frequently in the application. A significant improvement is seen in the patients doing these exercises [4]. But the major drawback of this virtual reality application is that it requires sophisticated settings and a dedicated place to perform these exercises. Virtual Reality also separates the patient from the real world, which makes it difficult to correlate the exercises done during the actual occupational therapy sessions.

On the other hand, with the development of the augmented reality technologies some of these problems have been addressed. Augmented reality blends the virtual objects seamlessly in the real world by capturing and processing the real world scene using trackers. The authors of the paper [8], [2] have integrated a training environment with AR in the process of repetitive grasp and release tasks. The major criticism of this system was that the patient required therapist intervention to assist in wearing the required equipments. The authors of the paper [3], have proposed a framework to take the advantage of the AR technology

using 2D cameras and fiducial markers. This system addresses the training of daily activities, but due to the use of the fiducial markers therapist intervention is necessitated and is to be performed in a confined environment.

To the best of our knowledge, this is the first framework to make use of the android mobile devices in the rehabilitation of the brain stroke patients. We propose the intuitive augmented reality application that can help the patients practice the fundamental motor movements. These movements are central to all daily life activities, such as hand stretching and fine finger movements. An active participation in such interactive activities is expected to develop a positive psychological feeling to the rehabilitation experience. Developing these exercises on the mobile platform will allow the patients to perform them in their free time, at home or in the garden, without the intervention of the occupational therapists. This on the other hand, would help the qualified occupational therapists to cater to more number of stroke patients. This is due to decrease in the number of patient-therapist sessions per patient in hospitals, as they can perform the same exercises on their mobile devices which in the earlier systems had to be performed in the scheduled session under the guidance of the therapist.

**The key contributions of the paper are:**

1. We propose a portable, low cost, interactive framework that will help in the speedy recovery of the brain stroke patients during their rehabilitation process.
2. We propose a hand exercise, AR- Ball, which addresses the fundamental hand exercise for the wrist, elbow and shoulder movements, that covers a wide range of stroke patients with different weaknesses.
3. We propose a finger movement exercise to address the fine motor skills in the form of an interactive AR-Maze solving game.
4. We provide the initial experimental results of the usability study performed on 12 healthy subjects.

The proposed system does not require any equipment other than the mobile device. This makes the feasibility and usability better than the currently available augmented reality rehabilitation systems.

The rest of the paper is organized as follows. Section 2 explains the core architecture with the implementation and design details of Cogni-Care Framework. Section 3 describes the AR-Ball exercise and the AR-Maze exercise, which are part of our framework. Section 4 presents the experimental setup and the results of the usability study we conducted on 12 healthy subjects. Finally in the Section 5, we summarize this paper‘s contents and provide outlook for future work.

## 2 Cogni-Care Framework

Our proposed framework is called Cogni-Care. It is developed to study the use of AR technique in the rehabilitation of the brain stroke patients. We also present two exercises namely, AR-Ball exercise and AR-Maze exercise, developed using

augmented reality technologies. The AR-Ball exercise focuses on the hand movement involving wrist, elbow and shoulder exercise. The AR-Maze exercise focuses only on the finger movement. In this section, we will explain the fundamental architecture and technology used in implementing this framework.

The Cogni-Care framework consists of patient module and the therapist module. The patient module consists of the front end application. It involves the mobile application in which 3D models are rendered using the AR technique. The patient first logs-in the system. Depending upon the patients profile, the exercises are selected. The patient selects one of these exercises and performs the necessary movement related to the task. The fine motor movements can be recorded for future analysis. The inbuilt accelerometers and the gyroscopes can be used to track the special movements of the patient. The selected augmented exercises are rendered to the patients mobile screen through the AR tracker system. The second module is for the therapists. In this module the therapists can design the exercises for the patients. The therapists can also control and modify the exercises remotely. In this paper, we will describe in detail only the patient module. In this framework we have used the Qualcomm Vuforia SDK [10] for the

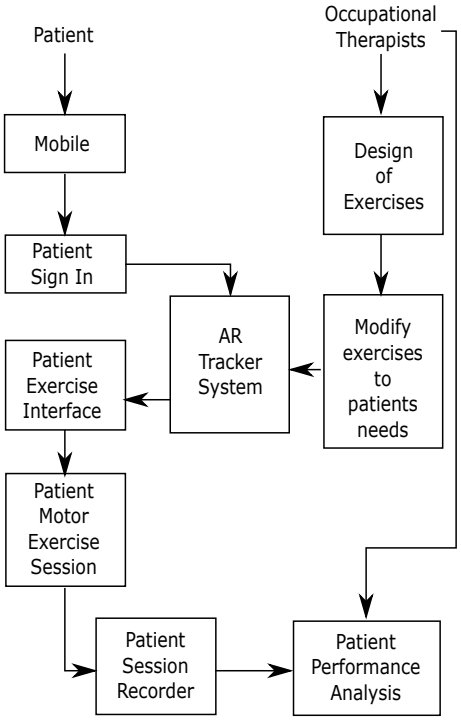


**Fig. 1.** Cogni-Care Architecture.

AR rendering mechanism. The example exercises are designed with the Unity3D

game engine [11] and are written in C# using the MonoDevelop IDE [12]. The application is deployed on the android mobile device for the preliminary usability study. The Vuforia SDK is used to capture the camera frames and search for the user defined target image. The user defined target image is the real world captured scene that the patient selects as the reference base to perform the tasks. To create an intuitive game like environment, we used Unity3D game engine for the game development and to detect the collisions involved in performing the tasks [13].

## 3 AR-Ball and AR-Maze exercises

### 3.1 AR-Ball exercise

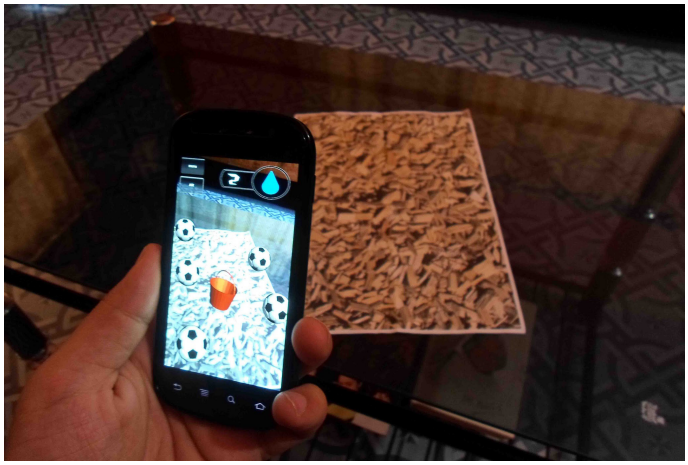

**Fig. 2.** The patient selects the target on which he wants to perform the task. On selecting the target the system will generate and render the 3D ball in the real world scene. The patient has to move his hand towards the ball to collect it.

The objective of the ball exercise is to perform the hand related exercises(see Fig. 2). The patient selects the reference base on which he wants to perform the task which is called the user defined target(target). On selecting the target the system will generate and render the 3D ball in the real world scene. To collect the ball, the patient has to move his hand, holding the mobile, towards the ball. As soon as the ball is touched, sound is triggered to show that the ball is collected. In addition, to have a game like experience scores are updated for collecting each ball. In this way we address the wrist, elbow and shoulder movements. The steps involved in the AR-Ball exercise are as follows:

1. The patient registers in the mobile application and selects the AR-Ball exercise.

2. The patient selects the target on which he wants to perform the task.
3. Once the camera recognizes the selected target the 3D balls are rendered in the real world scene.
4. Now the patient moves the mobile towards the balls.
5. Once the patient collects the ball, a sound is played and the score is updated.
6. This procedure is repeated again until all the balls are collected.
7. The time taken to perform the task is recorded and displayed.

### 3.2 AR-Maze exercise

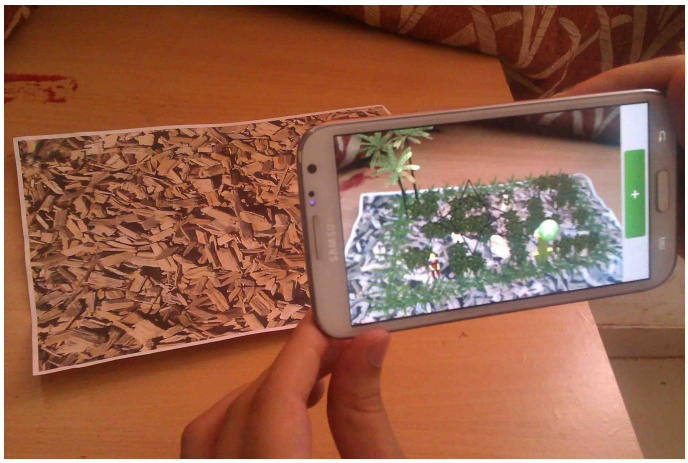

**Fig. 3.** The patient selects the target on which he wants to perform the task. On selecting the target the system will render the maze arena in the real world scene. The user taps his fingers on the mobile to control the chracter movement.

The main objective of this exercise is to specifically address the finger motor skills of the brain stroke patients. This is done by creating a Maze structure, in which the patient solves the maze by guiding the augmented character. The movement of the character is controlled by tapping the onscreen Graphical User Interface (GUI) by using the fingers (see Fig. 3 and 4). The steps involved in the AR-Maze exercise are as follows:

1. The patient registers in the mobile application and selects the AR-Maze exercise.
2. The patient selects the target on which he wants to perform the task.
3. Once the camera recognizes the selected target the system renders the maze in the real world scene.
4. The patient taps on up, down, right and left GUI to control the movement of the character.

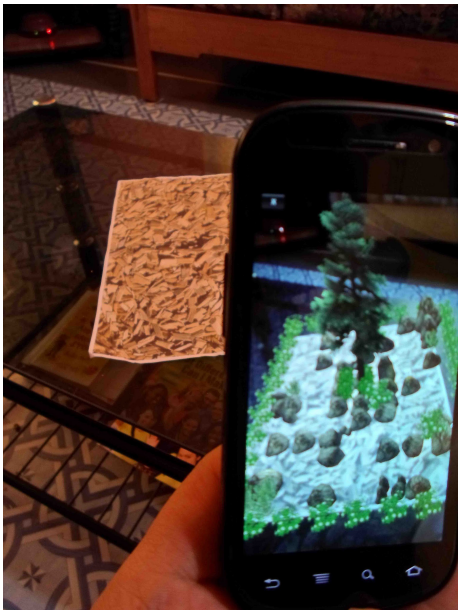

**Fig. 4.** This is the AR-Maze exercise with a different maze arena.

5. Once the patient solves the maze, a cheering sound effect is played to show that he/she has successfully completed the level.
6. This procedure is followed to complete the other maze level.
7. The time taken to perform this session is recorded and displayed.

## 4 Cogni-Care Usability study

In this section we present the outcomes of the usability study we conducted on this system. The main motive of this pilot study is to verify that our framework is interesting and motivating tool for rehabilitation. The study is conducted on 12 healthy subjects/participants (5 female and 7 male) randomly selected to perform these exercises. The mobile devices used in this study are Samsung Galaxy S3, Xolo A500S, HTC Explorer and Samsung Google Nexus S. Each subject is randomly given one of the mobile devices. The study is conducted in a classroom setting and all the 12 subjects are new to this system. The participants did not take part in any medical check-up prior to participating in the study. They self reported a normal eyesight and sense of touch. Each participant was tested two times for both exercises in which he/she undertook five consequent sessions of treatment per exercise. After the completion of the session, we requested every subject to fill in a questionnaire designed to evaluate the system. The subjects scored each question a numerical score of [1] to [10]. Here [1-3] represents that the subject strongly disagrees; [8-10] means that he/she strongly agrees with what have been asked and [4-7] means that they are not sure.

The following questions were asked to each subject:

1. The instructions on the mobile are clear.
2. I have used mobile phones before this time.
3. I have tried AR applications on mobile phones before this time.
4. I can perceive the depth in the scene.
5. I can easily control the game character with my fingers.
6. I was able to complete the task successfully.
7. I enjoyed playing the exercise.
8. Next time do you require any external assistance in performing this exercise.
9. I felt some hand pain in performing the exercises.
10. I felt that I was doing some sort of exercise.
11. I can perform the same exercise with my other non-dominant hand.

### 4.1 Results Discussion

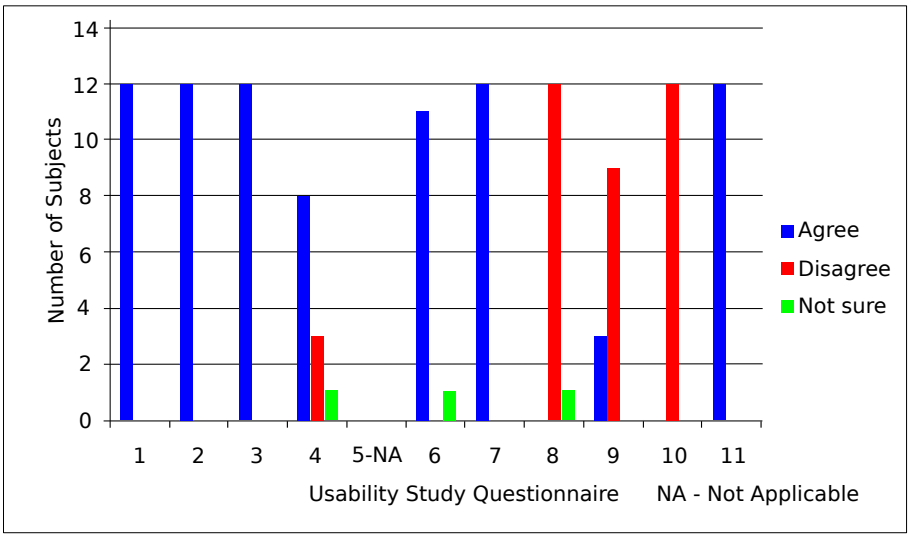


**Fig. 5.** This is the result of the Usability Study conducted on the AR-Ball exercise. The horizontal axis depicts the various questions used to analyse the system and the vertical axis represents the number of subjects in the study.

We can clearly see that from the Fig. 5 for the AR-Ball exercise and Fig. 6 for the AR-Maze exercise that most of the participants were motivated to perform the exercises. From the analysis of the scores of the questionnaire, we found that all the 12 subjects were interested to carry out the exercises. The AR-Ball exercise addresses the hand movement that involves the wrist, elbow and the shoulder movements. But, the AR-Maze exercise addresses the only the finger

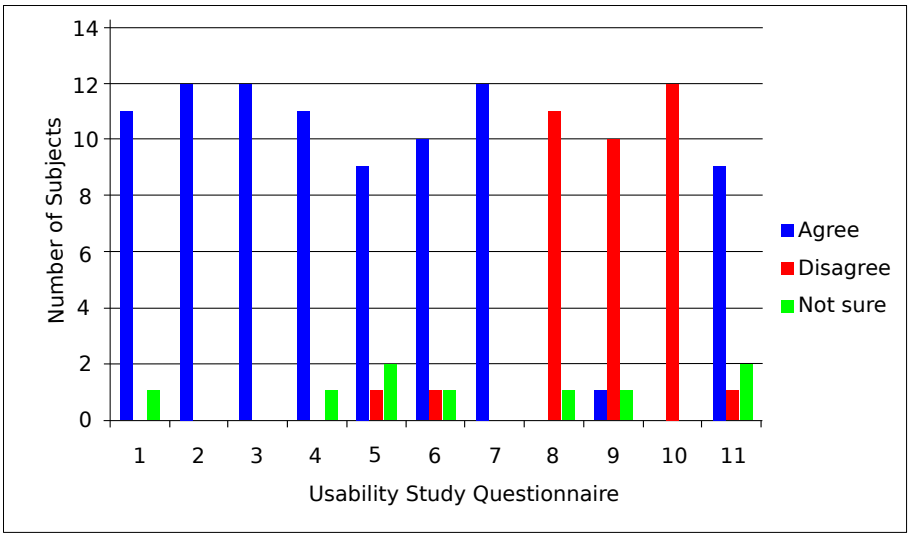


**Fig. 6.** This is the result of the Usability Study conducted on the AR-Maze exercise. The horizontal axis depicts the various questions used to analyse the system and the vertical axis represents the number of subjects in the study.

movements. Almost all the subjects agreed that they did not realize that they were doing some kind of a rehabilitation related exercises. Most of the subjects found the mobile instructions self-explanatory. In addition, all the subjects confirmed that this framework is easy to use and can be performed at home, garden and rehabilitation center easily. This corroborates that the framework can be used without any supervision.

Some subjects raised a difficulty in the depth perception during the AR-ball exercise. This is because they pointed the mobile camera at a distant place as the reference target image. This caused the difficulty in perceiving the depth of the 3D objects with reference to the mobile. On the other hand, this was not observed in the AR-Maze exercise, as the subjects did not require the depth at which the objects were rendered. In the AR-Maze exercise one person complained of hand fatigue, while the others finished the exercises without any difficulty. However, three subjects suffered hand fatigue in the AR-Ball exercise.

## 5 Conclusions and Future Work

In this paper, we have proposed an Cogni-Care framework that takes the advantage of the augmented reality technology for the brain stroke patients rehabilitation. We described the architecture of the framework and two exercises, AR-Ball and AR-Maze exercises. Here beautiful and attractive 3D models are overlaid on top of the real world, so that the patients enjoy the boring and repetitive tasks. The usability study has shown that the implemented framework achieves

**Fig. 7.** Future work includes development of new gaming exercises to facilitate a variety of therapy solutions to cater the individual patients specific needs.

these objectives completely. The potential ease of use and ability to blend motivating tasks in 3D are obvious advantages of this framework. In addition, the patient can work independently anywhere with no assistance from the family or occupational therapist.

In the future, we will register the patients activity on the server for the regular analysis by the occupational therapists. We will automate the tracking of patients hand and finger movement. For this we will use gyroscope and accelerometer inbuilt in the mobiles to track the hand trajectory and speed of the hand movement while performing the tasks. These additional results will help the therapists to gauge the overall improvement of the patient. Future work also includes development of new gaming exercises to facilitate a variety of therapy solutions to cater the individual patient's specific needs. This will enable the therapist to moderate the amount of hand movement exercises necessary to keep the rehabilitation advancing.

## References

1. Kwakkel G, Wagenaar RC, Koelman TW, Lankhorst GJ, Koetsier JC (1997) Effects of intensity of rehabilitation after stroke. Stroke 28:1550-1556
2. Sucar LE, Leder RS, Reinkensmeyer D, Hern andez J, Azc arate G, Caste neda N, Saucedo P (2008) Gesture Therapy - A Low-Cost Vision-Based System for Rehabilitation after Stroke. Paper presented at the First International Conference on Health Informatics, Funchal, Madeira, Portugal, 28-31 January 2008
3. Correa OAGD, Ficheman IK, Nascimento M. do, Lopes R de Deus (2009) Computer Assisted Music Therapy: A Case Study of an Augmented Reality Musical System for Children with Cerebral Palsy Rehabilitation. Ninth IEEE International Conference on Advanced Learning Technologies, 15-17 July 2009

4. Sveistrup H (2004) Motor rehabilitation using virtual reality. Neuro-Eng. Rehabil. 1:10
5. Hemi-Kids (1997) Hemiplegic Cerebral Palsy. http://www.hemikids.org/hemiplegia.htm. Accessed 25 Dec 2013
6. Wikipedia Hemiplegia. http://en.wikipedia.org/wiki/Hemiplegia. Accessed 20 Dec 2013
7. World Heart Federation (1978) Cardiovascular disease risk factors: Diabetes. http://www.world-heart-federation.org/cardiovascular-health/cardiovascular-disease-risk-factors/diabetes/. Accessed 12 Dec 2013
8. Ong SK, Shen Y, Zhang J, Nee AYC (2011) Augmented Reality in Assistive Technology and Rehabilitation Engineering. Handbook of Augmented Reality, Springer: 603-630
9. Nudo R, Wise B, SiFuentes F, Milliken G (1996) Neural substrates for the effects of rehabilitative training on motor recovery after ischemicinfarct. Science 272:1791-1794
10. Qualcomm Vuforia. http://www.qualcomm.com/Vuforia. Accessed 20 Jan 2014
11. Unity3D. http://unity3d.com/. Accessed 11 Jan 2014
12. MonoDevelop. http://monodevelop.com/. Accessed 15 Jan 2014
13. Unity3D Collision Detection. http://docs.unity3d.com/ScriptReference/Collision.html. Accessed 12 Mar 2014
14. American Heart Association - American Stroke Association : Post-Stroke Rehabilitation. http://www.strokeassociation.org/. Accessed 16 Dec 2013
15. Burdea G (2004) Virtual rehabilitation benefits and challenges. Review paper in Proc. Int. Med. Inf. Assoc. Yearbook Med. Inf., Heidelberg, Germany