AR based Upper Limb Rehabilitation System

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Abstract—More than 62,000 Australians were reported suffered from Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI) and Cerebrovascular Accident (CVA) or stroke in 2011. These injuries and accidents lead to physical disability that yields in limitation for performing a person’s daily life activities. To overcome such limitations, physical rehabilitation is conducted which requires one-to-one attention that creates a shortage in therapists and lead to high cost. In this paper, a development of an effective augmented reality (AR) based upper limb rehabilitation system with low cost is presented. Our development aims to close the gap in shortage of therapists, high health care cost of TBI, SCI and stroke. The proposed system can be used at home as well as in rehabilitation centers, units, and hospitals with minimum therapist supervision. It consists of two modules: AR based rehabilitation exercises module and real-time active muscle module. The first module aims to increase the upper limb range of motion via reaching exercises, and strengthen the associated muscles. In second module, the patient’s EMG signals were used as an input to monitor the muscle performance in real time during training. Our development had tested with 10 healthy subjects and had demonstrated in Port Kembla Rehabilitation Hospital.

I. INTRODUCTION

NEUROTRAUMA such as Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI) or Cerebrovascular Accident (CVA) or stroke is the main reason of physical disability. It reported that 2,493 cases of TBI, 362 cases of SCI and 60,000 stroke cases were occurred in 2011 [1]. The lifetime costs of TBI and SCI were estimated to be $10.5 billion and the cost of stroke has reported around 2.14 billion per year in Australia according to WAIMR [1]. People who suffer from TBI, SCI or stroke are faced with loss of control over one side of the body generally. Thus, patients cannot perform the daily live activities by themselves and this impact them and their families’ quality of life deeply. However, the studies had proven that performing of repetitive tasks and task-orientated activities can improve this type of motor impairment [2]. Hence, a lot of upper limb rehabilitation systems had researched and developed for restoration of lost functions. Such developments include robotic approach (end-effector based [3, 4] and exoskeleton based [5-7]), virtual reality (VR) based approach and augmented reality (AR) based approach. Generally, robotic systems aim to train for severe impairments and classified as expensive assistive device while VR and AR based systems aim for minor impairment or later stage of rehabilitation training at low cost. The latter approaches provide with better encouragement and motivation as these systems employ game based exercise as a training platform. Some researchers developed the combination of robotic and VR based approach as in [8]. Research studies had confirmed that the embedded of VR in rehabilitation system provides positive results [9, 10] which reflect on several developments [11, 12]. Stand-alone VR based rehabilitation system integrated with biofeedback system also can be found in [13]. Although VR based developments have proven with positive results, additional attachment of tracking device to the patient, their bulkiness and total immersive in virtual world are inconvenient and dangerous for patients especially if the patient is a child. Therefore, Augmented Reality (AR) based rehabilitation exercises have been developed for better and safer interactive environment. Augmented reality is the combination of real world and virtual world that enhance the user perception of reality. The user can view the computer generated virtual environment that is overlaid on top of real environment. As far as AR based rehabilitation system is concerned, J. W. Burke et al. [14, 15] have developed several exercises for upper-limb stroke patients. His development tracks the marker that is a defined color object to interact with virtual display on the display screen. His development aimed to obtain back the patient’s motor functions such as grasping, reaching, lifting, releasing and cognitive skills. Another AR based upper limb rehabilitation exercise is AR-REHAB. It was developed by Atif Alamri et al. [16] for post stork patient rehabilitation. The developed system was aimed to improve the patient’s arm reaching and hand grasping ability. AR drink, AR dance and AR fold were developed to improve the coordination of stroke patients in [17]. The system was developed to train the patients’ upper limb for daily life activities such as drinking, dancing and folding via virtual objects. Dunne et al. [18] invented the rehabilitation system with multi-touch display for the children with Cerebral Palsy (CP). One of the main features of this system was tracking the trunk position of patient and prevent from compensatory movement. The researchers in [19] developed two augmented environments (AE) for paediatric rehabilitation to improve the motor control via music playing AE and topographical orientation training to relearn the community mobility skills through decision making in AE. Another AR based rehabilitation musical system was developed in [20]. It was developed for children with CP to rehabilitate the arm movement via computer assisted music therapy. The rehabilitation purpose of this intervention is relearning cognitive, motor, psychological, social activities skill. AR based hand rehabilitation system was invented and reported in [21]. In this development, virtual piano as a hand rehabilitation therapy with self-designed data glove that detect the flexing movements of
real fingers and control the virtual fingers motion. Although the effectiveness of emotions and motivation using AR technique were studied in [22, 23], the current AR developments are only emphasized on game design principles and user convenient but integration of biofeedback system with AR based rehabilitation system is yet to be considered. The use of biofeedback has proven its benefit for retraining of muscles strengthening [24]. Therefore, this paper presents a home based rehabilitation system as well as the hospital based rehabilitation system that integrated with biofeedback system to retrain the plasticity of the brain for fast recovery. Our development aims to deal with the shortage of therapists, and to reduce the cost. The exploitation of our developed system is very simple as well as user-friendly. It allows the users to run it in easily and conveniently with very basic computer knowledge. Our development consists of rehabilitation exercise module and real-time active muscle module as shown in figure 1.

The rest of the paper is organized as follows. In Section II, developments of rehabilitation exercises are described. The development of real-time active muscle is presented in Section III. In Section IV, the testing and result are discussed. Finally, conclusion and future work is stated in Section V.

II. UPPER LIMB REHABILITATION EXERCISES

This module is a low cost system that can be used as a stand-alone rehabilitation system at home. It requires only a normal PC (or laptop) with cheap webcam and any color object. It worked based on tracking object with any color that attached to the user arm and used as a marker to track the current position of the user arm and interact with the virtual object on the display screen. The code for rehabilitation exercises were written with Action Script in Adobe Flash Professional. Setting up the game screen, display of elements and Graphical User Interface (GUI) were carefully considered. Tracking of colour marker is used based on 24-bit RGB true color space for most effective detection according to[25]. Collision detection of the marker and virtual interactive objects were done by checking the distance value of centre points of marker and virtual interactive object. Four exercises: Balloon Collection Rehabilitation (BCR), Ping Pong Rehabilitation (PPR), Transfer Object Game (TOG) and Feeding Animal Game (FAG) were designed and built in this mode as shown in figure 2. The developed exercises aimed to train upper limb reaching movement and strengthen the associated muscles in used within the specified time that can be adjusted depending on the patient’s impairment condition. These exercises also aim to replace the traditional reaching therapy rehabilitation exercises which can be easily boring and lost interest after used for few times.

A. Ping Pong Rehabilitation (PPR) Exercise

In PPR exercise, patient required to define which arm to be trained, either left or right arm as depicted in figure 3(a). The aim of the game is to maintain the bouncing ball within the game stage by moving of player’s arm up and down. The ball moves within the game stage with the limitation of upper and lower boundary of the stage. One side of the game stage border is limited by moving block that moves according to the ball movement direction to restrict the ball from to be out of game stage. The other side of the stage is the marker that attached to player’s arm to control the ball movement. Score will be awarded if the ball hits both user arm (marker) and moving block. The case if there is any missing ball, where the user cannot response correctly or it not blocked by moving block, no penalty will be imposed and new ball will coming out from the centre of the game stage again. The audio feedback is provided when ball touches with either marker or moving block. Countdown timer is displayed at the bottom of the game stage to encourage player to score as highly as possible score within the specified time. This exercise provides flexion movement as the user arm is force to move mainly for up and down based on predefined path of the ball motion. The muscles that trained in this exercise are deltoids and biceps brachii.

B. Balloon Collection Rehabilitation (BCR) Exercise

BCR exercise designed to interact with one arm as illustrated in figure 3(b). The aim of the exercise is to collect
the balloon which randomly generated from top of the display screen and place into the collection box which is located at the centre of the screen within the specified time. Once the balloon was placed in the box successfully, score will be awarded with audio feedback. Countdown timer was also presented to motivate the player. This exercise offered wider movements of shoulder, elbow and wrist joints that done based on the appearing and collection points of the balloon. The associated muscles: deltoids, biceps brachii, brachioradialis and flexor carpiradialis muscle were trained in this exercise.

**C. Transfer Object Game (TOG) Exercise**

TOG exercise was developed with five different solid shape elements at the bottom of the display screen and same shape with hollow elements at the top of the display screen as shown in figure 3(c). The aim of this exercise is to pick up one of the solid element at each time and to be placed in the same shape of hollow element. The maximum horizontal distance between the elements are within the average normal range of motion for horizontal adduction[26]. The vertical height between two rows was also developed within the maximum normal range of motion for shoulder flexion[26]. Like other exercises, present of timer, score and audio feedback to inspire the patient’s interest during playing of reaching exercise. This exercise targeted to train wider range of motion in shoulder flexion, horizontal adduction movements and strengthen the associated muscles. The associated muscles that support to move shoulder flexion are coracobrachialis, pectoralis major, anterior deltoid and biceps brachii. The horizontal adduction movement is achieved by contracting of coracobrachialis, pectoralis major and anterior deltoid.

**D. Feeding Animal Game (FAG) Exercise**

FAG exercise which shown in figure 3(d) developed based on pick up the food from the bottom row of the display screen and place into the indicated plate. The exercise can be played either left or right hand. In this exercise, the virtual dog is looking for the food around the screen. The food which indicates with red color arrow need to be picked by the patient with color marker and placed in the food plate which indicated with green color arrow. The different height of the placement of food plate will train the arm reaching movements which is normally conducted based on traditional way therapist exercise [26]. When the subject places the food correctly into food plate, the score will be increased as a reward and patient is required to pick and place all the food into food plate within the defined time. The present of visual feedback motivates the long training without boring. The rehabilitation purpose of this exercise is intended to increase the arm range of motions as well as increase strength of in used muscles: anterior deltoid, posterior deltoid, upper trapezius and pectoralis major.

### III. REAL-TIME ACTIVE MUSCLE

Under real-time active muscle module, BioGraph Infiniti system from Thought Technology [27] is utilized for extraction of patient’s muscle signal through Electromyogram (EMG). EMG is an electrical activity which produces by skeletal muscles. It can detect the abnormalities and muscle activation level of human movement. Therefore, it becomes very important information in many clinical and biomedical applications. There are numerous EMG based applications such as controlling of prosthesis or orthotic device movement [28], detection of user intended movement [29] and controlling of virtual models [13]. The EMG signals can be obtained via two different ways: surface EMG where sensor is attached to the user skin and intramuscular EMG where needle electrode is inserted via skin into muscle tissue. In our development, surface EMG sensors were employed to monitor the muscle performance. The signals were extracted during performing the rehabilitation exercise. The screen shot of real-time active muscle module can be found in figure 4 (left). In figure 4 (left), there are two animated muscle windows and four line graphs of EMG signals data. Animated muscle windows display the front and back view of the arm muscles while four line graphs display the current muscle signal. For instance, in FAG exercise, there are four electrodes to collect the patient’s EMG signals and electrode sites are as shown in figure 5. The collected signals presented in real-time as a line graph and utilized as an input data for activation of animated muscle at the same time. Animated muscle is represented by changing the muscle color. When the EMG signals are above predefined threshold value which is defined by therapist according to the patient’s muscle performance, the muscle color will be changed so that patient and therapist can observe the current active muscle. Four line graphs represent the real-time activity of upper trapezius, anterior deltoid, posterior deltoid and pectoralis major muscles performance. This module was developed in Matlab platform and integrated with rehabilitation exercises to complete the system as a hospital based rehabilitation system as portrayed in figure 4.
IV. TESTING AND RESULT
The test had conducted with ten healthy subjects and the age ranging from 18 to 35 and they participated in all the developed exercises. Each subject is requiring answering the questionnaire, which describes in Appendix, at the end of the exercise. The scoring ranks from ‘1’ to ‘4’ where ‘1’ refers to strongly disagree and ‘4’ refers to strongly agree. Before the training start, four EMG electrodes were attached to trained muscles according to the selected exercise. The marker was attached to the subject’s thumb for tracking and interacting with virtual objects. When the rehabilitation exercise starts, the subject been asked to select the color marker which worn at the thumb. The system then tracked the current position of the arm and interacted with virtual objects until end of the exercise. From the analysis of the questionnaire, which is illustrated in figure 6 (a-d), the participants found the exercises are interested and they enjoyed the exercises without any major discomfort. Almost all participants felt that the tracking of the color marker is good as well as the exercise is very easy to understand with motivated feedback. However some of the participants felt the muscle fatigue after the exercises. This was due to the muscle condition of individual and partly due to the holding pose of the color marker. This can be solved by using different color maker which is like glove to provide more convenient especially for patients who cannot even hold an object. In muscle activation module, the muscle animations were able to animate according to the predefined threshold and able to monitor by subject and therapist in real-time. A demonstration of the system had conducted in Port Kembla Rehabilitation Hospital and received valuable feedbacks from physical and occupational therapists for future implementation.

V. CONCLUSION AND FUTURE WORK
As a preliminary stage, we achieved the major aim of this development that is to provide the subjects and therapists with ability to monitor the trained muscles performance not only in real-time signal displays but also in real-time muscle animation during performing of rehabilitation exercises. The users were able to interact with the rehabilitation exercises easily via worn color marker and followed the indication to complete the exercise. The present of feedback such as scoring and exercise duration is additional features to prolong the patient interest in exercise. The test had conducted with ten healthy subjects and provided with positive results according to the questionnaire. We have demonstrated our development in Port Kembla Rehabilitation Hospital and received the valuable feedbacks from therapists and their requirements. As far as future work is concerned, we will improve our development to meet the therapists’ requirements and conduct the clinical trial in Port Kembla Rehabilitation Hospital for system performance validation.

APPENDIX
The questions for the questionnaire were as shown as below. The subjects responded the following questions based on numerical score where 4 represents strongly agree and 1 represents strongly disagree.
1. I have tried Augmented Reality games before.
2. The game is motivated and interested.
3. The given information and guide are easy to understand.
4. It is comfortable to wear the marker.
5. Tracking of the colour marker is good.
6. The present of feedback such as timer and scoring system are motivating.
7. It can feel the arm muscles fatigue.
8. It is comfortable throughout the exercise.
9. The benchmark time for healthy/ stroke person is appropriate.

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REFERENCES


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