Development of Augmented Reality Rehabilitation Games Integrated with Biofeedback for Upper Limb

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ABSTRACT
Stroke is one of the leading causes of disability in all over the world. This disability greatly impacts the stroke patients' daily life activities. Thus, rehabilitation exercises are essential for post stroke patients to restore their lost functions gradually for daily life activities. Traditional rehabilitation exercises do not motivate the post stroke patients as they are normally humdrum and required expensive equipments. Therefore, this paper presents the development of low –cost motivating webcam colour based visual tracking augmented reality (AR) system with biofeedback for upper-limb post stroke rehabilitation therapy. Augmented Reality is a novel form of human-computer interface which overlay the computer-generated information on the real world environment rather than replaces it. In the developed AR system, two games; Ping Pong Rehab (PPR) and Balloon Collection Rehab (BCR) are created based on game design principle. PPR game trains shoulder and arm muscles during rehabilitation therapy whilst BCR game trains shoulder, arm and forearm muscles. Both games have been built and integrated with Biograph Infiniti software to monitor the muscles' performance. The integrated system will obtain the biofeedback EMG signals from patients that will be utilised for future developments. It allows the patients to monitor their arms and muscles movements in real time on the display screen via low-cost webcam. The system aims for home based rehabilitation system and friendly used by patients themselves. The developed integrated system has tested with able subject and it worked perfectly during the test.

Keywords
Human-Computer Interface; AR Games; Colour Tracking; Biofeedback; Upper-Limb Stroke Rehabilitations.

1. INTRODUCTION
Stroke is one of the leading causes of death and disability in Australia. According to Australian Institute of Health and Welfare statistics, 8,484 of Australians were death in 2006 and 146,400 Australians had disability in 2003[1] due to stroke. Authors form [2] reported that out of pocket costs of first-ever stroke is an average of AUD 7,500 and maximum up to AUD 69,560 during first year which becoming the burden to patients and their family. Major contributions of this out of pocket costs are private therapy, home modifications and respite care.

This disease burden takes place when the plaque in the blood vessel to the brain is blocked or ruptured [3]. As a result, part of the brain cell is dead which lead to stroke which is normally paralysed one side of the body and thus person's daily life activities are affected. Therefore, rehabilitation therapies are required to restore for lost functions. They are normally conducted in hospitals, inpatient rehabilitation centres and nursing homes. However, the costs of such treatments are expensive as mentioned earlier [2], thus inexpensive rehabilitation systems are studied to overcome this burden. In terms of low-cost rehabilitation systems, computer games system integrated with virtual reality and augmented reality technologies are becoming very popular and useful for rehabilitation purpose.

The remainder of this paper is constructed as follows. Section 2 provides literature reviews of recent developments for post stroke rehabilitation. Section 3 discusses about game design principle in rehabilitation system. Section 4 presents the game development. Rehabilitation game methods are presented in session 5 while integration with biofeedback system is presented in section 6. Lastly, Section 7 comprises with conclusion and future work.

2. LITERATURE REVIEW
There are a lot of interventions for upper and lower limbs post stroke rehabilitation systems. In this paper, the upper limb rehabilitation exercises have been investigated that include computer games system integrated with virtual reality (VR) and augmented reality (AR). The VR is completely immersed in the synthetic environment while AR allows the user to communicate with real world and it supplements reality rather than replaces it. Recent developments of rehabilitation systems are mainly focus on VR and AR techniques due to their low cost, better clinical assessment and options and more effectiveness of rehabilitation task over traditional method.

Immersive VR systems have developed by [4-6]. Although VR provide positive contribution to rehabilitation therapy, the

attachment of traking device, cyber glove, data glove or any haptic device to user arm become inconvenience due to its size and weight. Thus, many researchers started to develop rehabilitation AR system with light weight marker tracker and video capturing system. AR-REHAB system [7] has developed for upper limb rehabilitation. The system is developed with two exercises and framework that provide more convenience to therapists and patients. However, there is an occlusion problem in player's depth perception in his development. Moreover, the vision-based finger measurement system is needed to develop for reading the finger angles. Another computer-generated graphics game or task-driven scenarios has developed in [8]. It uses marker and webcam to detect the position and orientation of the object movement. Rehabilitation games were developed within the system and interact with marker which user is holding. Yet, the camera position, depth perception and lighting condition needed to improve in current system in order to provide an effective rehabilitation task. The rehabilitation games which using low-cost video-capture technology was being developed by Burke et al.,[9]. In his system, the design of the video games has been developed according to rule of play and aims to deploy at home. For this system, the developed games are required to improve in speed changes, additional feedback notifications and the method of scoring according to case studies that conducted.

The reviews of above VR and AR developments have motivated our group to develop our rehabilitation system for post stroke patients. Our group have developed bio-driven system-based virtual reality for prosthetic and rehabilitation systems. 10-calss EMG-based motions: radial deviation, ulnar deviation, hand open, wrist extension, wrist flexion, key grip, chuck grip, rest state, forearm pronation and forearm supination driven system is implemented to stimulate limb model within the virtual world. Details of this development can be found in [10]. Moving forward from this, the development of augmented reality based rehabilitation system came into our interest due to its more realistic interaction with real world than virtual reality which is completely immersed in the virtual world. This paper presents detail of the development of the system. The use of colour tracking method in developed integrated system provides consistent tracking under minimum variation of lighting conditions. There is no issue with depth perception as the elements in the integrated system are rendered as two dimensional graphic elements. The depth sensation of the integrated system provides precise movements (tracking) and detections in developed integrated system.

3. GAME DESIGN PRINCIPLE IN REHABILITAION

Depression is one of the important implications due to stroke and it may impede post stroke rehabilitation therapy [11]. As a result, patients' quality of life, their recovery chance and caregiver health will be affected. Research of Jack et al., have shown that integration of the gaming feature in rehabilitation system enhance the adult patients in physical therapy [12]. Thus, games as rehabilitation tasks are encouraged in AR rehabilitation system to rehabilitate their impaired physical abilities and the importance of game design principle is come into interest for rehabilitation system. Salen and Zimmerman [13] mentioned that successful game design is depending on "discernible" and "integrated". Former represents player to observe the immediate outcome of their action as can be called real time feedback while latter represents the outcome of their action which will reveal in the later point in the game such as increasing challenge during playing game. Without this function, player can be easily bored and give up playing game. Thus, becoming an enjoyable game much relies on game design principle especially in rehabilitation therapy as patient can easily lost interest during rehabilitation session.

4. GAME DEVELOPMENT

The system requires just a PC (or laptop) with any webcam and marker to be run. Thus, the rehabilitation game system is relatively low cost system. In this paper, two games; Ping-Pong Rehab (PPR) and Balloon Collection Rehab (BCR) are developed as rehabilitation tasks. Both games were built up in Adobe Flash Professional, ActionScript 3.0 and interface with webcam. The game design is implemented based on game design principle as described in section 3. The real time feedbacks such as timer, score, own movements were able to observe by players in both PPR and BCR games. This feedback will lead the players to concentrate in the game world. The present of different levels in both games will attract the players to keep on playing without boring. Developed games are aimed to promote the upper limb reaching movements and strengthen the shoulder, arm and forearm muscles. In this work, both games were developed with careful consideration in setting up the game screen and game elements, defining and tracking colour marker and collision detection method. Details of these considerations are explained as follow.

4.1 Setting Up the Game Screen and Elements

To provide the user with flexibility, two set up options have been designed to be used by the user to play the game. One of the options is playing game with integrated biofeedback system on one PC (or laptop). Another option is using two PCs (or laptops); one for running biofeedback system while the other is running the game system. In integrated option, the width and height of the game screen is set to 500 and 350 pixels respectively while the other option can play with Full-Mode screen display. As a testing purpose in this development, one PC option was being used.

The Graphical User Interface (GUI) of both games was carefully considered with well-designed GUI principle. The colour of the game elements and buttons were chosen with obvious and contrast colour to catch the users' eyes for both games.

4.2 Defining and Tracking Colour Marker

Users are asked to select the colour of the marker at the beginning of the game. In this work, 24-bit RGB true colour space is chosen for most effective detection according to Gonzalez et al. [14]. The defining and tracking of selected colour is based on getPixel and getColorBoundsRect function. The getColorBoundsRect function will define the rectangular region of all the pixels of that colour value which is at x and y positions of mouse clicked. The defined rectangular region of the pixels will be surrounded with colour rectangular by drawRect function and it will appear as a visual feedback to the users. Selected colour is recognized in the system and tracked every frame to detect the current position of that colour in order to achieve tracking of the marker in real time.

4.3 Collision Detection

Collision Detection method, to find out the collision of the object (ball or balloon) with the user arm (marker) that used in this work, is done by checking the distance of marker point and interactive game element (object) point. The defining of points for both marker and game elements are required in the program prior to checking the distance. If the difference is less than defined distance value, marker and interactive game element consider hit and will proceed with next function.

5. REHABILITAION GAME METHOD

5.1 Ping Pong Rehab (PPR)

Ping-Pong Rehab (PPR) game is played using either left or right arm which is affected due to stroke. Before starting the game, player is asked to choose either left or right arm to begin the game. The aim of the game is to maintain the bouncing ball within the game stage by moving of player's arm up and down as shown in figure 1. 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. PPR game provides shoulder and elbow joints movements as the player arm is force to move mainly for up and down, flexion, movements and minimum movement to left and right direction, transverse flexion. The muscles that provide those movements are deltoids which are located at the shoulder and biceps brachii which is situated at the arm are trained in PPR game exercise.

5.2 Balloon Collection Rehab (BCR)

Balloon Collection Rehab (BCR) game is designed to be played with one arm: either left or right hand which is affected due to stroke. The goal of the game is to collect the balloon which spawns randomly from top of the game and place in the box which is located at the centre of the game stage as figure 2 showed. Once the balloon is place in the box successfully, score will be awarded with audio feedback. Like PPR game, countdown timer is also presented to motivate the player. This game provides wider movements of shoulder, elbow and wrist joints. The muscles that support to move those joints are deltoids which is placed at shoulder, biceps brachii which is situated at the arm, brachioradialis and flexor carpi radialis muscle which are located at forearm are trained in BCR game exercise.

6. INTEGRATION WITH BIOFEEDBACK SYSTEM

Integration of biofeedback is another effective technique for motor rehabilitation [15]. In this work, BioGraph infiniti software from Thought Technology [16] is utilized for recording, reviewing and reporting of the electromyography (EMG) signal.

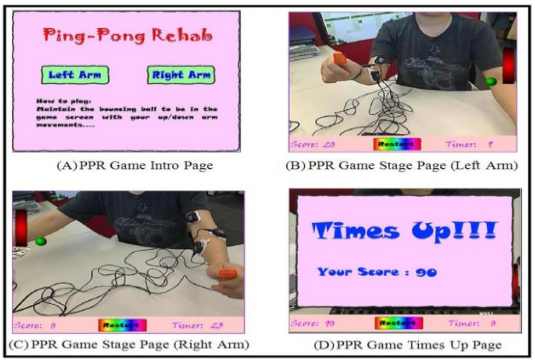

Figure 1. Ping Pong Rehab (PPR) Game

Figure 2. Balloon Collection Rehab (BCR) Game

The surface EMG electrodes are used to measure the action potentials of users' skeletal muscles while playing the games. There are four muscles to be measured during training namely deltoids, biceps brachii, brachioradialis and flexor carpi radialis muscle. BioGraph Infiniti software is integrated with both games and figure 3 illustrated the integrated system for PPR game. The screen, can be divided into 5 sessions. At the top left corner, numerical value of current EMG and current mean EMG for individual muscle is displayed. At the top middle, the bar graphs are represented the thresholds value of muscle activities with audio feedback. At the top right corner, active muscle animation screen is display as visual feedback to the user. This animation lets the user to observe that which muscles are being trained and where are they located. There are four line graphs for EMG signal at the lower left corner of the screen. The individual line graph represents the activities of each muscle within 30 seconds and performance of each muscle can be monitored and compared. The game session is place at the lower right corner of the screen.

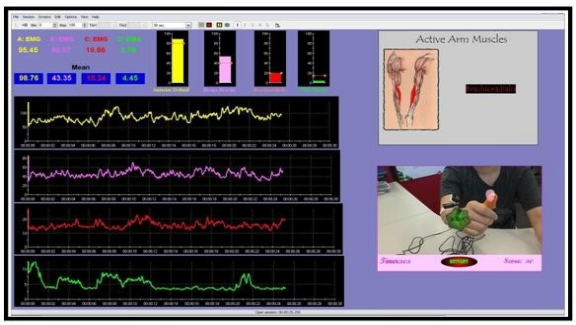

Figure 3. Integrated Biofeedback System

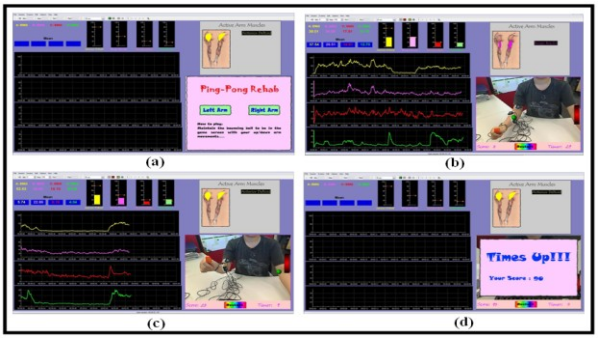

Figure 4. Screen Shots of Integrating System during Testing

7. EXPERIMENT AND RESULT

The integrated PPR and BCR games were tested with healthy subject. The subject is asked to be seated in front of the monitor. The EMG electrodes are placed on the subject's arm muscles that want to monitor. The colour marker is attached to the subject's thumb to track the arm movement. The figure 4 shows the screen shots of integrated PPR game system where (a) shows the starting of the game, (b) and (c) demonstrate the subject in action during playing game with visual (EMG line graph, muscle animation) and audio (sound of the muscle names) feedbacks and (d) shows the ending of the game. During playing game, subject is found to be enjoyed and motivated with developed games and its feedbacks. The present of muscle animation provides the addition information about the trained muscles. The real time EMG data were recorded and displayed for therapist or even patients or their families can be monitor the muscle performance on every rehabilitation exercise. Although the developed system worked perfectly under testing with motivated feedbacks according to game design principle, clinical trial has to be done in near future with post stroke patients for validation.

8. CONCLUSION AND FUTURE WORK

Computer games system offers various advantages in post stroke rehabilitation systems. According to game design principle, the system has been developed with highly motivated game design and low cost vision tracking system which is suitable to use at home. Colour segmentation is used to track the movement of player's arm without the needs of any special devices, techniques or knowledge to access the system. Thus, it is very flexible and convenient to operate by patient or family members themselves. Interface with biofeedback system offers benefit to both patients and therapists by monitoring and tracing the muscles improvement over the training period of time. The testing has conducted with both integrated system and they worked perfectly. The next step is to interface the EMG signal and AR environment.

9. REFERENCES

[1] Australian Government, Australian Institute of Health and Welfare,. (2011, Febuary). *Stroke in Australia*. Available: http://www.aihw.gov.au/cvd/stroke.cfm

[2] Dewey, H. M., Thrift, A. G., Mihalopoulos, C., Carter, R., Macdonell, R. A. L., McNeil, J. J., and Donnan, G. A., "'Out of pocket' costs to stroke patients during the first year after stroke - results from the North East Melbourne Stroke Incidence Study," *Journal of Clinical Neuroscience,* vol. 11, no. 2, pp. 134-137, 2004.

[3] Longmore, M., Wilkinson, I. B., Davidson, E. H., Foulkes, A., and Mafi, A. R., *Oxford Handbook of Clinical Medicine*, 8 ed. New York: Oxford University Press, 2010.

[4] Morrow, K., Docan, C., Burdea, G., and Merians, A., "Low-cost Virtual Rehabilitation of the Hand for Patients Post-Stroke," *In: Intl. Workshop on Virtual Rehabilitation '06,* pp. 6-10, 2006.

[5] Subramanian, S., Knaut, L. A., Beaudoin, C., McFadyen, B. J., Feldman, A. G., and Levin, M. F., "Virtual Reality Environments for Rehabilitation of the Upper Limb after Stroke," in *Virtual Rehabilitation, 2006 International Workshop on*, 2006, pp. 18-23.

[6] Rand, D., Kizony, R., and Weiss, P. L., "Virtual reality rehabilitation for all: Vivid GX versus Sony PlayStation II EyeToy," *In: Proc. 5th Intl. Conf. on Disability, Virtual Reality & Associated Tech '04,* pp. 87-94, 2004.

[7] Alamri, A., Jongeun, C., and Saddik, A. E., "AR-REHAB: An Augmented Reality Framework for Poststroke-Patient Rehabilitation," *Instrumentation and Measurement, IEEE Transactions on,* vol. 59, pp. 2554-2563, 2010.

[8] Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., and McDonough, S. M., "Augmented Reality Games for Upper-Limb Stroke Rehabilitation," in *Games and Virtual Worlds for Serious Applications (VS-GAMES), 2010 Second International Conference on*, 2010, pp. 75-78.

[9] Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., and McDonough, S. M., "Optimising engagement for stroke rehabilitation using serious games," *The Visual Computer,* vol. 25, pp. 1085-1099, 2009.

[10] Al-Jumaily, A. and Olivares, R., "Bio-driven system-based virtual reality for prosthetic and rehabilitation systems," *Signal, Image and Video Processing,* pp. 1-14, 2010.

[11] Sinyor, D., Amato, P., Kaloupek, D., Becker, R., Goldenberg, M., and Coopersmith, H., "Post-stroke depression: relationships to functional impairment, coping strategies, and rehabilitation outcome," *Stroke,* vol. 17, pp. 1102-1107, 1986.

[12] Adamovich, S. V., Boian, R., Burdea, G. C., Jack, D., Merians, A. S., Poizner, H., Recce, M., and Tremaine, M., "Virtual reality-enhanced stroke rehabilitation," *Neural Systems and Rehabilitation Engineering, IEEE Transactions on,* vol. 9, pp. 308-318, 2001.

[13] Salen, K. and Zimmerman, E., *Rules of Play: Game Design Fundamentals*. Cambridge: MIT Press, 2004.

[14] Gonzalez, R. C. and Woods, R. E., *Digital Image Processing*, 2nd ed.: Pearson Education, 2001.

[15] He, J., Huang, H., and Wolf, S., "Recent developments in biofeedback for neuromotor rehabilitation," *Journal of NeuroEngineering and Rehabilitation,* vol. 3, p. 11, 2006.

[16] Thought Techonology. (2010, February). Available: http://www.thoughttechnology.com/