A Novel Upper Limb Rehabilitation System with Self-Driven Virtual Arm Illusion

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***Abstract*— This paper proposes a novel upper extremity rehabilitation system with virtual arm illusion. It aims for fast recovery from lost functions of the upper limb as a result of stroke to provide a novel rehabilitation system for paralyzed patients. The system is integrated with a number of technologies that include Augmented Reality (AR) technology to develop game like exercise, computer vision technology to create the illusion scene, 3D modeling and model simulation, and signal processing to detect user intention via EMG signal. The effectiveness of the developed system has evaluated via usability study and questionnaires which is represented by graphical and analytical methods. The evaluation provides with positive results and this indicates the developed system has potential as an effective rehabilitation system for upper limb impairment.**

I. Introduction

In Australia, stroke or Cerebrovascular Accident (CVA) is the leading cause of disability. Over 420,000 Australians were living with the effects of stroke in 2012 which was over 1.77% of the Australian population according to National Stroke Foundation [1]. To recover from such disability, rehabilitation programs are conducted in hospitals and clinics by a rehabilitation team that includes staff with different skills. Rehabilitation is the process of training to recover or improve lost functions due to injury or illness. According to physiotherapy board of Australia, only 23,301 people were registered as physiotherapists by 2012 which is a ratio of 12:1 (Patients : Therapist) [1]. This leads to shortage of physiotherapist and become one of the major problems in Australia. Another major problem is the burden of disease costs for stroke which is about AU$50 billion in 2012. To overcome above mentioned major problems, researchers are trying to develop low cost rehabilitation system which requires less supervision by therapist. Such developments include Virtual Reality (VR) based rehabilitation systems [2] and Augmented Reality (AR) based rehabilitation systems [3, 4] which provide better motivation by integrating with games like exercises as rehabilitation exercises. In addition to that, researchers have integrated with biofeedback system to AR system [5] to provide fast recovery and such studies have proven with positive results via clinical trials [6]. Biofeedback is a process that enables an individual to learn how to change the physiological for the purposes of improving health and performance. Another type of low cost approach for upper limb rehabilitation is called Mirror Therapy (MT). In MT treatment, patient is asked to sit in front of the mirror that is put between left and right arm. The mirror side is faced towards unaffected arm while impaired arm is hid behind the mirror. Therefore, when patient looks into the mirror, he/she will see the reflection of the unaffected arm as his/her impaired arm by creating the visual illusion. This approach has been used to treat the stroke patients [7] and proven results of MT have reported in [8].

However, up to our knowledge, there are no systems have developed for whole arm rehabilitation based on self driven virtual arm illusion to provide fast recovery. Therefore, the very first and low cost upper limb rehabilitation system named Augmented Reality based Illusion System (ARIS) has designed and developed with user own intention. The system integrates with AR technology, computer vision technology, and real-time biofeedback system to achieve effective fast recovery.

This paper is organized as follows: section II describes the ARIS framework and its architecture. Section III details the usability study of system. Section IV depicted the results and discussion from the usability study and finally, in section V, conclusion and future work are presented.

II. ARIS Framework and Architecture

A. System Framework

The overall framework and sub-modules of ARIS is portrayed in Fig. 1. It requires only a standard personal computer or laptop with webcam and EMG acquisition device. The main framework is developed in Flash Professional CS6 platform with the help of Matlab platform. Firstly, sEMG data from user are recorded via sEMG acquisition device from Thought Technology [9] and then, extract the features of sEMG signal via Matlab platform. The extracted features will then send to Flash Professional for further process in ARIS to detect user intention. ARIS is made up of five modules: live video background and multiple color tracking module, illusion module, VA modelling module, AR based rehabilitation exercise module and real time sEMG detection module. In additional to that, the graphical measurement: real-time trajectory graph and analytical measurements: sEMG threshold value, current hand position in X and Y, and kinematics data are able to monitor and evaluate the user's progress during the

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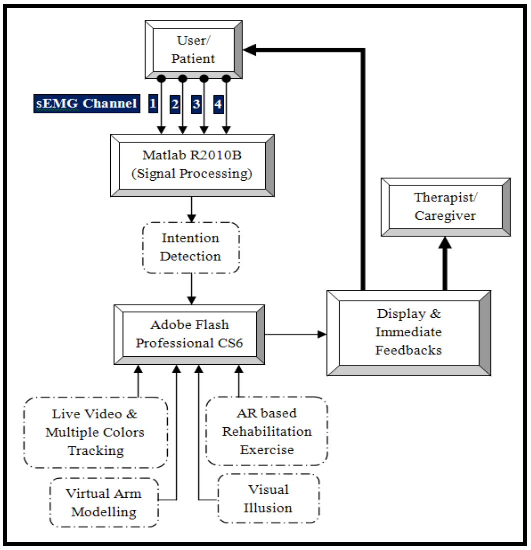


Figure 1. ARIS framework and its sub-modules

rehabilitation process via display screen by both user and therapist/caregiver.

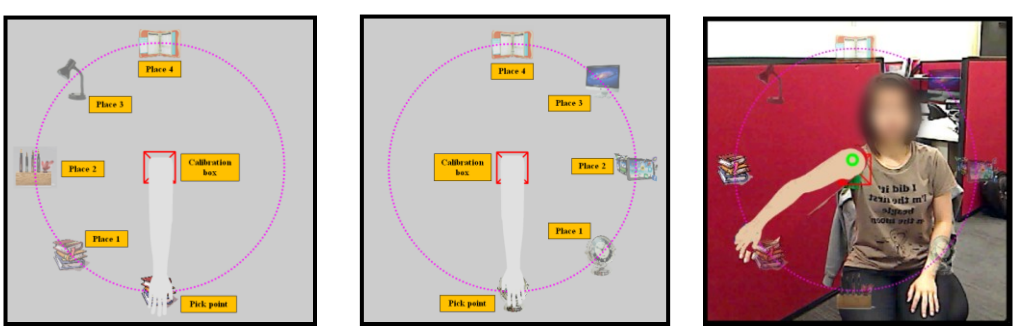
B. *System Architecture*

Before starting the exercise, user requires to choose either left or right arm training as depicted in Fig. 2(a-b), depending on which side of the arm is paralysed. In addition to that, three different levels of rehabilitation therapy: initial level, intermediate level and advanced level are available in the system and user needs to choose one of the levels based on his/her arm degree of impairment. Then, the appropriate training exercise and level will display to the user. Step by step information is provided to the user for ease of understanding on how to manipulate the system and exercise. Before starting the exercise, the system will ask user to capture the current background so that in the later stage, this background image will integrate to create illusion scene. After that, user skin color is requested to choose by just clicking on the user's own skin color which is seen via webcam. At the same time, the VA model which coloured with selected skin color will be loaded in the system and ready to display to the user but yet to display. Once the skin color has chosen, the color markers which attach to the shoulder joint, elbow joint, wrist joint and finger tip will be asked by the system to track the position in real time. After all the colors have selected, VA model will be displayed to the user by overlapping on top of the real arm and the real arm will cover with oval shape object which is filled with current background image that taken by webcam earlier as shown in Fig. 2(c). This will create the visual illusion scene to the user and make the system ready to perform the VA simulation. The attachment of the VA model depends on the choice of level by the user. In the case of initial level, the model attaches to the calibration box which locates at the centre of the training trajectory. In the case of intermediate and advanced level, VA model attach to the user's shoulder color marker. The activation of the VA model simulation depends on the sEMG user dependent threshold value that measured before the exercise with FlexComp EMG acquisition device. This measured threshold value will be processed in Matlab and exports to Flash platform and set as a threshold value in ARIS by user, therapist or caregiver. Above such measured value will be considered as user has intention to move and VA will perform simulation otherwise VA model will remain unchanged. The system will be started when the user presses the start button. In the case of initial level, the simulation of pick and place will be done by VA model while user own movement is contributed less than 25% of the whole trajectory. In the case of intermediate level, pick and place will be performed by both user and VA model. When user cannot move to the desired position (for instance, user only can move up to 50% of the trajectory), VA model will be taken over the job of real arm. In the case of advanced level, real arm will perform most of pick and place movement (for instance, 85% of the trajectory) and then VA model will take over the job of real arm to complete the training. In all levels, the performance of the real arm can be observed in real-time under real-time trajectory graph as well in X and Y position under real hand position. VA model moves according to the predefined trajectory by means of forward and inverse kinematics.

III. USABILITY STUDY

A. *Participants*

Ten healthy participants participated in the experiment and all of them are right handed. Two of the participants were requested to perform for initial level with right arm training. As for intermediate level, six participants were selected. Among six, three of the participants were requested to perform left arm exercise while another three were



(a) (b) (c)

Figure 2. (a) Left Arm Training without AR background (b) Right Arm Training without AR background (c) Visual illusion concept (real arm is hidden and virtual arm is overlaid) while performing Left Arm Training

requested to perform right arm exercise. The rest, two participants, were requested to perform advanced level with left arm training.

B. Experiment Setup and Design

The experiment was conducted in one of the laboratory rooms at Faculty of Engineering and Information Technology, University of Technology Sydney. To perform the experiment, participant was asked to sit in front of the desk where personal computer with webcam and FlexComp sEMG acquisition device were placed. After that, four color markers and four sEMG electrodes were attached to the participant's arm and the locations are as shown in Fig. 3. Subsequently, every user was requested to move his/her arm in circular shape freely to record the threshold values of all muscles. After that, the distance between the webcam and participant's arm position was adjusted to align the size of VA model and real arm for the visual illusion as well as define the distance for the real arm range of motion with respect to radius of rehabilitation exercise. The adjustment was completed by placing the real arm shoulder joint to the calibration box (rectangular box) which is displayed at the centre of the rehabilitation exercise which can illustrated in Fig. 2. After all the settings had completed, participant was ready to perform the experiment.

In usability study, two phases: training phase and testing phase were conducted. During training phase, the procedure was explained to familiar with the system and rehabilitation exercise for every participant. Afterwards, every participant was trained for one or more sessions on how to perform the ARIS rehabilitation exercise, what would be the measurements and what types of measurements should take note. The sEMG value was also observed during this stage to determine the appropriate threshold value to activate VA model simulation. For those participants who were novice in AR environment and illusion concept, more training sessions were provided during this stage. There was resting time between every training session to prevent from muscle fatigue. When the participant achieved confident level to perform independently, testing phase was conducted. In testing phase, every participant was expected to perform the rehabilitation exercise independently which is exactly same

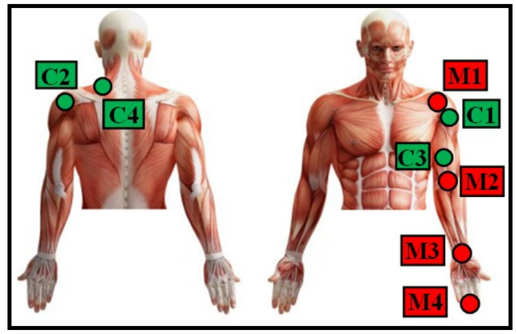


Figure 3. Position of electrode sites (C1, C2, C3 & C4) and color marker positions (M1, M2, M3 & M4)

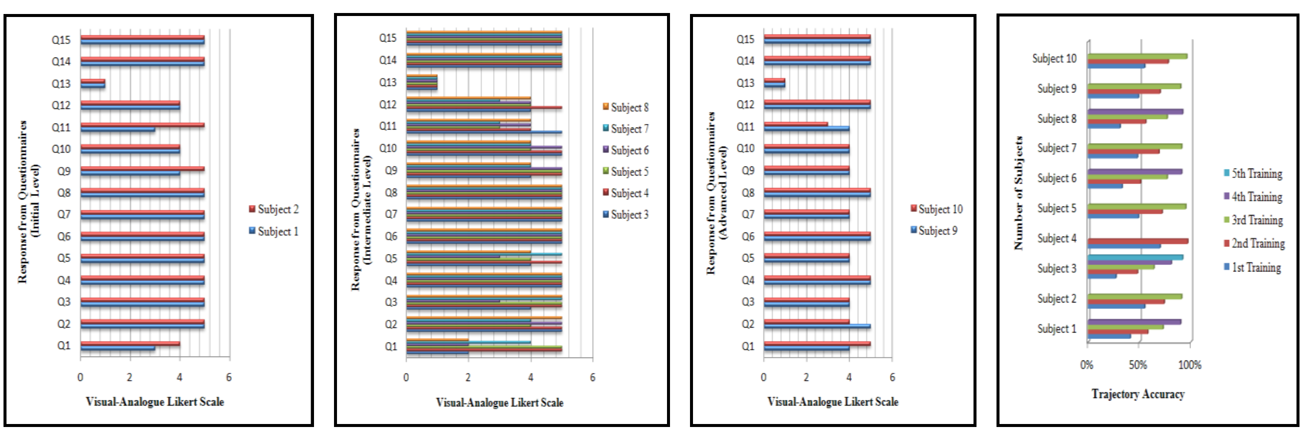
as training sessions. The same value for the threshold value from the last training session was set to determine the participant's intention of movement. In this phase, participant was asked to concentrate on the movement intention, feeling of visual illusion as well as observing the real arm movement performance via trajectory graph.

C. Feedbacks and Measurements

As far as feedback is concerned, questionnaires were assessed by every participant at the end of the testing phase. The answers for the questionnaires are based on visual-analogue likert scale [10] where '5' refers to strongly agree and '1' refers to strongly disagree. The set of questions that stated in the questionnaires are described in Appendix. Other types of measurements such as graphical measurement: real-time trajectory and analytical measurements: threshold value, kinematics values and current hand position value are available in developed system.

IV. Result and Discussion

The results from questionnaire and arm movement accuracy by every subject are as depicted in Fig. 4. It shows that all the participants were enjoyed and interested to perform the rehabilitation training during the experiment. Although most of the participants don't have AR experience, they understood the system and improved the movement trajectory after few training sessions as participants received



(a) (b) (c) (d)

Figure 4. (a) Questionnarie result from initial level training (b) Questionnarie result from intermediate level training (c) Questionnarie result from advanced level training (d) Trajectroy accuracy result and number of training sessions for individual participant

enough training sessions as depicted in Fig. 4(d). This measurement provides that the more training was provided, the better results in controlling of own arm movement which is above 90% of accuracy. The user intention was able to detect successfully via sEMG threshold value of anterior deltoid that defined before training and testing phase and VA model was received real-time activation command to simulate the VA model. The feeling of visual illusion was also evaluated via questionnaire and the responses from the participants were very encouraging. In all training levels, most of the participants were perceived as if real arm was moving. They also found that when they had intention to move their real arm, the virtual arm was moved at the same time. As a result, VA movement encouraged the real arm to follow its trajectory. This is very important and one of the main objectives of ARIS as this encouragement will provide user to reestablish the neural pathways and synapses that able to control the mobility by oneself. The rehabilitation exercise in ARIS was also reported that very easy to manipulate and understandable. Participants were also felt the good sense of immersion in AR environment. In additional to that, all participants were enjoyed with real-time immediate feedback and measurements. They were strongly agreed that all of these feedbacks and measurements benefit to the caregivers or therapists or even to users. Although, the overall questionnaire results were provided with positive feedback, some of the participants were suggested very good ideas to improve in some parts of the system and those will implement in near future.

V. Conclusion and Future Work

In this paper, a novel upper extremity rehabilitation system with self-driven virtual arm illusion (ARIS) is proposed. The effectiveness of the system has evaluated with usability study and the results provide with positive feedback. It has also proven that it requires minimum supervision of caregivers or therapists. Therefore, as a preliminary stage, the developed system can be considered as a very successful rehabilitation system. As far as future work is concerned, the appearance of the VA model will be improved for more realistic appearance and this work is currently undertaking. In addition to this, the system will blending with our previous developments to provide the various choices of upper limb rehabilitation exercises [5]. After upgrading has completed, new version of ARIS will be conducted for both non-clinical and clinical trials at Port Kembla Hospital, NSW, Australia where the previous works of our group had demonstrated [11].

Appendix

The set of questions that stated in the questionnaires are as follow:

- Q1. I have Augmented Reality/Video Games experience.
- Q2. The Graphical User Interface (GUI) is user-friendly and easy to adapt.
- Q3. AIRS provide with enough information such as current hand position and joint angles.
- Q4. During the training phase, I received enough information and training sessions.
- Q5. The multiple colors tracking in ARIS is good.
- Q6. AR environment was good and immersive.
- Q7. AR exercise was doable and easy to perform. (Reaching movements)
- Q8. The virtual objects in AR exercise were easy to pick up. (Collision detection)
- Q9. During training and testing phase, I felt that when my real arm moved, virtual arm would move.
- Q10. During training and testing phase, if the virtual arm moved, my real arm was moving.
- Q11. During training and testing phase, I felt that virtual arm was my own arm.
- Q12. During training and testing phase, I felt that I am picking up the virtual object by my own arm.
- Q13. During training and testing phase, I felt that my upper limb muscles were fatigue.
- Q14. The immediate feedbacks such as real-time trajectory tracking, threshold value, hand position and joint angles are very good and useful.
- Q15. As a whole, the ARIS is interesting, motivating and enjoyable.
- Q16. Suggestion and improvements are welcome.

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