Illusion Approach for Upper Limb Motor Rehabilitation

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Abstract: Taking the advantage of human brain plasticity nature, Augmented Reality (AR) based Illusion System (ARIS) for upper limb rehabilitation has developed. The ARIS aims to restore the lost functions of upper limb due to various motor injuries. It incorporates with AR technology to build up the upper limb rehabilitation exercise and computer vision with color recognition technique to comply "Fool-the-Brain" concept for fast recovery of neural impairments. The upper limb exercise that developed in ARIS is to promote the impaired arm range of motion by moving along the predefined trajectory of the AR based exercise. In ARIS, the real impaired arm will be overlapped by the virtual arm throughout the rehabilitation exercise to create the illusion scene. In the case of real arm cannot perform the required task, virtual arm will take over the job of real one and will let the user to perceive the sense that he/she is still able to perform the reaching movement by own effort to the destination point which is the main idea of ARIS. The validation of ARIS was conducted as a preliminary stage and the outcome are discussed.

1 INTRODUCTION

Neurotrauma such as Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI) or Stroke survivors are facing with functional neurological deficit including motor deficit resulting loss of control over whole body or one side of the body in accordance with the degree of impairment. Therefore, patients cannot perform the daily live activities and this will greatly impact their quality of life. According to the Physical Disability Australia (PDA), it was estimated that 13% of the Australian population have suffered from physical disabilities that limits the mobility and self-care activities (Physical Disability Australia., 2013). To improve such limitations, rehabilitation is essential to perform. Rehabilitation is the physical therapy that regains mobility, strength of muscles and relearning skills. Research studies had proven that the motor impairment can be treated by intense use of active movement in repetitive tasks and task-orientated activities which will result in improving motor skills and muscular strength by preventing muscle spasticity, muscle atrophy and osteoporosis (Riener et al., 2005). Thus, a lot of researchers have been trying to develop low cost effective rehabilitation systems by employing various technologies that including virtual reality and augmented reality for therapeutic purposes as these technologies have proven their effectiveness in the area of upper limb rehabilitation (Al-Issa et al., 2012).

This paper provides a short review of recent developments for upper limb rehabilitation with augmented reality technology. Following a brief overview, the proposed novel system will be described which is AR based Illusion System (ARIS) for upper limb rehabilitation. The proposed system integrates physical and psychological rehabilitation possibilities for fast recovery in upper limb motor deficit. In term of physical rehabilitation, AR based reaching exercise has developed to attain the wider range of movements at shoulder joint. In term of psychological rehabilitation, ARIS employs "Fool-the-Brian" concept to create the "illusion scene" to provide "fool the sense" to the patients. This concept will provide with artificial visual feedback to the system user to reestablish the neural pathways and synapses that able to control the mobility by oneself. The term "Fool-the-Brain" was defined by the group of researchers from (Giraux and Sirigu, 2003) as their studies had proven that motor cortex activity was able to restore successfully by illusory movements of paralyzed limb and able to "fool" the brain to improve the arm/hand movements. It is because of the ability of human neuroplasticity which is

mediated by beliefs, perceptions and emotions that react in ever-changing ways, through thoughts and activities based on environmental input.

2 RELATED WORK

Recently, Augmented Reality (AR) technologies in upper limb rehabilitation area provide promising results as a useful tools for physical, psychological and occupational therapies. AR is the combination of real and virtual environment where virtual objects lay on top of the real environment which is fed by camera as a live video background image on the computer display screen. Therefore, this approach will provide better interactive training environment and more realistic. As far as AR based upper limb rehabilitation systems are concern, researchers in (Aung et al., 2012a; Dinevan et al., 2011) have developed AR based system to promote the reaching movements of upper limb and strengthen the associated muscles. Our group has previously developed AR based upper limb rehabilitation system which integrated with biofeedback system to access the performance of trained muscles and provide with more motivational approach (Aung et al., 2012b; Aung and Al-Jumaily, 2013). In terms of "Fool-the-Brain" concept, the motivation is arisen from the positive results of mirror box therapy (Lin et al., 2012) and TeraMem System (Regenbrecht et al., 2012) which has employed "Fool-the-Brain" concept successfully. The numbers of studies have embarked on employing mirror therapy to enhance motor deficit and provide with positive results (Lee et al., 2012; Thieme et al., 2013).

However, up to our knowledge, the existing developments based on this concept are only developed with forearm and/or hand rehabilitation with mirror box to attain the artificial visual feedback. Therefore, the very first novel system that training for the whole arm with artificial visual feedback is proposed in this paper. The detail of the development is described in the following section.

3 DEVELOPMENT OF "ARIS"

The AR based Illusion System (ARIS) is a low cost rehabilitation system that only requires PC with cheap webcam and any color as a marker. Employing of AR technology in ARIS aims to motivate the patients' willpower to perform the long term rehabilitation therapy. The ARIS is developed

in Adobe Flash Professional CS6 platform. It works based on capturing the video scenes, displaying of virtual objects, manipulating of 3D Virtual Arm (VA) that is loaded with Papervision 3D, detecting the color marker and checking for the collision detection between marker and virtual objects. The system architecture and the development of the ARIS detail as below.

3.1 System Architecture

The overall architecture of the proposed system is shown in figure 1. The upper limb rehabilitation therapy system starts with displaying the therapy window on the monitor that includes the information for user, rehabilitation exercise and tracking result. Then, the system will request the permission to access the webcam to start the therapy. Once user allows the webcam access, live video image will feed at the defined position on the therapy window. This live video will serve as a background for AR based rehabilitation exercise. Subsequently, the user will be requested to click on the desired color at shoulder joint to track the current joint position and then the shoulder joint of Virtual Arm (VA) will be attached at clicked position. This attachment will overlay the virtual arm on top of the real impaired arm to perceive "fool-the-brain" concept from user.
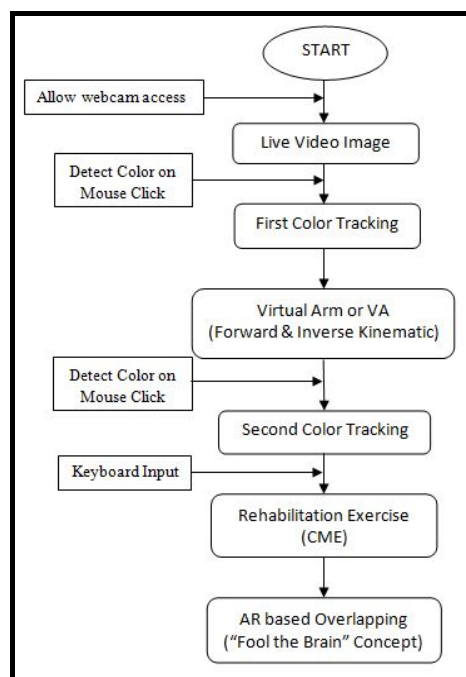

Figure 1: System Architecture.

After that, the user will be requested to click again on second color at wrist joint and this selected color will interact with virtual objects to perform the rehabilitation exercise. After all of the above steps are completed, the user/therapist will have to press the keyboard to activate the exercise and auto movement of VA. The developed system allows the user and therapist to monitor the performance of real arm motion under "Real Arm Trajectory Graph" in therapy window. The complete system is made up of four different modules: computer vision and multicolour tracking, modelling of virtual arm, modelling of kinematic chain and AR based upper limb rehabilitation exercise as depicted in figure 2. The detail developments of each module are explained in the following sections.

3.2 Modelling of Virtual Arm

The Virtual Arm (VA) is created in blender software as portrayed in figure 2(b) and then exported as ".dae" format to load in the Adobe Flash CS6 via Papervision 3D which is an open source real-time 3D engine for Flash. In blender software, the arm kinematic chain is defined correctly in such a way that the upper arm as a parent link of the forearm link, the forearm link as a parent link of the hand link. This arrangement will ensure any motion of the parent link will have an effect on the child link during simulation. The defining of pivot point on each link is very important as this will define the centre of rotation of the link joint and is carefully defined in developed VA. After developing VA in blender software, the kinematic model of the VA is developed as shown in figure 2(c). In the kinematic model, the shoulder joint is considered as spherical joint that permits the wide range of joint motions. However in this paper, the shoulder joint is limited to 3DOF, the elbow joint, forearm and wrist joint is modelled as cylindrical joint which allows the flexion/extension of the elbow and wrist and internal rotation of the forearm with 1DOF each. Therefore

total of 6DOF model is developed and Denavit-Hartenberg (D-H) parameters are assigned for kinematics calculation as detail in next section.

3.3 Modelling of Kinematics Chain

The mathematical modeling of VA was formulated with Denavit-Hartenberg (D-H) convention (Denavit & Hartenberg, 1964). The D-H model was created by relating each link's frame of reference on the virtual arm with the preceding link frame of reference. The four parameters: a, α, d and θ which represents the link length, link twist, link offset and joint angle, respectively are defined at respective joint as shown in Table 1.

Table 1: D-H parameters and anatomical motion and limit.

Joint		Motion	α	a	θ	d	Joint Limit
1		Internal/External Rotation	$-\pi/2$	0	θ_1	0	(-90˚, 30˚)
2	Shoulder	Abduction/Adduction	$\pi/2$	0	θ_2	0	(-40˚, 180˚)
3		Flexion/Extension	0	L3	θ_3	0	(0˚, 180°)
4	Elbow	Flexion/Extension	0	L4	θ_4	0	(0˚, 130˚)
5	Wrist	Flexion/Extension	$\pi/2$	0	θ_5	0	(-45˚, 45˚)
6	Forearm	Internal/External Rotation	0	L6	θ_6	0	(0˚, 160˚)

The frame of reference is established depending on the translation and rotation in x-axis (a and α) and the translation and rotation in z-axis (d and θ). Each property used in D-H convention is constant, except if the joint is a revolute type, link twist "α" is variable, or when the joint is prismatic, link offset "d" is variable. Although the real arm has wider articulation range, the VA is limited to safe articulation range and the values of such range, D-H parameters of VA and anatomical motions with respect to joints are presented in Table 1. Forward and inverse kinematics calculation is performed to reach the predefined position according to the desired trajectory that based on developed exercise. The inverse kinematic is computed for each link angle, following the link by link downward from shoulder to wrist.
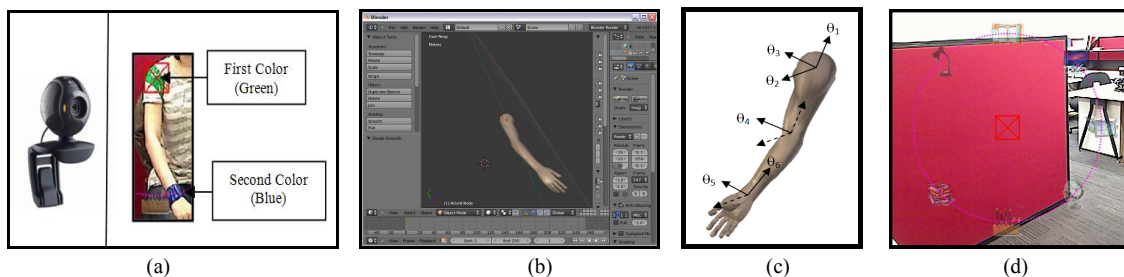

Figure 2: Individual module in ARIS (a) Computer vision & multicolor tracking (b) Modeling of virtual arm (c) modeling of kinematic chain (d) AR based rehabilitation exercise.

There are total in seven desired points that real arm and VA require to move as an upper limb rehabilitation exercise which is in circular motion. The circular motion as a rehabilitation exercise has been chosen and development will be explained in the following section.

3.4 AR based Rehabilitation Exercise

Rehabilitation exercise is essential for post stroke patients and any motor injured patients as this will help the patients to improve their lost functions by performing repetitive tasks and task-oriented activities. To perform such repetitive task-oriented movement, Circular Motion Exercise (CME) has developed in ARIS. The trajectory of CME is chosen as the circular motion because it involves almost largest range of motion of the shoulder articulations such as shoulder flexion, adduction and abduction, internal and external rotation which is an optimum goal to achieve as upper limb rehabilitation. CME is built based on AR technology where virtual world and real world are merged.
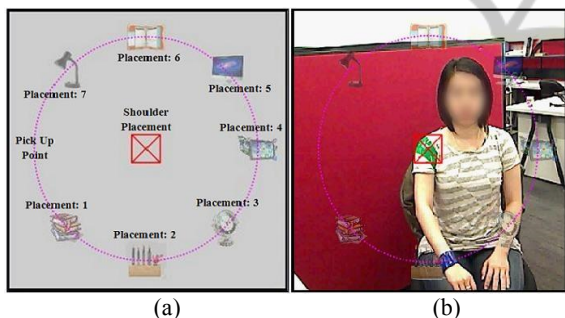

(a) (b)

Figure 3: Circular Motion Exercise (CME) for Upper Limb Rehabilitation (a) Without video Background (b) With video Background.

The aim of the CME is to collect the virtual objects that indicated by animated arrows and place them on the respective transparent virtual objects that are displayed on the screen. The screen shot of CME is portrayed in figure 3. There are total of seven virtual objects that user requires to pick and place as shown in the figure 3(a). To pick the virtual object, user requires moving his/her arm to pick up point and then the color that selected at wrist joint (in this case is blue color) will check the collision detection with virtual object. If the color and the virtual object are collided to each other, it defines as picking of the object and then virtual object will attach to the color at wrist joint. This will appear on the display screen as user is picking up the virtual object. When the object reaches to placing position, the collision

between virtual object and predefined placing position will check again to place the virtual object. The place positions of all seven virtual objects are appeared as same translucent virtual objects in circular shape for easy understanding.

The rehabilitation purpose of the CME is to provide the wider range of motion at shoulder joint which is one of the most important exercises in rehabilitation hospital. By performing CME, user arm will train in shoulder flexion, abduction, adduction, internal and external rotation movements. As a result, the associated muscles that involved in these movements will be trained and strengthen over time.

3.5 Multicolour Tracking

In this work, only two joints: shoulder joint and wrist joint position are interested to be tracked as the current position of that particular joint. The shoulder joint position is required to overlay the VA so that wherever the real shoulder joint is captured by webcam, the VA will always overlay correctly on top of the real arm and display on the monitor. As for wrist joint position, this is where interacting with real hand and virtual object collision is occurred.
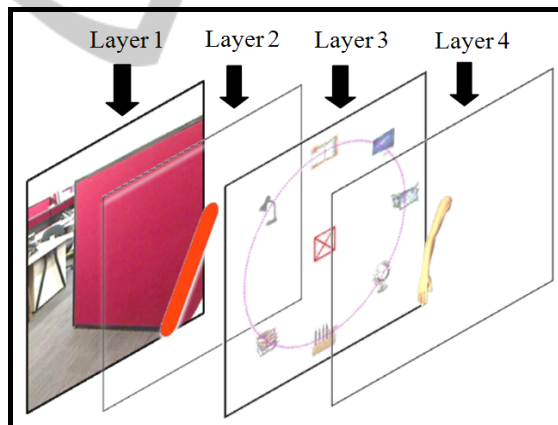

Figure 4: Four layer to built up "Fool-the-Brain" concept.

Another purpose of the wrist joint tracking is to track the performance of the real hand trajectory that user and therapist are able to monitor. This performance can be observed in real-time under "Real Arm Trajectory Graph" in the therapy window. Therefore, we have developed multicolor tracking algorithm that the system is able to track the multiple colors properly with minimum effect due to the surrounding light changes.

4 "FOOL-THE-BRAIN" CONCEPT

In ARIS, "Fool-the-Brain" concept is developed via overlaying of live video image and virtual objects with multiple layers to create the illusion of user's perception. The idea of overlaying concept is as portrayed in figure 4. There are four layers in total to achieve the concept. The very first layer is fed with live video image to create AR environment. On top of that layer, rectangular shape with rounded edges object is overlaid which defined as second layer. In this layer, webcam captured image is imported. However, this imported image can be only seen inside of the rectangular shape object. The rest of the region (out of rectangle shape) is set as transparent so that the active region is only inside the rectangular shape object. By overlaying the rectangular object, this will appear as covering the actual human arm on the display screen and will appear as removing of real arm on the display screen. The placement of the rectangular shape object is attached to the user defined color at shoulder joint. Therefore, current position of the real arm will be always tracked and overlapped with user's arm size image which captured via webcam wherever the user's arm moves. Then the CME will overlay at third layer in ARIS to serve as an upper limb rehabilitation exercise. At fourth layer, VA will be overlaid on top of the real arm and appear as it is covering on top of rectangular shape object. Therefore, this appearance will create the illusion as a user real arm. This means that the real arm of the user will be removed and replaced with VA by means of computer vision and color tracking technique. Therefore, from the user point of view, he/she will perceive the VA as his/her own arm. When CME start, both VA and real arm will move together to reach the desired position where the real arm is moved by user effort and VA will move by predefined trajectory via inverse kinematic. In the case of real arm cannot reach to the desired position, VA will take over the job of real arm as if the user arm is still moving and reach to the desired position while the real arm is covered up with rectangular shape object with same background of live webcam so that user will not see his/her real arm. This will let the user to perceive the sense that he/she is still able to perform the reaching exercise by his/her own impaired arm to the destination point. This sense will help the patients in fast recovery of motor impairment due to human brain plasticity.

5 PROOF OF CONCEPT STUDY

Non-clinical study has tested for novelty aspects of overlaying or illusion, augmentation and believability. In this work, a healthy subject (user) is requested to sit in front of the computer monitor and webcam. After that, ARIS program will run and the therapy window is appeared on the display screen. The instruction on how to perform the rehabilitation exercise and its step by step procedure is stated at the right bottom of the therapy window. The current X, Y, Z positions and joint angle values of shoulder, elbow and wrist joints of the VA is able to monitor by the user in real-time on the therapy window. Before the rehabilitation exercise starts, the request command for the webcam is appeared. After user has accepted the request, seven translucent virtual objects are appeared which displayed in circular shape on top of the real-time video background image. Then the user is asked to select the color at shoulder joint (in this case is green). Once the color has chosen at shoulder joint, VA is appeared on top of the real arm that capture by webcam. The VA that overlay on top of the real arm is moved and tracked correctly according to the real arm movement. This shows that the developed tracking algorithm is able to track quite accurately and less response to light changes. Once VA is overlapped, the user is asked again to choose another color at the real wrist joint that captured by webcam (in this case is blue). Then, the system calculates the distance between the shoulder joint and wrist joint to calculate the length of rectangular shape object. Subsequently, the webcam captured image is cover up on top of the real arm. After that the selected color is interacted with seven virtual objects to perform pick and place action. We observed that the real arm is successfully covered up and picking and placing of virtual objects are able to perform smoothly. The collision detection method that checking the pixels distance between wrist color marker and virtual object is able to detect precisely. Throughout the performing of rehabilitation exercise, VA is able to move according to the predefined trajectory which is driven by forward and inverse kinematic algorithm. The desired position and joints angles are able to be displayed correctly on the therapy window as well. The testing of overtaking task has also conducted where if there is a case that the real arm cannot move to the desired position. It has found that VA is successfully continued to carry out the task by placing the virtual objects at desired positions. This approves that "Fool-the-Brain" concept is successfully adopted in this development. The

tracking of real hand movement is able to monitor in real-time under "Real Arm Trajectory Graph" effectively. The screen shot of the proof of study is depicted in figure 5.
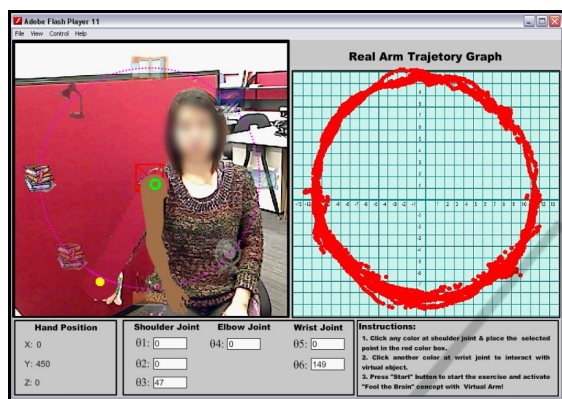

Figure 5: Result from proof of concept study.

6 CONCLUSIONS AND FUTURE WORK

In this paper, ARIS was developed to improve the upper limb range of motion especially for shoulder joint motion with "Fool-the-Brain" concept. The AR based computer game is chosen as a rehabilitation exercise as integrating with AR technology in rehabilitation field provides high motivation for long term training. Therefore, AR based CME was developed in ARIS to attain the wide range of shoulder joint motions via reaching exercise. Throughout the performing of CME rehabilitation exercise, the real arm was overlapped by VA model to fool the user perception to attain artificial visual feedback that provides fast recovery of user's neural impairment. If the user cannot reach to the particular point, VA will take over the job of real arm and will let the user to perceive the sense that he/she is still able to perform the reaching movement by own effort to that particular point. Non-clinical study was conducted to validate the novelty aspects of ARIS and provided with positive observations to carry on with future works.

As far as future work is concerned, improvement of the appearance of the VA model will be made. The model will be replaced with user skin texture that can be adjusted according to the individual user complexion. This will perceive the more realistic appearance of virtual arm as a real user arm. To make it more effective rehabilitation system, the system will be integrated with biofeedback system to detect the intended movement of the user via surface

eletromygraphy (sEMG) signals. Non-clinical trials with more participants will be conducted in near future to attain the improvement on illusion, perception and understanding the level of interest of developed rehabilitation exercise. Then, the clinical trial to be conducted at Port Kembla Rehabilitation Hospital in Australia after all the necessary improvements have made and result will be reported soon.

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