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AUGMENTED REALITY SYSTEM FOR REHABILITATION: NEW APPROACH BASED ON HUMAN INTERACTION AND BIOFEEDBACK

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(B.Eng & M.Sc.)

THIS THESIS IS SUBMITTED

FOR THE REQUIREMENT OF DOCTOR OF PHILOSOPHY TO

FACULTY OF ENGINEERING & INFORAMTION TECHNOLOGY

UNIVERSITY OF TECHNOLOGY SYDNEY

JANUARY 2016

Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Date: 24 Jan 2016

Acknowledgements

First and foremost, I would like to express my appreciation to my supervisor, Associate Professor Dr. Adel Al-Jumaily for his immense knowledge, continuous advice, insightful ideas and discussions, patience, motivation, and remarks on many occasions that are extremely helpful in improving my research work and thesis. Without his leadership and vision this work could not be possible.

My special thanks to non-clinical trials participants who provided me with their own EMG data for my research. Thanks also extend to all colleagues and staff members in the Center of Health Technology, University of Technology Sydney. I also place on record my sense of gratitude to one and all who directly or indirectly having lent me a helping hand during my candidature.

Special thanks and gratitude must go to my parents, Mr. Aung Thein and Ms. San San Cho for their continuous support in numerous ways, love, encouragement, and for motivating me to seek higher education. I would also like to sincerely thank to my husband, Dr. Myo Min Latt for sharing expertise, and sincere and valuable suggestion and encouragement extended to me. I am also very grateful to my sisters, Ms. May Mon Aung and Ms. Su Mon Aung who were always there to support me spiritually, their continuous encouragement and making it easy for me to concentrate on my research.

Finally, thank you UTS for the great experience and knowledge you gave me, I acknowledge your support by granting me the Australia Postgraduate Award (APA) scholarship.

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List of Abbreviations

3-D	Three Dimensional
AABB	Axis-Aligned Bounding Box
AD	Anterior Deltoid
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
APTA	American Physical Therapy Association
AR	Augmented Reality
ARIS	AR based Illusion System
BB	Biceps Brachii
BCR	Balloon Collection Rehabilitation
BPNN	Back Propagation Neural Network
BV	Bounding Volumes
CIMT	Constraint Induced Movement Therapy
CMR	Circular Motion Rehabilitation
CNS	Central Nervous System
CPM	Continuous Passive Motion
CT	Computed Tomography
CVA	Cerebrovascular Accident
D-H	Denavit-Hartenberg
DOF	Degree of Freedom
DOPs	Discrete Orientation Polytopes
EE	Elbow Extension
EF	Elbow Flexion

ELM	Extreme Learning Machine
EMD	Electromechanical Delay
EMG	Electromyogram
FAR	Feeding Animal Rehabilitation
FK	Forward Kinematic
fMRI	Functional Magnetic Resonance Imaging
FP	Forearm Pronation
FS	Forearm Supination
IAV	Integrated Absolute Value
IK	Inverse Kinematic
IMU	Inertial Measurement Unit
IR	Inward Rotation
LE	Lower Extremity
MAV	Mean Absolute Value
MRI	Magnetic Resonance Imaging
MT	Mirror Therapy
MVC	Maximum Voluntary Contraction
MVF	Mirror Visual Feedback
NRMSE	Normalised Root Mean Squared Error
OBB	Oriented Bounding Box
OR	Outward Rotation
PD	Posterior Deltoid
PM	Pectoralis Major
PNS	Peripheral Nervous System
PPR	Ping Pong Rehabilitation
PV3D	Papervision3D
RE	Real Environment
RF	Radial Flexion
RGB	Red, Green, Blue
RHI	Rubber Hand Illusion
ROM	Range of Motion
SAB	Shoulder Abduction

SAD	Shoulder Adduction
SCI	Spinal Cord Injury
SE	Shoulder Extension
SEC	Series Elastic Component
sEMG	Surface Electromyography
SF	Shoulder Flexion
SHE	Shoulder Hyperextension
SLFNs	Single-hidden Layer Feedforward Networks
SSLs	Sphere Swept Lines
SSPs	Sphere Swept Points
SSRs	Sphere Swept Rectangles
TBI	Traumatic Brain Injury
TDF	Time Domain Feature
TIA	Transient Ischemic Attack
TMS	Transcranial Magnetic Simulation
TOR	Transfer Object Rehabilitation
TOT	Task Oriented Therapy
UDP	Universal Datagram Protocol
UE	Upper Extremity
UF	Ulnar Flexion
VAR	Variance
VE	Virtual Environment
VHA	Virtual Human Arm
WA	Willison Amplitude
WE	Wrist Extension
WF	Wrist Flexion
WHE	Wrist Hypertension
WL	Waveform Length
ZC	Zero Crossing

Abstract

Rehabilitation is the process of training for someone in order to recover or improve their lost functions caused by neurological deficits. The upper limb rehabilitation system provides relearning of motor skills that are lost due to any neurological injuries via motor rehabilitation training. The process of motor rehabilitation is a form of motor learning via practice or experience. It requires thorough understanding and examination of neural processes involved in producing movement and learning as well as the medical aspects that may affect the central nervous system (CNS) or peripheral nervous system (PNS) in order to develop an effective treatment system. Although there are numerous rehabilitation systems which have been proposed in literatures, a low cost upper limb rehabilitation system that maximizes the functional recovery by stimulating the neural plasticity is not widely available. This is due to lack of motivation during rehabilitation training, lack of real time biofeedback information with complete database, the requirement of one to one attention between physiotherapist and patient, the technique to stimulate human neural plasticity.

Therefore, the main objective of this thesis is to develop a novel low cost rehabilitation system that helps recovery not only from loss of physical functions, but also from loss of cognitive functions to fulfill the aforementioned gaps via multimodal technologies such as augmented reality (AR), computer vision and signal processing. In order to fulfill such ambitious objectives, the following contributions have been implemented.

Firstly, since improvements in physical functions are targeted, the ***Reha***bilitation system with ***Bio***feedback simulation (RehaBio) is developed. The system enhances user's motivation via game based therapeutic exercises and biofeedback. For this, AR based therapeutic games are developed to provide eye-hand coordination with inspiration in

motivation via immediate audio and visual feedback. All the exercises in RehaBio are developed in a safe training environment for paralyzed patients. In addition to that, real-time biofeedback simulation is developed and integrated to serve in two ways: (1) from the patient's point of view, the biofeedback simulation motivates the user to execute the movements since it will animate the different muscles in different colors, and (2) from the therapist's point of view, the muscle simulations and EMG threshold level can be evaluated as patient's muscle performance throughout the rehabilitation process.

Secondly, a new technique that stimulates the human neural plasticity is proposed. This is a virtual human arm (VHA) model that driven by proposed continuous joint angle prediction in real time based on human biological signal, Electromyogram (EMG). The VHA model simulation aims to create the illusion environment in Augmented Reality-based Illusion System (ARIS).

Finally, a complete novel upper limb rehabilitation system, Augmented Reality-based Illusion System (ARIS) is developed. The system incorporates some of the developments in RehaBio and real time VHA model to develop the illusion environment. By conducting the rehabilitation training with ARIS, user's neural plasticity will be stimulated to re-establish the neural pathways and synapses that are able to control mobility. This is achieved via an illusion concept where an illusion scene is created in AR environment to remove the impaired real arm virtually and replace it with VHA model to be perceived as part of the user's own body. The job of the VHA model in ARIS is when the real arm cannot perform the required task, it will take over the job of the real one and will let the user perceive the sense that the user is still able to perform the reaching movement by their own effort to the destination point. Integration with AR based therapeutic exercises and motivated immediate intrinsic and extrinsic feedback in ARIS leads to serve as a novel upper limb rehabilitation system in a clinical setting.

The usability tests and verification process of the proposed systems are conducted and provided with very encouraging results. Furthermore, the developments have been demonstrated to the clinical experts in the rehabilitation field at Port Kembla Hospital. The feedback from the professionals is very positive for both the RehaBio and ARIS systems and they have been recommended to be used in the clinical setting for paralyzed patients.