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UPPER EXTREMITY ASSESSMENT AND REHABILITATION SYSTEM FOR STROKE PATIENTS

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Dedicated to all readers, especially you

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ABSTRACT

Stroke is the leading cause of disabilities worldwide. Upper extremity impairments are very common after stroke. To support the recovery process, conventional assessment methods such as Fugl-Meyer Assessment (FMA) and Motor Assessment Scale (MAS) are widely used to assess motor performance of stroke patients. However, the assessments face some limitations such as being subjective and time-consuming. Many research have been done to solve the limitations of conventional assessments by using motion capture sensor or robotics for objective assessment. The main objective of this research is to design and develop a vision-based automated rehabilitation and assessment system to assess upper extremity of stroke patients. A Kinect-based system was used as an upper extremity stroke rehabilitation assessment system with isolated training movement namely Shoulder Abduction-Adduction (SAA). Three experiments were conducted involving a total of eight healthy subjects and three stroke patients. A total of six out of nine collected features have been proved being significantly different using t-test method. The suitable features were selected using three different features selection methods, namely Relief-F, Principal Analysis Component, and Correlation-based Feature Selection. These three feature sets were then trained with four different classifiers: Artificial Neural Network (ANN), Support Vector Machine (SVM), Random Tree and Random Forests in order to achieve the best predictive model. With a total of three feature sets and four classifiers, a total of 12 predictive models were constructed in this thesis. The 12 models were evaluated based on correlation-analysis. The result shows that the combination of ReliefF and SVM achieved accuracy of 91.04%, highest correlation coefficient of 0.9929 and lowest root mean square error of 0.1183 among all the constructed models.

ABSTRAK

Strok ialah penyebab utama kecacatan di seluruh dunia. Kemerosotan ekstrimiti atas sangat biasa selepas strok. Untuk mencepatkan proses pemulihan, kaedah penilaian konvensional seperti Penilaian Fugl-Meyer dan Skala Penilaian Motor digunakan secara meluas untuk menilai prestasi motor pesakit strok. Bagaimanapun, kaedah penilaian ini masih menghadapi beberapa batasan iaitu bersifat subjektif dan memakan masa. Banyak penyelidikan telah dilakukan untuk menyelesaikan batasan tersebut dengan menggunakan sensor tangkapan gerakan atau sistem robotik untuk penilaian objektif. Objektif utama penyelidikan ini adalah untuk mereka bentuk dan membangunkan sistem pemulihan dan penilaian automatik berasaskan sistem penglihatan untuk menilai ekstrimiti atas pesakit strok. Sistem berasaskan Kinect digunakan sebagai sistem pentaksiran pemulihan strok dengan gerakan terpencil iaitu *Shoulder Abduction-Adduction* (SAA). Terdapat tiga eksperimen telah dijalankan dan melibatkan lapan subjek yang sihat dan tiga pesakit strok. Sebanyak enam daripada sembilan ciri yang dikumpulkan telah terbukti mempunyai perbezaan ketara dengan menggunakan kaedah ujian-t. Ciri-ciri yang sesuai dipilih dengan tiga kaedah pemilihan ciri yang berbeza iaitu *ReliefF*, *Principal Component Analysis*, dan *Correlation Feature Selection*. Set tiga ciri ini kemudian dilatih dengan empat pengelas berbeza: Rangkaian Neural Buatan, *Support Vector Machine* (SVM), *Random Tree* dan *Random Forests* untuk mencapai model ramalan yang terbaik. Dengan sejumlah tiga set ciri dan empat pengelas, sebanyak 12 model ramalan telah dibina dan dinilai berdasarkan analisis korelasi. Keputusan menunjukkan bahawa kombinasi *ReliefF* dan *SVM* mencapai ketepatan sebanyak 91.04%, pekali korelasi tertinggi sebanyak 0.9929 dan ralat min punca kuasa dua terendah iaitu sebanyak 0.1183 di kalangan semua model yang dibina.

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LIST OF ABBREVIATIONS

ADL	-	Activities of daily living
ANN	-	Artificial Neural Network
AR	-	Augmented Reality
AROM	-	Active range of motion
ASAP	-	Accelerated Skill Acquisition Program
CFS	-	Correlation-based Feature Selection
CNS	-	Central nervous system
CoM	-	Center of mass
EROM	-	Elbow range of motion
F	-	Female
FCBF	-	Fast Correlation Based Filter
FIM	-	Functional Independence Measure
FM-UE	-	Fugl-Meyer Upper Extremity Scale
GUI	-	Graphical User Interface
HAMRR	-	Home-based Adaptive Mixed Reality Rehabilitation
HRQOL	-	Health-Related Quality of Life
HSA	-	Hospital Sultan Aminah
HTS	-	Hit target score
IR	-	Infrared
L	-	Left
M	-	Male
MAE	-	Mean absolute error
MAS	-	Motor Assessment Scale
NASAM	-	National Stroke Association of Malaysia
NS	-	Non-significant difference

NUI	-	Natural User Interface
OpenNI	-	Open Natural Interaction
PCA	-	Principal Component Analysis
PR	-	Path ratio
PROM	-	Passive range of motion
PV	-	Peak velocity
QoM	-	Quality of Movement
R	-	Right
RMSE	-	Root mean square root
RMT	-	Reaching movement time
ROM	-	Range of Motion
RT	-	Reaction time
S	-	Subject
SAA	-	Shoulder abduction-adduction
SDK	-	Software development kit
SG	-	Savitzky-Golay
SROM	-	Shoulder range of motion
ST	-	Stability time
STD	-	Standard deviation
SVM	-	Support Vector Machine
TPV	-	Time to peak velocity
TR	-	Target reached
UE	-	Upper extremity
VR	-	Virtual reality
WMFT	-	Wolf Motor Function Test

LIST OF SYMBOLS

r	-	Correlation coefficient
W_i	-	Weight of the i^{th} feature
M_S	-	Heuristic "merit" of a feature subset
rcf	-	Mean feature-class correlation
rff	-	Average feature-feature inter correlation
W_r	-	Width vector of player real width
W_p	-	Width vector of player pixel
α	-	Angle of shoulder
°	-	Degree of angle
%	-	Percentage rate
s	-	Time in second
mm/s	-	Instantaneous velocity in millimeters per second
K	-	K-fold cross validation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Problem Backgrounds

Stroke is defined as a neurological deficit of cerebrovascular commonly caused by central nervous system (CNS) infarction. CNS infarction occurs when a blockage of blood flow in the arteries to the brain [1]. Insufficient blood flow to the brain will lead to oxygen deprivation and then to cell death. There are two main types of stroke, namely ischemic stroke (caused by blocked artery) and hemorrhagic stroke (bursting of a blood vessel) [2]. According to the health report, about 80% strokes are ischemic while 20% strokes are hemorrhagic [3]. Figure 1.1 shows the illustration of the ischemic and hemorrhagic stroke.

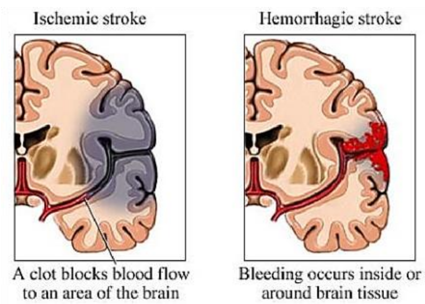

Figure 1. 1 Illustration of the ischemic and hemorrhagic stroke [4]

Stroke is a non-negligible global health problem. In Malaysia, stroke was ranked as the third leading cause of mortality for males and second for females in 2009 [5]. The mean age of stroke onset in Malaysia was between 54.5 and 62.6 years old. Figure 1.2 shows the annual mortality rate of ischemic stroke by sex over a lifetime in Malaysia. According to the Global disease burden study, Malaysia women encountered the highest mortality rate from ischemic stroke at age above 80 years old [6]. The peak of mortality rate for Malaysia women was higher than the Malaysia men.

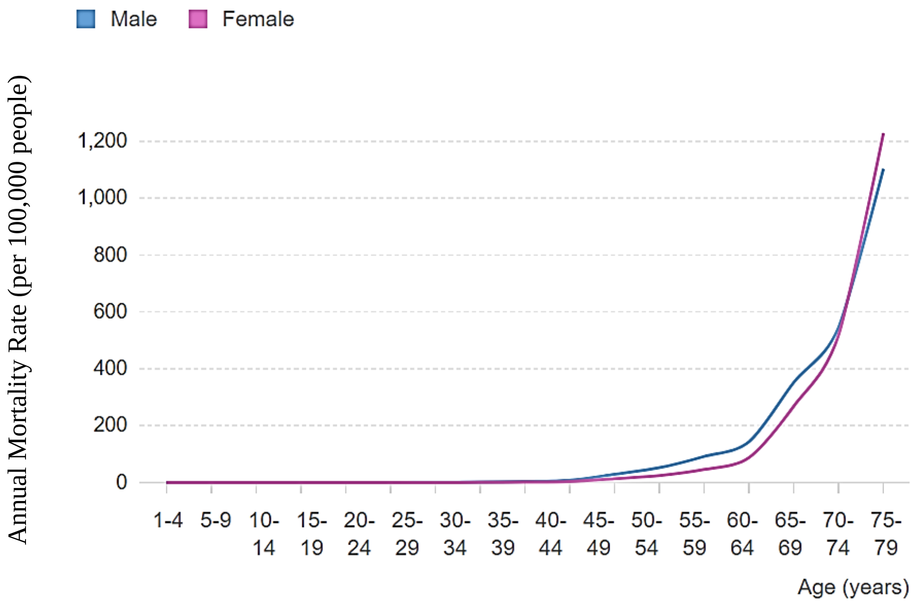

Figure 1. 2 The annual mortality rate of ischemic stroke by sex over a lifetime in Malaysia [6]

Those who survived after a stroke are commonly suffered with severe motor impairment. Upper extremity disability is one of the most significant motor deficits after a stroke [7] [8]. Loss of upper extremity motor function after stroke results in decreasing the level of independence with the activities of daily living (ADL) such as eating, bathing, dressing, toileting etc. From the research study, stroke patients today were discharged from hospital to home more quickly than in the past due to shifting economic realities [9]. Stroke rehabilitation is increasingly being shifted to an outpatient setting such as rehabilitation center or at home. Stroke patients have to continue to regain the motor function skills by taking expensive outpatient therapy [10]. Therefore, comprehensive stroke rehabilitative service has been shown to be cost-effective and effective intervention for patients.

1.2 Conventional Rehabilitation Program

In current clinical evaluation of upper extremity (UE) impairment after stroke, the functional performance of UE is accessed by using standardized clinical outcome measures [10], such as Motor Assessment Scale (MAS) and Fugl-Meyer Upper Extremity Scale (FM-UE). MAS [11] is one of the most common performance-based scale that accessed in local rehabilitation centers. For example, Hospital Sultan Aminah (HSA) [12], National Stroke Association of Malaysia (NASAM), and Persatuan Kebajikan Amal Lexin. MAS is defined and recommended to access everyday motor function in stroke patients. However, most of the clinicians cannot access the patients daily due to the large population of patients that limited the amount of time intervention between the clinicians and the patients [13]. Other than that, current clinical assessment method is lacking of objective assessment [14]. Objective assessment is independent of the observation of clinician. The assessment is done by measuring metric using devices or sensors. In contrast, subjective assessment is highly dependent on the observation of the clinician based on their experience. For example, the performance rating of the Motor Assessment Scale (MAS) is dependent on the observer as detailed in Appendix C.

1.2.1 Motor Assessment Scale (MAS)

The Motor Assessment Scale (MAS) is a task-oriented approach that was developed to access the stroke patient's ability of movement every day. MAS consists of eight criteria (items) for scoring. There are supine to side lying onto intact side, supine to sitting over side of bed, sitting to standing, balance sitting, walking, upper arm function, hand movements and advanced hand activities. Each item is recorded on a scale of 0 to 6. The total range of score for MAS is from 0 to 48 while range of score for upper extremity MAS (UL-MAS) is from 0 to 18. The higher the score represents the better the motor function performance. The scale has been shown to have an inter and intra reliability of r=0.95 and r=0.98 respectively [12]. From the studies, it reported the administration times ranging is from 15 to 60 minutes.

1.3 Current Technology Solutions and Limitations

Motion capture is an important element of developing an autonomous robot to resolve the limitations of conventional therapy [15]. It refers to the process of recording the movement of the patients. Many researches have been done to develop a robotic system coupled with motion sensors to measure the patient's abilities objectively [16]. Robot-assisted therapy able to provide high intensity, repetitive, consistent treatment and task-specific for efficient recovery of the motor function. Motion capture system can be defined by either optical tracking system, inertial wearable sensors or video-based system (marker-less sensors). Optical tracking system is capable of providing high precision data and retrieving body information data such as velocity, distance and joints angle. It required a huge space to setup the complete equipment with markers or sensors attached to the patient. Inertial wearable sensors consisting of accelerometers, gyroscopes and magnetic sensors placed on specific body segments such as wrist, arm or trunk to track the kinematic movement. Accumulative error arises while estimating the position by integrating accelerations or angular velocity [15]. Video-based system used to track the body movement without requiring any markers to attach to the body segments. It is popular with massive potential in research area due to its low costs and easy to use which suitable for physiotherapist and families to monitor the patient's performance either in clinical center or home.

Virtual reality game incorporated with motion capture system has emerged as a new approach in stroke rehabilitation and assessment [17]. It provides the advantage of practicing exercises with visual and audio feedback which may encourage a higher number of repetitions of the exercise than conventional therapy.

1.4 Problem Statement

The major issues faced by current rehabilitation program are the limited availability of physiotherapists for therapy [18], repetitiveness of the therapy [19], subjective assessment [14] and limited amount of time intervention between clinicians and patients due to high medical cost [13]. Normally 1 physiotherapist has to assist up to 10 stroke patients during each training session. This phenomena will result in decreasing the effectiveness of physical therapy. Many robotic rehabilitation system have been developed to reduce the burden of the physiotherapists during rehabilitation program. The use of vision based system is found to be effective for rehabilitation therapy after a stroke, but assessment using these types of devices is still at research level. Also, therapists are still required to spend much time in setting up the system and monitoring the patients.

Current motor rehabilitation after stroke emphasizes and highlights the importance of repetitive functional training and task specific training [20][21]. Repeated practice of specific task (e.g., lifting cup, combing hair, answering telephone etc.) is a goal-directed treatment approach used to improve the stroke recovery rate [22]. Combining of task-oriented and repetitive training show to be greater improvement and effective than non-specific repetitive training alone [23][24]. Research studies have shown that the robotic rehabilitation of upper extremity function can provide high intensity repetitive movement therapy and increase the performance of upper extremity than conventional therapy [25]. However, repeating the same exercises may lead to stroke patients' lack of motivation on the therapy process [26]. Lack of motivation may resulting in delayed physical recovery [27]. As a solution, virtual reality game incorporated with vision based system has shown the potential to enhance the motivation of the patients on the therapy process. However, commercial virtual reality game is not so suitable for most of the patients due to the high difficulty level. Therefore, development of a rehabilitation game is highly recommended to provide adaptable difficulty level for stroke patients and maintain their enjoyment in virtual reality training.

In order to overcome the subjective assessment, many researches have been done in developing an automated assessment system by using machine learning algorithm. However, most of the studies is only focus on assessment, it would be good if can integrate the assessment with the virtual reality training system. Therefore, a better solution for assessment model using low cost vision-based system is highly needed.

1.5 Research Objectives

This research aims to investigate the feasibility of predictive modelling in assessing Quality of Movement (QoM) of stroke survivors via the following objectives:

1. To design and develop an objective vision-based upper extremity assessment system which able to integrate with the virtual reality training system.

2. To investigate the suitable kinematic variables that can be used for classification of stroke performance.

3. To evaluate suitable classifier and combination of input features for classifying stroke performance of chronic stage stroke patients.

1.6 Research Scopes

The aim of this study is to design and implement the virtual reality training system for use in automated upper extremity assessment after stroke.

The upper extremity assessment predictive model is developed to identify the kinematic variables to evaluate motion quality of patients. The system is successfully tested by healthy subjects and stroke patients. The inclusion criteria for the stroke patients allowed chronic patients only due to the limited number of stroke patients available. The conventional assessment scale that is being studied in this work is the Motor Assessment Scale (MAS) because only this scale is being used in NASAM and Persatuan Kebajikan Lexin.

Kinematic variables with significance difference between the healthy subjects and stroke patients are applied as features in upper extremity assessment model. The features are pre-processed using three different feature selection methods, which are Relief-F, CFS, and PCA. Then, predictive models are constructed based on four different modelling methods (classifiers), namely ANN, SVM, Random Tree and Random Forests. The designed predictive model will be evaluated and selected based on its model correlation coefficient and model accuracy.

The virtual reality rehabilitation system was designed and developed using Microsoft Visual Studio with support of XNA Game Studio. The subjects' data were collected using Kinect-based sensor. Data analysis was carried out using MATLAB and Waikato Environment for Knowledge Analysis (WEKA) software.

1.7 Thesis Outline

This thesis consists of five chapters to detail the work done throughout the research. Chapter 1 contains general information regarding the motivation based on background of studies, problem statements, research objectives and research scopes.

Chapter 2 presents the literature review of vision-based technology that used for upper extremity training and assessment after stroke. This chapter explained in details about the previous study on stroke, stroke assessment methods, and assessment models.

Chapter 3 presents the research methodology of the research study. This chapter details the study design and interviewing, hardware implementation, software implementation and how the pilot study protocol conducted. In the subsequence chapter, it presents the methods of pilot study I, pilot study II and development of predictive model for upper extremity after stroke. In pilot study I, it aims to evaluate the usability of task-specific interactive game-based virtual reality UE-ARM for stroke patients. The pilot study was conducted with two chronic patients to investigate appropriate upper extremities training schedule and evaluate the usability of the developed task-specific interactive game-based virtual reality UE-ARM. In pilot study II, it aims to evaluate the motion quality of shoulder abduction-adduction after stroke using UE-ARM. The experiment was conducted with a total of eight healthy subjects and three stroke patients to analyze and identify suitable kinematic variables by finding the significant differences between healthy subjects and stroke patients using T-test method. In development of predictive model for upper extremity, it aims to present an automated predictive model that able to classify the motor impairment level that corresponding to the Motor Assessment Scale (MAS). A combined feature selection with the different classifiers were implemented to improve the accuracy of the model performance.

Chapter 4 presents the results of the study on pilot study I and pilot study II, as well as the results from the predictive model for upper extremity assessment after stroke. The kinematic variables that showed significance difference were used as input and combination of the input attributes for classifying stroke performance.

At last, Chapter 5 concludes the summary of the research, contributions of the study and suggestions for future work. References are included at the end of the thesis.

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