DEVELOPMENT OF GESTURE-CONTROLLED ROBOTIC ARM FOR UPPER LIMB HEMIPLEGIA THERAPY

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To my beloved parents, supervisor, siblings, family, best friends, and my ‘special’ friend, thank you for the endless motivation and support.

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ABSTRACT

Human-computer interactions using hand gesture recognition has emerge as a current approach in recent rehabilitation studies. The introduction of a vision-based system such as the Microsoft Kinect and the Leap Motion sensor (LMS) provides a very informative description of hand pose that can be exploited for tracking applications. Compared to the Kinect depth camera, the LMS produces a more limited amount of information and interaction zone, but the output data is more accurate. Thus, this study aims to explore the LMS system as an effective method for hand gesture recognition controlled robotic arm in improving upper-extremity motor function therapy. Many engineering challenges are addressed to develop a viable system for the therapy application: a real-time and accurate system for hand movement detection, limitation of robot workspace and hand-robot coordination, and development of hand motion-based robot position algorithm. EMU HS4 robot arm and controller have been retrofitted to allow 3 degrees of freedom (DOF) moment and directly controlled by LMS-based gesture recognition. A series of wrist revolving rehabilitation exercises are conducted that provides a good agreement where the robot can move according to hand movement. The potential of the proposed system has been further illustrated and verified through comprehensive rehabilitation training exercises with around 90% accuracy for flexion-extension training. In conclusion, these findings have significant implications for the understanding of hand recognition application towards robotic-based upper limb assistive and rehabilitation procedures.

ABSTRAK

Interaksi manusia-komputer menggunakan pengecaman isyarat tangan muncul sebagai pendekatan semasa dalam kajian pemulihan baru-baru ini. Pengenalan sistem berasaskan penglihatan seperti Microsoft Kinect dan sensor Leap Motion (LMS) memberikan penerangan yang sangat bermaklumat tentang gaya tangan yang boleh dieksploitasi untuk aplikasi penjejakan. Berbanding kamera kedalaman Kinect, LMS menghasilkan jumlah maklumat dan zon interaksi yang lebih terhad, namun menghasilkan data output yang lebih tepat. Oleh itu, kajian ini bertujuan untuk meneroka sistem LMS sebagai kaedah yang berkesan untuk pengecaman isyarat tangan kawalan lengan robot dalam meningkatkan terapi fungsi motor bahagian atas anggota badan. Banyak cabaran kejuruteraan ditangani untuk membangunkan sistem yang berdaya maju untuk aplikasi terapi: sistem masa nyata yang tepat untuk pengesanan pergerakan tangan, had ruang kerja robot dan penyelarasan robot tangan, dan pembinaan algoritma kedudukan robot berasaskan gerakan tangan. Lengan pengawal robot EMU HS4 telah dipasang semula untuk memberi 3 darjah kebebasan (DOF) dan dikawal secara langsung oleh pengecaman gerak isyarat berasaskan LMS. Satu siri latihan pemulihan pusingan pergelangan tangan dijalankan dan telah menunjukkan hasil yang baik di mana robot boleh bergerak mengikut pergerakan tangan. Potensi sistem yang dicadangkan telah diilustrasikan dan disahkan lebih lanjut melalui latihan latihan pemulihan yang komprehensif dengan ketepatan kira-kira 90% untuk latihan *'flexion-extension'*. Kesimpulannya, penemuan ini mempunyai implikasi yang signifikan terhadap pemahaman aplikasi pengecaman tangan terhadap prosedur bantuan dan pemulihan bahagian atas anggota badan berasaskan robotik.

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LIST OF SYMBOLS AND ABBREVIATIONS

°	–	Degrees
3D	–	Three-dimension
AC	–	Alternating Current
API	–	Application Programming Interface
AR	–	Augmented Reality
CAD	–	Computer-aided Design
CI	–	Confidence Interval
cm	–	Centimeter
CT	–	Computed Tomography
DOF	–	Degree of Freedom
EMG	–	Electromyography
FES	–	Functional Electrical Stimulation
fps	–	Frame per Second
g	–	Gram
HRI	–	Human-robot Interaction
IMU	–	Inertial Measurement Unit
IDE	–	Integrated Development Environment
IR	–	Infrared
kg	–	Kilogram
LMS	–	Leap Motion Sensor
MCI	–	Motion Control Interface
mm	–	Millimeter
ms	–	Millisecond
PC	–	Personal Computer
RGB	–	Red Green Blue
RGB-D	–	Combination Of RGB Camera And Depth-Sensing Camera

RMSE	–	Root Mean Square Error
ROM	–	Range Of Movement
RRR	–	Three Revolute Joints
RUPERT	–	Robotic-Assisted Upper Extremity Repetitive Therapy
s	–	Second
SCARA	–	Selective Compliance Assembly Robot Arm
SCARA	–	Selective Compliance Articulated Robot Arm
sEMG	–	Surface Electromyography
SDK	–	Software Development Kit
t	–	Time
USB	–	Universal Serial Bus
V	–	Voltage
VR	–	Virtual Reality
YSSA	–	Yarn-based Stretchable Sensor Arrays

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

Globally, there are over 12.2 million new strokes each year (World Stroke Organization, 2022). Stroke is the third most common cause of mortality rate in Malaysia (Ganasegeran *et al.*, 2020). Based on the database on hospital admissions from Malaysia's Ministry of Health hospitals, they detected a substantial increase in stroke incidence in those under 65 years of age, the largest increase of 53.3% and 50.4% in men and woman respectively (Tan & Venketasubramanian, 2022). Sampane-Donkor (2018) mentioned that the most commonly identified stroke risk factors were paralysis and hemiplegia, and stroke disease has accounted for 34.4% in developing countries.

Hemiplegia is a type of paralysis that affects one side of the body. Usually, it affects only an arm and a leg on one side of the body and extends partially to the torso (Spinalcord.com, 2019). Hemiparesis is a related condition described as weakness or significant loss of strength and mobility on one side of the body. Unlike a person with hemiplegia, which results in total paralysis on one side of the body, a person with hemiparesis might be unable to make movements using their arm or leg or feel a tingling or other unusual sensations on just one side of the body (Villines, 2019). Generally, hemiplegia occurs when the brain receives damage on either side of the brain. Figure 1.1 shows a computed tomography (CT) scan of an abscess in the left hemiplegia brain.

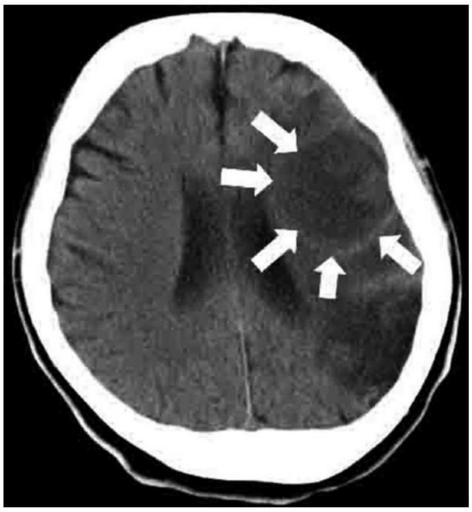

Figure 1.1: CT scan of abscess left hemiplegia brain (arrows) (Shiba *et al.*, 2015)

As the brain is divided into two hemispheres, the right side of the brain is in charge of controlling muscles and other functions on the left side and vice versa. Paralysis only occurs on the opposite side of the affected part of the brain, which for example, the person who experiences paralysis on the left side of the body means that the right side of the brain is damaged (Children's Hemiplegia Stroke Association, 2019).

Based on Epilepsy Society (2010), hemiplegia is a permanent condition and non-progressive, which means that it cannot be cured but will not get worse. A person who is diagnosed with hemiplegia is referred to a hospital, where different therapists will work with the patient to reduce the effects of the condition and improve the weak side of the body.

Therapeutic intervention is vital in aiding the hemiplegics to adapt to their new lifestyle. Spinalcord.com (2019) mentioned that physical therapy and mental imagery can help the hemiplegics to improve their motor skills. Physical therapy can help to prevent muscle atrophy and sores occurrence, while mental imagery is theorized that some brain structures can be activated by imagining or looking at specific images.

Hand gesture recognition has shown a growing interest in its applications in various fields notably, robotics and human-computer interaction (Dawes, Penders & Carbone, 2019). Traditionally, invasive methods were used to track muscle activity using an invasive intervention that causes discomfort to the patients. Over the years, technology-based rehabilitation may improve the standard way of therapy with outcomes such as motivating tasks with user feedback, repetitive motion and motor learning, and hand movement monitoring. Panduranga & Mani (2018) proposed hand gestures based non-invasive methods such as glove-based or vision-based.

Guzsvinecz, Szucs, & Sik-Lanyi (2019) conducted a survey to compare the usability of the vision-based method such as, the Microsoft Kinect sensor and the Leap Motion sensor, which latter has better accuracy and precision as compared to the Microsoft Kinect. It was found that the Microsoft Kinect is suitable to be used as the whole body gesture tracking device while the Leap Motion sensor can be used to track and detect hand motion accurately.

Nowadays, many types of robots are used in medical rehabilitations industries, such as ARMin, RUPERT, and MIT-MANUS robots (Nikafrooz *et al.*, 2019). Segal *et al.,* (2020) mentioned that for effective treatment, repetitive and coordinated movements are required which relies on the motivation and compliance of the patients. Therefore, the involvement of gesture-controlled and robots through intuitive gesture control, a user-friendly and engaging activity can encourage therapy acceptance to the patient. A research study by Xu *et al.*, (2018) has shown that the participants in a robot therapy group improved faster than the participants in a human therapy group.

Thus, this study aims to develop a hand gesture-controlled robotic arm for human-robot interaction to enhance hemiplegia patients' rehabilitation therapy process. The introduction of the robotic arm in this study improves engagement in rehabilitation therapy and promotes motivation for repetitive movements and prolonged treatment. The robotic arm also plays a role in assisting the therapist during rehabilitation sessions due to the high number of patients versus therapists which if with inadequate patient-therapist quality sessions will result in ineffective rehabilitation.

1.2 Problem statement

In recent years, hand gesture recognition has been studied by many researchers as a method in helping hemiplegia patients during the rehabilitation process, which consists of contact and non-contact technique such as data glove and vision-based systems, respectively. However, the main disadvantage of contact techniques is the restrictions on the user's hand size and the required markers device that could bring discomfort to the patient's hand.

Extensive research has shown an emerging sensing technique on the vision-based system, such as the RGB-D camera, Microsoft Kinect, and Leap Motion sensor for the non-contact application. This approach nevertheless also has its downsides in terms of cost, computational burden, and unnatural therapy, such as the usage of virtual reality (VR), which may seem unnatural for first-time users and may influence the quality of the rehabilitation process.

Recent developments in the field of non-contact and vision-based systems have led to a renewed interest in the Leap Motion sensor (LMS) as a promising method to be used in hemiplegia therapy. Although extensive research has been carried out on the LMS, no single study exists on the real robot implementation. By implementing a real robot in the study, further performance evaluation can be conducted towards contributing to a real hemiplegia therapy process, such as the latency, accuracy, and range of movement limitation.

In addition, a robot-based motorized technique has been integrated to motivate the patients to voluntarily move their hands to achieve consistency in therapy. Thus this study aims to explore a hand gesture-based robotic system to improve the hemiplegia rehabilitation process in terms of accuracy, real-time, and movement consistency.

1.3 Hypothesis

The hypothesis of the research are:

1) A Leap Motion sensor has a possibility to be utilized to capture human hand movements accurately.
2) The hand gesture-based robotic system is capable to perform upper limb therapy in real-time to assist hemiplegia patients.

1.4 Objectives

The following objectives have been set up to achieve the aim of this project:

1) To establish LMS data acquisition system to capture and track human hand movement in real-time.

2) To develop a heuristic method for hand gesture-controlled algorithm to control the robot movements.
3) To evaluate the performance and effectiveness of the developed system via a series of an experimental programs.

1.5 Scopes of study

The scopes of the research are:

1) This study focuses on hand gesture controlled 3-DOF robotic arm development to help hemiplegic patients with their upper-limb rehabilitation training process.
2) A Leap Motion sensor is used to detect hand gestures. The Leap Motion sensor has a field of view of about 150 degrees. The effective range of the Leap Motion is approximately 2.5 cm to 60 cm from the device. The sensor works best when it has a clear, high contrast view of the object's silhouette.
3) The algorithm was developed based on the Leap Motion API, Processing programming language and Arduino programming language to control the movement of the robotic arm based on the hand gesture captured by the Leap Motion device.
4) EMU HS4 is a 3-DOF robot arm used to imitate the human hand.
5) Various tests are carried out to assess the performance of the developed device.
    a) Preliminary test
        - Hand gesture recognition by Leap Motion sensor
        - Optimal detection distance between hand and Leap Motion sensor
        - Integration of Leap Motion sensor with EMU HS4 robotic arm
        - Calibration of Leap Motion sensor and robot position
        - Performance measure test
    b) Experimental program
        - Four hand training sessions are performed; grasping-release test, radial-ulnar deviation test, flexion-extension test, and radial-ulnar deviation and flexion-extension movement test.
        - Accuracy, error, and confidence interval measurement test of Leap Motion and robotic arm.

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APPENDIX B

LIST OF PUBLICATIONS

1. W. N. Wan Azlan, W. N. Wan Zakaria, N. Othman, M. N. Haji Mohd, M. N. Abd Ghani, “Evaluation of Leap Motion Controller Usability in Development of Hand Gesture Recognition for Hemiplegia Patients” 2019 Proceedings of the 11th National Technical Seminar on Unmanned System Technology, vol 666, pp.671-682.
   Location: Pahang, Malaysia, Date of conference: 2-3 December 2019
2. W. N. Wan Azlan, W. N. Wan Zakaria, N. Othman, M. N. Haji Mohd, “Development of Hand Gesture Controlled Robotic Arm for Hemiplegia Patients” 2021 International Conference on Electrical & Electronic Engineering 2021 (ICon3E'2021)
   Location: Virtual, Date of conference: 6-7 September 2021
   Status: Accepted

APPENDIX C

VITA

The author was born on January 12, 1995, in Kuala Lumpur, Malaysia. She was raised in Selangor and went to SMK (P) Sri Aman, in Petaling Jaya, Selangor, for her secondary school. She pursued her pre-university studies for one year at the Perak Matriculation College in a science course. Later, she enrolled in her degree at the Universiti Tun Hussein Onn Malaysia (UTHM) and graduated with a B.Eng. (Hons) in Electronic Engineering in 2018. Currently, she is pursuing her studies for a Master's degree in Electrical Engineering at Universiti Tun Hussein Onn Malaysia (UTHM).