DESIGN AND DEVELOPMENT OF ROBOT END-EFFECTOR FOR THE USE IN LOWER-LIMB STROKE REHABILITATION EXERCISES

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRACT (BM)

Strok merupakan punca kematian kedua terbesar di dunia dan juga menjadi antara penyebab utama kecacatan jangka panjang seperti kecacatan berjalan kaki. Proses pemulihan sangat penting dalam membantu pesakit mendapatkan semula fungsi motor sebanyak mungkin. Pemulihan dibantu robot adalah teknologi terkini dalam bidang pemulihan ini. Namun, penggunaan teknologi ini masih tidak meluas, terutamanya di negara-negara membangun seperti Malaysia. Oleh sebab itu, terdapat ruang bagi produk seperti ini dikembangkan dan dikomersialkan. Jadi, sebuah prototaip effektor hujung anggota badan bawah pintar yang boleh dipasang pada robot kolaboratif untuk membantu pesakit melakukan senaman seperti plantarflexion, dorsiflexion, penculikan pinggul dan penambahan pinggul telah dibangunkan. Porjek ini dimulakan dengan melakar reka bentuk end efecktor yang mempunya empat bahagian dengan menggunakan applikasi Soliworks. Kemudian proses slicing dijalankan dengan menggunakan Ultimakker Cura. Seterusnya, proses cetekan keempat bahagian tersebut dijanlankan disertai dengan mencantumkan mereka. Pada masa yang sama, sensor MPU6050 pula dokodkan dengan menggunakan applikasi Arduino Uno dan dikuasai NodeMcu. Sensor ini kemudianyan diletakan pada bahagian pemegang kaki untuk mengukur sudut. Sensor ini juga dihubungkan dengan aplikasi Blynk dimana nilai sudut X˚, Y˚ and Z˚ dipaparkan. Seterusnya, dua subjek yang sihat dipilih untuk menjalini eksperimen ini. Keputusan yang diperoleh menunjukkan bahawa sudut yang direkodkan berada dalam lingkungan manusia untuk menjalankan latihan tersebut (20-35° bagi dorsiflexion, 15-30° bagi plantarflexion, 30–55° bagi penculikan pinggul dan 15–30° bagi penambahan pinggul).. Ini menunjukkan bahawa end efecktor ini sangat efektif

untuk digunakan bagi membantu ahli fisioterapi dan pesakit untuk menjalani latihan tersebut.

ABSTRACT (ENGLISH)

Stroke is the second largest cause of human death worldwide and is also a major cause of long-term disability such as walking gait abnormalities. Rehabilitation is essential in helping patients regain as much motor function as possible. Robot assisted rehabilitation is currently the forefront in this regard. However, no solutions are currently widely available for use in developing countries like Malaysia. Therefore, there is space for such a product to be developed and commercialized. Thus, a smart lower-limb end-effector prototype that can be installed on a collaborative robot to aid patients performing exercises such as plantarflexion, dorsiflexion, hip abduction and hip adduction was developed. The project kick started by designing the end effector as four different parts on in Solidwork. This step is then followed by slicing process using Ultimaker Cura and then 3D printing. The 3D printed is then assembled up and tested for strength and design accuracy. At this stage, any design failure is then followed by redesigning and 3D printing again. Meanwhile, MPU6050 sensor was coded using Arduino Uno and powered by NodeMcu. This set up was placed on the foot holder to measure the rehabilitation angle. The sensor is also connected any app which was developed using Blynk to showcase the data obtained in terms of angle X˚, Y˚ and Z˚ Then, two healthy subjects, a male and female were choosen to carry out all four type of exercises mentioned above. The results obtained shows that angle recorded falls within the range of a human to carry out those exercise (20-35° of dorsiflexion, 15-30° of plantarflexion, 30–55° of hip abduction and 15–30° of hip adduction). This shows that the end effector perms well and can be used to aid physiotherapist and the patient. Therefore, a smart lower-limb end-effector prototype that can be installed on a collaborative robot to aid patients performing various leg exercises has been successfully created which also incooperates IoT elements.

CHAPTER 1

INTRODUCTION

1.1 Overview of Overall Project

Age-adjusted stroke rates have fallen globally during the past 20 years. However, it continues to be the second leading cause of death worldwide (after ischemic heart disease). Additionally, it contributes significantly to long-term disability. Stroke can result in symptoms including paralysis or difficulty controlling movement, sensory abnormalities, difficulty speaking or understanding what is being said, issues with thinking and memory, as well as emotional disturbances.

One of the more common stroke consequences is difficulty walking. Gait problems persist throughout the chronic stage of stroke (beyond 6 months), despite the fact that 65 to 85% of patients can walk on their own by that time (Eng J & Fang Tang, 2011). Only 15% of stroke victims are thought to fully recover their motor skills. Hemiparesis causes a gait correction known as hip hiking and circumduction, which results in a sluggish and ineffective gait. A paretic ankle is a significant factor in asymmetric gait. Reduced forward propulsion symmetry and reduced ground clearance during walking are both effects of paretic ankle dysfunction. As previously mentioned, this causes walking to require more energy and increases the risk of tripping and falling.

After a stroke, expenses can run high. Costs associated with hospitalisation and therapy are also included. Three months after having a stroke, the ordinary Malaysian can anticipate spending 30% of their monthly income on medical expenses (Julia Patrick Engkasan, 2015). The goal of this initiative is to assist in lowering the price of the rehabilitation procedure, particularly walking training. allowing patients to continue their recovery after the regular six-month period is up. This study primarily intends to address these issues by providing cost-efficient mechanical help to the paretic ankle during walking using cables and motors. This will enable a longer and more successful rehabilitation process.

There is still debate over whether robots may help stroke sufferers recover. Even though not all trials demonstrate an appreciable improvement in the recovery of a stroke patient, the ones that do have encouraging outcomes. This is valid, especially for carefully planned experiments with a sizable participant pool. This initiative aims to increase the number of assistive devices that can aid a chronic stroke patient with lower limb hemiparesis in regaining a normal stride. This will enable us to conduct research in the future to improve technology-based rehabilitation solutions.

It appears that traditional physiotherapy mixed with robot-assisted rehabilitation is superior to physiotherapy on its own. Even if the robotic procedure is as effective in helping stroke patients recover, it still has additional advantages. One of them is that the therapy is not physically taxing on the therapists, which is difficult when the patient is larger in stature.

The interest in the lower limbs compared to other body parts is extremely different, despite the growing number of studies and research in the field of robot assisted motor rehabilitation (arms and spine). Therefore, the goal of this study is to advance this crucial area of stroke rehabilitation, which frequently receives less attention. The price is just another barrier preventing this technology from being more generally available. Due to the high initial cost of the devices, most solutions demand a significant initial outlay of funds. In this project, because it is less expensive, a soft exosuit (cable actuated) technique was chosen instead of an exoskeleton approach.

Meanwhile, stroke is one of Malaysia's top five causes of death and one of the top ten reasons for hospitalization. Stroke is also one of the top five diseases with the highest disease burden in terms of disability-adjusted life years. However, there are few prospective studies on stroke in Malaysia. To yet, neither the prevalence nor the incidence of stroke has been documented at a nationwide level. The leading cause of stroke is hypertension. Stroke patients in Malaysia range in age from 54.5 to 62.6 years (Akhavan Hejazi SM & Mazlan M, 2015)

The area of rehabilitation robots has grown rapidly in recent years, and robotic therapy is anticipated to become more common in clinical settings in the coming years. Because developing general-purpose rehabilitation devices would be extremely difficult, most robots are built to do specialized jobs. The two primary reasons for incorporating robots into stroke rehabilitation are to expand rehabilitation therapy without the need for more therapists and to deliver therapy that is superior to traditional therapy. To date, evidence suggests that robot-assisted therapy provides equivalent or little improvements to traditional therapy (Yeung L-F, 2018).

Moreover, traditional method also has its own disadvantage such as needing a constant both emotional and physical commitments from physiotherapist. Since the practices are done repetitively with minimal rest time, physiotherapist can be easily drained out especially when the patients are over-weight. Moreover, there is also no proper monitoring system parallel to current IoT development which makes it harder for the physiotherapist to keep track of the patient`s progress. Therefore, this design focuses not only on meeting the needs of the patient but also the physiotherapist.The fabrication of smart lower limb end effector that can be installed on the arm of UR16e collaborative robot. The design of the end effector would allow the patient to undergo plantarflexion, dorsiflexion, hip adduction and hip abduction which are similar to the one practiced by the physiotherapist. It will also be able to show angle at which the exercises being done which can be used to observe the patient`s progress.

1.2 Problem Statement

It is said that the ratio of physiotherapist to the number of people in Malaysia is 1: 13, 000(*Malaysia Short of Physiotherapists, Says Dr Hilmi*, n.d, 2014). This proves that the nation suffers from shortage of physiotherapist and therefore they would have to work longer in order to treat patients causing physical problems such as lumbago due to carrying lower limbs of patient with bad postures. Lack of a commercial end effector to hold the patient's limbs during the rehabilitation process adds to the pain of physiotherapist. There is also a deficiency in the traditional method of doing rehabilitation is insufficient automatic collection and monitoring of patient`s progress. Current stroke rehabilitation practices focus on intensive, cognitively demanding, time-consuming and repetitive exercise regiments. The available rehabilitation programs are time-consuming and labour intensive due to the manual interaction between the physiotherapist and patient

1.3 Objective

1) To develop a smart lower-limb end-effector prototype that can be installed on a collaborative robot to aid patients performing various leg exercises.
2) To incooperate IoT elements by developing an app using Blynk to record and measure angle of rehabilitation exercises for progress monitoring purpose.

1.4 Scope of Project

The project started with designing out the end effector for the UR16e robot through Solidwork 3D CAD Design app. This was followed by the 3D printing designed parts using a 3D printer and assembling them up. Few hardware such as MPU6050 sensors, Node Mcu ESP8266 and OLED screen were purchased and coding was done to measure and observe the angle required for the exercise. The robot arm of UR16e was codded and was tested out on a healthy patient. The angle measured was used to validate the results. Then the AI and IoT functionality was analyzed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Stroke

Stroke is defined by the World Health Organization (WHO) as "rapidly developing clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than that of vascular origin, lasting more than 24 hours or leading to death, with no apparent cause other than that of vascular origin (Eisenblatter et al., 1995) . The American Heart Association (AHA)/American Stroke Association (ASA) has attempted to update this definition by taking into account everything that has been discovered in the more than 40 years since the previous definition. The American Heart Association/American Stroke Association amended their definition of stroke in 2013 to include silent infarctions (including cerebral, spinal, and retinal) as well as silent haemorrhages (Blank et al., 2014). However, for the purposes of this research, this is not the case (Abbott et al., 2017) .

Stroke is a form of cerebrovascular disease that is divided into two types: ischemic and hemorrhagic. When the vascular blood supply to a region of the brain is cut off, an ischemic stroke occurs (Krebs et al., 2004). Thrombotic stroke, embolic stroke, systemic hypoperfusion, and venous thrombosis are some of the subtypes of ischemic stroke. Because of its entire reliance on aerobic metabolism and minimal respiratory reserves, the brain is particularly sensitive to ischemia(Kadir, n.d.). A haemorrhagic stroke occurs when a blood vessel in the brain bursts. Intracerebral haemorrhage and subarachnoid haemorrhage are the two forms of haemorrhagic strokes. Hypoxia caused by a disruption in vascular supply and a rise in intracranial pressure (ICP) are two variables that contribute to the detrimental effects of haemorrhagic stroke(Deb et al., 2010). Haemorrhagic stroke is thought to have a greater death rate than other types of stroke. When it comes to the occurrence of these two stroke types, however, there is some disagreement (Shiber et al., 2010) .

2.2 Overview of Stroke in Malaysia

Stroke is the third largest cause of death in Malaysia, after ischemic heart disease and pneumonia (is also and after effect of stroke)(Chang & Kim, 2013a). Malaysian study is very fresh when compared to the United States of America (USA), where stroke and cardiovascular data on the population can be found dating back to the 1980s. The Ministry of Health launched the National Stroke Registry (NSR) in 2009, which led to the beginnings of stroke research in Malaysia. However, while membership in the register is voluntary, not all clinical facilities that treat stroke, including the majority of private hospitals in the country, are participating (Chang & Kim, 2013b). It's tough to deduce information like stroke regional variance because of this constraint (Deb et al., 2010).

X.W.Chen et al. analysed national registry data from 2009 to 2017 and came up with some interesting conclusions about stroke epidemiology in Malaysia. Malaysia's mean stroke age (62 years) is comparable to that of other nations in the region, especially Indonesia (59 years), Thailand (65 years), Singapore (67 years), and China (68 years) (66 years) (X.W.Chenet al, 2016). However, there is space for improvement because certain countries, such as the United Kingdom, have a far higher average age (74 years) than others. The research also demonstrates that compared to other ethnic groups, the Malay community has a disproportionately high rate of stroke. This is most likely due to data bias, given a big chunk of the data originates from Hospital Sultanah Nur Zahirah in Terengganu, a Malay majority state. As a result, this cannot be regarded as a true depiction of the country's ethnic distribution of stroke. In our society, hypertension and diabetes mellitus are the two most common risk factors and comorbidities for stroke. At discharge from the hospital, patients were classified using the modified Rankin Scale for Neurologic Disability (MRS). Overall, 36 percent of patients are released as functionally independent (FI, MRS 0-2) and 53% are discharged as functionally dependent (FD, MRS 3-5), respectively. In Malaysia, substantial unsolved issues about the impact of socioeconomic class, geography, and racial differences on the occurrence of stroke remain (Tan et al., 2022). Future data and study should hopefully reveal some of these underlying inequalities (if any exist) so that they can be utilised as a guide to improve stroke care across the country.

2.3 Post Effect of Stroke

Stroke is the most common cause of mortality and disability in the globe (Katan & Luft, 2018). The brain is a complicated organ that controls a great number of our biological activities. It is divided into numerous zones with diverse functions. As a result, a stroke in one part of the brain is more likely to disrupt that part's bodily control. This, combined with the fact that mo st stroke patients have comorbidities such as hypertension, heart disease, or diabetes, means that stroke recovery often results in a slew of consequences (Cheung & Hachinski, 2004). However, there are various direct consequences of the brain damage, either as a result of the disability or immobility, or as a result of the treatments used. The digestive, respiratory, urinary, reproductive, circulatory, and neurological systems all show signs of these impacts. Following are some of the most common problems that post-stroke patients confront (Yeung et al., 2018).

Swallowing problems (dysphagia) are a common side effect that affects up to half of all stroke survivors. After 7 days, the majority of patients regain normal swallowing function, with only 11-13 percent remaining dysphagic after 6 months. After a stroke, dysphagia can lead to further issues for a patient. One aftereffect of the ingestion of thickened beverages and modified diets is dehydration and malnutrition. Meals become less enjoyable, lowering quality of life; patients have been known to have anxiety and panic episodes during mealtimes (González-Fernández et al., 2013). Aspiration pneumonia is the most serious consequence of dysphagia. When food, drink, or vomit is inhaled into the lungs by unintentionally, it causes a lung infection(Finlayson et al., 2011).

Stroke can also cause emotional disturbances, such as clinical depression, according to the American Heart Association/American Stroke Association (AHA/ASA). These alterations could be the result of a physical damage that causes chemical changes in the brain, or they could be the result of a patient experiencing post-stroke symptoms. Within five years of a stroke, 29-31% of patients will have acquired post-stroke depression, according to research (PSD). Several genetic variables, such as the 5-HTTLPR and STin2 VNTR polymorphisms of the serotonin transporter gene, have been identified as probable risk factors in PSD (SERT). A patient's medical and psychiatric background has an impact as well. PSD is more common in patients with diabetes mellitus, a previous bout of depression before the stroke, or a family history of depression (Choi et al., 2022). A well-known risk factor is the severity of cognitive impairment produced by a stroke (Forster et al., 2022). PSD has been shown to cause a considerable increase in the risk of death, hence it should be addressed and treated as soon as possible (Cai et al., 2019).

The heart is one of the key organs that can be damaged by brain problems. Both of these organs are intertwined. Electrocardiographic (ECG) alterations, cardiac arrhythmias (irregular heartbeat), arterial hypertension, and arterial hypotension are all examples of these side effects (Loo & Gan, 2012). Strokes can affect bodily functions including speech/language issues, memory loss, and visual impairments, depending on which section of the brain they occur in (Kim et al., 2016).

After 5 years, a considerable number of persons (36 percent) who have had a stroke have serious disability. Another significant fraction (>40%) still requires assistance with daily tasks. One of the most common and well-known stroke side effects is partial or complete paralysis. This adds a slew of problems to one's daily life, making everyday chores far more difficult and, in some cases, impossible to complete. This bodily paresis might lead to other issues in the future, such as bone demineralization. After 3-4 months, a significant loss in bone mineral density is to be predicted, especially on the hemiparetic limb, due to the decline in daily functionality. This study will focus on disability and paresis of the lower limb, specifically the ankle. International Classification of Functioning, Disability, and Health (ICF) of the World Health Organization (WHO) allows us to categorise the effects of stroke on a person based on pathology (disease or diagnosis), impairment (symptoms), activity limitation (disability), and participation restriction (handicap). The affected functions, as well as certain measurement scales for those functions, are depicted in the diagram below. ADL stands for 'activities of daily living (Langhorne et al., 2011)

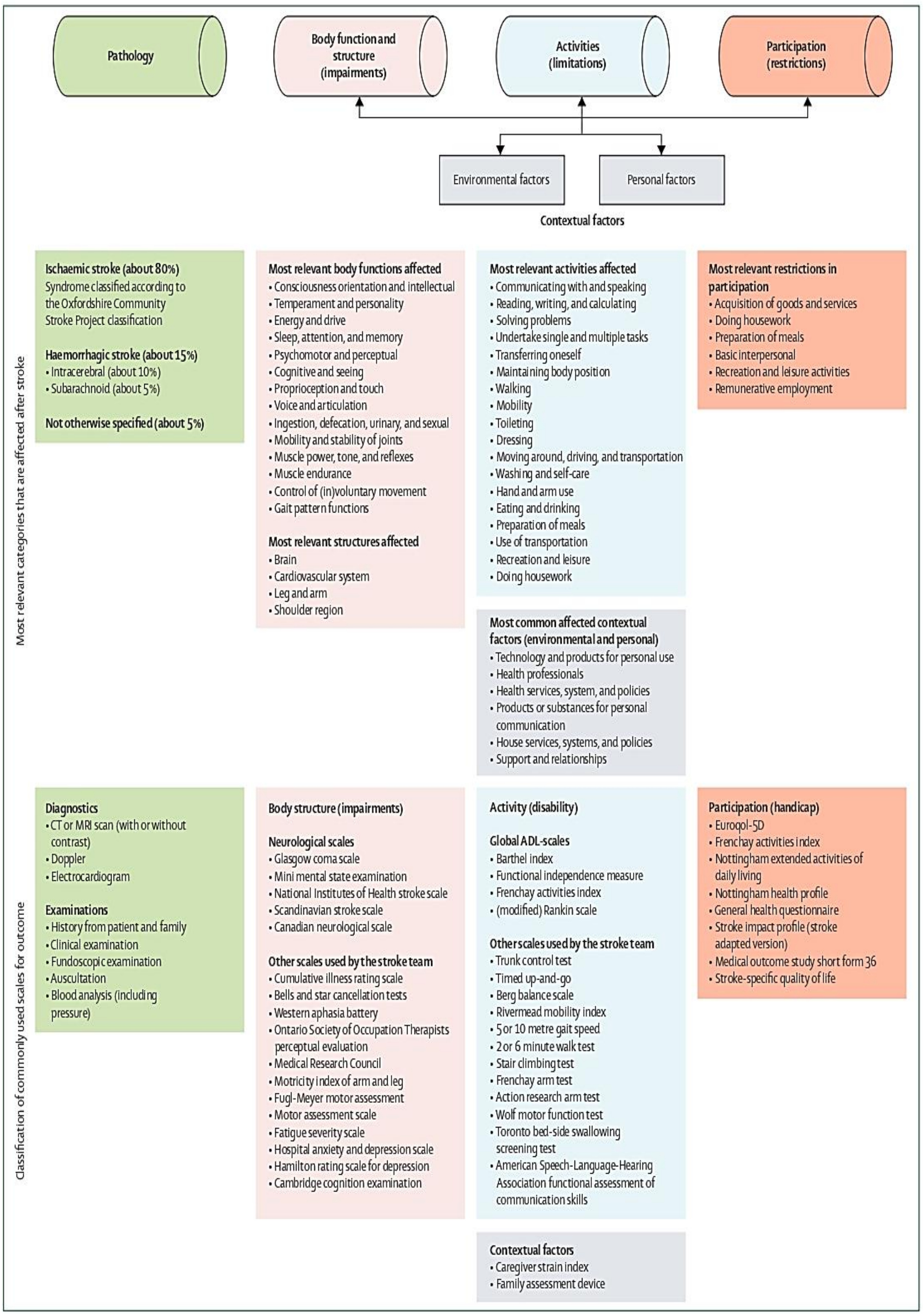

Figure 2.1 : The international classification of function, disability, and health framework for the effect of stroke on an individual

This figure 2.1 summarises key features of WHO's international classification of function, disability, and health model; the most relevant categories affected after stroke; and examples of measurement scales used in those categories. ADL=activities of daily living.

2.4 Stroke and Disabilities

Paralysis and motor dysfunction are common side effects of stroke. According to the American Heart Association/American Society of Anesthesiologists, paralysis is the inability of a muscle group to move voluntarily(Aprile, Guardati, et al., 2020). To control muscle contraction and relaxation, the brain sends messages to motor neurons. This ability to communicate becomes less effective when a section of the brain is destroyed due to a stroke. The side of the body that is paralysed is usually the opposite side of the brain that has been injured by the stroke. Lockedin syndrome is a severe kind of paralysis in which a patient can only move the muscles that control eye movement. Hemiparesis (one-sided weakness), spasticity, hemiplegia (one-sided paralysis), dysphagia (as previously stated), balance issues, and foot drop are all examples of paralysis.

Foot drop is common in patients with a paretic lower limb, resulting in an aberrant walking gait cycle. According to the American Health Association and American Stroke Association (AHA/ASA), patients with foot drop have trouble doing ankle dorsiflexion because the muscles that elevate the foot are paralysed or weak. Patients drag or scuff their toes on the ground during the swing phase of the walking stride because their foot cannot be elevated as high. When standing, having a foot drop produces unsteadiness and balance issues. Patients solve this challenge by altering their walking patterns, resulting in aberrant gaits. To clear the ground, patients with the'steppage gait' compensate by lifting their leg higher than usual through excessive knee and hip flexion (Aprile, Germanotta, et al., 2020). Circumduction gait is the act of bringing the foot forward by swinging the entire paretic leg to the side in a big circular motion. All of this leads to inefficient walking, which causes patients to use more energy than necessary, resulting in weariness. Walking becomes more difficult and painful, and falls become more common.

2.5 Importance of Rehabilitation Post Stroke Analysis

The nature of stroke healing varies greatly. The severity of the original stroke, as well as the quality of the subsequent recovery, have a significant impact on the long-term effects of stroke. Stroke rehabilitation generally follows a regular pattern of: 1) assessment, in which a patient's needs are identified and quantified using an appropriate measurement scale; 2) setting realistic and achievable goals in the appropriate time spans; 3) intervention (treatment), which aids in the achievement of set goals; and 4) reassessment, in which progress is evaluated based on set goals.

When should you begin therapy after a stroke? Despite its apparent simplicity, this question has yet to be definitively answered and remains a focus of research. The complexity of stroke, as discussed throughout this paper, makes even this a difficult parameter to quantify. In the AVERT (A Very Early Rehabilitation Trial for Stroke), a large-scale randomised controlled trial involving 56 acute stroke units in five countries (Australia, New Zealand, Singapore, the United Kingdom, and Malaysia), one group received usual care (UC) while the other received very early mobilisation (VEM). Within 24 hours of the commencement of the stroke, the patients in the VEM group were mobilised. The results demonstrate that the VEM group fared marginally (but considerably) worse than the UC group in the 3-month follow-up assessment. The median time for first mobilisation was only 4.8 hours in both groups; 18.5 hours' vs 22.4 hours for the VEM and UC groups, respectively. Despite being statistically significant, this appears to be a minor difference. In comparison to the UC group, the VEM group had a substantially longer total intervention period (201.5 minutes vs. 70

minutes). The overall quantity of intervention reveals an even higher gap (almost three times more) between the groups when compared to the time for first mobilisation, indicating that this may be the key contributing factor. The best timing to begin rehabilitation after a stroke is yet unknown. Current research is beginning to demonstrate that, while urgent treatment (within 24 hours) must be used with caution, there are few reasons to delay initiating rehabilitation during the first two weeks after a stroke(Coleman et al., 2017).

According to the AHA/ASA guideline for adult stroke rehabilitation and recovery, numerous alternative approaches to stroke rehabilitation and recovery have been studied and are currently being used. There is varied degrees of study and proof that a wide range of therapy options actually aid stroke recovery. From ankle foot orthoses (AFO) for the treatment of gait impairment, which has a lot of evidence behind it, to virtual reality treatment, which hasn't gotten enough proof to become a popular treatment yet. Stroke recovery is not a one-man show; family members, friends, caretakers, nurses, physicians, and others all play a crucial role in making it a success. This review will concentrate on regaining upper and lower limb function. Physiotherapy, ankle-foot orthotics, and robot-assisted rehabilitation modalities will all be investigated(Duret et al., 2019).

2.6 Overview of Lower Limb Rehabilitation Robots

Robots or machines for stroke rehabilitation for lower limbs have been created and applied in health institutions and shown to assist in the recovery of stroke patients who are still suffering from hemiparesis. These lower limb rehabilitation robots are developed to provide motion of the various joints of lower limbs with various activities and modalities. There are a variety of exercise that involve training of multiple joints, for instance, leg press, gait trajectory following, cycling, and customized movement. Generally, one or several kinds of these exercises can be selected in order to accomplish different aspects of recovery(Prakash et al., 2016).

Lower limb rehabilitation machines can be generally categorized into two main categories, which is end effector robots and exoskeleton robots. Based on their principles of rehabilitation, end-effector robots are usually platform-based or footplate based; while the exoskeleton robots are leg orthoses-based or treadmill-based(Wu et al., 2016)

Exoskeleton robots are usually fixed in different parts of the lower extremities, while producing forces or torques to assist the exercise(Dongo et al., 2017). However, the exoskeleton robots may be ineffective in improving certain stroke survivor's lower limb motor function due to its poor adaptability. On the other hand, end-effector robots are generally at a certain point in contact with the patient's lower limb. The end effector robots have higher adaptability to different patients as there is no restriction on the patient's movement(Zhang et al., 2017).

2.7 Designing Foot Support for the Patient's Limb

Based on another research paper by Pual Taucan (Tucan et al., 2021) which uses Kuka robots to assist the rehabilitation process of plantarflexion, dorsiflexion, abduction, adduction and inversion. To in cooperate the Kuka robotic system for ankle rehabilitation, several modifications was made to the system in order to ensure the patient's leg and foot were supported. For instance, by using a sophisticated 3D printer, a customised plate was designed (as shown in figure 2.2 below) and manufactured that allows for simple leg rest while also providing a means of limiting the leg during recovery. The leg plate was put in place while the patient is sat in a chair or in bed, on a low table to provide leg rest. In addition to the leg plate, an end-effector was created and constructed from the same material.

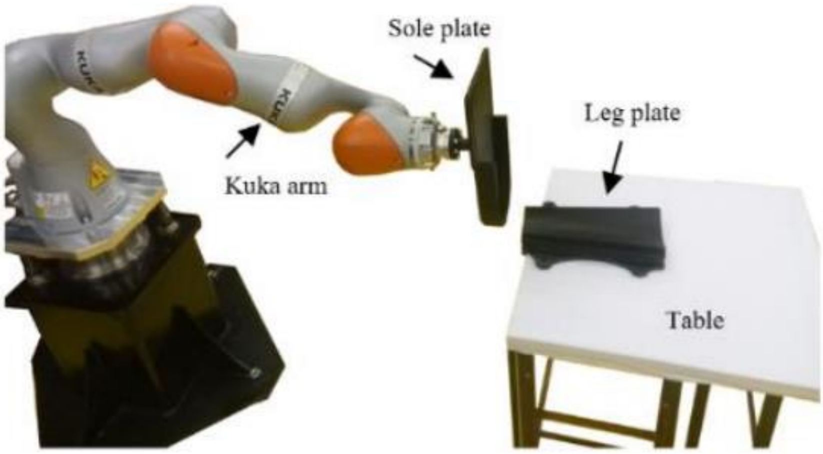

Figure 2.2 The rehabilitation system set up (Tucan et al., 2021).

There were no system problems during the experimental tests, simply a few unintended robot stops due to some exceeding torques in the system discovered by the Human Robot Interference (HRI) toolbox. Because of the unplanned stops, a special section was added to the rehabilitation program's source code in order to create a protocol based on involuntary spasms that patients might experience (Krebs et al., 2004). In this case, the robot would stop for a few seconds and if the torque disappeared, it would continue the motion; otherwise, it would interrupt the motion and warn the clinician by flickering the flange LED light.

However, as shown in figure 2.3, the use of a low table to rest the patient's leg was feasible when the patient was seated in a chair, but most patients are bedridden and unable to be stable in a chair, so a higher table would be required. This would not be an impediment to the system because the leg plate could be easily mounted and removed, and the Transmission Control Procedure (TCP) is always computed with the patient's leg. In this experiment, the result obtained shows that the plantarflexion reading was $20^{\circ} \mp 2$, d0rsiflexion $20^{\circ} \mp 2$, adduction , $30^{\circ} \mp 2$ and abduction $45^{\circ} \mp 2$ (Acute type stroke)

Figure 2.3 Patient-robot position (Tucan et al., 2021).

2.8 Overview

of Plantarflexion and Dorsiflexion

Based on the research done by Brcokett on the biomechanics on angkle, the foot and ankle are made up of thirty-three joints which is made up of the twenty-six separate bones of the foot and the long bones of the lower limb. Although the 'ankle joint' is commonly referred to, there are a variety of articulations that allow the foot to move. The talocalcaneal (subtalar), tibiotalar (talocrural), and transverse-tarsal (talocalcaneonavicular) joints make comprise the ankle joint complex. The malleoli of the tibia and fibula act to limit the talus, making it a hinge joint that predominantly contributes to the foot's plantar- and dorsiflexion motion (Brockett & Chapman, 2016)

The range of motion for ankle would normally vary from person to person due to various factor such as geographical, cultural variation and daily activities. The direction of motion for both movements can be observed in figure 4 below. The method used in assessing or carrying out the experiment could also influence the angle values (Da Silva et al., 2019). The sagittal plane is where the ankle moves the most, with the tibiotalar joint doing the majority of the plantar- and dorsiflexion. According to several studies, the overall ROM in the sagittal plane is between 65° and 75°, ranging from 10° to 20° of dorsiflexion to 40–55° of plantarflexion. In the frontal plane, the entire range of motion is roughly 35° (23° inversions 12° eversion). The ROM required in the sagittal plane is substantially lower in ordinary activities, with a maximum of 30° for walking and 37° and 56° for ascending and descending stairs, respectively (Brockett & Chapman, 2016).

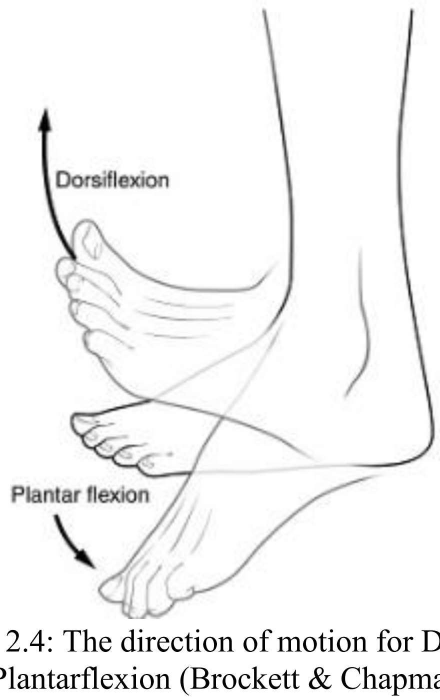

Figure 2.4: The direction of motion for Dorsiflexion and Plantarflexion (Brockett & Chapman, 2016).

In another experiment by Suga et al on association between plantar flexor muscle volume and dorsiflexion flexibility in healthy young males: ultrasonography and magnetic resonance imaging studies,subjects were instructed to refrain from extending for at least 2 hours prior to the evaluation of dorsiflexion flexibility. Changes in dorsiflexion flexibility parameters (e.g., passive ROM and stiffness) after acute plantar flexor stretching exercises were observed to revert within 30 minutes in previous research

Based on a research, it can be seen that the patient show changes in ankle joint angles of plantar flexion (PF) 20º, 0º, and DF 20º, during the passive stiffness measurement (Can be observed in figure 2.5 below). On a dynamometer, subjects were put in a sitting position with full extension at the knee joint. Seat belts were used to keep the hip in place. The foot was securely fastened to a footplate attached to the dynamometer's lever arm. To assess active ROM, the patients' ankle joints were placed to a 20˚ plantar flexion, and then they were asked to do voluntary dorsiflexion as slowly as feasible(Suga et al., 2021).

2.9 Overview of Hip Abduction and Hip Adduction

Figure 2.5: The direction of motion for Plantarflexion, normal position and Dorsiflexion (Suga et al., 2021).

The displacement of the leg away from the body's midline is known as hip abduction. Every day, this action has been used by humans to step to the side, get out of bed, and exit the car. The hip abductors are crucial but often overlooked muscles that let us stand, walk, and rotate our legs comfortably. This form exercise has various benefits such, for instance, it reduces knee valgus. Knee valgus is a condition in which the knees cave inward, creating the appearance of being "knock-kneed." This is especially common in young ladies and elderly adults, as well as those who have muscular imbalances or poor exercise form. Knee valgus has been linked to a lack of hip strength in studies, and hip abduction exercises have been proven to help (Dix et al., 2019).Adduction is when a joint moves a section of the body in one plane toward the midline. When standing up straight, the midline is an imaginary line that runs from the top of the head to between the feet, passing through the abdominal cavity. Abduction, on the other hand, is the polar opposite of adduction, or movement away from the midline.

Based on a research done by R.T Floyd, this study enlisted the participation of 20 healthy young individuals (10 males and 10 females). All subjects alternated between normal bridge exercise, isometric hip abduction (IHAB) using a blue Thera-band (Hygenic Corp., USA), and isometric hip adduction (IHAD) with a Swiss ball (Hygenic Corp.). Hip abduction, the best result was seen with greater angle (in the experiment, angle of 10 degrees, 20 degrees and 30 degrees was used). This proves that the greater the angle, the accurate the result would be (maximum angle should not exceed 45 degree) (Hwanga et al., 2017). The maximum angle of abduction and adduction can be seen in figure 6 below, thus, the limit should not exceed those values.

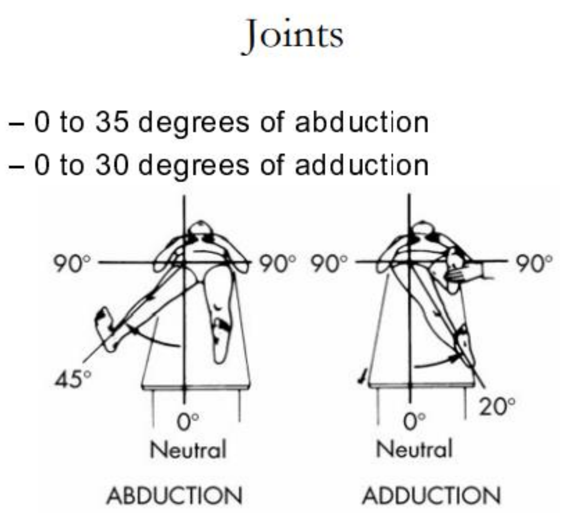

Figure 2.6: The angle of abduction and adduction (R.T. Floyd, n.d.)

2.10Angle Measuring Sensors / Technology

MPU6050 is a sensor module that has three different sensors packed in it, 3-axis Gyroscope, 3-axis Accelerometer (based on figure 2.7) and a Digital Motion processor allowing it to function as a 6-axis Motion Tracking device. The gyroscope comes with a system called Micro Electro Mechanical System (MEMS) that allows it to sense rotational velocity along ll 3 axes.

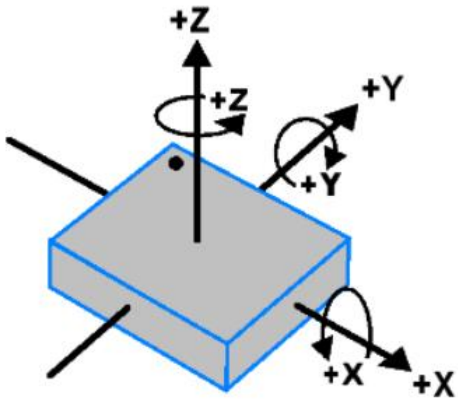

Figure 2.7: Three axes at which a gyroscope detects rotational velocities

On the other hand, Micro Electro Mechanical (MEMs) system exist in the accelerometer which helps to detect inclination or tilt angle along the axes. Additional any sensors such as magnetometer can also be used, and the Digital Motion Processor would compute the algorithm for the motion. Then this sensor later can be connected the blynk app and datas can be transferred to a smartphone (IoT)

The same sensor was used in an experiment of Physical Extraction and Feature Fusion for Multi-Mode Signals in a Measurement System for Patients in Rehabilitation Exoskeleton, where it was demonstrated that the measuring system can give accurate real-time input for exoskeleton feedback control in their experiment(Yang et al., 2018).

Table 2.1: Measurement accuracy of detection using MPU6050 angle sensors (Yang et al., 2018).

Practical Angle °	Measurement Angle°	Relative Angle°
0	0.69	/
15	15.44	2.93
30	30.24	0.8
45	45.12	0.27
60	60.12	0.2
75	75.08	0.11
90	89.65	0.39

Based on table 2.1. it can be seen that the relative error values are lesser than 3 which shows these sensors are suitable to be used to measure angles of limb movements. Thus, this sensor has been chosen to be used in this experiment to measure the angle in X °, Y °, and Z ° direction

In another rearch by Ikuhiro Morikita in year 2017 on the reliability and validity of angle measurements using radiograph and smartphone applications, five condition images were taken at distances of 50 cm (AM50), 100 cm (AM100), 150 cm (AM150), 200 cm (AM200), and 250 cm (AM250), and then the angle was measured using the app (Measurement of ROM Angle). AM50-sized images were modified and standardised. One day separated the measurements made for each condition, and they were made once for each photograph. Computer software was used to randomise the measurement order. After the image was magnified in the app, the angle was calculated so that the measurement axis was parallel to the protractor's blade. A smartphone touch pen was used to take the measurement. Angle measurements were made at 0.01° interval.

Application Measurement (AM) were shown to have good inter-rater reliability, low error, and high validity. As a result, angle measurements made from photos taken vertically and at a specific distance from the subject were precise for the given angle. The findings validated the validity of high-quality earlier research that utilised RM as a criterion for validity and demonstrated what angle measurements utilising pictures may employ as a validity criterion. However, AM offers many clinical advantages, including the fact that it is a quick, painless, and economical procedure. As a result, AM can offer high-quality data for clinical investigations and be utilised as a validity criterion. It is advised that the AM leave about 2 metres between the smartphone and the subject. However, this type of measurement could cause more hassle since it can continuously measure the angle and requires the subject to stop and pause to measure the angle/ This could be a drawback to be considerate for rehabilitation processes

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Structure of the Lower Limb Stroke Rehabilitation Machine

A lower limb stroke rehabilitation machine was developed and employed to conduct the experiment. As this project is in it is first few steps, most effort was put on designing, 3D printing and putting everything together. The designed was done using Solidwork software followed by slicing done in Ultimaker Cura. The final assembly of the drawing can be observed in Figure 3.1 below. Since it is a rehabilitation robot which was specifically designed for lower limb stroke patients to undergo stroke rehabilitation exercise. The end effector was designed to be attached together with a UR16e robot arm. This can be seen in Figure 3.2 below.

Based on Figure 3.1 below, the leg pad functions to hold the foot in position during the different motion of exercises. It also has hollow spaces where the valcro strap will be used to hold the leg in position tightly. The leg pad is placed on the shin and same valcro strap is used to strap it on to the shin. It also serves as the place of attachment for the linear guide which fuctions to transfer the linear motion to the cylinder head. The cylinder head on the other hand transfer the linear motion to the leg hinge and then its finally transferred to the foot holder.