SMART LEG REHABILITATION SYSTEM

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DECLARATION

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.

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Acknowledgement

The completion of this project is not possible without the help from many people. First of all, I would like to express my gratitude to Universiti Sains Malaysia for giving me the chance to complete this four-year course in Mechanical Engineering. Sincere gratitude towards the School of Mechanical Engineering for all the instruments and necessities provided.

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Abstrak

Fungsi anggota badan berisiko untuk diserang oleh strok, kemalangan atau penuaan. Lumpuh pada sebelah badan yang mengurangkan kekuatan dan kawalan anggota badan merupakan kesan strok. Anggota badan ini boleh dipulihkan melalui senaman. Senaman pasif merujuk kepada otot yang digerakkan dengan bantuan luar manakala senaman aktif merujuk kepada otot perlu menjana daya bagi melaksanakan sesuatu pergerakan. Pelbagai senaman pasif ditujukan khas untuk mangsa strok yang mengalami kesan sampingan yang ringan atau rempuh yang teruk. Senaman ini membantu mencegah kekejangan otot dan kekebasan yang mengehadkan pergerakan otot. Senaman aktif melibatkan tenaga fizikal yang perlu dijana oleh otot.

Tujuan projek ini adalah untuk menghasilkan satu sistem pemulihan yang menggabungkan senaman pasif dan aktif yang meliputi “flexion/extension” kaki kerana indeks mengakat bagi fisioterapi melebihi 1 menandakan ia berisiko untuk mengakibatkan sakit belakang (mengikut NIOSH). Senaman pasif menetapkan 6 ulangan bagi setiap minit membantu pesakit menjalankan senaman yang berintensi tinggi dan berulangan. Pad input digunakan untuk mengisi data dan memaparkan data bagi tujuan pemantauan pemulihan pesakit. Simulasi bagi kaki yang terjejas bagi seseorang yang beratnya 45kg telah menjalankan simulasi senaman pasif dan mendapat daya puarat 35N. Daya kaki yang sihat diukur dengan meminta seseorang itu mengenekan daya yang maksimum untuk menolak sistem tersebut. Daya purata 120N telah diperolehi untuk kes simulasi ukuran daya kaki sihat.

Senaman aktif sesuai untuk pesakit yang telah pulih secara beransur-ansuran. Ia bertujuan untuk memulihkan daya otot melalui pembentukan laluan neural di dalam otak. Daya yang dikenakan oleh kaki pesakit ketika gerakan lanjutan kaki akan diukur oleh alat pengukur daya di tapak kaki. Bacaan dari alat pengukur akan disalurkan ke myRIO bagi menentukan amoun yang mencukupi untuk membolehkan sistem melanjutkan silinder. Nilai daya pra-set 40N telah ditetapkan dalam senaman aktif. Program yang dihentikan jika daya yang dikenakan tidak mencapai daya pra-set. Daya yang direkodkan oleh myRIO akan diprosess bagi menilai kadar pemulihan pesakit. Hal ini merupakan satu cara untuk memantau pemulihan motor pesakit secara kuantitatif bagi memberikan motivasi kepada pesakit melalui maklu balas positif sistem

tentang kadar pemulihan otot mereka. Sistem yang dibangunkan menonkolkan kelebihan sistem dalam pengumpulan data, membantu pergerakan, menyediakan tahap rintangan yang sesuai serta merekodkan tahap pemulihan pesakit.

Abstract

The function of the lower limb can be affected by stroke, accident or even aging. Paralysis on one side of the body is a common effect of stroke which diminishes the strength and control of the lower limb. The lower limb can be rehabilitated by means of exercise. The passive exercise is when the muscle is moved by the means of external force and the active exercise is when the muscle exerted the force necessary to create the motion. Passive range of motion exercises are for stroke survivors who are left with mild to severe paralysation, or paresis. These exercises can help prevent muscle stiffness and spasticity which is the limited coordination and muscle movement. Resistive exercises involve conscious control of the muscle and physical effort exerted into muscular activity to improve neural path formation.

The aim of this project is to develop a combination of rehabilitation system based on assistive and resistive mode of motions which cover the flexion-extension of the leg as it is found that the lifting index of conventional rehabilitation by physiotherapists is more than 1 which indicates a high risk of back pain (according to NIOSH). The assistive mode of motion is set at 10s per motion at 6 cycles per minute which allows a high intensity and repetitive form of knee extension and flexion and also dorsi-plantar motions. The input pad is used as the data entry and also for data display for monitoring and recording purposes. A simulated paretic limb for a 45kg person has carried out the passive mode of motion and an average force of 32N is obtained. Then healthy leg force measurement is carried out at which the person has exerted the maximum pushing force when the cylinder is at rest in retraction mode and obtained a simulated maximum force of 120N.

Resistive rehabilitation exercise is for patient who has slowly regain some strength. It aims to regain lost movement after stroke by strengthening the neural pathways in the brain that enable the performance of the movement. The patient is required to exert force on the leg and the force being exerted by the patient during the hip-knee joint extension will be measured by the load cell at the foot rest. The reading from the load cell is taken as an input to a control system within myRIO to determine whether enough force has been applied to allow the motion. A pre-set force value of 40N is set in active mode of motion. The system will only complete the knee extension motion if the paretic limb has achieved the pre-set force value and it will end the process when it is unable to

achieve the pre-set value. This provides a mean for quantitatively monitoring the motor recovery during rehabilitation. This active mode of motion provides positive feedback on the recovery of the muscle strength that motivates the patient to work harder to overcome the pre-set force value. The developed system highlight the advantages of the system in collecting data, driving the actuators, providing suitable resistance level for active exercise based on closed loop control system and to record the achievement of the patient.

CHAPTER 1 INTRODUCTION

1.1 Introduction

Every year, 15 million people worldwide suffer from stroke and nearly five million are left permanently disabled with paralysis and weaknesses. This has made stroke as one of the leading causes of disability, according to the World Heart Federation [1]. In Malaysia, according to the latest WHO data published in May 2014, stroke deaths reached 15,497 or 12.19% of total deaths. The age adjusted death rate is 80.59 per 100,000 of population ranks Malaysia number 97th in the world [2]. According to an article by National Stroke Association in 2016, stroke is the fifth leading cause of death in the US with approximately 800,000 people suffered from stroke each year and, 40 percent of all stroke survivors suffer serious falls within a year after their stroke [3].

1.2 Principles of Stroke Rehabilitation

Stroke rehabilitation is a long journey of process with the focus to recover any motor impairment. It is an individualized program for stroke survivor and helps to prevent the recurrent of stroke. The aim of the rehabilitation exercise is to retraining the brain and the body as well. An effective rehabilitation program should be able to encourage the improvement of neuroplasticity where the undamaged axons grow new nerve endings to reconnect neurons whose links were injured or severed [4]. This is important to form new neural pathways so that the lost function can be recovered. This can be achieved when the patient is paying full attention in the rehabilitation session and make conscious control over the affected leg. The formation of new neural pathway requires a huge investment of energy and thus the patient is required to undergo a high intensity exercise on a specific type of motion. The basic idea for assistive rehabilitation is to reduce muscle hypertonia and muscle pain. This assistive rehabilitation is of utmost important for non-ambulatory patient which helps to reduce the detrimental effect of bed rest which include decreased volume of blood plasma, increased resting heart rate, depressed in immune system and risk of joint contractures that will further complicate the prolonged inactivity [5]. The most common way of conducting active exercise is with the help of physiotherapist who functions not only to move the patient’s limbs but also to motivate and provide some form of care to the patient. However, the service of the physiotherapist is sometimes not readily available and also there is a shortage of physiotherapy services in some areas.

1.3 **The physiotherapy dilemma-cost and accessibility**

Private session with the physiotherapy can be costly. In London, a 30-minute session will cost £60 [6]. In Kuala Lumpur the price is RM80-RM120 per session [7]. It is clear that the cost of physiotherapy is significant may well be beyond reach of the general population. There are physiotherapy services in the public hospital. A survey of two teaching hospitals in Kuala Lumpur in 2106 showed that 37% of the patients reported that their expectations were not met indicating a relatively average level of services where more than 1 in 3 patients are dissatisfied with the services [8].

The top three ranking of services utilised in the management of post stroke patients while at primary care are Physiotherapy, Dietitian and followed by Speech & Language Pathologist. Patients highlighted the need for availability of rehabilitation facilities to be based at primary care, i.e. health centres as not all health centres in Malaysia have facilities for rehabilitation services [9].

Although there has been a recent move by the Ministry of Health to provide this facility at selected health centres with either physiotherapy alone or together with occupational therapy services. In some health centres, a visiting physiotherapist or occupational therapist provide services on rotational basis for health centres. However, the rehabilitation service at health centres is not solely for stroke rehabilitation. Therapists also have to cater for other services such as acute pain service, rehabilitation for amputees for example [10]. It is clear that there is a gap between the demand and the level of services provided by the public hospitals.

1.4 Objectives

1) To determine the lifting index for the physiotherapist when working on the lower limb of a stroke patient.
2) To design a leg rehabilitation system with passive and active mode exercises.
3) To design a rehabilitation machine that can measure the muscle strength of the stroke patient non-paresis limb as a baseline for recovery measurement of the paresis limb.
4) To determine the effectiveness of the system by using simulated

patient.

1.5 Scope of Research

The smart leg rehabilitation system focuses on the development of a combination of both assistive mode and resistive mode of rehabilitation program together with recovery measurement of the patient. Besides, the algorithm of LabVIEW is also important to sequence the rehabilitation programs of the lower limb and involves in the control of the sequence of the solenoids during rehabilitation program. Next, this design has the recovery measurement system that is able to generate quantitative data on the recovery rate of the patients. All the data obtained will be stored in the system.

CHAPTER 2 LITERATURE REVIEW

2.1 Rehabilitation therapy and the back pain risk

The rehabilitation work of the lower limbs by the physiotherapist require the lifting and moving the lower limbs. Some of the movements require the lifting of the whole thigh and leg which are the two heaviest limbs of the human body as shown in the Figure 2.1 below. In this figure a physiotherapist is lifting the leg for the knee flexion-extension movement. Even in this position the physiotherapist is loading her back and the risk of back injury increases with the weight of the leg. Stroke incidence is relatively high in obese patients which incidentally will increase the number of patients with heavy lower limbs.

Figure 2.1: A leg rehabilitation session conducted by the physiotherapist *(accesses from http://www.dailymail.co.uk/news/article-3857668/NHS-stroke-patients-suffer-devastating-delays-rehab-treatment.html)*

As the patient is usually located at a distance from the physiotherapist, this created a bending moment about the spine and can be a source of backpain. One method to assess the risk of backpain is with the use of the lifting index (LI) based on the recommended weight limit as indicated in the Revised National Institute for Occupational Health and Safety (NIOSH) Lifting Equation [11]. The LI can be used to estimate the relative magnitude of physical stress for a task or job. The greater the LI, the smaller the fraction of workers capable of safely sustaining the level of activity. Lifting tasks with a Lifting Index greater than 1.0 pose an increased risk for lifting-related low back pain. For LI higher than 3.0 than nearly all physiotherapist will be at an increased risk of work-related injury. The LI for the physiotherapy action for the lower limb are listed in Table 1, the values are based on a patient of 80-kg weight [12].

From this Table 1 the highest lifting index is 3.29 for the hip flexion-extension with the leg in a straight condition followed by the hip-knee flexion-extension movement. All the remaining motion has lifting index of less than 1. It is clear that to have repetitive motion for the two exercises with LI more than 2.0 pose high risk to the physiotherapist and a solution is needed.

RWL = LC × HM × VM × DM × AM × FM × CM

RWL= Recommended Weight Lifting

LC= Load Constant

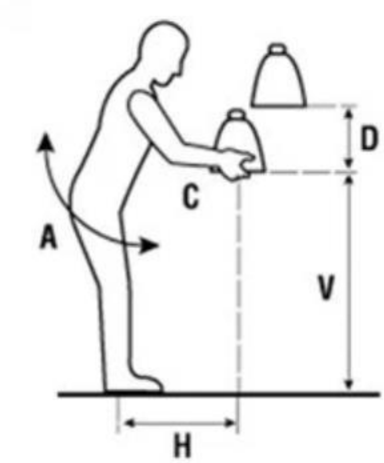
HM= Horizonal Multiplier

VM= Vertical Multiplier

DM= Distance Multiplier

AM= Asymmetric Multiplier

FM= Frequency Mutiplier



CM= Coupling Multiplier

$$\text{Lifting index, LI} = \frac{\text{Load Weight}}{\text{Recommended Weight Limit}} = \frac{L}{RWL}$$

Mode of rehabilitation motion	Percentage of Total Body Weight (Plagenhoef e al., 1983)	Lifting Index
Straight leg raise	17.555	3.29

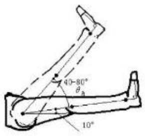
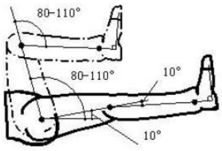
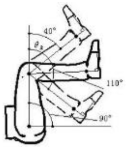
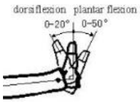
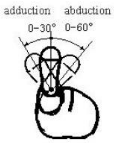
		
Hip-Knee Extension flexion 	17.555	3.22
Knee extension Flexion 	5.05	0.93
Dorsi-plantar flexion 	1.38	0.23
Adduction/Abduction 	1.38	0.23

Table 2.0 - Five Different Modes of Rehabilitation Motions

Traditionally, physical training programs in post-stroke rehabilitation are usually time consuming and labor demanding as these require one-to-one manual interaction. The controversy in current rehabilitation treatment implies that conventional rehabilitation approaches need to be improved for better outcome and the improvement should depend on the increased understanding of brain plasticity and also on the development of rehabilitation devices [13]. It is important to enhance motor function in the early rehabilitation period. Long term regular physical training is also needed in order to maintain the function improvement after hospitalization.

2.2 Conventional and Robot-Assisted Rehabilitation

One way to overcome the issue of lower back pain risk and also the issue of accessibility and the cost of service in the rehabilitation of the lower limb by using a rehabilitation machine which has the ability to reproduce the majority of the motion made by the physiotherapist. In this case, the machine can help the physiotherapists to overcome the excessive demand to their services by relegating the repetitive tasks to the machine-assisted rehabilitation [14, 15, 16, 17]. This can increase the productivity and eventually drive down the costs of healthcare services. Positive effects on the motor recovery have been reported in many studies on robot-assisted post stroke training when compared to the conventional treatments [18]. However, robot-assisted training with continuous passive movement (CPM) can only provide program that in general is fixed, although there are some machines providing adjustable rehabilitation program. These robotic devices are mainly different from the treatment by physiotherapist as they have a feeling of the status of the muscle recovery of the patient which can be communicated back to the patients as a form of feedback. These robotic devices are in general unable to adjust the rehabilitation program accordingly to the rate of recovery of the post stroke patients. Besides, this type of motion only effective in temporarily reducing the post-stroke hypertonia [18].

2.3 Active Mode of Exercise

The resistive rehabilitation will serve its function after the patient has regained some strength in the muscle. In order to help building the new neural pathways between the limb and the brain is by consciously focus on the motion and being aware of the motion being performed by the patient during the exercise. This requires the patient to generate muscle force to move the limb to overcome the opposing resistive force. The brain is able to rebuild the damage neuron paths through the conscious control of the limb's motion [19]. As such the new rehabilitation machine must have a form of patient interaction to initiate the motion in the exercise and this is part of the characteristic of the rehabilitation machine developed here. Active mode of rehabilitation program should be introduced to help in the axonal sprouting in the brain as the patient is required to concentrate in performing the task [20]. Active mode of motion that is challenge-base helps in the recovery of the impairment in the sensorimotor system. According to the sensorimotor integration theory, the voluntary motor efferent and the afferent sensor experiences together are important and helpful in promoting the recognition of the brain during active-mode motion [19]. Biofeedback can help to improve the outcome in the rehabilitation due to the reason that the patient is able to gain conscious control over the undamaged neuron pathways which are in turn able to promote the restoration of the missing functions.

2.4 Measuring muscle strength as an indication of recovery

30% of the post stroke patients will suffer from depression [21]. Thus motivation is needed to encourage the patients during the whole rehabilitation journey. One way to effectively motivate the patient is by making their progress known as a form of feedback [22]. The quantitative representation of the recovery rate of the patients can help to elevate the mood of the patients. The use of portable dynamometry is a common way to measure the strength of muscle in the knee joint, hip and ankle joint. Supine position is most commonly used during the assessment of the strength of lower limb muscle. The differences in strength between the paretic side and non-paretic sides for a specific muscular group is obtained. The smaller the differences indicates a better strength of the symmetry between the limbs of the stroke patient [23]. However, the data collection protocols which include the number of trials, contraction time and resting time intervals are not standardize [23].

CHAPTER 3 SYSTEM OVERVIEW AND METHODOLOGY

3.1 System and Control Overview

The project begins with the design of mechanical linkages of the leg rehabilitation system with SolidWorks. This visual prototyping is important to help us in fulfilling the requirement of designing a linkage-system that is able to provide smooth extension and flexion motions of the leg. The algorithm would be designed to perform the closed loop active control on the challenge-based motion of the rehabilitation system by controlling the speed of air flow into the pneumatic cylinder. After the mechanical linkage-system and the control blocks are ready, we would like to evaluate the functions by integrating the system control to the mechanical linkage-system to ensure the effective functionality of the leg rehabilitation system. Next, data collection on the force measured by the load cell would be done to ensure the optimal efficacy of the rehabilitation device for post-stroke patients.

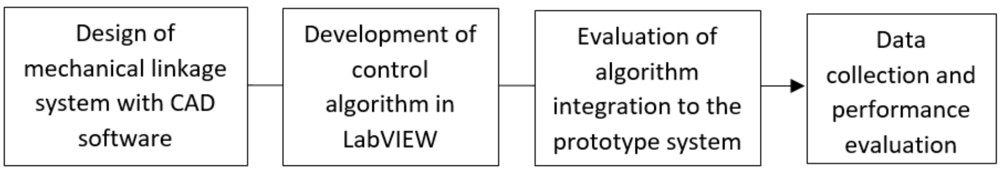


Figure 3.1: Overall Flow of Project Execution Timeline

To achieve the project goals of developing a smart leg rehabilitation system for post stroke patients, the main actuating system of pneumatics is chosen. It provides a safer solution compared to hydraulic actuator. For the force recording and processing, National Instruments myRIO controller is used. The overall system can be illustrated in Figure 2.

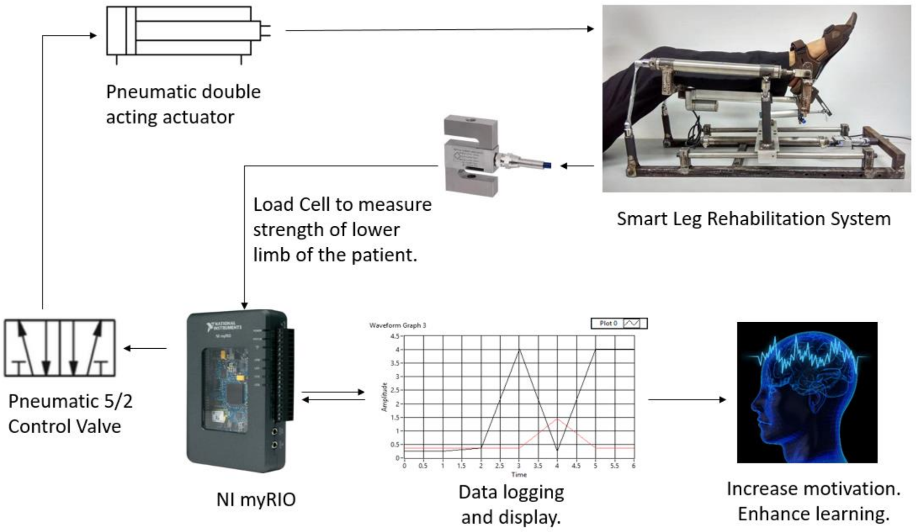


Figure 3.2: Overall system layout of Smart Leg Rehabilitation System

Components	Roles & Functions
Linkages for leg exercising system	Exoskeleton of leg as a platform to locate the leg of the patient and thus providing motion.
myRIO microcontroller	Mastermind to control automation sequences and to serve platform for data acquisition of force sensors in real time.
Pneumatic Cylinders	Actuators for creating guided motion to the linkage-system with different magnitude of resistance.
Load cell	To measure the force exerted by the patient's leg.
Solenoid Operated Directional Valves	To control either extension or retraction motion of the cylinders by switching the flow paths in the directional valves

Table 3.0: Overall system layout for the smart leg rehabilitation system

3.2 Measurement of the flexion and extension of knee using inertial measurement unit sensor

When the prototype is done, the angular displacement of the knee extension and flexion motion that can be performed by the machine is being measured. This measurement is carried out by using two sensors, at which one is being placed at the thigh and the other sensor is placed at the leg. The lower limb is then placed in the right position on the machine. Passive mode of motion is chosen to allow the machine to extend and retract automatically. At the same time, the angular difference collected by the two sensors will be processed by the inertial measurement unit (IMU) system.

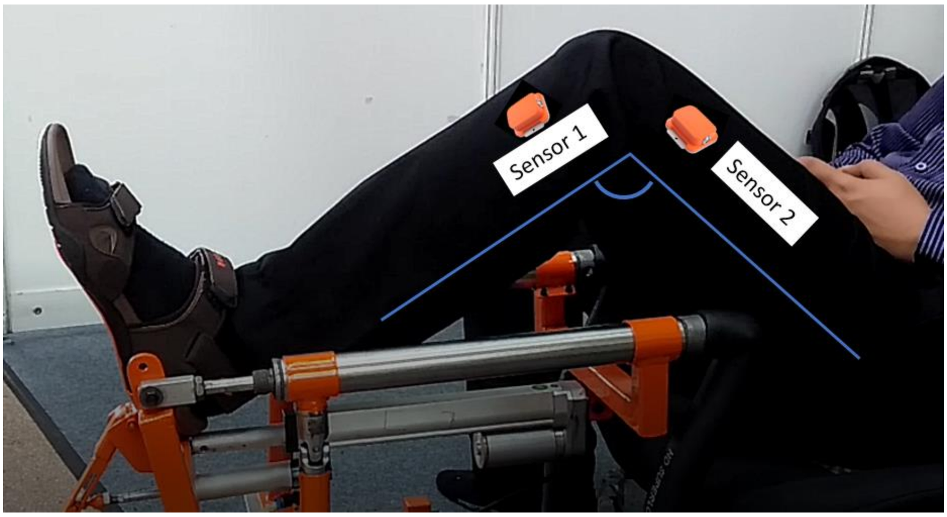


Figure 3.3: Measurement of angular displacement using IMU sensor

3.3 Measurement of the Force of the Paretic Leg in the Assistive Mode of Motion

Assistive mode of motion consists of 6 cycles per minute. The non-paretic leg will be placed in the correct position on the machine. No force is required to be generated by the leg as the motion will be performed by the external force that comes from the pneumatic cylinder. The value of the force registered along the passive mode of motion has been recorded. This is done to know the magnitude of force that is contributed purely by the weight of the leg to the system.

3.4 Measurement of the Force of the Non-Paretic Leg

The force of the non-paretic leg is measured using the same program as the assistive mode of motion. However, the patient is required to exert the pushing force on the non-paretic leg when the cylinder is at rest in the retraction mode. All the forces which have been registered at each retraction state of the cylinder will be recorded.

3.5 Measurement of the Force of the Paretic Leg in the Resistive Mode of Motion

Resistive mode of exercise is performed in the similar way as the measurement of force on the non-paretic limb. The patient is requested to exert pushing force on the paretic leg when the system is at rest in retraction mode. The difference in the resistive mode of motion is that there exists an interaction between the patient and the rehabilitation machine. The force generated by the paretic limb is required to be equal to or more than the pre-set value in the system in order to allow the cylinder to extend to complete the knee extension of motion. The program will stop if the patient is unable to reach the pre-set force value.

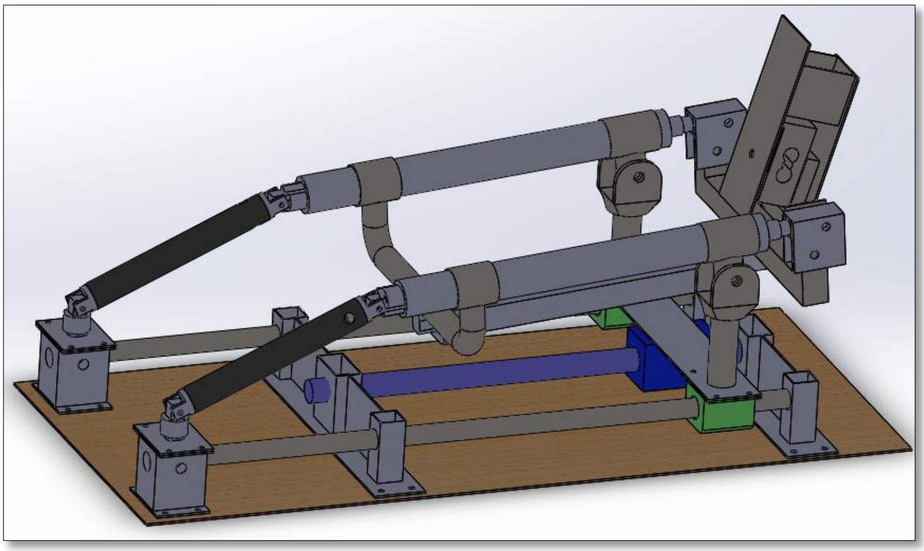
CHAPTER 4 RESULTS AND DISCUSSION

4.1 Control system

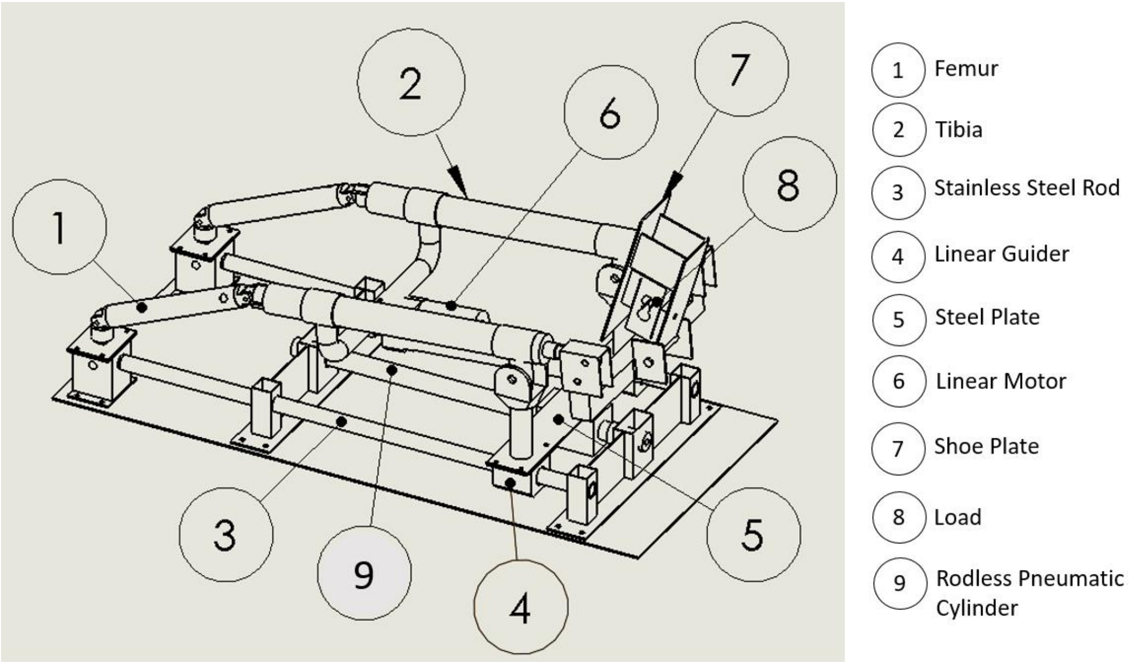
The rehabilitation system is an exoskeleton device. The patient can place the paretic limb on top of the exoskeleton with length adjustable feature in order to optimize the cozy level of the patient. The foot of the patient is tied nicely to ensure the lower limb is in a correct position throughout the whole rehabilitation process. The lower limb of the patient is driven by the force from the pneumatic cylinder when the system is being activated.

The system consists of a pneumatic cylinder as the main force driven actuator, a smaller cylinder for dorsi-plantar motion, a linear motor which involves in length adjustment and a load cell at the end of the foot to record the force that is generated by the lower limb. The femur is fixed in length while the length of tibia can be adjusted. There are two linear guides at the side to allow the smooth movement when the rod-less pneumatic cylinder extend and retract. The rod-less pneumatic cylinder and the two linear guides are connected to each other via a metal plate so that three of them are aligned properly and can move simultaneously.

When the prototype is done, the angular displacement of the knee extension and flexion has been measured using the inertial measurement unit sensor. A graph of force versus angular displacement has been plotted as shown in Figure 3.5. The range of motion is between 0^o to 64^o.



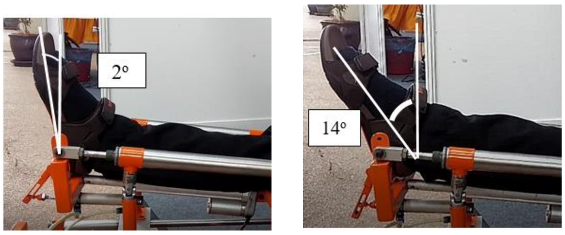
(a) 3D drawing



(b) 2D drawing

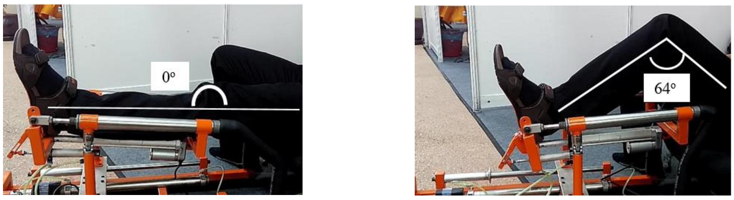
Figure 4.1 Solidworks drawing

Figure 4.2: Photo of the fabricated prototype



(a) Dorsi Flexion (b) Pantar Flexion

Figure 4.3: Dorsi-Plantar Flexion



(a) Hip-Knee Extension (b) Hip-Knee Flexion

Figure 4.4: Hip-Knee Extension-Flexion

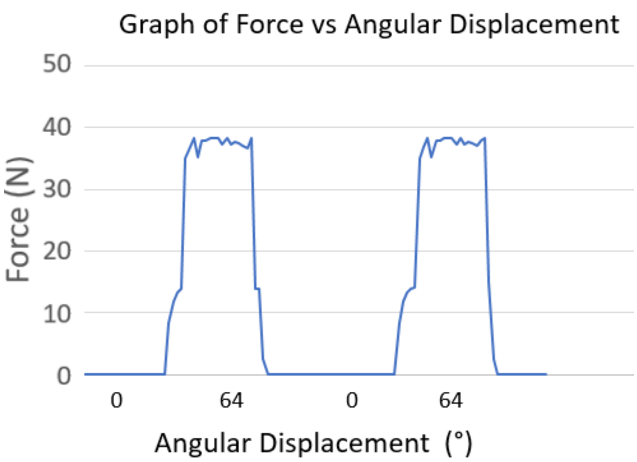


Figure 4.5: Graph of Force versus Angular displacement

4.1.1 Assistive mode of exercise

Assistive mode of exercise is suitable for the early phase of rehabilitation as the force to lift the leg is drive by the pneumatic cylinder.

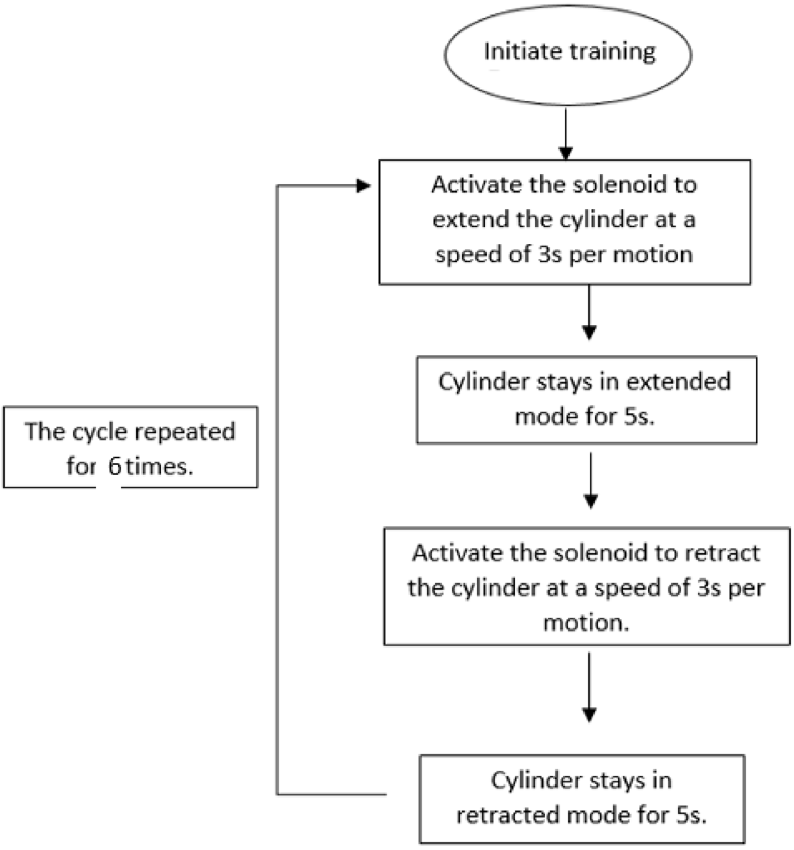


Figure 4.6: Flowchart of assistive mode of exercise

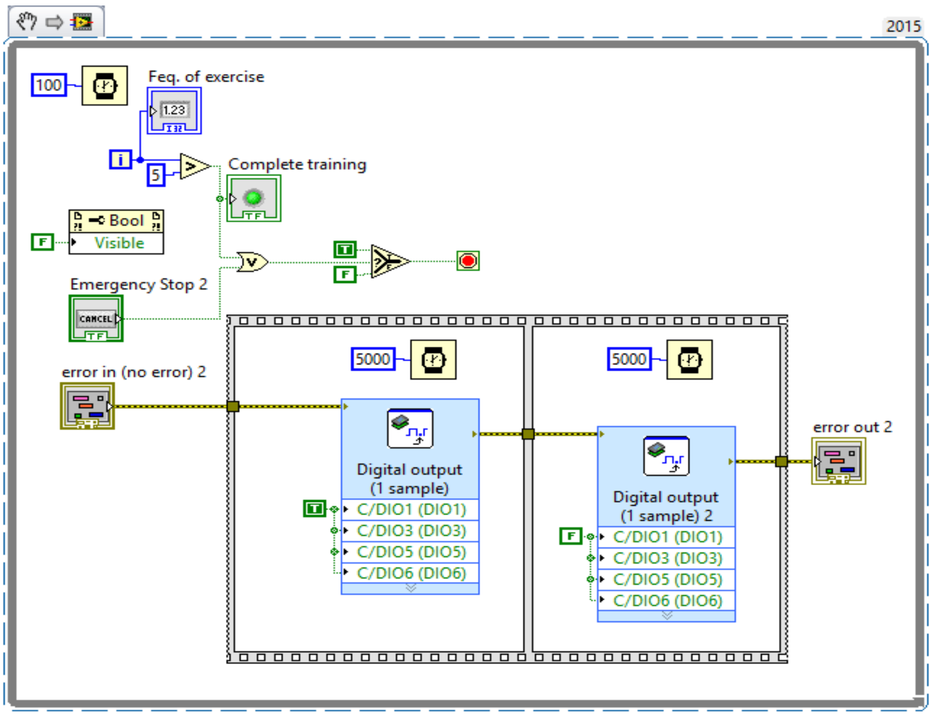


Figure 4.7: Coding on assistive mode of exercise

4.1.2 Active Mode of Exercise

The patient will go through active mode of motion once he has regained some strength. The force applied by the leg will be measured during active mode of exercise.

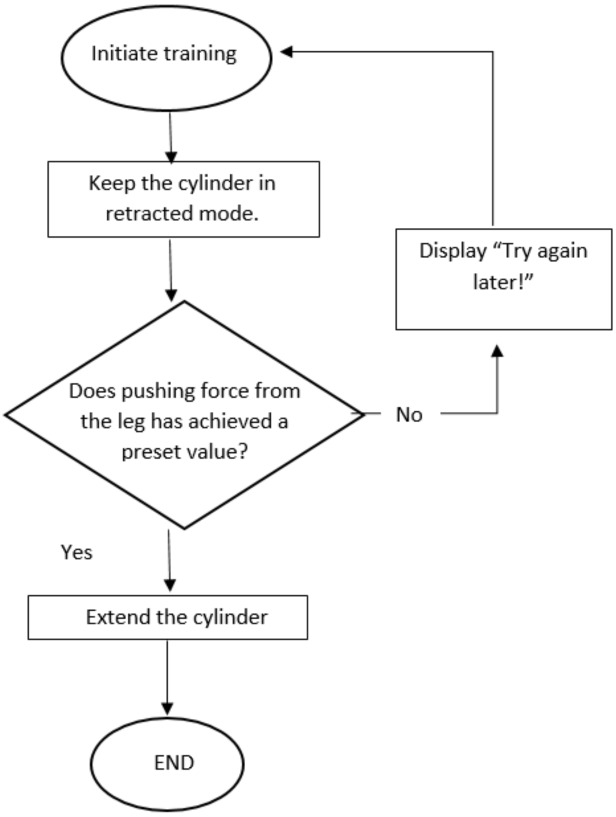


Figure 4.8: Flowchart of active mode of exercise

The cylinder will extend to allow for knee extension of motion if the pushing force from the leg achieve the preset value. The preset force value will increase by 20N each time the user has succesfully achieved the previous preset value. If the user fails to achieve the preset value, the system will display "Try again later" and the system will stop at retraction mode. The user is required to either go back to passive mode of motion or restat the active mode of motion.

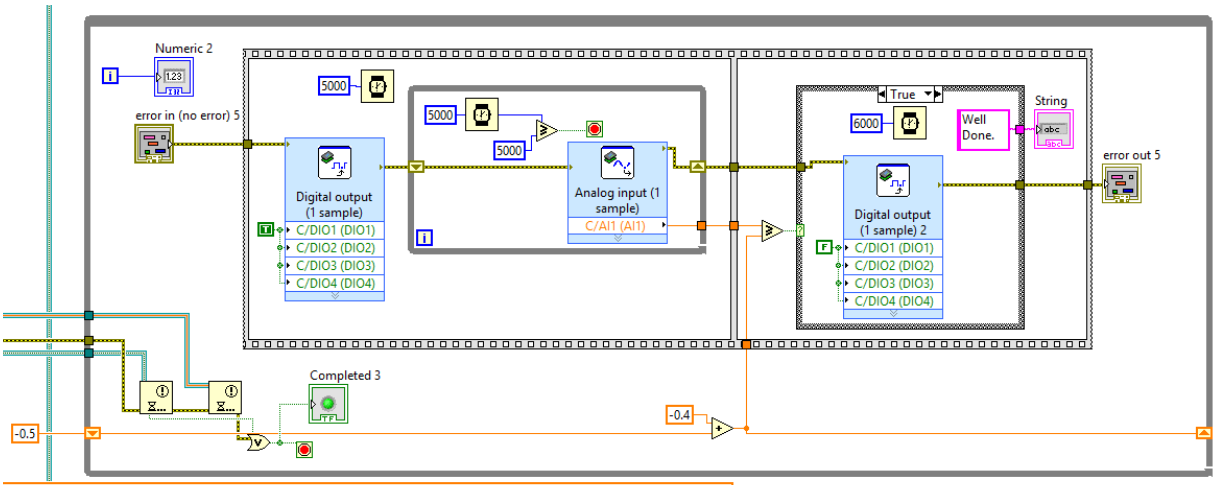


Figure 4.9: Coding on active mode of exercise.

The “Enum” allows the user to choose the number of cycles of exercise to be performed for each set of exercises. The highest number of repetitive cycle of exercise is 20 which will give a preset force value of 425N. This is the highest preset force value in this system.

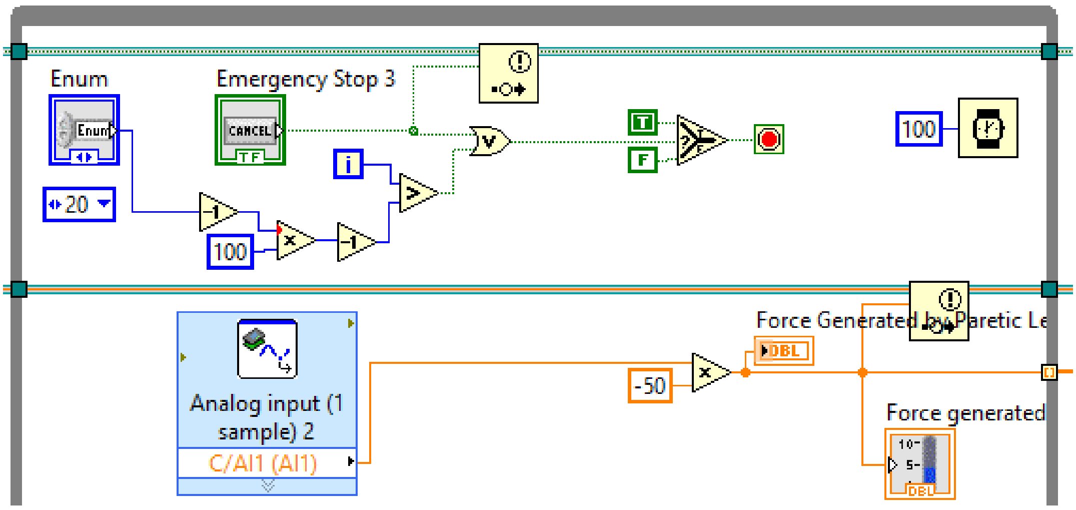


Figure 4.10: Coding shows the user can choose the number of repetitive motions for active mode of exercise.

4.1.3 Data Storing and Data Transfer

The maximum force that can be exerted by the healthy leg of the patient is measured before the patient proceed to the active mode of exercise.

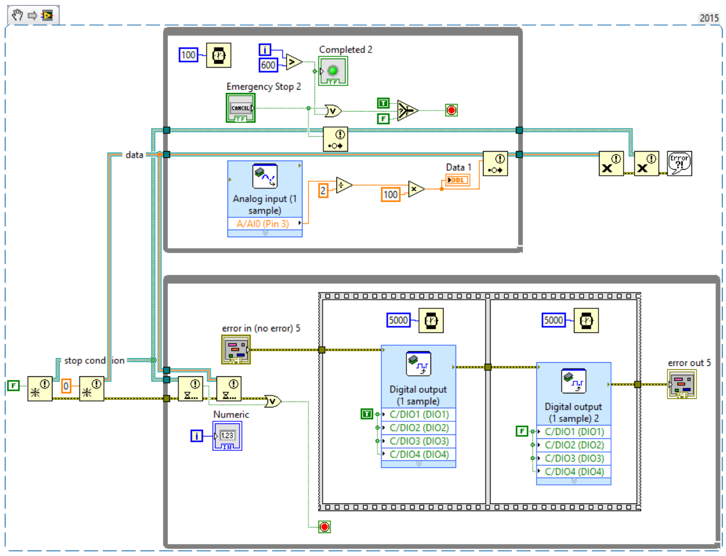


Figure 4.11: Coding on measurement of force of non-paretic leg

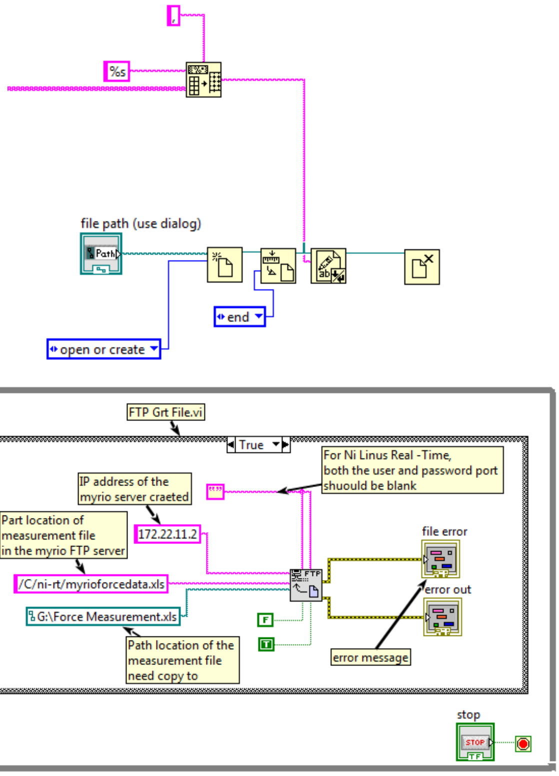


Figure 4.12: Coding on data storage

4.1.4 System Control and Data Display

Ni Data Dashboard is used to connect the myRIO with tablet via server. This allow the user to select the mode of exercise via the button created at the front page inside the tablet. All the data will also display in the same page.

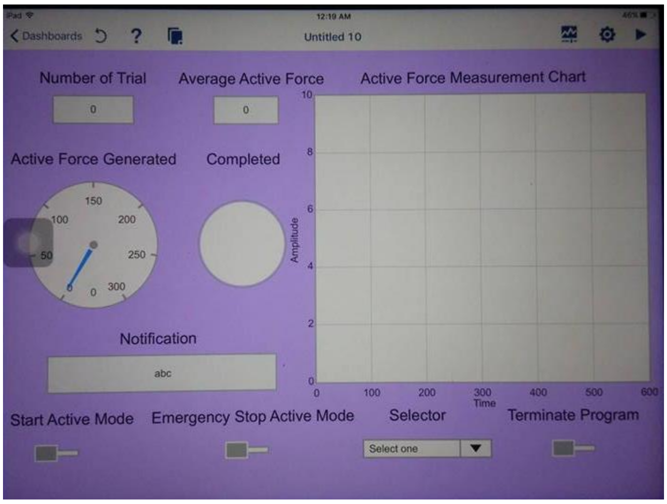


Figure 4.13: Front panel at tablet

4.2 System performance

A simulated condition for both assistive and resistive mode of motions has been carried out by a 45kg-weight person.

The average force acting on the system without placing any load on it during passive mode of exercise is obtained. Figure 4.14 shows that there is always an everage error of 1N acting on the system. The system registers only 0.05N when it is at rest. An average of 2N force is acting on the system at the moment the cylinder starts to move from rest. This force might due to weight of the metal plate together with the shoe that are placed on top of the load cell. The plate will deflect slightly when the system starts to move suddenly due to inertia thus exerting a force on the load cell. The same trend occurs when paretic leg is placed onto the system (Figure 4.15). However, the average force obtained will include the weight of the leg into the system thus giving a higher value.

During healthy leg measuremnt, the same program is being used. The patient will put his/her non-paretic limb to carry out the strength measurement process. The patient will only exert pushing force to extend his/her leg when the cylinder is at retraction mode. From Figure 4.16, an average 120N has been exerted by the leg when the cylinder is in retraction mode. The constant alternating 32N of force is due to the opposing force by the leg of the patient (which is initially in th extension mode) when the cylinder starts to move. No force is recorded when the system is at rest.

In this system, the average force being computed has included all the force registered during the whole rehabilitation process. This is because the period of time where the patient exerts the force is different from one patient to another eventhought the patient should exert force during the 5s buffer when the cylinder is set to be at rest at retraction condition.

Figure 4.17 shows the force generated by paretic leg. The patient is given command to exert pushing force when the cylinder is retracted. The cylinder will extend if the patient is able to achieve the preset value. The initial preset value is 40N. The cycle will be repeated if the patient is able to achieve the preset value and the preset value will increase by 20N each time the patient has successfully overcome the previous preset value. The system will stop in retraction mode when the patient is unable to overcome the preset value.

Figure 4.18 shows the graph comparing both the force exerted by the paretic and non-paretic limbs. The force exerted by the non-paretic limb is used as a baseline strength to indicate the full recovery of the paretic limb. This is because the strength of the lower limb of each person is different form one another. The paretic limb is considered to recover fully once it is able to exert the same magnitude of force as the non-paretic limb. When it is being observed carefully, there is a slight lag off in the graph on force exerted by the paretic limb. This is because the load cell will register the force value at all times but the patient might react differently to the command given by the physiotherapist or care giver depending on the condition and health status of the patient when conducting the rehabilitation process.

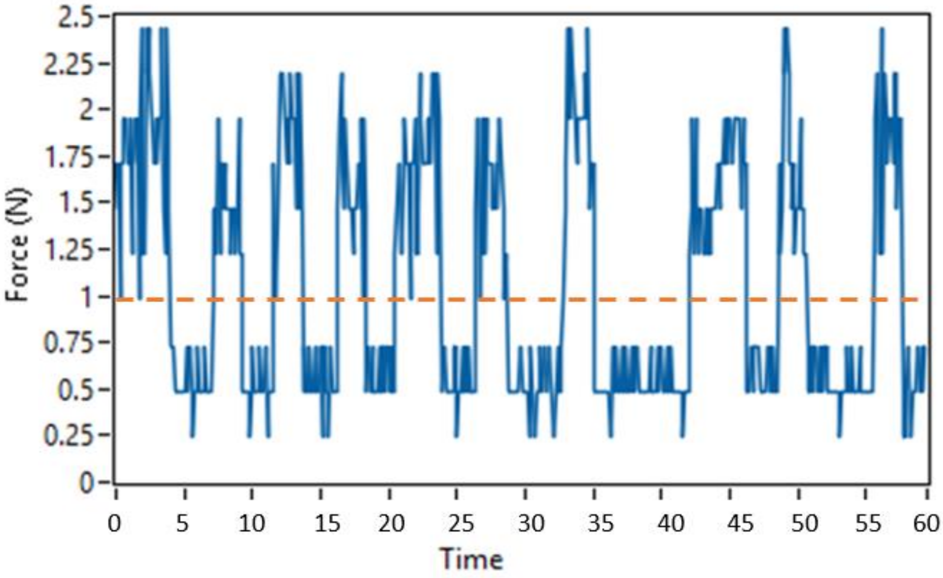


Figure 4.14: Graph without placing any load to the system during passive mode of motion

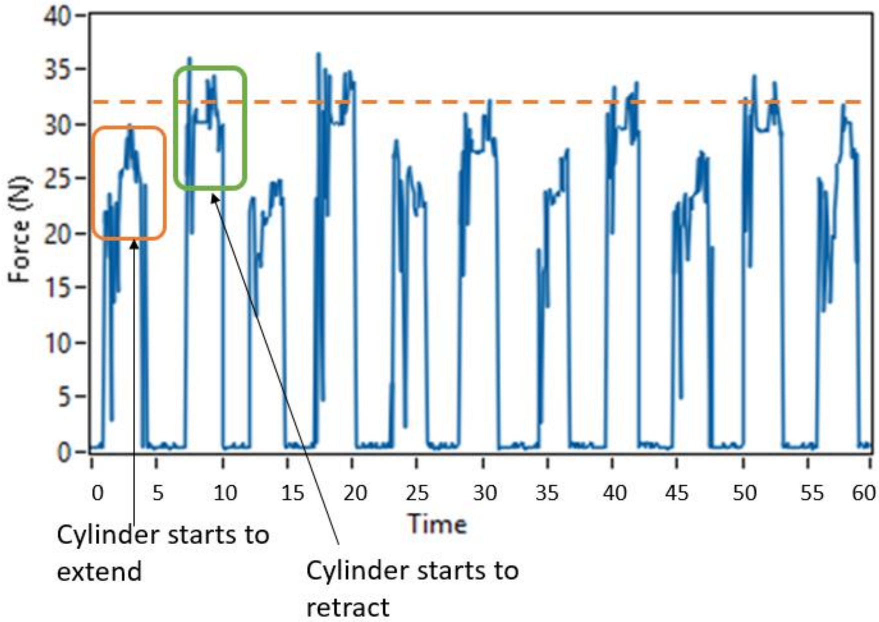


Figure 4.15: Graph of paretic limb during passive mode of motion

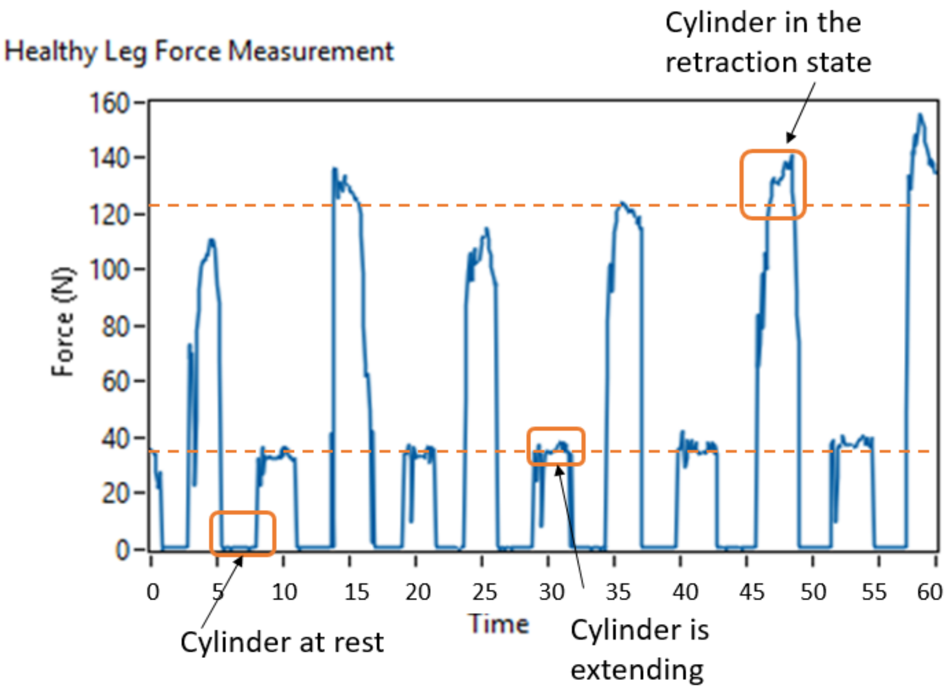


Figure 4.16: Graph of healthy leg measurement

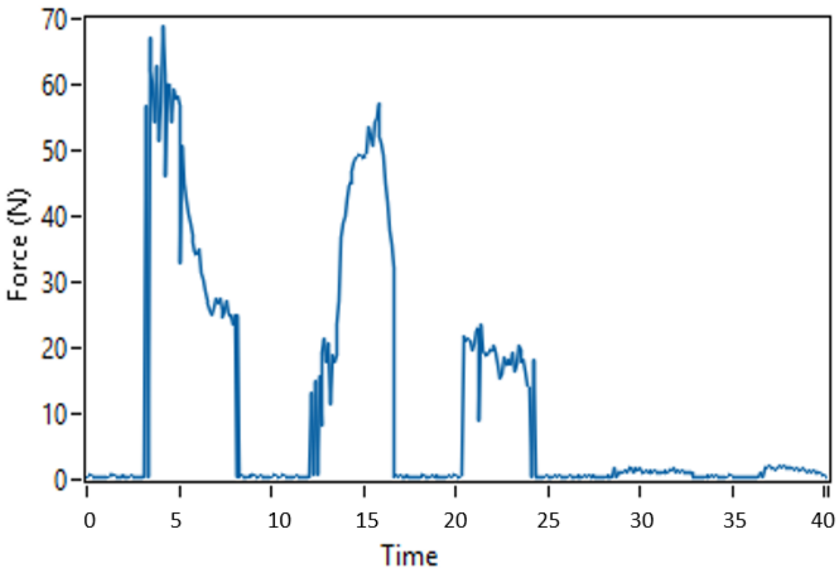


Figure 4.17: Graph of force generated by paretic leg

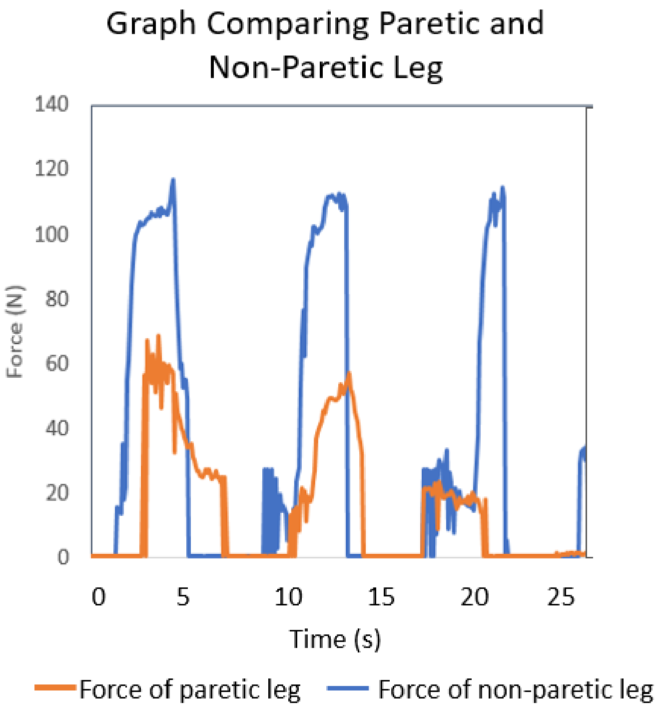


Figure 4.18: Graph Comparing Paretic and Non-Paretic Leg

CHAPTER 5 CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

5.1 Conclusion

1. The lifting index for the physiotherapist when working for the lower limb rehabilitation is found to be larger than 1 which possesses high risk of back pain. It is envisaged that the risk of back injury to the physiotherapist can be lowered by offloading the repetitive motion to the mechanical system developed here.

2. A system for the rehabilitation of the lower limb for the use of patients suffering from stroke or other types of injury or diseases has been developed which can provide continuous passive movement, active movement exercise and also measure the strength of the paretic and non-paretic legs

3. The system provided a passive mode of exercise motion at 6 cycles per minute with 0^o- 64^o of knee extension and flexion of motion. A simulated paretic limb has been carried out by a 45kg weight of person on the passive mode of motion which registered an average value of 35N. The healthy leg measurement simulation gave an average force of 120N. This 120N is used as the baseline strength for the patient at the active mode of motion indicating full recovery of the patient if his/her paretic limb is able to generate this force value.

4. The resistive mode when tested using simulated paretic leg has shown that the system will stop when the patient is unable to achieve the pre-set force value of 40N. The active mode is achieved with the participation of the patient in the exercise.

5.2 Recommendation for future work

- For the next step, we want to further perfecting the prototype and adding the functionality. The pneumatic cylinder will be replaced by the linear motor to reduce the overall cost of the machine and to make the displacement of knee extension and retraction adjustable. The number of different modes of exercise for training the lower limb will be increased and included into the mechanical system. The brain wave of the patient will be measured to determine the effectiveness of recovery rate of the patient by involving the brain in the rehabilitation process.Clinical trial and assessment will be carried out to