Robotic Rehabilitation System in Malaysia

by

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Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

MAY 2012

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the:

Mechanical Engineering Programme

Universiti Teknologi PETRONAS

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Approved by,

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(Mrs. Rosmawati binti Mat Zain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Ajwad Bin Zaidan)

ABSTRACT

The goal of this project entitled Robotic Rehabilitation System in Malaysia is to examine the purpose of robotics to therapeutic procedures for achieving the finest possible motor and functional recovery for persons with impairments following various diseases such as amputations, life-threatening wounds, brain injury, pain management issues, orthopaedics, pulmonary, spinal cord injuries and strokes. Feasibility study and research concerning robotic rehabilitation system are prepared for the development of robotic based rehabilitation system in Malaysia to be fulfilled. However, there are significant research challenges in developing and testing rehabilitation robots so that they meet the requirements of the patients. The technology must be capable of improving person's impaired limbs or part of the body. In addition, robots must be able to understand the complexity of human type of movements. Thus, non-robotic rehabilitation centre can be transformed to a robotic based rehabilitation centre by analysing the possibility of transforming the current practice of rehabilitation programs conducted via physiotherapist to an automated rehabilitation activity by means of robot follows with good evidence on how robots might enhance the delivery of robotic rehabilitation to people of all ages.

ACKNOWLEDGEMENT

First praise is to Allah, the Almighty, on whom ultimately we depend for sustenance and guidance. My deepest gratitude is dedicated to my father and mother for giving me the strength and guidance to recover when my steps faltered. I am also grateful towards my siblings for their encouragement and practical advice. Author would not have been able to complete his final year project.

Second, my sincere appreciation goes to my supervisor, Mrs Rosmawati binti Mat Zain, Lecturer of Mechanical Engineering Department whose guidance, careful reading and constructive comments was valuable. During the project development, author has experienced difficulty in determining the course of action for the whole project to be taken into measure. Her timely and efficient contribution helped me shape this into its final form and I express my sincerest appreciation for her assistance in any way that I may have asked.

My salutation would be incomplete without giving credit to KPJ Tawakal Specialist Hospital which is located at Kuala Lumpur, especially Dr. Munirah Khudri, General Manager and Pn. Siti Suraya Yusa, Physiotherapist Specialist whom have allowed me to accomplish my research. Both respectable people were very generous in providing me information regarding conventional rehabilitation system in Malaysia.

Thank you all for the help in completing my final year project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A robot is a machine capable of acclimatizing to and acting upon its environment thus extending human abilities or replacing them in some activities. It is composed of a mechanical structure made of one or several mechanisms with the capacity to make a movement, translation or rotation, around or along an axis in space. Robotic systems used for rehabilitation are called cooperative or co manipulative because there is physical contact between the robot and the human and that despite exchanges which can take place between the two (J.V.G. Robertson, 2010). Based on this project, statistic pertaining injuries such as amputations, life-threatening wounds, and pain management issues, orthopaedic, pulmonary, spinal cord injuries and strokes must be studied in order to enable the progress on analysing the possibility of transforming the current practice of rehabilitation activity conducted via physiotherapist to a robotic based rehabilitation system.

Based on (SS Ooi, 2005) Malaysia recorded the highest frequency of cervical spinal injuries. Statistics on spinal cord injuries in Malaysia shows that for non-fatal injuries, the incidence of spinal injuries involving fracture of vertebra was 13 out of 226 patients (5.75%). Plus, the number of neck injuries was reported to be 11 out of the 186 cases (5.9%) (Zarir Hafiz Zulkipli, 2009). In addition, the incidence (new spinal cord injuries) is expected to be much higher in our country for example, in the Neurosurgical service in Sarawak General Hospital, there is a case of spine injury every month for patients admitted with head injury (Wong, 2009).

Stroke is the third largest cause of death in Malaysia after heart disease and cancer. More often than not stroke does not kill. It results in disabilities that affects a person's ability to continue working or living a normal life (Dr Tai Keen Sang, 2011). In Malaysia, six new cases of stroke are reported each hour, Health Minister Datuk Seri Dr Chua Soi Lek said. For about 52,000 Malaysians suffered from strokes annually although it is the most preventable of all life-threatening health problems (KRISHNAMOORTHY, 2007). Moreover, in 2005, 17 909 stroke victims were admitted into government hospitals alone throughout the country. Of these, 3,245 of them were fatal. By 2020, this figure is expected to exceed 25,000 every year (Ahmad firdaus, 2009).

Amputation is another common type of injuries that can be seen in Malaysia. According to (Department of Orthopaedics, 2008) based on 2 years research in Kelantan from July 2003 to June 2005, there are approximately 200 patients underwent amputation which is a quite a large number of amputee. The reported prevalence of Diabetes Mellitus (DM) in Malaysia was 14% in 2006. It is estimated that 15% to 20% of diabetics will be hospitalized with a foot complication at some point in time during the course of their disease and 12-24% of affected individuals with foot ulcers require amputation (Anwar, 2008). A retrospective review of amputations in Malaysia showed that 66% of all the amputations were DM related. 80% of amputations were below the knee, the majority of the patients less than 60 years old (Yusof M, 2007). Thus, it is undoubtedly shows that large number of injuries specifically spinal cord injuries, amputation and stroke arisen in Malaysia gives burden to Malaysian citizen including elderly people. The increasing number of patients applied for rehabilitation will lead to the insufficient power in terms of physiotherapists and specialist. Thus, the robotic rehabilitation technologies that are being introduced nowadays lead to a new world of possibilities might overcome the problem encountered by us. People will be able to regain the functions that they have lost with the help of rehabilitation robotics.

Amputation (Mafauzy M, 2011)

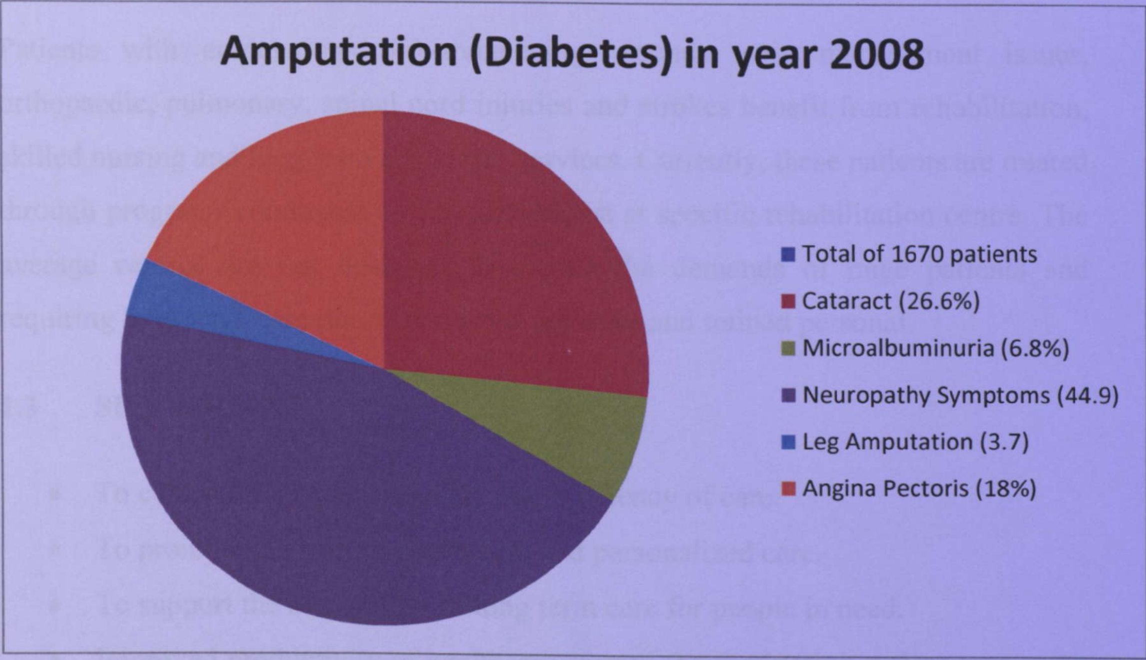


Figure 1 : Statistical data for Amputation due to diabetes in year 2008

Musculoskeletal (Veerapen K, 2007)

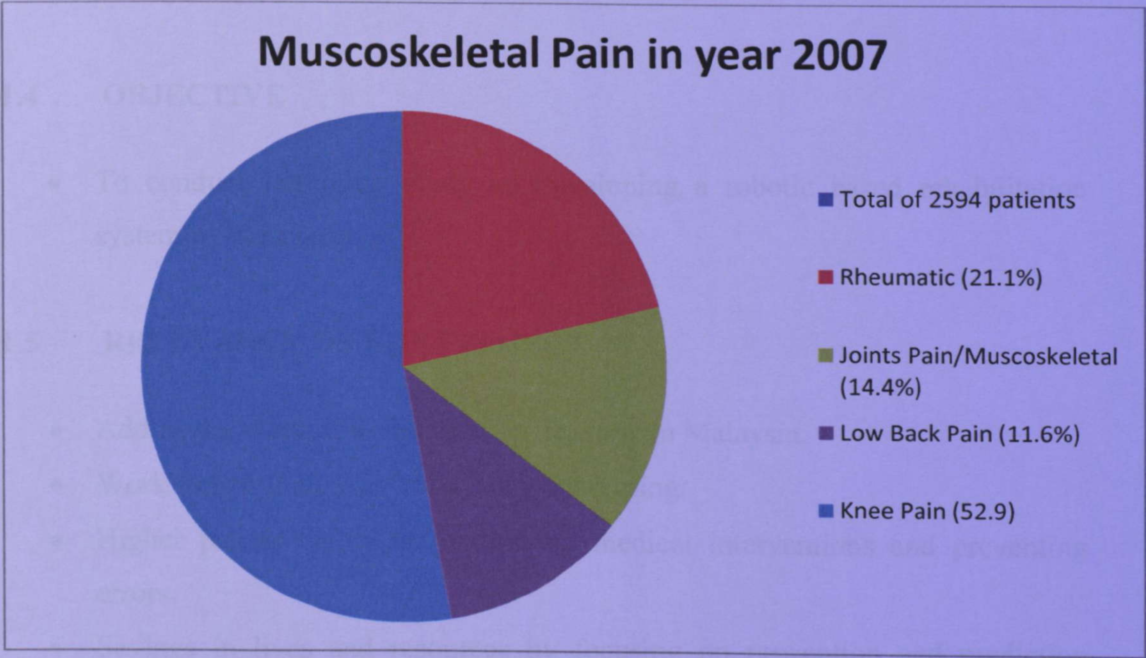


Figure 2 : Statistical data for Musculoskeletal problem in year 2007

1.2 PROBLEM STATEMENT

Patients with amputations, life-threatening wounds, pain management issues, orthopaedic, pulmonary, spinal cord injuries and strokes benefit from rehabilitation, skilled nursing and long term acute care services. Currently, these patients are treated through programs conducted by physiotherapist at specific rehabilitation centre. The average centres are not designed to handle the demands of huge patients and requiring long-term care due to restricted facilities and trained personal.

1.3 SIGNIFICANT

- To contribute to quality, safety and efficiency of care.
- To promote the shift to preventive and personalized care.
- To support the availability of long term care for people in need.
- Improved productivity of healthcare systems by facilitating patient care at the point of need.
- Continuous and more personalised care solutions, addressing the informed and responsible participation of patients, and responding to the needs of elderly people.

1.4 OBJECTIVE

- To conduct feasibility study on developing a robotic based rehabilitation system in Malaysia.

1.5 RELEVANCY OF THE PROJECT

- Add new system of Rehabilitation Therapy in Malaysia.
- Work Rehabilitation in Malaysia is increasing.
- Higher patient safety by optimising medical interventions and preventing errors.
- Savings in lives and resources by focusing on prevention and prediction rather than on costly medical interventions after symptoms and diseases have developed.

1.6 FEASIBILITY OF THE PROJECT

The project will be carried out in two semesters consisting of FYP I (Final Year Project I) and FYP II (Final Year Project II). The objective is to conduct a viability study and a lot of research pertaining articles or journals with related contents.

FYP 1 period

- Review of literature on related topic based on technical papers and journals.
- Survey and site visit.
- To acquire statistic on visited rehabilitation centre.

FYP 2 period

- Propose layout design for robotic based rehabilitation centre in Malaysia.
- Propose budget for robotic based rehabilitation system.
- Cost needed to build robotic rehabilitation based in Malaysia
- Propose technology used in robotic rehabilitation.

CHAPTER 2

LITERATURE REVIEW

2.1 Conventional Rehabilitation System

Rehabilitation system helps individuals distressed by chronic illness and physical impairments to acclimatize to their disabilities, regaining their confident by undergoing physical and metal training by means of physiotherapist. Rehabilitation physiotherapist will work to assist disabled patients soon after the onset of a disabling injury or chronic illness. They provide healthcare training based on patients condition and in the case of chronic illness which needs a long-term treatment, they need to provide extra time and work which might lead to distress of tiredness. Plus, with the increasing number of work rehabilitation each year, rehabilitation hospitality needs to as well improve their service quality and efficiency of one's treatment period. Thus, robotic rehabilitation is introduced to lower the burden of traditional physiotherapist to the extent of producing high level of therapeutic service towards patients. Below is the list of current work rehabilitation team.

Work Rehabilitation Team (Chiar, 2011)

1. Case Manager
2. Occupational Therapist
3. Physiotherapist
4. Physician/Surgeon
5. Registered Counsellors
6. Clinical Psychologist
7. Speech Therapist

Work Rehabilitation Flow Chart (Chiar, 2011)

Flow chart is essential in determining the flow of rehabilitation treatment in a healthcare service. Once the patient is subjected into particular rehabilitation activity, the patient will start his healthy life journey towards retrieving their motivation and cure impaired body parts.

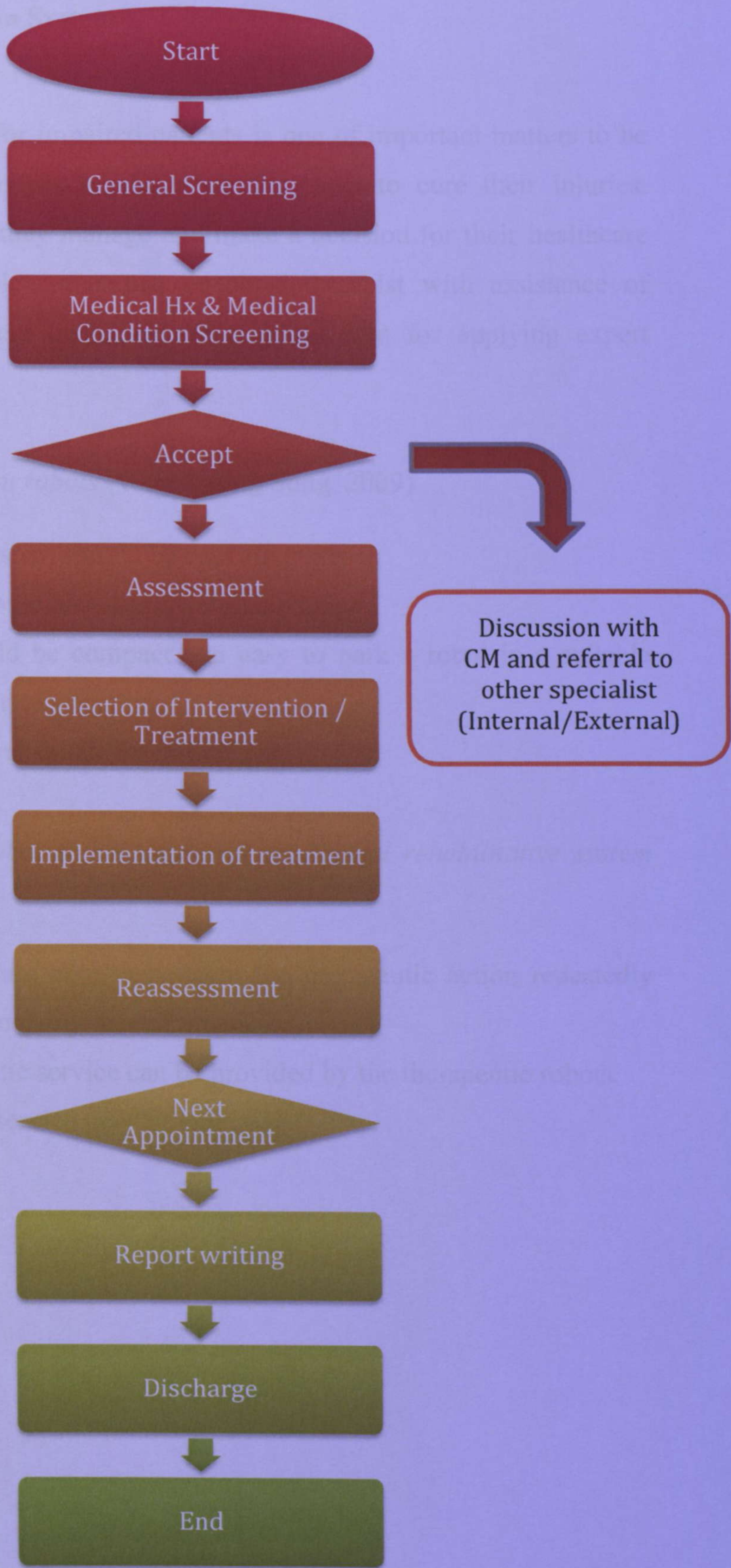


Figure 3 : Work Rehabilitation Flow Chart

2.2 Robotic Rehabilitation System

Improving the quality of life for impaired patients is one of important matters to be looked at. Disabled person needs rehabilitation for them to cure their injuries. However, it depends on how they manage and make a decision for their healthcare training either via normal physiotherapist or physiotherapist with assistance of robots. Rehabilitation treatment decisions are a prime area for applying expert robotic systems (J, 1998).

Requirements for rehabilitation robots (Won-Kyung Song, 2009)

1. The price of robotic system should be cost effective.
2. The robotic system should have light weighted body.
3. The overall size should be compact and easy to park a robot in a suitable location during the unused situation.
4. The energy consumption should be minimized.

Advantages of therapeutic robot technology over traditional rehabilitative system (Won-Kyung Song, 2009)

1. Rehabilitation robots are able to perform the therapeutic action repeatedly and continuously without any fear of tiredness.
2. High level of therapeutic service can be provided by the therapeutic robots.
3. Cost of rehabilitation service may be reduced.

2.2.1 History of Functional Prosthesis (Christopher Frumento, 2010)

The history of rehabilitation engineering can be traced back to the development of functional prosthesis. Functional prosthesis can be considered the backbone of rehabilitation robotics.

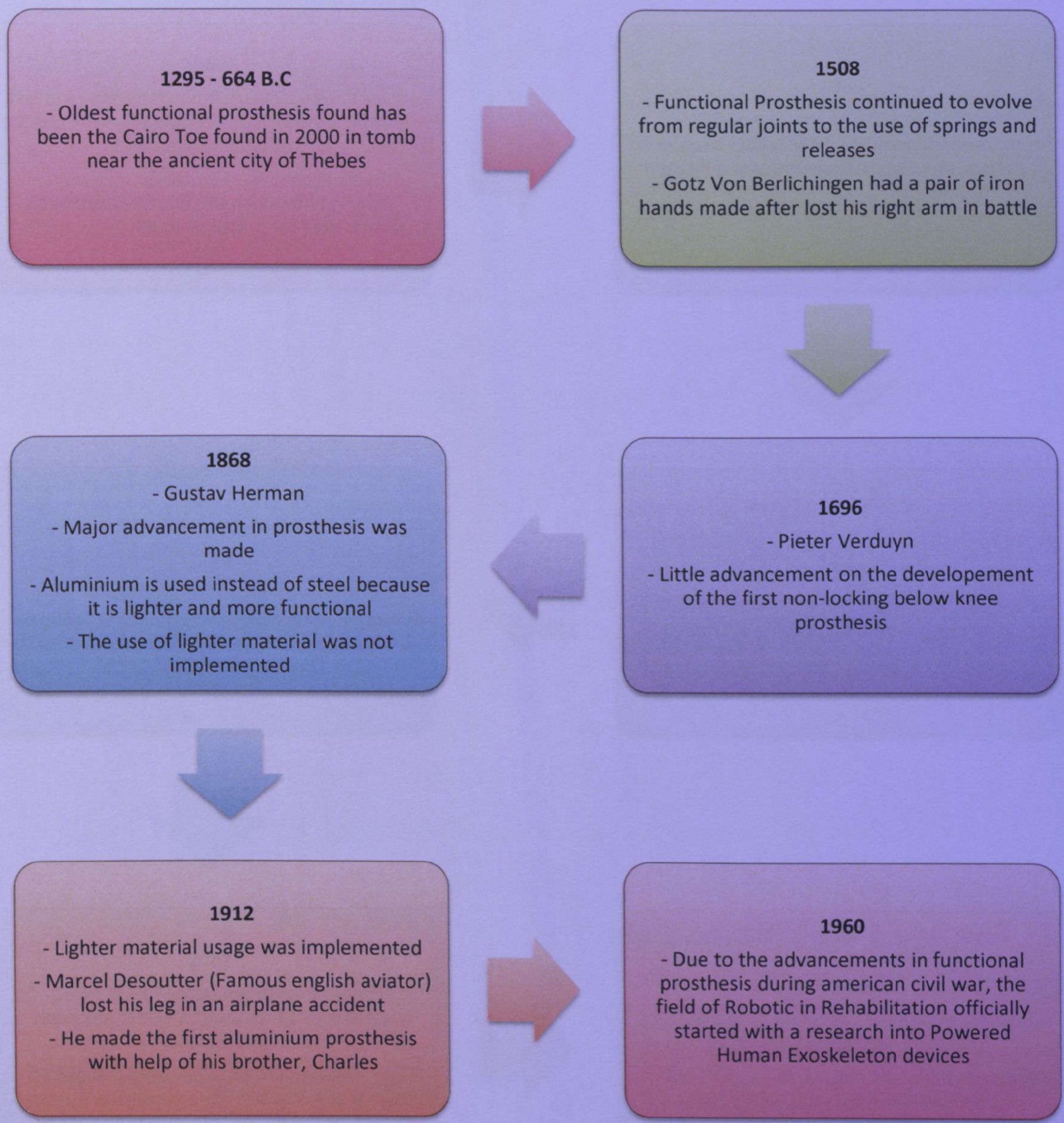


Figure 4 : History of Functional Prosthesis

2.2.2 History of Exoskeleton (Christopher Frumento, 2010)

The field of Robotics in Rehabilitation Engineering officially started with the research into Powered Human Exoskeleton Devices in the 1960s.

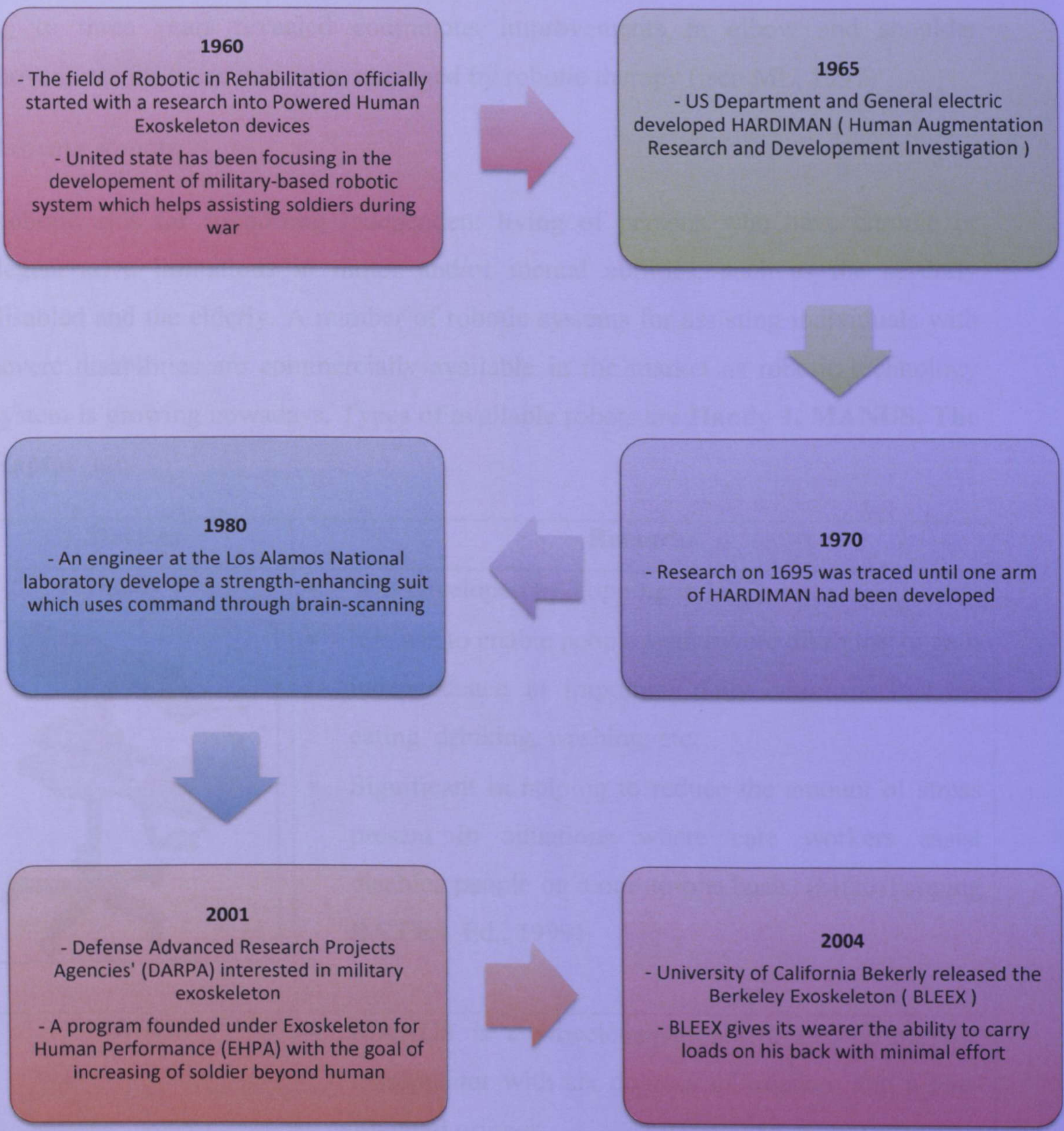


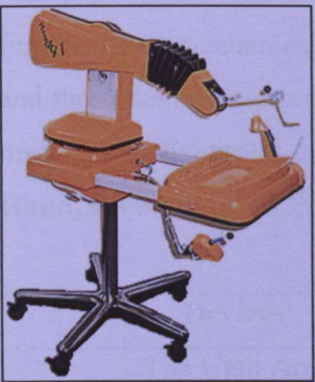
Figure 5 : History of Exoskeleton

2.2.3 Robotic Rehabilitation Treatments

The most far-reaching use of robotic technology in robotic rehabilitation includes **assistive robots, prosthetics, orthotics** and **therapeutic robots**. Numbers of injuries as stated in the problem statement might be inter-related with the types of chosen robots for rehabilitation purposes. In one clinical trial even follow up evaluations for up to three years revealed continuous improvements in elbow and shoulder movements for those who were managed by robotic therapy (isen ML, 1997)

Assistive Robots

Robotic aids for supporting independent living of persons who have chronic or degenerative limitations in motor and/or mental abilities, such as the severely disabled and the elderly. A number of robotic systems for assisting individuals with severe disabilities are commercially available in the market as robotic technology system is growing nowadays. Types of available robots are **Handy 1, MANUS, The Raptor, etc**.

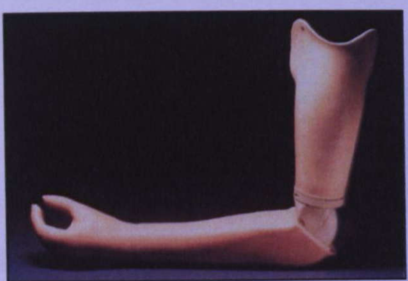
Devices	Remarks
Handy 1 	• Was developed by Topping in 1987. • It is use to enable people with severe disability to gain independence in important daily activities such as eating, drinking, washing, etc. • Significant in helping to reduce the amount of stress present in situations where care workers assist disabled people on a one-to-one basis. (Mike Topping BA Cert. Ed., 1999)
MANUS	• MANUS is a wheelchair-mounted, general-purpose manipulator with six degrees of freedom and a two-fingered gripper. • It allows the gripper to be freely moved and oriented into any direction within the working envelope. • Lifting movement allows the user to position the shoulder joint at different height to retrieve objects.

	(Kwee, 1998)
The Raptor 	• 4-DOF wheelchair-mounted robot that allows individuals with disabilities to feed themselves as well as to grasp unreachable objects. • The user directly controls the arm with either a joystick or a keypad controller. The manipulator cannot be controlled in Cartesian coordinates because it does not have encoders. (Dubey, 2007)

Table 1 : Example of Assistive Robot in Robotics Rehabilitation Technology

Prosthetics

Prosthetics deals with the application of artificial body parts such as artificial hand or finger. It is a mechanical device that is used to replace the missing part of the body and these devices are normally used to provide mobility or handling abilities when a limb is lost. Examples of prosthetics are **The Utah Arm, Two-Fingered Prosthetic Hand, Five-Fingered Prosthetics Hand, Prosthetics Knee, etc.**

Devices	Remarks
The Utah Arm 	• Developed at Motion Control, Inc., U.S.A • Sophisticated prosthesis with new components technology with high strength plastic, simpler electronics and battery pack can last for several days. Recharge in 2 ½ hours. (Harold H. Sears, 1999). • The hand is controlled by using feedback from electromyography (EMG).

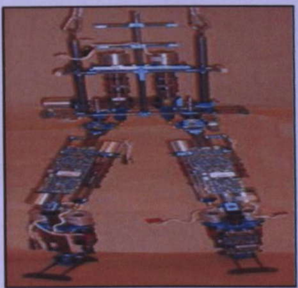
Two-Fingered Prosthetic Hand	• Developed at Motion Control, Inc., U.S.A • The two-fingered prosthetic hand is controlled using myoelectric signals from the remainder limb.
Five-Fingered Prosthetics Hand 	• Developed at the Scuola Superiore Sant'Anna, Italy and Rutgers University. • Robotic prosthetic hand with five fingers and twenty DOF using shape-memory alloy as artificial muscle.
Prosthetics Knee 	• Developed at MIT Leg lab • Allows above-knee amputee to talk and climb stairs with a natural gait process. • Adapting the swing rate of knee based on human gait system.

Table 2 : Example of Prosthetics Devices in Robotics Rehabilitation Technology

Orthotics

An orthotics is a mechanism used to support, align and correct the function of movable parts of the body. For instance, shoe inserts are orthotics that are intended to correct an abnormal or irregular walking pattern, by altering slightly the angles at which the foot strikes a walking or running surface. Most of orthotics utilizes robotic technology as they normally used an exoskeleton as the medium of rehabilitate. For instance **Wrist-Hand Orthosis (WHO)** and **Exoskeleton Arm** may help patient in regaining their impairments.

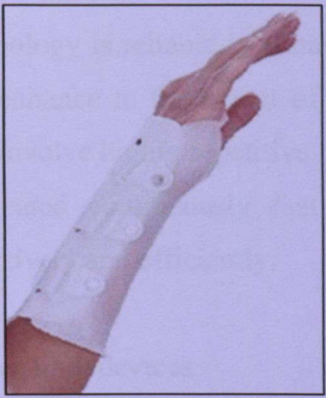
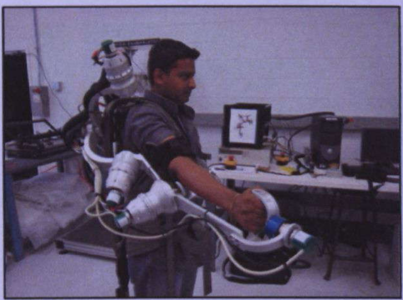
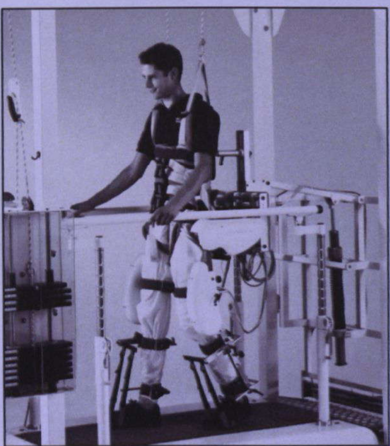
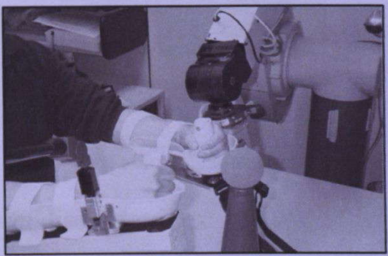
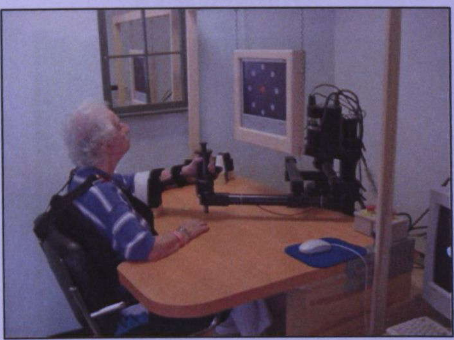
Devices	Remarks
Wrist-Hand Orthosis (WHO) 	• It uses shape memory alloy actuator to provide a grasping function for quadriplegic patient. • It uses a long-life battery pack and graduation of force is possible with its light weight. • An integrated approach is required, considering aspects of mechanical, metallurgical and electrical engineering. (John B. Makaran, 1993)
Exoskeleton Arm 	• Central controller is used to simultaneously move all joints. • The remote center of compliance is any joint-muscle group in the arm being targeted for therapy. • Force-torque sensor is placed at the wrist or hand and additional force sensor emplace is needed for better movement sensing. (Craig R. Carignan, 2008)
Lokomat 	• Orthosis with actuated hip and knee joints. • The structure is fixed to the treadmill by a four-bar linkage for stabilization. • It is performed with a fixed gait pattern for the ease of users. (Sa˘so Jezernik, 2004)

Table 3 : Example of Orthotics Devices in Robotics Rehabilitation Technology

Therapeutic Robots

Robots have the capabilities to be respected tools for rehabilitation therapy. Robotic technology is reliable in enhancing the traditional way of treatment. The reason is it can enhance to the extent of precise and consistent therapy especially in therapies that involve highly repetitive movement training. Data collection of therapeutic robot is treated continuously that can be used to measure progress of the patients effectively and efficiently.

Upper-limb devices

Devices	**Remarks**
MIME (Mirror-Image Motion Enabler) 	• Clinical trials at Stanford University and by the Veterans Affairs Palo Alto Health Care System. • It uses a 6-DOF PUMA 560 robot to interact with the impaired arm. • The system can operate in three unilateral modes and one bilateral mode.
MIT-MANUS (Interactive Motion Technology) 	• Developed at Burke Medical Research Institute • Computer-based training or rehabilitation. • Specific training and task from moderate to severe. It demonstrates positive benefits with 250 stroke patients. • This recovery is most pronounced in the trained muscle groups and limb segments. (Hermano I Krebs, 2004)
ARM Guide	• Developed at University of California • Consists of hand piece that is attached to a linear track and actuated by a DC servomotor.

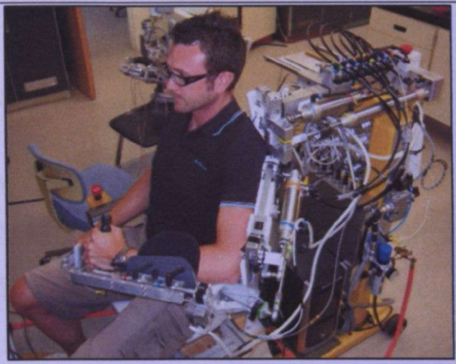
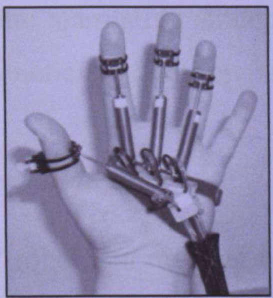
	• ARM Guide can be used to directly test the role of movement practice versus robotic forces in rehabilitate patients with chronic stroke. (Leonard E. Kahn, Peter S. Lum, W.Zev Rymer, & David J. Reinkensmeyer, Sept 2006)
RMII (Rutgers Master II-ND) 	• Glove position sensing/force feedback structure. • Provide smooth hand movements. • The shape is design comfortably behind the middle line of the palm. • Three sensing joints and five degrees of freedom (DOF). (Mourad Bouzit, June 2002)

Table 4 : Example of Upper-limb Devices in Robotics Rehabilitation Technology

Lower-limb devices

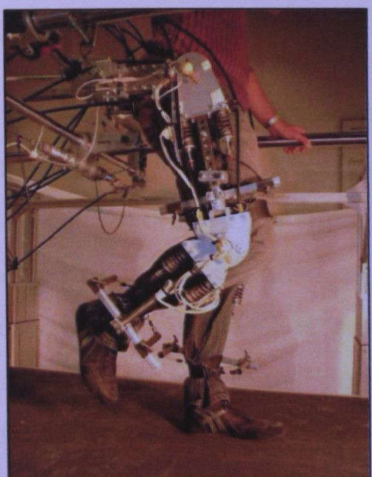
Devices	Remarks
LOPES (Lower Extremity Powered Exoskeleton) 	• Implemented for gait rehabilitation by using a treadmill training system. • Designed to offer assistance in leg movements while keeping lateral balance. • Two(2) operation modes: 1. The patient in charge mode. 2. Robot in charge mode. (Christopher Frumento, 2010, p. 19)

Table 5 : Example of Lower-limb Device in Robotics Rehabilitation Technology

2.2.4 Operating Systems

Brain-Computer interface

A brain–computer interface (BCI) is normally called a mind-machine interface (MMI), or sometimes called a direct neural interface or a brain–machine interface (BMI). It can provide a direct communication pathway between the brain and an external device. BCIs are often directed at assisting, augmenting, or repairing human cognitive or sensory-motor functions. For instance, neurorehabilitation is currently finding the alternative strategies by decoding of motor imagery with BCI and has shown beneficial effects on patients with stroke recovery rate. (E. Buch, 2008)

MRI compatible robots

An MRI robot is a medical robot capable of operating within a magnetic resonance imaging (MRI) scanner for the purpose of performing or assisting in image-guided interventions (IGI).

IGI interventions are commonly performed manually by physicians operating instruments such as needle based on medical images, in most medical field and in the interventional radiology specialty. IGI robots help manipulating the instrument or provide guidance for image-navigation. (Wikipedia, MRI Robot, retrieved on 25 April 2012)

EMG controls

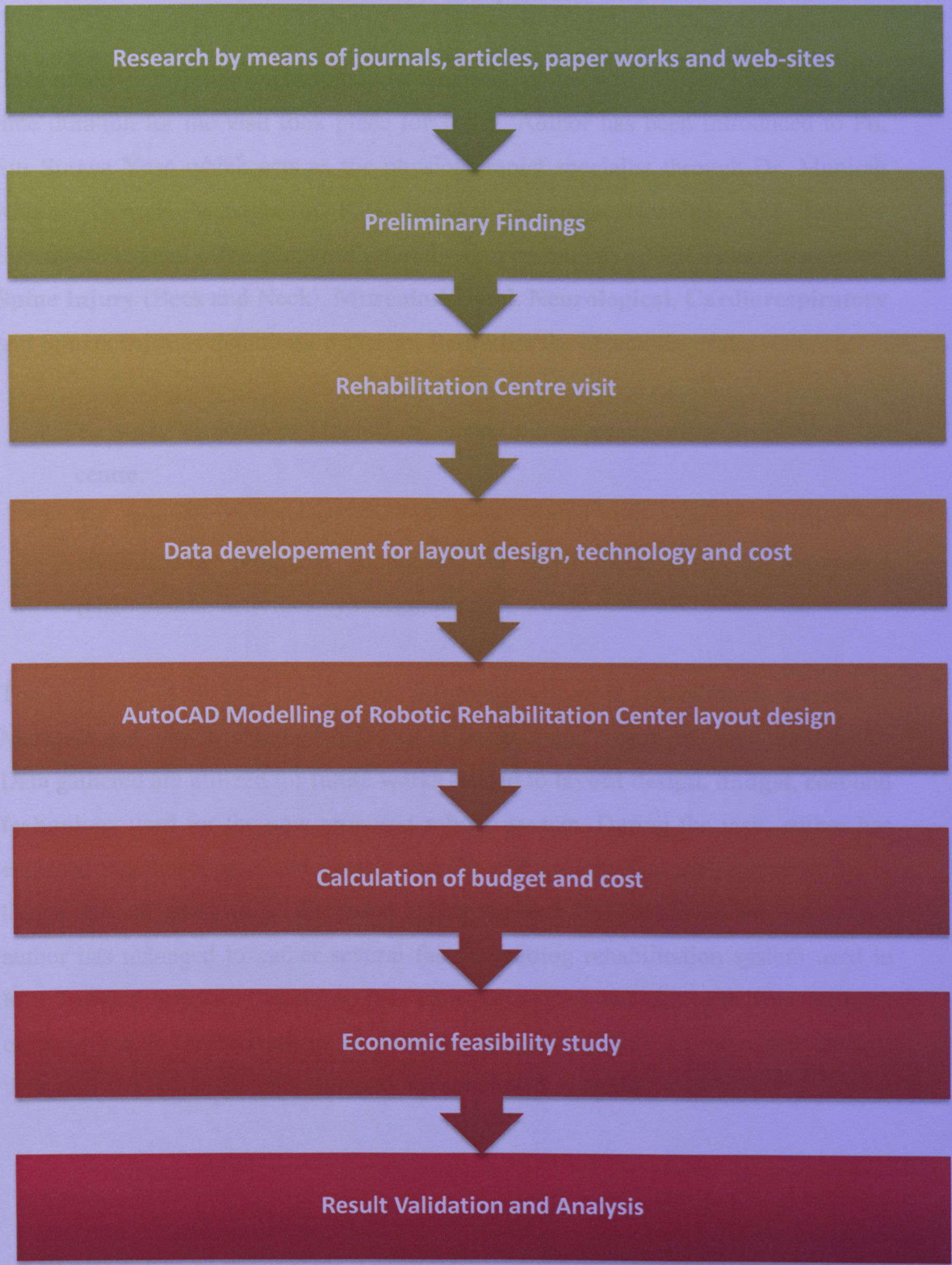
EMG records and measures the electric activity in muscles at rest and during contraction. Nerve is used as means for conduction to occur and it is proven that nerves can send electrical signal pretty fast. Nerves control the muscles in the body by electrical signals known as impulses where it makes the muscles to react in specific ways. An EMG is read by inserting a needle through the skin into the muscles and the needle will detect electrical activity sent to it. In addition, it is very useful in creating robotic prosthetics. While, the EMGs used on the exoskeleton are read by multiple sensors that detect when electrical current is being transmitted (Christopher Frumento, 2010). Thus, the usefulness of EMG in robotic rehabilitation must be recognized as it is essential to the system.

Wii-habilitation

Wii-habilitation therapy is a developing trend with doctors and physical therapists by using the popular Nintendo Wii games as a method of rehabilitation for their patients. Wii-habilitation can provide effective muscle movement where it is almost the same as exercising via games console. Patients are likely to play games rather than attending normal work rehabilitation. The added level of competition that comes with the Wii games encourages patients to push themselves farther without the fear of tiredness. Thus, it might lead to fastest injuries recovery as it takes less time. Patients are motivated by the games and see the benefits right away. Games such as Guitar Hero, golf, tennis, boxing and bowling are among the most popular games used for Wii-habilitation. (Wiihabilitation, retrieved on 25 April 2012)

CHAPTER 3

METHODOLOGY



3.1 Rehabilitation Centre Visit

3.1.1 KPJ Tawakal Rehabilitation Specialist Hospital Visit

Conventional rehabilitation hospital visit has been done on the 19th of June 2012. The time duration for the visit took place for 1 day. Author has been introduced to Pn. Siti Suraya Yusa which acts as the physiotherapist specialist through Dr. Munirah Khudri, General Manager of KPJ Tawakal Specialist Hospital. KPJ Tawakal Specialist Hospital offers plenty of rehabilitation treatments which include **Amputee**, **Spine Injury** (Beck and Neck), **Musculoskeletal**, **Neurological**, **Cardiorespiratory** and **Sports Injury** rehabilitation system. Below are the objectives of the visit.

1. To study the current practise of rehabilitation arrangement installed at the centre.
2. To analyse the possibility of transforming the current practice of rehabilitation programs conducted via physiotherapist to an automated rehabilitation activities by means of robot.

The relevancy of the visit is to acquire information of work rehabilitation services in Malaysia and also to obtained statistics of patients and treatments they applied for. Data gathered are utilized for future works related to **layout design**, **budget**, **cost** and **technology** used for the new proposed robotic system. During the visit, author has enclosed together a proposed agenda and list of questions that are representative of things that are going to be discussed during the visit. As the discussion went well, author has managed to gather several facts regarding rehabilitation system used in KPJ Tawakal Specialist Hospital. It is their philosophy and aim to deliver the most efficient health care service to all patients and visitors who are interested towards their services. Thus, the data gathered are concluded as below.

Questionnaires

Questionnaires	Remarks		
Availability	**Yes**	**No**	**How many?**
a) Physiotherapist	✓		11
b) Occupational Therapist	✓		1
c) Speech Therapist	✓		1
d) Clinical Psychologist	✓		1
e) Registered Councelors		✓	
f) Physician/Surgeon	✓		Multidisciplinary
g) Case Manager		✓	
Treatments	**Remarks**		
a) Amputee Rehabilitation	Below knee amputee – Due to diabetic Wound Healing – Stump care		
Number of patients :	10 per month		
Age Range :	20 - 50 years old		
Cost :	RM20 - RM50 per session		
b) Spine Injury (Back & Neck)	Disc problem, Postural, Degeneration of spine/disc		
Number of patients :	110 per month		
Age Range :	15 – 80 years old		
Cost :	RM 80 – RM 120 per session		
c) Musculoskeletal Rehabilitation			
Number of patients :	110 per month		
Age Range :	6 – 75 years old		
Cost :	RM 80 – RM 120 per session		
d) Neurological Rehabilitation	Stroke, Parkinson, Guillain-Barre syndrome (GBS), Traumatic Brain Injury (TBI)		
Number of patients :	11 per month		
Age Range :	3 – 80 years old		
Cost :	RM 80 – RM 160 per session		

e) Cardiorespiratory	Lung infection, Asthma, Chronic obstructive pulmonary disease (COPD), Pulmonary tuberculosis (TB)
Number of patients :	70 per month
Age Range :	1 day – 90 years old
Cost :	RM 40 – RM 80 per session
f) Spinal Cord Injury Rehabilitation	Traumatic spine injury (Rarely applied)
Number of patients :	1 per month
Age Range :	15 – 45 years old
Cost :	RM 80 – RM 160 per session
g) Sports Injury Rehabilitation	Anterior Cruciate Ligament (ACL), Posterior Cruciate Ligament (PCL), Meniscus Injury, Pre & Post Surgery Management, Non-Surgical Management.
Number of patients :	100 per month
Age Range :	15 – 50 years old
Cost :	RM 80 – RM 120 per session

Table 6 : Questionnaires prepared for visited hospital (KPJ Tawakal Specialist Hospital)

Rehabilitation hospital has their own policy on how they handle their patients and types of treatment need to be undergone. KPJ Tawakal Specialist Hospital provides applicants with procedures accordingly. Few **additional questionnaires** were answered by the physiotherapist specialist are as listed below.

a) What is the method use for rehabilitation activities?

There are three types of plan treatment provided by the hospital which consists of manual therapy, exercise therapy (active-free, bicycle) and thermal electrotherapeutic modalities (mechanical, heat). Basically, in physiotherapist there are gym and electrical motor system with different rooms (for agitated patients). Patients with the same case will be placed in the same group for peer motivation system approach to easily motivate each other.

b) How is the treatment plan developed?

Basic development of patient's plan of treatment is as shown below. Typically, it is depending on the type of illness undergone by the patients and caters to the patient needs.

1. Initial Assessment – Patients information findings
    - List of problems
    - Patient activity daily living – Examine patient as a whole
    - Goal of treatment
2. Reference form (Qualified for treatments)
    - Preference of treatment from doctors.
    - No preference of treatment from qualified person but possess enough evidence which includes previous attended patients, health status and pass medication history
3. Plan treatment for patient
    - Manual therapy
    - Exercise therapy
    - Thermal electrotherapeutic modalities

c) Are there enough nurses to provide high quality care to every patient?

Not enough therapists in patient point of view. Normally, each patient requires 1 person in charge for their therapeutics session. Therapist handles 2 to 3 patients in a time. According to Pn. Suraya, they are having enough physiotherapist but not for the patients.

d) How is the rehabilitation being finance?

KPJ Tawakal Specialist Hospital prefers self-financing and corporate finance from other companies.

e) Are there special insurance requirements for rehabilitation care?

Insurance coverage for 60 days after the patient has been fully discharged. According to Pn. Suraya, physiotherapist specialist, in Malaysia there is no special insurance requirement to cover the rehabilitation activities as Malaysia is too rigid and strict to their clients compare to United Kingdom, United States, Australia and some other European countries.

Statistic of Patients Applied For Rehabilitation

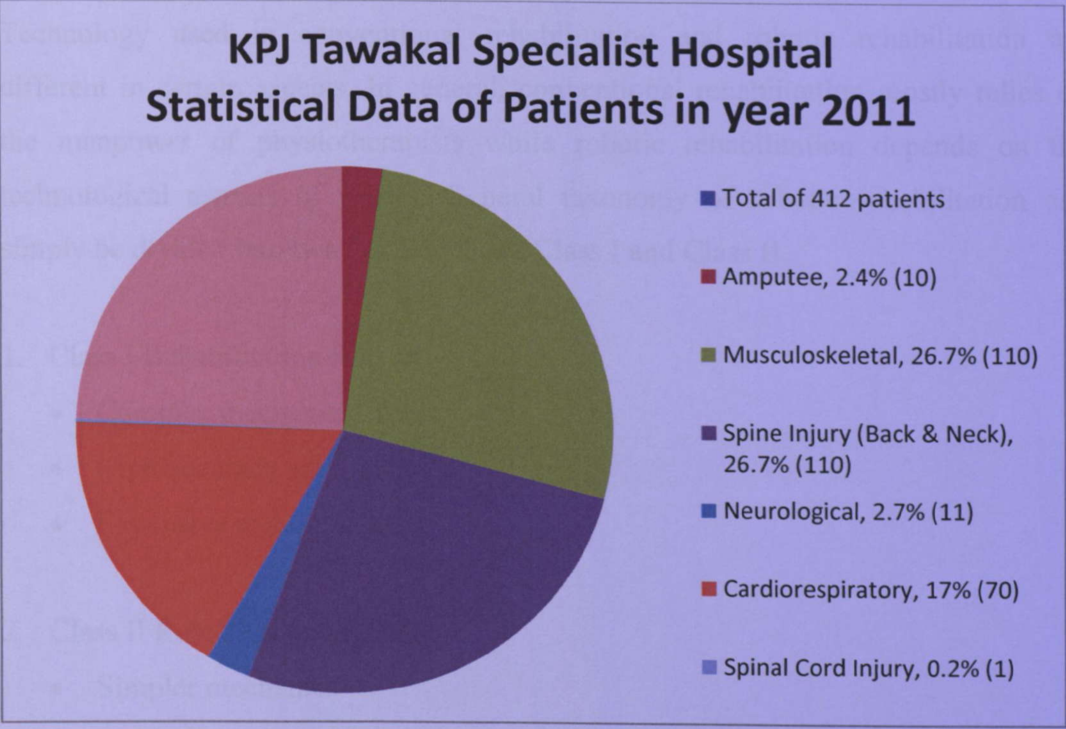


Figure 6 : KPJ Tawakal Specialist Hospital Statistical Data of Patients in year 2011

Above data shows the statistics of patients applied for KPJ Tawakal Rehabilitation treatment in year 2011 which is certified by the physiotherapist department. Muscoskeletal (26.7%) and Spine Injury (26.7) recorded the highest application from patients. The causes of musculoskeletal pain are varied. Muscle tissue can be damaged with the wear and tear of daily activities. Malaysia recorded the highest frequency of cervical spinal injuries (SS Ooi, 2005) where it is fall under spine injury problems. Sport Injury recorded the second highest statistics which is 24.3%. Sports are daily activities that are being conducted by most of the people in Malaysia. Thus, without any doubt the statistics of patient with sport injury is numerically high. Cardiorespiratory (17%) is normally due to lung infection, asthma, chronic obstructive pulmonary disease (COPD) and pulmonary tuberculosis (TB). Although spinal cord injury has the lowest number of applicant which is averagely 1 person per month, a total of 84 patients who have had traumatic Spinal Cord Injury for at least 2 years and were between 15 and 64 years reported to the Malaysian Spinal Injury Association. This shows that spinal cord injury is also one of the major symptoms in health problem.

3.2 Robotic Rehabilitation Technology

Technology used in conventional rehabilitation and robotic rehabilitation are different in certain aspects. In general, conventional rehabilitation mostly relies on the manpower of physiotherapists while robotic rehabilitation depends on the technological aspects of robots. General taxonomy of robotic rehabilitation can simply be divided into two (2), which are Class I and Class II.

1. Class I Rehabilitation Robots
   - Complex mechanics
   - High accuracy and precision
   - Expensive and quite bulky

2. Class II Rehabilitation Robots
   - Simpler mechanics
   - Low\medium accuracy and precision
   - Lightweight, portable systems
   - Low cost

Each robot in robotic rehabilitation industries has their own functional approach and different market price. Apparently, the costs of robots for rehabilitation are expectedly high due to the complex technological aspect of it. Some if the European and United State countries are slowly applying this technology where they have the capabilities of doing it. While in Malaysia, most of the hospital provides its rehabilitation treatments by means of physiotherapist. Robotic technological approach is important to favour an 'industrial revolution' in the rehabilitative scenario by means of methods and tools of bio-engineering combined with automation and robotics technologies. Examples of robots and devices that are being used for rehabilitation activities are as shown below.

3.2.1 Types of Robotic Devices

Robotic rehabilitation devices can be classified into several classes as listed below. Each robotic devices has its own type operating system which is generally consists of Brain Computer interface, MRI compatible robots, EMG controls, Wii-habilitation, Gait Training, Wheel-Chair Mounted Robotic Arm (WMRA), Scanning and pick system, Functional Electrical Simulation (FES) assistance, Force-Feedback system, Virtual Model Control (VMC), etc.

Handy 1

Manufacturer	**Mike Topping from Staffordshire University.**
Description	The Handy 1 is a rehabilitation robot designed to enable people with severe disability to gain or regain independence in important daily living activities such as eating, drinking, washing, shaving, teeth cleaning and applying make-up. (Mike Topping BA Cert. Ed., 1999)
Health Problem	Cerebral Palsy, Motor Neuron Disease, Multiple Sclerosis, Stroke, Elderly and people involved in accidents.
System	Scanning and pick based system.
Price	UK Market (September 1996) **Purchase** = £ 3950.00 = RM 19 392.00 (Ed, 1992)

MANUS (F. Farelo, 2010)

Manufacturer	**Exact dynamics, Netherlands.**
Description	The Manus manipulator arm can be programmed in a manner comparable to industrial robotic manipulators. It has been under development since the mid-1980s and it entered into production in the early 1990s. It is a 6 DOF arm, with servomotors all housed in a cylindrical base.
Health Problem	Neuromuscular Disease, Spinal Cord Injury, Stroke
System	Wheel-Chair Mounted Robotic Arm (WMRA) based system.
Price	**Purchase** = £ 21,000 = RM 103 098.00 (Hillman, 2006)

The Raptor (F. Farelo, 2010)

Manufacturer	Applied Resources, U.S.A
Description	Also called Robots-Agents-People Team: Operation Rescue. This manipulator has four degrees of freedom plus a planar gripper. The user directly controls the arm joints with either a joystick or a 10-button controller. Typically, the joystick that controls the manipulator arm is located on the armrest opposite to the input device that controls the steering of the power wheelchair.
Health Problem	Lower body impairments, Spinal Cord Injury, Elderly, Stroke
System	Wheel-Chair Mounted Robotic Arm (WMRA) based system.
Price	US Market **Purchase** = £ 7500 = RM 36 820.00 (Hillman, 2006)

The Utah Arm (Sears, 2007)

Manufacturer	Motion Control, Inc., U.S.A
Description	Sophisticated prosthesis with new components technology with high strength plastic, simpler electronics and battery pack can last for several days. Recharge in 2 ½ hours. The hand is controlled by using feedback from electromyography (EMG).
Health Problem	Amputation, Sport injury
System	Electromyography (EMG) based system.
Price	**Purchase** = \$8,000 to \$25,000 = RM 25 379.00 to RM 79 312.00 (Collins, 2003)

Five-Fingered Prosthetics Hand (I-Limb)

Manufacturer	Touch Bionics, Scotland
Description	The I-LIMB Hand is the most advanced bionic hand in the market, the hand looks just like a real hand with 4 fingers and a thumb. It utilizes electromyography (EMG) system as the medium to move the prosthetic hand. (Christopher Frumento, 2010)

Health Problem	Amputation, Sport injury
System	Electromyography (EMG) based system.
Price	**Purchase** = $18,000 = RM 57 104.00

Prosthetics Knee

Manufacturer	**JaipurKnee, Joel Sadler and Hasso Plattner Institute of Design, Stanford University**
Description	Knee replacement through a surgical reconstruction. The purpose is to relieve pain and restore joint stability and motion. It allows above-knee amputee to talk and climb stairs with a natural gait process. Plus, adapting the swing rate of knee based on human gait system.
Health Problem	Amputation, Sport injury
System	Electromyography (EMG) based system.
Price	Oil-Filled Nylon Polymer knee joints **Purchase** = $20 = RM 63.00 (Greig, 2009)

Wrist-Hand Orthosis (WHO)

Manufacturer	**American Academy of Orthotists and Prosthetists**
Description	It uses shape memory alloy actuator to provide a grasping function for quadriplegic patient. It also uses a long-life battery pack and graduation of force is possible with its light weight. An integrated approach is required, considering aspects of mechanical, metallurgical and electrical engineering.
Health Problem	Pain management, Neurological disorder
System	Hand Support Braces based system.
Price	**Purchase** = $31.95 = RM 101.00 (Worldwide, 2012)

Exoskeleton Arm

Manufacturer	**A. I. DuPont Hospital for Children**
Description	WREX - Wilmington Robotic Exoskeleton Arm possesses central controller is used to simultaneously move all joints.

	The remote center of compliance is any joint-muscle group in the arm being targeted for therapy. Force-torque sensor is placed at the wrist or hand and additional force sensor emplace is needed for better movement sensing.
Health Problem	Stroke, Neurological and Orthopedic rehabilitation movement.
System	Force-Feedback based system
Price	**Purchase** = $3,995.00 = RM 12,726.00 (Horizons, 2012)

Lokomat

Manufacturer	Hocoma
Description	Known as automated treadmill training. A four-degrees-of-freedom (DOF) robotic orthosis called Lokomat was built to increase the duration of the training and to reduce the effort of the physiotherapists.
Health Problem	Stroke, Spinal Cord Injury, Neurological disorder, Sport injury, Muscoskeletal
System	Gait Training based system
Price	**Purchase** = $250,000.00 = RM 79,376.00 (heathbw, 2010)

MIME

Manufacturer	Rehabilitation Research and Development Centre (RRDC), Stanford University
Description	Known as Mirror-Image Motion Enabler. The MIME system operates in unilateral or bimanual mode. Unilateral mode has 3 modes which are passive, active assisted and active constrained. While, the bimanual mode is where the robot is controlled by the healthy limb to create mirror movements.
Health Problem	Stroke
System	Unilateral and Bilateral 3-dimensional movements based system.
Price	Purchase = $200.00 = RM 636.00 (David J. Reinkensmeyer, 2001)

MIT-MANUS (Interactive Motion Technology)

Manufacturer	Burke Rehabilitation Hospital, White Plains, New York
Description	MIT-MANUS was introduced as a test bed to study the potential of using robots to assist in and quantify the neuro-rehabilitation of motor function. It proved an excellent fit for the rehabilitation of shoulder and elbow of stroke patients with results in clinical trials showing a reduction of impairment in these joints. (Dustin J. Williams, 2011)
Health Problem	Stroke
System	Functional Electrical Simulation (FES) assistance based system.
Price	**Purchase** = $70,000 = RM 222,215.00 (Mann, 2012)

Assisted Rehabilitation and Measurement (ARM) Guide

Manufacturer	University of California at Irvine
Description	A linear robotic trainer, it is found that mechanically assisted reaching improved motor recovery is similar to unassisted reaching practice. It is related to a therapeutic paradigm where subjects will use biofeedback of arm forces to consciously direct their movements towards a desired target until the patients are fully heal. The ARM Guide shows that the system produces quantifiable benefits in the neuro-rehabilitation of stroke patients.
Health Problem	Stroke, Brain injury (impairment)
System	Functional Electrical Simulation (FES) assistance based system.
Price	**Purchase** = $ 80,000.00 = RM 253,960.00 (Pankretz, 2006)

RMII (Rutgers Master II-ND)

Manufacturer	Human-Machine Interface Laboratory at Rutgers University
Description	The Rutgers Master II-ND glove is a haptic interface designed glove which performs position sensing or force feedback structure. It provides smooth hand movements. The shape is design comfortably behind the middle line of the palm and has three sensing joints and five degrees of freedom. The glove provides force feedback up to 16 N each to the thumb, index, middle, and ring fingertips. It uses custom pneumatic actuators arranged in a direct-drive configuration in the palm.
Health Problem	Stroke
System	Force-Feedback based system.
Price	**Purchase** = $ 16,000.00 = RM 50,792.00

LOPES (Lower Extremity Powered Exoskeleton)

Manufacturer	Institute for Biomedical Technology Biomechanical Engineering , Department of Engineering Technology ,University of Twente
Description	LOPES aims for an active role of the patient by selective and partial support of gait functions during robotic treadmill training sessions. Virtual Model Control (VMC) is used as a medium to translate manual treadmill gait rehabilitation into robotic therapy.
Health Problem	Stroke, Sport Injury, Neurological disorder
System	Virtual Model Control (VMC) based system
Price	**Purchase** = $100,000.00 = RM 317,450.00 (Wikipedia, Berkeley Robotics and Human Engineering Laboratory, 2012)

3.3 Robotic Device Systems

Robotic rehabilitation devices provide various advantages towards disabled patients. Current robotic rehabilitation such as MANUS, Prosthetic Hand, Exoskeleton Arm and LOPES offer extra working strength for the patient. Example of robotic devices mechanism and kinematics are shown as below.

3.3.1 Assistive Robotic Device – MANUS (Redwan Alqasemi, 2005)

Kinematic Analysis

Individuals with disabilities are placed inside a workspace which reflects several types of hand-picking movement which consists of:

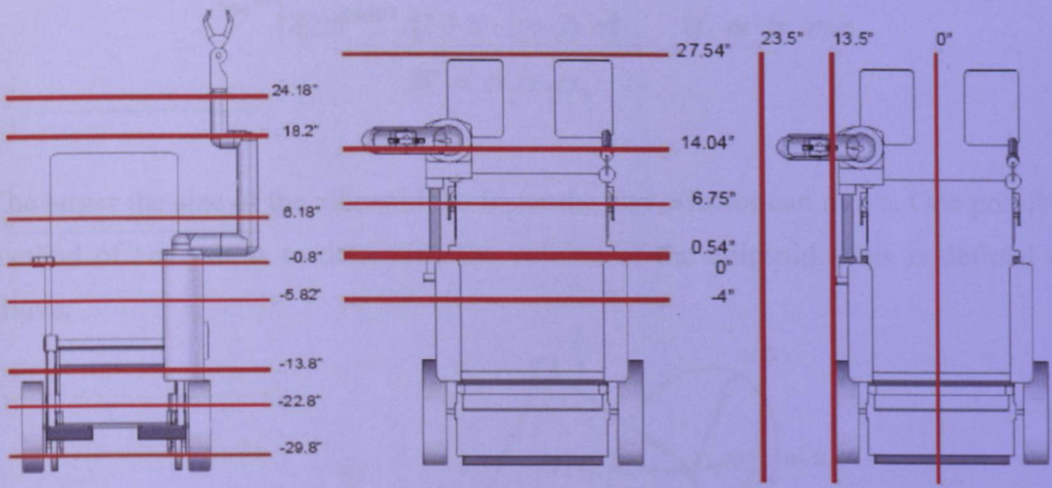


Figure 7 : Workspace (Horizontal and Vertical planes)

Workspace	
Front Movements	**Distance**
Small objects on the floor	-29.8''
Larger light objects on the floor	-22.8''
Height of electric socket	-13.8''
Low coffee table	-5.82''
Height of standard table and door knob	-0.8''
Kitchen counter top	6.18''
Wall-mounted light switch	18.2''
Low shelf above kitchen counter top	24.18''

Table 7 : Workspace distance provided by the MANUS

$$v = J(q)\dot{q}$$

Manipulability ellipsoid is introduced as well as the volume of the ellipsoid as the manipulability measure. The equation above shows manipulability ellipsoid with the determinant of the Jacobian matrix (J) of the positional sub-matrix of the final transformation matrix of the manipulators arm reference frame.

$$\|\dot{q}\| = \sqrt{\left(\dot{q}_1^2 + \dot{q}_2^2 + \dot{q}_3^2\right)}$$

Above equation shows the volume of the manipulability ellipsoid. The equation is obtained by considering the set of all possible joint velocities and the resultant end effector velocities.

$$C_m = \begin{cases} 2\pi^{m/2} / [2 \cdot 4 \cdot 6 \cdots (m-2) \cdot m] & \text{if } m \text{ is odd} \\ 2(2\pi)^{(m-1)/2} / [2 \cdot 3 \cdot 5 \cdots (m-2) \cdot m] & \text{if } m \text{ is eve} \end{cases}$$

$$W = \sigma_1 \sigma_2 \sigma_3$$

The larger the size of the ellipsoid the faster the end effector can move. One possible method of analysis is to determine the volume of the ellipsoid. This is defined as above.

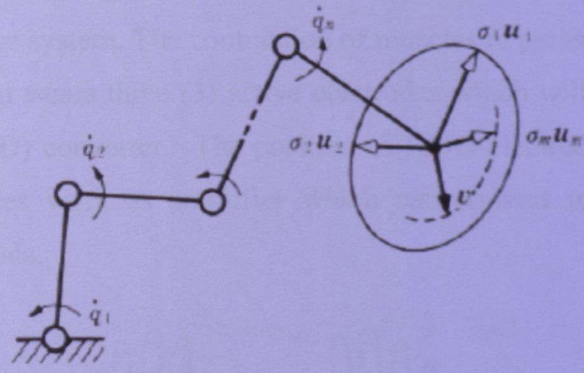


Figure 8 : Manipulability ellepsoid

$$W = |\det J(q)|$$

The manipulability measure, which is the volume of the manipulability ellipsoid, is the determinant of the Jacobian.

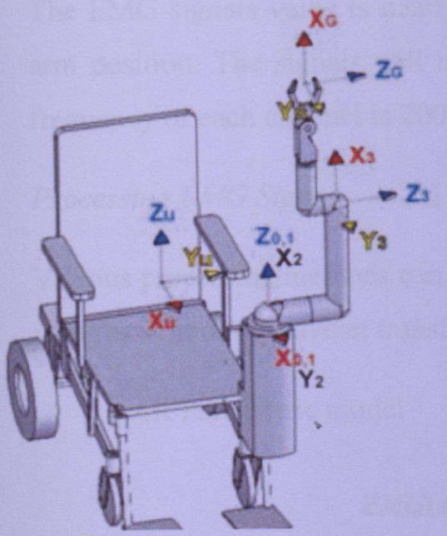


Figure 9 : Reference Frame

The kinematic system of robotic arm is programmed with MatLAB to determine the joint angles of robotic arm in 3-D space. Figure shows the reference frame for the power wheelchair which is MANUS. It is a 3-DOF robotic system which possible to ease patient to move things around and overcome their disabilities.

3.3.2 **Prosthetics Robotic Device** - Five fingered prosthetics hand (Jingdong Zhao, 2006)

Control Algorithms

Electromyography (EMG) signals are used to control and move a prosthetic hand by means of human nerve system. The contraction of muscles in patient forearm leads to finger motion. Patient wears three (3) active electrodes which will be digitalized via analog-to-digital (A/D) converter. The position of EMG electrodes is as shown as below. The electrodes work as amplifier which can convert up to 10000 times stronger electric signals.

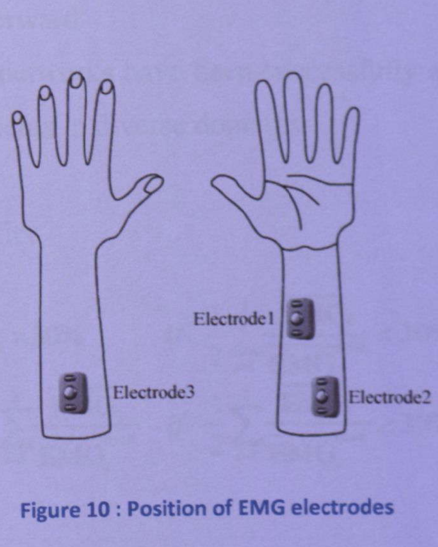


Figure 10 : Position of EMG electrodes

Pre-processing EMG Signals

The EMG signals value is nearly zero and changes in the rage of 0.01V in relaxed arm position. The signals will be sampled by the A/D converter and the sampling frequency of each channel is 2000 Hz.

Processing EMG Signals

Various processing methods can be used to represent EMG signals such as AR parametric model, wavelet transform and integral of EMG signals.

1. AR Parametric model

$$EMG(n) = \sum_{k=1}^{P} A_k EMG(n-k) + e(n)$$

2. Integrals of EMG Signal

$$\overline{\text{EMG}} = \frac{1}{N}\sum_{i=1}^{N}|EMG(i)|$$

3. Wavelet transform

   Wavelet transform is a powerful time-frequency method for non-stationary signal analysis. It can decompose signals into different scales and provide more information in time and frequency domain

Feature Classification

1. Three-layer Feed forward

   Multi-layer neural networks have been successfully applied to some difficult and nonlinear problems in diverse domains.

2. Motor speed classifier

$$Speed = \begin{cases} V_{\max} \times 30\% & if \ \frac{1}{2}\sum_{i=1}^{2}\frac{\overline{\text{EMG}_i}}{\overline{\text{EMG}_i}^{\max}} < 30\% \\ V_{\max} \times \frac{1}{2}\sum_{i=1}^{2}\frac{\overline{\text{EMG}_i}}{\overline{\text{EMG}_i}^{\max}} & if \ \frac{1}{2}\sum_{i=1}^{2}\frac{\overline{\text{EMG}_i}}{\overline{\text{EMG}_i}^{\max}} \geq 30\% \end{cases}$$

*V*max is the maximum speed of the driving motor.

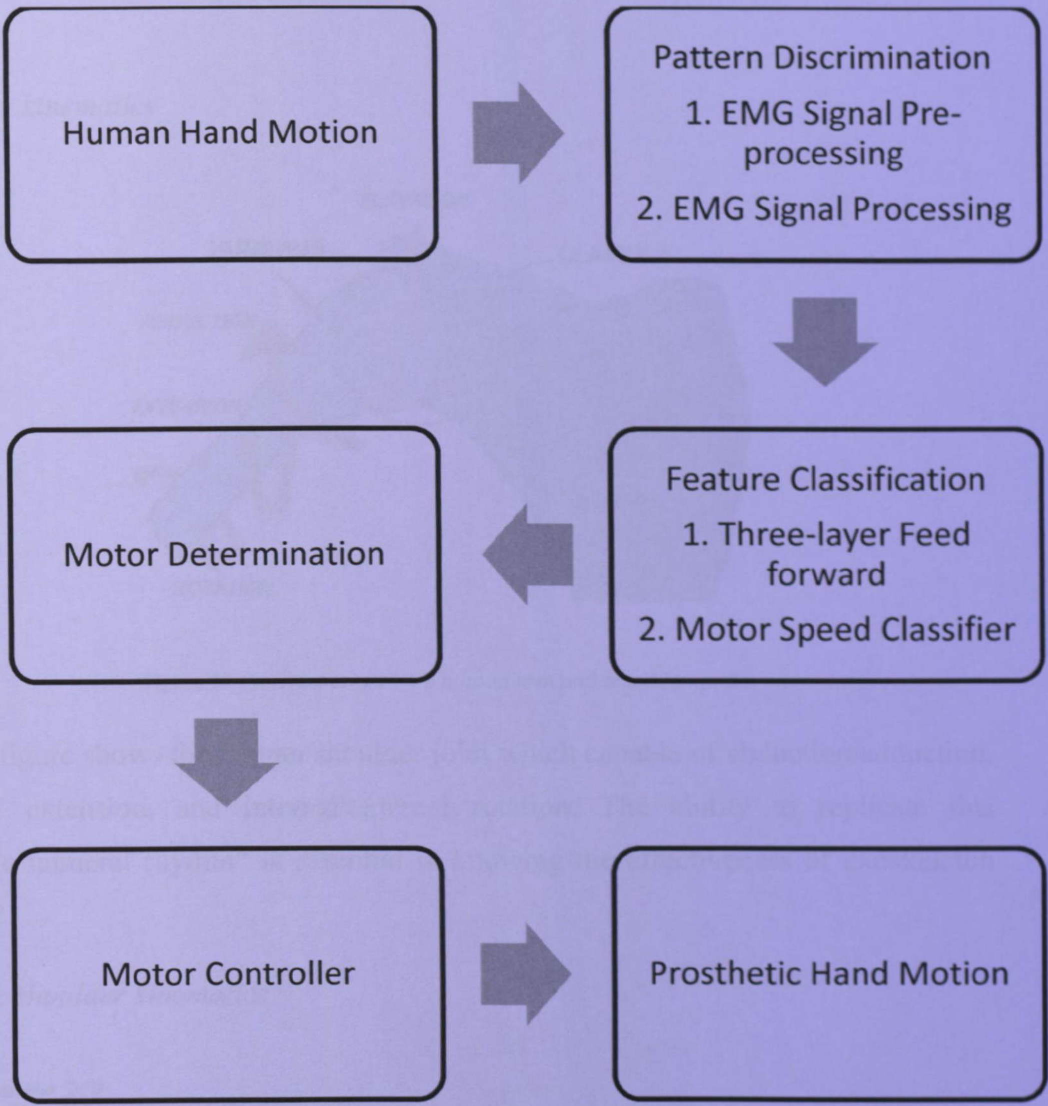


Figure 11 : Prosthetic hand control flow scheme

3.3.3 Orthotics Robotic Device – MGA Exoskeleton Arm (Craig R. Carignan, 2008)

Fundamentally, in most manipulator applications, the remote centre of compliance is located at the tool tip and controlled using force readings from a sensor located in the wrist. Exoskeleton arm applies a force feedback technology which enables patient to only provide a certain amount of work for the robotic device to perform extension works.

Shoulder kinematics

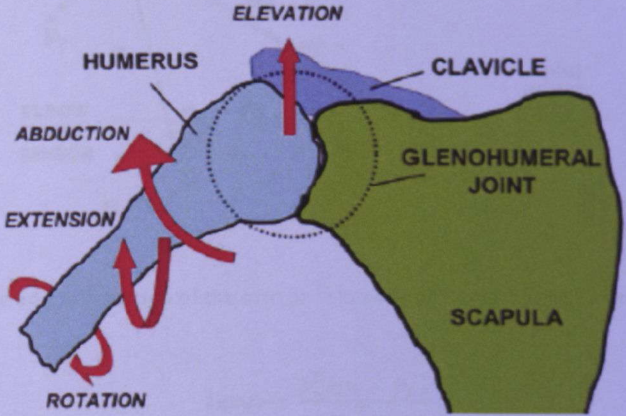


Figure 12 : Movements of the human arm and shoulder girdle

Above figure shows the human shoulder joint which capable of abduction/adduction, flexion/ extension, and internal/external rotation. The ability to replicate this "scapulo-humeral rhythm" is essential in knowing the effectiveness of exoskeleton arm.

Robotic shoulder kinematics

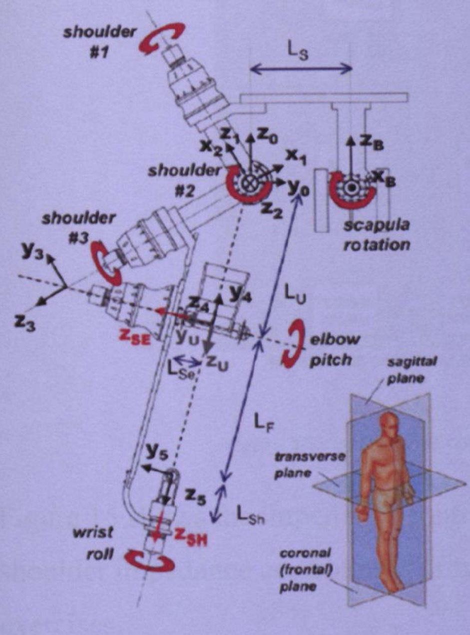


Figure 6 shows the kinematics configuration of the MGA Exoskeleton.

Figure 13 : MGA Exoskeleton link frame

Isolateral exercise control

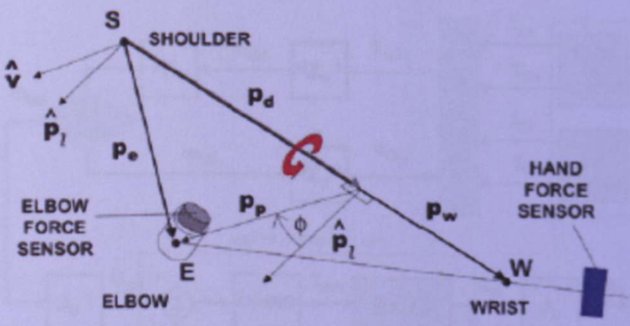


Figure 14 : Self-motion of the arm or "elbow orbit" occurs about a line from

$$tan\phi = \frac{\hat{p}_w^T (p_\ell \times p_P)}{{p_\ell}^T p_P}$$

Let the vectors from the shoulder to the wrist and elbow be defined as pw and pe, respectively, and let ˆv denote an arbitrary fixed unit reference vector in frame 0. The roll angle of the SEW plane or "elbow orbit angle" is defined as the angle between pp and pl.   is calculated by using the forward kinematics to compute pw and pe.

Shoulder impedance module

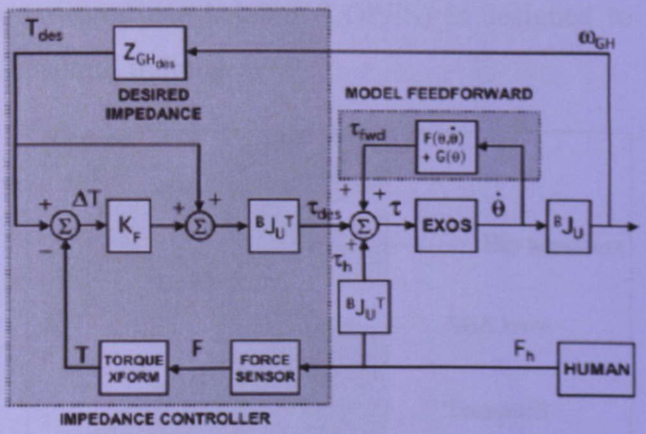


Figure 15 : Impedance controller used for shoulder axis rotation

Figure 15 shows the impedance controller used for shoulder axis rotation. The shoulder impedance controller is primarily used for low resistance shoulder rotation exercises.

Shoulder admittance module

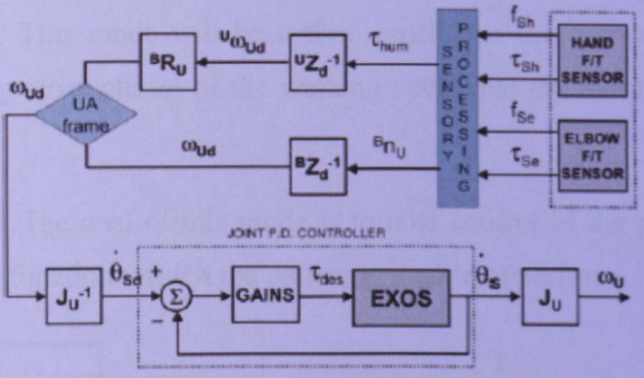


Figure 16 : The admittance controller for the shoulder uses force inputs from

Figure 16 shows the shoulder admittance controller. The elbow and hand force torque sensors are used to derive the humerus and the azimuth-elevation torques. Rotational kinematics was developed for controlling the shoulder joints of an arm exoskeleton for several isolateral exercise protocols.

3.3.4 **Therapeutic Robotic Device** – LOPES

Lower extremity powered exoskeleton (LOPES) is designed to implement a gait rehabilitation for treadmill training.

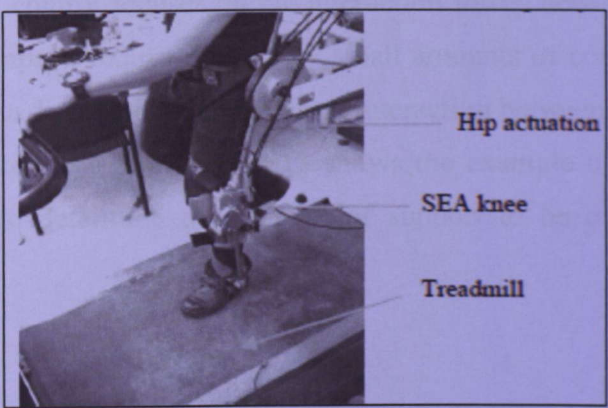


Figure 17 : Current 2 DOF LOPES setup

LOPES aims to support and not take over those tasks that the patient is unable to perform without help using an impedance control scheme. There are two (2) basic control schemes for LOPES consists of patient in charge and robot in charge.

Patient in charge: The goal of the robot is to minimize the interaction forces between the patient and the robot in order for the patient to walk freely without feeling the robot. This mode will be active mostly for the non-paretic side of the patient and during those phases of the walking cycle that the robot does not need to assist.

Robot in charge: The goal of this mode is to take control of the patient. The robot will take over the functions which the patient is unable to perform.

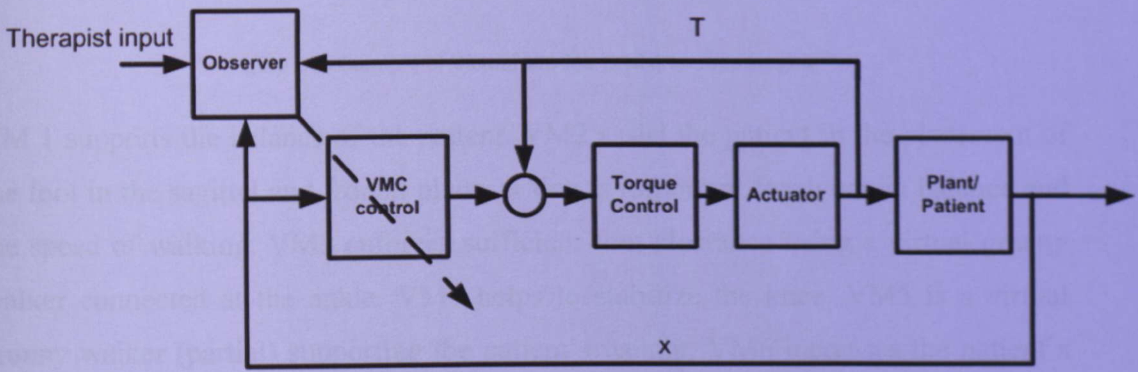


Figure 18 : Control schemes of LOPES

The control of LOPES consists of three (3) levels which are observer, Virtual Model Control (VMC) control and output movement. Observer acts as the decision maker and to determine the current gait phase based on patients need. The second level which is the VMC control focuses on the interaction forces between patient and the robot. VMC is compact, requires relatively small amounts of computation, and can be implemented in a distributed manner. Each interaction between the patient and the therapist is translated to a VM. Figure 12 shows the example of VM mode which enables therapist to determine the amount of support to be offered towards the patient.

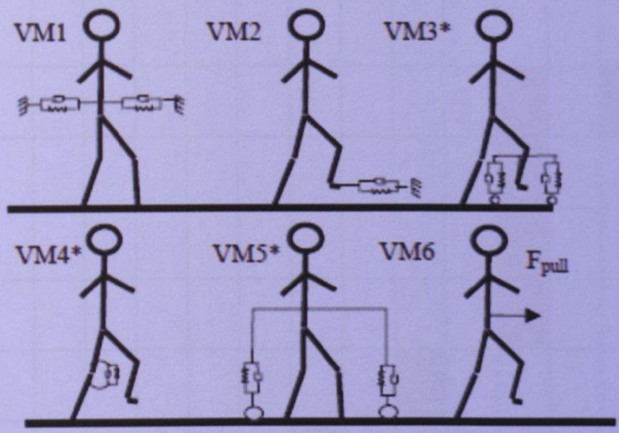


Figure 19 : Example of Virtual Models (VMs) to support gait

VM 1 supports the balance of the patient. VM2 assist the patient in the placement of the foot in the sagittal and frontal plane, which is important for dynamic balance and the speed of walking. VM3 enforces sufficient foot clearance using a virtual granny walker connected at the ankle. VM4 helps to stabilize the knee. VM5 is a virtual granny walker (partial) supporting the patient's weight. VM6 increases the patient's push off.

CHAPTER 4

GANTT CHART

Milestone for Final Year Project I

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of the project title entitled : Robotic Rehabilitation System in Malaysia								M							
									I							
2	Review on papers and statistics gathering								D							
3	Submission of Draft Extended Proposal								S							
									E							
4	Submission of Extended Proposal								M							
5	Proposal Defense								B							
									R							
6	Advanced papers review and study on reviewed papers								E							
									A							
7	Submission of Interim Draft Report								K							
8	Submission of Interim Report															

Table 8 : Milestone for Final Year Project I

Milestone for Final Year Project II

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Work Rehabilitation center visit															
2	Data collection and preparation for layout design, cost and technology								M							
3	Submission of Progress Report 1								I							
4	Listing of equipment and dimensioning								D							
5	Robotic rehabilitation center draft drawing								S							
6	AutoCAD modeling of Robotic Rehabilitation Center layout design								E							
7	Submission of Progress Report 2								M							
8	Calculation of budget and cost for rehabilitation center development								B							
9	Economic feasibility study								R							
10	Result Validation and Analysis								E							
11	Poster Exhibition								A							
12	Submission of Dissertation Final Draft								K							
13	Oral Presentation															
14	Submission of Dissertation (hard bound)															

Table 9 : Milestone for Final Year Project II

CHAPTER 5

RESULT AND DISCUSSION

5.1 Relevancy of Robotic Rehabilitation

General Review

As stated in the report of KPJ Tawakal Specialist Hospital visit, there are several types of diseases and disabilities that contribute to a high number of patients applied for rehabilitation service. KPJ Tawakal Specialist Hospital acts as a platform to obtain the average statistics of patient and several questionnaires are prepared to provide information regarding current conventional rehabilitation works in Malaysia. Musculoskeletal, Spine Injury (Back & Neck) and Sport Injury recorded high statistics of patients which exceeds 100 people per year. This number might even become bigger from year to year due to accidents while driving or sports. Thus, an action of safety must be taken to ensure the efficiency of work rehabilitation remain like usual. Based on the questionnaires prepared, the number of physiotherapist is not enough in patient point of view. According to Pn. Suraya (KPJ Tawakal Specialist Hospital Physiotherapist Specialist) each therapist might handle 2 to 3 patients for each therapeutic session. Although it is sufficient in therapist point of view, patient needs is likely to be fulfil.

Methods

Conventional Rehabilitation

Typically, there are three (3) types of plan treatments provided which are the manual therapy, exercise therapy either active-free or bicycle and thermal electrotherapeutic modalities.

1. Manual Therapy

   It is a clinical approach which utilized the skill of the therapist and it is a physical type of treatment. Physical therapist entertains patients with a health problem diagnosis and end up with a structure of treatment to be applied towards patients.

2. Exercise Therapy

   Exercise therapy will usually be trained in the principles of rehabilitation, how pain works and the role of exercise in body repair. Numbers of therapeutic exercise options are provided depending on patient state of health.

3. Thermal electrotherapeutic modalities

   Thermal therapeutic application has potential therapeutic effects on several areas of physiologic functions in soft tissue disorders. Health problem ranges from blood circulation, neuromuscular disorders, soft tissue disorders and local and central neural activity can be treated by means of heat transfer mechanism which consists of conduction, convention, radiation, evaporation and conversion.

The basic application in current rehabilitation activities are stated as above. There are more ways to treat people using various different kinds of rehabilitation techniques which at the same time will widen the treatment efficiency in terms of more continuous and more personalised care solution.

Robotic Rehabilitation

Robotic rehabilitation has proven the effectiveness in healthcare training according to some country such as United States and United Kingdom. They have progressively applied some of the robotic devices in their field of treatment. As stated in the literature review part, numerous kinds of robotic devices can be seen which have successfully projects a good therapeutic activity approach. Several example of robotic therapeutic activity can be discussed for further understanding so that it can be applied in Malaysia meritoriously.

Robot-Assisted Movement

In most cases either in general or visited hospital health status which consists of stroke, brain injury, neurological disorders, musculoskeletal problem or anything that is related to physical malfunction can typically be seen in rehabilitation activities. In terms of physical rehabilitation, compared with conventional treatment of equal intensity and duration, a program of robot-assisted movements had advantage after 2 months of treatment in terms of decreasing impairment, improving strength, and increasing reach extent (Peter S. Lum, 2002). Significant physical movement percentages are as shown below.

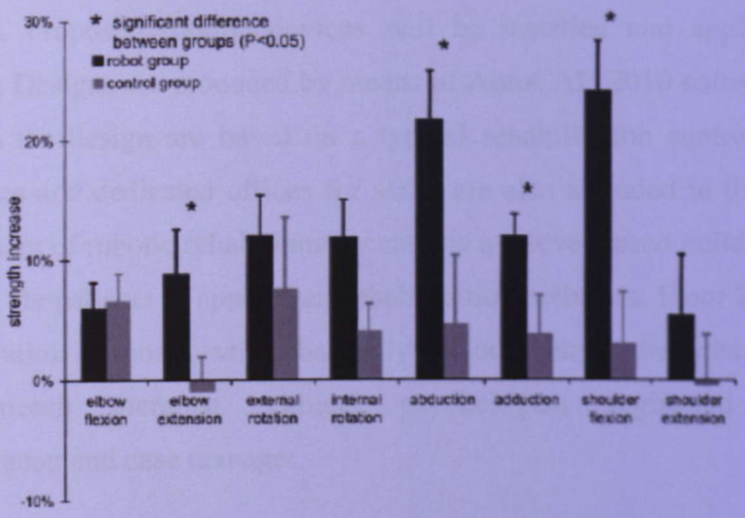


Figure 20 : Average strength gains in 8 shoulder and elbow joint actions (Peter S. Lum, 2002)

According to figure 20, the different in percentage of movements between conventional and robotic rehabilitation are relatively high and much more reliable. Robotic assisted movement can be programmed to interact with the patient with low impedance, giving it a soft and compliant feel during movements to assure the effectiveness of treatment. Another example of robot-assisted technology in terms of physical disorders is robotic gait training. According to (Institute, 2012) study done by Prasat Neurological Institute has proven that robotic gait rehabilitation can reduce and utilize time consumption with more critical training and enough rest is assured.

Robot gait training: Robotic gait training for 20 minute include preparing and rest time for 10 minute plus conventional physical therapy program for 30 minute, totally 60 minute per day for 5 working days per week.

Conventional gait training: Conventional physical therapy program for 60 minute per day for 5 working days per week.

5.2 Robotic Rehabilitation Centre Design

5.2.1 General Considerations

Robotic rehabilitation centre is capable of sustaining disabilities and life-threatening injuries while at the same time providing specialized intensive rehabilitation of medical care. Proposed robotic devices will be installed and applied based on patients need. Designs are produced by means of AutoCAD 2010 software. Facilities included into the design are based on a typical rehabilitation centre. Facilities of robotic devices and dedicated offices for staffs are also included in the design. The proposed system of robotic rehabilitation centre is a 2-level based building. Floor 1 is dedicated for the patients to apply their rehabilitation activities. Floor 2 is mainly for the administration purposes which basically includes physiotherapist, occupational therapist, speech therapist, clinical psychologist, registered counsellors, physician/surgeon and case manager.

1. **Floor 1** : Rehabilitation Treatment
   - Assistive Robots
   - Prosthetics Robots
   - Orthotics Robots
   - Therapeutics Robots

2. **Floor 2** : Administrative office
   - **Physiotherapist:** Deal with patients to improve and identify their movement and function. Plus, assisting the rehabilitation process for their wellbeing.
   - **Occupational Therapist:** Design activities need to be undergone by the patients to achieve functional outcomes which promote health and prevent injuries.
   - **Speech Therapist:** Training specialist in the diagnosis and behaviour of speech, voice and language disorders. Deals with people which having difficulties to make speech sounds clearly.
   - **Clinical Psychologist:** Highly skilled and specialized in diagnosis and psychological treatment of mental illness.

- **Registered Counsellors:** Help patients with emotional and physical disabilities to live independently in terms of personal, social and professional effects of disabilities.
- **Physician/Surgeon:** Coordinates the efforts of the rehabilitation team which include physical, occupational, speech or other therapists.
- **Case Manager:** Predominantly in charge of coordinating needed services by the patients and serve as a link between various health professionals.

5.2.2 Technical Considerations

Architectural

1. Partition
   Interior partition around patient rooms should have a sound-proof features. Other areas where noise may be generated should have sound attenuation features.
2. Floors
   Floor in patient: Vinyl composite tile is recommended to support areas at high risk infections.
   Floor in high-traffic: Offices and administrative service areas should be carpeted with a 100mm high resilient base.
   Floor in toilet: Non-slip floor is recommended, ceramic tile or vinyl composition tile with 100mm high resilient base.
3. Ceilings
   Ceilings primarily should be lay-in acoustic ceiling tile installed in an exposed or semi concealed suspension system.
4. Interior door
   Normal door: 44mm thick flush-panel wood doors
   Patient or toilet door: 1220mm thick flush-panel wood doors

5.2.2 Heating, Ventilation and Air Conditioning

Codes and standards

1. Operation

   HVAC can be installed to provide heat, cool and ventilation for all rooms.
2. Air quality and distribution

   Clean environment is essential for patient to exhale or inhale air. Corridor air may be used to ventilate toilets and housekeeping closets.
3. Exhaust system

   Efficient exhaust system is crucial to be designed to control and transfer odour and provide proper room pressurization.

a. Ventilation for Acceptable Indoor Air Quality – ASHRAE Standard 62.1-2007, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
b. Design Guide for Humidity Control in Commercial and Institutional Buildings; 2001, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Electrical

1. Illumination

   Lighting should follow the Illuminating Engineering Society (IES) safety levels which are adequate for patients and staffs.
2. Power

   Dedicated duplex or special receptacles are provided for the use of refrigerators, freezers and ice makers. Multiple receptacles are used to power staffs work station and several other location.

Codes and standards

a. National Electrical Code (NEC).

Waste management

1. Medical waste

   Medical waste is generated in medical exam rooms or in patients' room. It must be collected and transported via special containers for the waste to be offloaded.
2. General waste

   This type of waste is produced in all spaces and is held in waste containers.

Communications

1. Telephone

   A telephone should be located and available near patient treatment room for the ease of emergency call. Telephone for each staff work station is needed too prior to administrative purposes.
2. Nurse Call

   A staff call system is provided for all patient rooms including toilets and other space used by patients. Detailed needs call button used by most hospital should be located near patient spaces.
3. Television

   Each room should hold its own cable and electrical outlets for television purposes.

5.3 Building Design Considerations

5.3.1 Floor 1: Proposed Design

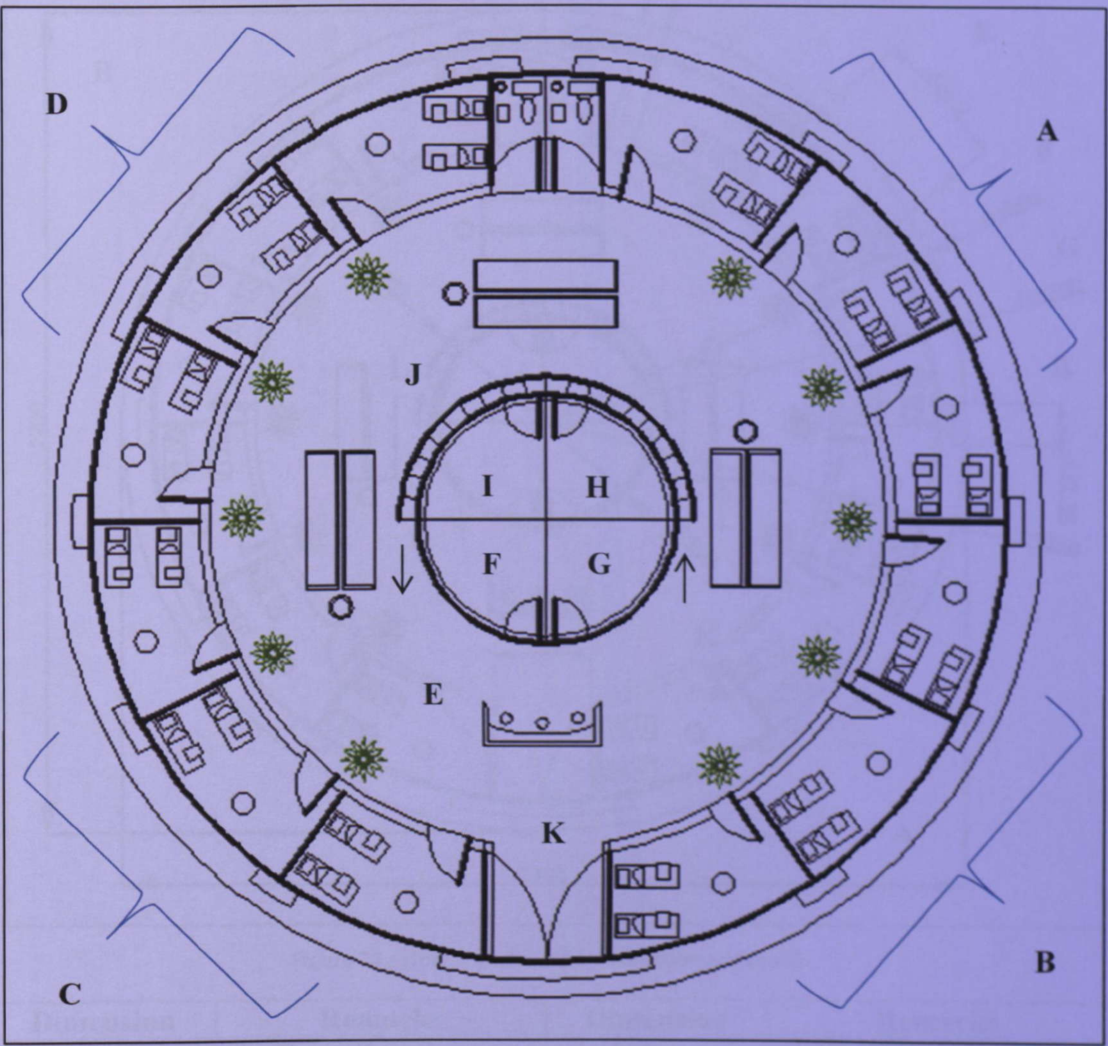


Figure 21 : Floor 1 Design Approach

A	Assistive Robots Rooms	F	Security Office
B	Prosthetics Robots Rooms	G	Admitting Office
C	Orthotics Robots Rooms	H	Pharmacy
D	Therapeutics Robot Rooms	I	Storage/Utilities
E	Reception Counter	J	Semi-circle Staircase
K		Main Entrance	

5.3.2 Floor 1: Design Dimensioning

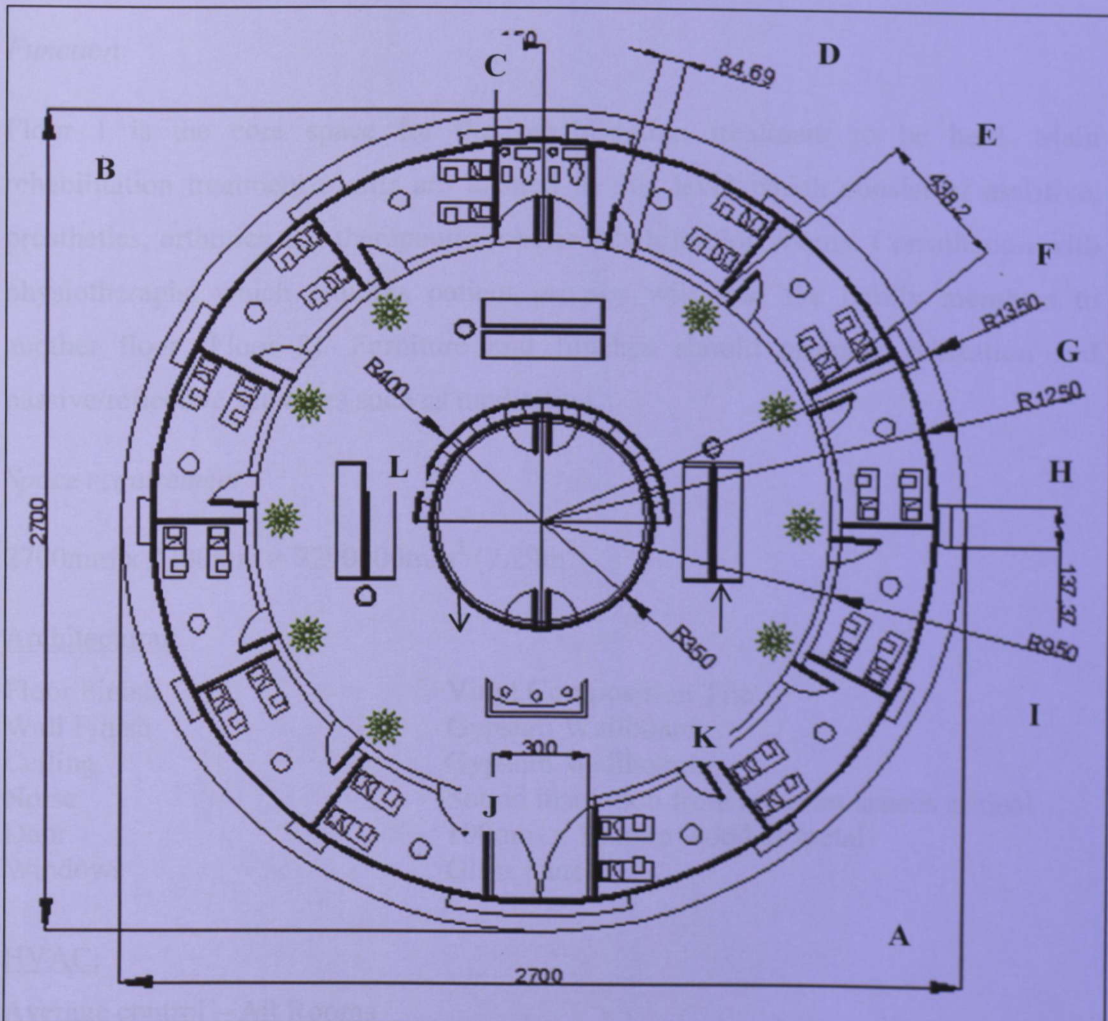


Figure 22 : Floor 1 Technical Specification Approach

Dimension	Remarks	Dimension	Remarks
2700 mm	A : Front Building Length	1250 mm	G : Inner Building Radius
2700 mm	B : Side Building Length	137.37 mm	H : Window Length
150 mm	C : Toilet	950 mm	I : Building Hall Radius
84.69 mm	D : Door Length	300 mm	J : Entrance Length
438.2 mm	E : Room Length	350 mm	K : Center Room Radius
1350 mm	F : Outer building radius	400 mm	L : Staircase Radius

*Floor Height: 500 mm

Technical Specifications – Floor 1

Function

Floor 1 is the core space for the rehabilitation treatment to be held. Main rehabilitation treatment rooms are located in this level which consist of assistive, prosthetics, orthotics and therapeutic robotic rehabilitation rooms. Consultation with physiotherapist which requires patient privacy will lead the family members to another floor (Floor 2). Furniture and finishes should promote relaxation and passive/reflective activities such as meditation.

Space requirement

2700mm x 2700mm = 7290000mm^2 (7.29m^2)

Architectural:

Floor Finish	Vinyl Composition Tile
Wall Finish	Gypsum Wallboard
Ceiling	Gypsum Wallboard
Noise	Sound insulation from adjacent spaces critical
Door	100mm x 180mm wood or metal
Windows	Glass panel

HVAC:

Average control – All Rooms	
Temperature Control	20 – 24 degree Celsius
	30% - 60% RH
Min. Air Changes/Hour	6 AC/H
Min. % Outside Air	33%
Pressure	Neutral
% Filtration	30%

Electrical:

Lighting Levels:	
General Illumination	10 foot-candle
Task Illumination	20 foot-candle Dimmable fluorescent down lights
Over Bed	30% integrated in casework
Emergency illumination:	
Medical Gases	Yes
Night Lights	Yes
Vanity Light	Yes

5.3.3 Floor 2: Proposed Design

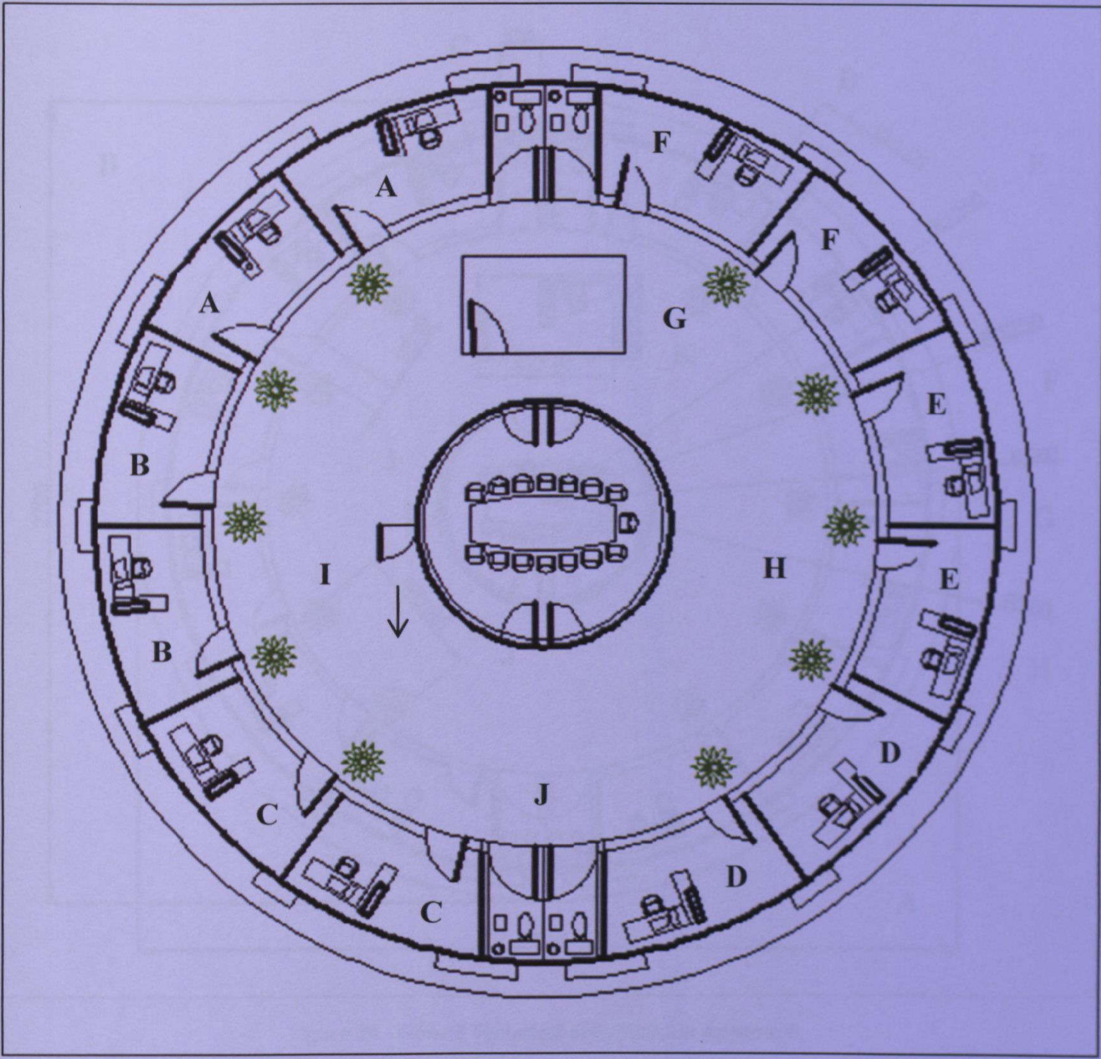


Figure 23 : Floor 2 Design Approach

	Remarks		Remarks
A	Physiotherapist Offices	F	Physician/Surgeon Offices
B	Occupational Therapist Offices	G	Case Manager Office
C	Speech Therapist Offices	H	Meeting Room
D	Clinical Psychologist Offices	I	Staircase Exit Door
E	Registered Counselors Offices	J	Toilets

5.3.4 Floor 2: Design Dimensioning

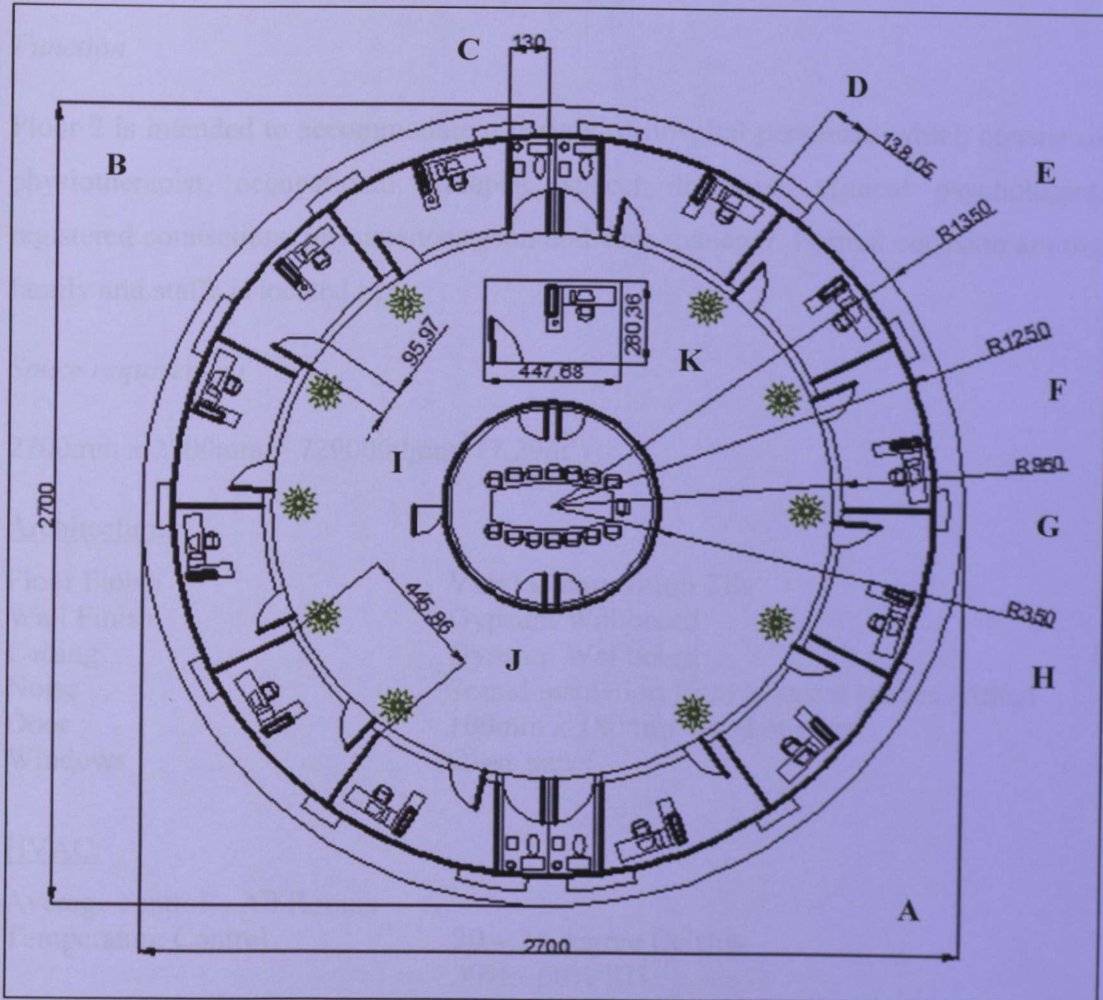


Figure 24 : Floor 2 Technical Specification Approach

Dimension	Remarks	Dimension	Remarks
2700 mm	A : Front Building Length	950 mm	G : Building Hall Radius
2700 mm	B : Side Building Length	350 mm	H : Meeting Room Radius
130 mm	C : Toilet	95.97 mm	I : Door Length
138.05 mm	D : Window Length	445.86 mm	J : Room Length
1350 mm	E : Outer building radius	447.68 mm	K : Square Room Length
1250 mm	F : Inner Building Radius	280.36 mm	K : Square Room Length

*Floor Height: 500 mm

Technical Specifications – Floor 2

Function

Floor 2 is intended to accommodate a variety of hospital personnel which consist of physiotherapist, occupational therapist, speech therapist, clinical psychologist, registered counsellors, physician/surgeon and case manager. Formal occasion among family and staffs is located here.

Space requirement

2700mm x 2700mm = 7290000mm^2 (7.29m^2)

Architectural:

Floor Finish	Vinyl Composition Tile
Wall Finish	Gypsum Wallboard
Ceiling	Gypsum Wallboard
Noise	Sound insulation from adjacent spaces critical
Door	100mm x 180mm wood or metal
Windows	Glass panel

HVAC:

Average control – All Rooms	
Temperature Control	20 – 24 degree Celsius
	30% - 60% RH
Min. Air Changes/Hour	6 AC/H
Min. % Outside Air	33%
Pressure	Neutral
% Filtration	30%

Electrical:

Lighting Levels:	
General Illumination	10 foot-candle
Task Illumination	20 foot-candle Dimmable fluorescent down lights
Over Bed	30% integrated in casework
Emergency illumination:	
Medical Gases	No
Night Lights	No
Vanity Light	No

Layout design of the robotic-based rehabilitation system represents one of the outcomes of this project to be fulfilled. The chosen robotic devices were based on statistical analysis of patients in Malaysia whom applied for rehabilitation services. Data of patient with Stroke, Amputation, Spinal Cord Injuries, Sports Injuries and Muscoskeletal issues which recorded as the highest health problem encountered in Malaysia. Four (4) different sections which are assistive, prosthetic, orthotic and therapeutic robots were chosen as the platforms to divide patients based on impairments and disabilities that they are facing. Patients are going to be separated and received treatment by means of therapists and robotic devices where each session provides different costing. Design approach and design dimensioning for both Floor 1 and Floor 2 are as shown below. The idea of the concept design is based on the actual rehabilitation centre around Malaysia as Malaysia possesses quite a few number of rehabilitation centre but they are not standalone which means the proposed concept focused on one building/centre approach.

5.4 Robotic Rehabilitation Cost

5.4.1 Conventional Rehabilitation Treatment Cost (per session)

Disabilities	Number of patients	Cost per session (RM)	Estimated cost (RM)
Amputation	10	50.00	500.00
Spine Injury	110	120.00	13,200.00
Musculoskeletal	110	120.00	13,200.00
Neurological	11	160.00	1,760.00
Cardiorespiratory	70	80.00	5,600.00
Spinal Cord Injury	1	160.00	160.00
Sports Injury	100	120.00	12,000.00

Table 10 : Rehabilitation Treatment Cost

Above table shows the estimated cost for various kind of treatment in rehabilitation hospitality which is based on data taken from the visit. Spine Injury, Musculoskeletal and Sport Injury display high number of patients apply for the treatments. Proposed robotic devices have the capabilities to handle most of the listed impairments shown above. The exact cost for the rehabilitation treatments rely on the number of session and cost for each rehabilitation session. Approximately, a total of RM 46,420.00 can be gained within a year for a conventional rehabilitation (KPJ Tawakal Specialist Hospital). This figure shows that if the number of patient applies for rehabilitation increases, it can cover the whole expenditure on the new proposed system. In addition, study has showed that the number of patient with injuries and impairments keep increasing from year to year in many areas of rehabilitation activities.

5.4.2 Proposed Robotic Devices Overall Costing

Product Name	System	Approximate Cost (RM)
	Assistive Robots	
Handy 1	Scanning and pick	19,392.00
MANUS	WMRA	103,098.00
The Raptor	WMRA	36,820.00
	Prosthetics Robots	
The Utah Arm	EMG	79,312.00
Five-Fingered Prosthetics Hand	EMG	57,104.00
Prosthetics Knee	EMG	63.00
	Orthotics Robots	
Wrist-Hand Orthosis (WHO)	Hand Support Braces	101.00
Exoskeleton Arm	Force-Feedback	12,726.00
Lokomat	Gait Training	79,376.00
	Therapeutic Robots	
MIME	Unilateral and Bilateral	636.00
MIT-MANUS	FES assistance	222,215.00
ARM Guide	FES assistance	253,960.00
RMII (Rutgers Master II-ND)	Force-Feedback	50,792.00
LOPES	VMC	317,450.00
Total Price		1,233,045.00 ≈ 1.2 millions

Table 11 : Robotic Rehabilitation Devices Overall Costing

Purchasing price for robots and devices vary with time and current technology that is being used nowadays. Figures of the approximate purchasing cost for robots and devices for robotics rehabilitation purposes are as shown below. Proposed devices were chosen based on the findings and statistics of injured patients in Malaysia. Approximately, a total of RM 1.2 million is needed to purchase all the devices. Price ranges from RM 63.00 to RM 253,960.00 and it is economically feasible for a long period practice.

CHAPTER 6

CONCLUSION

Robotic technology has positively formed valuable means for rehabilitation system and medical training with new and improved assistive, prosthetics, orthotics and therapeutics devices for people with disabilities. Future applications of robotic technology that is going to be proposed for future implementation in Malaysia will continue to provide advances in these and other areas of medicine. The most substantial role of medical robots is most likely to perform task that is not yet implemented in any Malaysian hospitality such as robots for rehabilitation. General comparison between traditional rehabilitation system and robotic rehabilitation can be seen throughout this report.

Research activities included:

1. Rehabilitation centre visit.
2. Research on current therapeutic robotic rehabilitation technology.
3. General statistical data of patient in Malaysia.
4. Statistical data of patient in conventional rehabilitation centre (KPJ Tawakal Specialist Hospital).
5. Robotic rehabilitation centre layout design.
6. Calculation of budget needed for robotic rehabilitation devices to be installed.

CHAPTER 7

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