DESIGN AND DEVELOPMENT OF REHABILITATION DEVICE FOR HEMIPARETIC PATIENTS

KHAIRUL FADZLI BIN SAMAT

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

FEBRUARY 2012

To my beloved mother, father and wife

ACKNOWLEDGMENT

Firstly, I would like to express my greatest gratitude to Allah S.W.T., for His will, this project has finally completed. Thousands of thanks to my supervisor, Assoc. Prof. Dr Mohamed Hussein for his kind and patience, his valuable advices, concern, guidance and support throughout the process of completing my master project. Nevertheless, my great appreciation dedicated to my wife Yuhaniz binti Anuar for all her helps and encouragement that she had given to me.

I would also like to express my sincere gratitude to my parents and family, who had continuously giving out their support financially and emotionally for me to complete my project. Also lots of thanks to my dearest friends and lectures for all the knowledge, helps, and guidance to complete this project. I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) for its financial support and assistance on various matters.

Last but not least, I have the greatest hope that my master project, 'Design and Development of Rehabilitation Device for Hemiparetic Patients' will give its benefit in making more discovery of new technology in the future.

ABSTRACT

In this thesis, the development of rehabilitation device for patients who encounter walking weakness due to post-stroke effect is presented. . In order to design an efficient new mechanism, studies were carried out regarding kinematic of human walking. In the study, the motion of a healthy physical subject in walking situation of 1 km/h speed is used as guide to design the device. Thereafter, a mechanism was developed to produce similar motion. The device functions to actuate knee and hip rotation. The device is driven by a single actuator to drive both the hip and the knee joints mechanism. The kinematic analysis of constructed device has been performed and the results conformed the functionality of the suggested mechanism. The fabricated prototype shows the combination of DC motor and cam mechanism can actuated the movement of hip and knee joint simultaneously and may significantly reduced the power consumption. The computer based controller has also been developed with simple and practical application. With the combination of the controller and the fabricated model, the output profile of the rehabilitation device is acceptable by comparing with profile of actual data.

ABSTRAK

Dalam tesis ini, pembangunan rekaan peranti pemulihan untuk pesakit-pesakit yang mengalami gajala lemah untuk berjalan disebabkan oleh kesan sakit strok dibentangkan. Dalam usaha untuk mereka bentuk mekanisma baru yang cekap, kajian telah dijalankan berkaitan dengan kinematik manusia berjalan. Dalam kajian ini, profil pergerakan subjek yang sihat dengan kelajuan 1 km/h digunakan sebagai panduan untuk reka bentuk peranti. Oleh itu, satu mekanisma telah dibangunkan untuk menghasilkan pergerakan yang sama. Peranti berfungsi untuk menggerakkan pergerakan lutut dan pangkal peha yang dipacu oleh satu putaran motor. Analisis kinematik peranti yang dibina telah dijalankan dan semua keputusan menepati fungsi mekanisma yang disyorkan. Prototaip yang dibina membuktikan bahawa gabungan DC motor dan mekanisma *cam* boleh menggerakkan pergerakan kaki untuk berjalan dan pada masa yang sama kurang menggunakan sumber kuasa. Kawalan berasaskan komputer juga telah dibangunkan dengan penggunaan yang mudah dan praktikal. Dengan kombinasi kawalan dan model peranti yang telah direka, profil pergerakan bagi proses pemulihan dapat dihasilkan dan diterima pakai apabila ia dibandingkan dengan profil data sebenar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

θ	-	Angle
R_b	-	Base circle of cam
R_p	-	Prime circle of cam or radius on the cam
$\emptyset$	-	Pressure angle of the cam
V	-	Velocity
s	-	Instantaneous displacement of the follower
$\dot{s}$	-	Time derivative in units of length per second
v	-	Velocity of the follower in units of length per radian
ω	-	Angular speed
b	-	The distance to the instant center of the cam
ε	-	Eccentricity
L	-	Length
d	-	Displacement
Pa	-	Pascal

Abbreviations

PT	-	Physical Therapy
OT	-	Occupational Therapy
SBO	-	Spring Brake Orthosis
MIT	-	Massachusetts Institute of Technology
PhAFO	-	Power harvesting ankle-foot orthosis
HAL-5	-	Hybrid Assistive Limb Suit
HAL-3	-	Hybrid Assistive Leg-3
DC	-	Direct Current

PC	-	Personal Computer
PGO	-	Powered Gait Orthosis
KAFO	-	Knee-ankle foot orthosis
AFO	-	Ankle-foot-orthosis
MR	-	Magnetorheological
SCKAFO	-	Stance-control knee-ankle-foot orthosis
SCOKJ	-	Stance Control Orthotic Knee Joint
GUI	-	Graphical User Interface

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the problem

According to fact, stroke disease is reported as the second biggest cause of death worldwide. A stroke occurs when blood supply to part of the brain is disrupted, causing brain cells to die [1]. Although stroke is a disease of the brain, it can affect the entire body. Some of the disabilities that can result from a stroke include paralysis, cognitive deficits, speech problems, emotional difficulties, daily living problems, and pain. Paralysis is a common disability that results from stroke. Paralysis can be on any part of the body. Paralysis on one side of the body is called Hemiplegia. However, there is another type of paralysis that relates to one-sided weakness, which is called Hemiparesis. The weakness may affect only the arm, face or leg.

Basically, there are three types of treatments for stroke: prevention, therapy directly after stroke, and post-stroke rehabilitation. Hemiparesis patient can be able to walk again if a right rehabilitation therapy is applied. That is why the third stage of stroke treatment (post-stroke rehabilitation) is important for the post-stroke patients to prevent disabilities damage from becoming more serious. There are four types of post-stroke rehabilitation: Physical Therapy (PT), Occupational Therapy

(OT), Speech Therapy and Psychological/Psychiatric Therapy. If a stroke patient has a problem of walking weakness, generally the treatments of Physical Therapy and Psychological or Psychiatric Therapy are used to cure disabilities. Usually Physical Therapy consists of scheduled training, exercises and physical manipulation of the stroke patient's body with the intent of restore movement, balance, and coordination.

As stroke patients frequently have difficulty with everyday functional movement and activities; the lost of function can be decreased through rehabilitation therapy during the critical post-stroke period. Such rehabilitation therapy involves carefully designed repetitive exercise, which can be passive and active. In passive exercise, the therapist or a robot actively helps the patient to repeatedly move the stroke-affected limb as prescribe. In active exercises, the patient does the work by him/herself, with no physical assistance. From that particular therapist, assistive robotic technology has the potential to provide novel means for monitoring, motivating and coaching.

1.2 Statement of the problem

There are several methods of training for the physical therapy such as using a rehabilitation device. Most of the rehabilitation devices currently used high power consumption to perform the therapy and having a complex control system. This may be solved by proposing a new design of mechanism for the rehabilitation device. The rehabilitation device should provide a physical assistance through rehabilitation therapy to increase the possibility to cure the walking weakness.

1.3 Objective of the study

The objectives of this project are:

- To design and develop a rehabilitation device base on the best selected mechanism of knee and hip joint
- To fabricate a prototype for testing the functioning of the designed mechanism
- To develop a computer-based control system for the rehabilitation device system

1.4 Scope of the study

In this study, designations of the assistive robotic system only focus on the one side of the leg. It will encompass the development of mechanism at knee and hip joint. In order to make sure the project will achieve the objectives stated, the scopes of this project comprise the following aspects:

- To design a device called orthosis device (known as exoskeleton) for lower extremity (leg)
- The mechanism focuses on the hip and knee joint only
- The device is classified as Rehabilitation Device
- The device does not support the balance of stroke patient's body
- The subject/patient is a Hemiparesis patient (leg weakness)

1.5 Significant of the study

The results from this study has the potential to help stroke survivor in activities they do in real life and decrease long-term healthcare costs on stroke patients. This study is important in order to give a new hope to post-stroke patients who had lost their ability to walk. The possibility is high to be a device that will help any patients who experience leg weakness and disability.

1.6 Research Methodology

Basically, the project has been carried out in regular procedure of research. This section briefly shows the general procedure of the project and the flow chart of the project (Figure 1.1). The time consumed on the specific task and the target time to finish the particular activity is presented in the project schedules shown in Table 1.1 and Table 1.2.

1.6.1 Procedure of the Project

i. **Development of conceptual design:** to conceptually design based on data and information obtained from literature, patents, discussions, brainstorming, and reviewing of proposed design concept.

ii. **Final Design Concept:** to carry out the completed engineering drawing subsequently for kinematic analysis purpose in order to obtain the most appropriate final design.

iii. **Fabrication of prototype:** to fabricate all components based on the completed engineering drawing, hence to test the proposed design concept.

iv. **Development of Computer-based control system:** using Visual C++ to develop user interface (control) which able to handle the operation of the device and carry out the best performance according to gait cycle of subject/patient.

v. **Testing, Performance evaluation and Validation:** to carry out the experiments (measurement of knee joint angle of the device) to evaluate the prototype performance and validate the results of experimental knee data angles.

1.6.2 Flow chart of Project

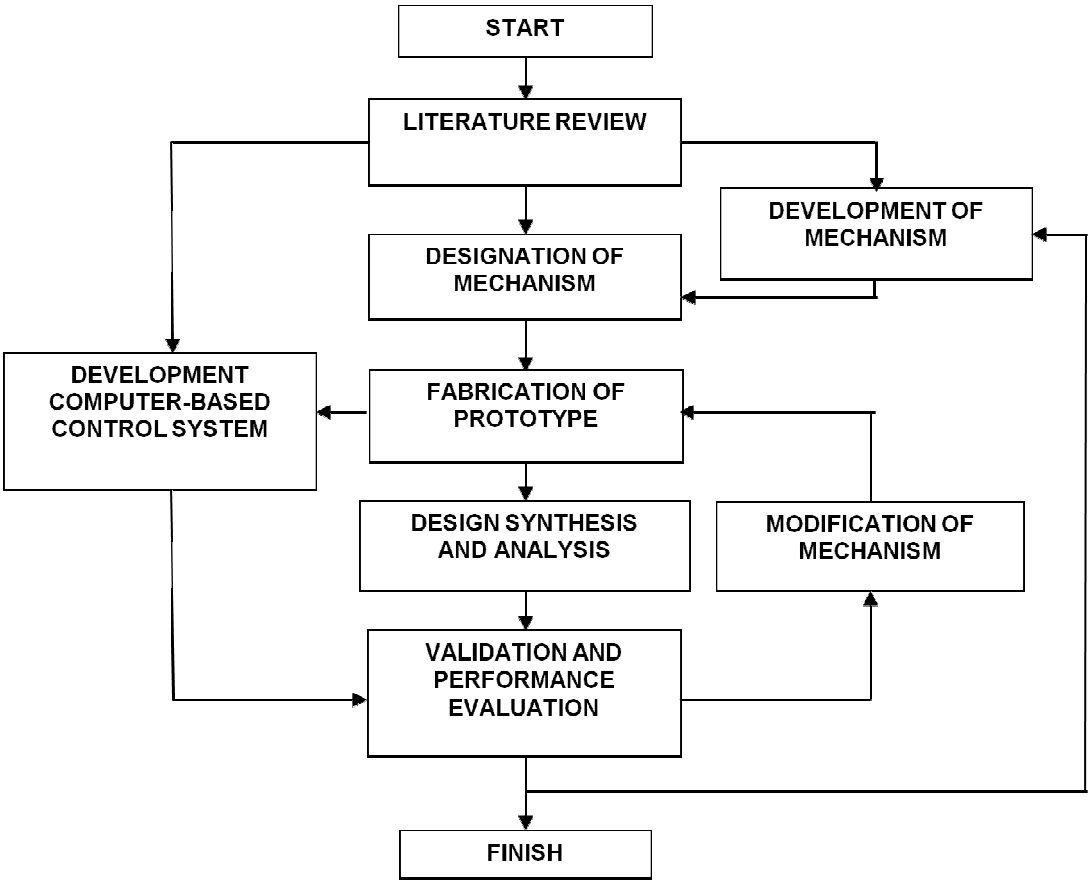

Figure 1.1: Flow chart of the Project

1.6.3 Project Schedule

Table 1.1: Project schedule for Master Project 1

Activities/ Time Scale*	1*	2*	3*	4*	5*	6*	7*
Literature Review							
Development of Conceptual Design							
Final Conceptual Design							
Kinematic Study (Model)							
Prototype Fabrication							
Report Writing							

***1 unit = 2 weeks**

Table 1.2: Project schedule for Master Project 2

Activities/ Time Scale*	1*	2*	3*	4*	5*	6*	7*
Modification							
Development of Controller							
Performance Testing and Data Collection							
Data Analysis							
Report Writing							

***1 unit = 2 weeks**

REFERENCES

1. Sutherland, D. H., Kaufman, K. R. and Moitoza, J.R. *Kinematics of Normal Human Walking*. 2nd edition. Baltimore: Williams & Wilkins. 1994. 23-44.
2. Perry, J. *Gait Analysis: Normal and Pathological Function*. Thorofare, NJ.: SLACK Inc. 1992. 431-433.
3. Choo Y. C., *Simulation and Animation of human motion using models obtained from identification techniqu*es. Undergraduate Thesis. Universiti Teknologi Malaysia. 2009.
4. Winter D. A., *The biomechanics and motor control of human gait: normal, elderly and pathological*. 2nd edition. Waterloo: University of Waterloo Press. 1991.
5. Donnan G.A., Fisher M., Macleod, M., and Davis, S. M. *Stroke.* Lancet. 2008. 1612–1623.
6. Hugh, H. *Exoskeletons and Orthoses: classification, design challenges and future direction.* Journal of Neuro Engineering and Rehabilitation, 2009, Vol. 6. 1-9.
7. Chu, A., Kazerooni, H and Zozz, A. *On the biomimetic design of the Berkeley Lower Extremity Exoskeleton (BLEEX).* Barcelona, Spain : IEEE International Conference on Robotic and Automation, 2005.
8. Roper, B. A. *Rehabilitation After A Stroke.* The Journal of Bone and Joint Surgery,1982, Vols. 64-B, 2. 1262-1266.
9. Yamshon, L. J. Rehabilitation of Patients with Hemiplegia. Los Angeles, 1950. Cited from *http://*www.ncbi.nlm.nih.gov. Vols. 73, No 2, 181-191.
10. Gery, C., Matthias, J., Reinhard, S. And Volker, D. *Treadmill training of paraplegic patients using robotic orthosis.* Journal of Rehabilitation Research and Development. Vol. 37, No 6. 693-700
11. Gharooni, S., Heller, B. and Tokhi, M. O. *A New Hybrid Spring Brake Orthosis for Controlling Hip and Knee Flexion in the Swing Phase.* IEEE

Transaction of Neural System and Rehabilitation Engineering, March 2001, 106-107.

12. Banala, S. K., Kulpe, A. and Agrawal, S. K. *A Powered Leg Orthosis for Gait Rehabilitation of Motor-Impaired Patients.* IEEE International Conference on Robotics and Automation. Roma, Italy: IEEE. 2007. 4140 - 4145
13. Robin, C., Elizabeth, T. H., Eric, L., Géza, K., Scott, D. M., Serena N. T., Alex, S. and Joel, N. G.*A pneumatic power harvesting ankle-foot orthosis to prevent foot-drop.* Journal of Neuro Engineering and Rehabilitation. 2009. Vol. 6. 10-19.
14. Herr, H. and Kornbluhb, R. *New horizons for orthotic and prosthetic technology: artificial muscle for ambulation.* Smart Structures and Materials 2004: Electroactive Polymer Actuators and Devices (EAPAD), San Diego, USA. 2004. Vol. 5385. 1-9.
15. Kawamoto, H and Sankai, Y. *Comfortable power assist control method for walking aid by HAL-3.* IEEE International Conference on Systems, Man and Cybernetics. IEEE. 2002. Vol.4. 1-6.
16. Suzuki, K., Kawamura, Y. Hayashi, T., Sakurai, T., Hasegawa, Y., and Sankai, Y., *Intention-Based Walking Support for Paraplegia Patient.* IEEE International Conference on Systems Man and Cybernetics. IEEE. 2007. Vol.3, No. 12. 2707-2713.
17. Ruthenberg, B. J., Wasylewski, N. A. and Beard, J. E. *An experimental device for investigating the force and power requirements of a powered gait orthosis.* Journal of Rehabilitation Research and Development. 1997. Vol. 34. 203-213.
18. Sawicki, G. S. and Ferris, D. P. *A pneumatically powered knee-ankle-foot orthosis (KAFO) with myoelectric activation and inhibition.* Journal of Neuro Engineering and Rehabilitation. 2009, Vol. 6. 23-38.
19. Chen, J. and Liao, W. H. *A Leg Exoskeleton Utilizing a Magnetorheological Actuator.* IEEE International Conference on Robotics and Biomimetics. IEEE. 2006. 824 – 829.
20. Hatton, B. J., Hatton, D. L. and Wallace, Z. G. *Articulating knee support. US Pattern: 20020169402.* 2001.

21. Hatton, B. J., Hatton, D. L. and Wallace, Z. G. *Articulating knee support. US Pattern 6635024.* 2003.
22. NASA Commercial Technology Division. *Quicker Rehabilitation for Knee Brace Wearers.* Washington: Aerospace Technology Inovation. 1997. 1- 5.
23. Shadoan, M. and Myers, N. *Horton's orthotic lab licensed to manufacture NASA-Designed Knee Orthosis.* O&P Business News. Vol. 13. 1998.
24. Van, L. NG. *The Swinging UTX Orthosis, Biomedical Fundamentals and Conceptual Design Undergraduate Thesis.* Enschede, Netherlands. University of Twente, 1993.
25. Van, L. NG. and Kunst, E. E. *New UTX-swing orthosis: Normal gait and safe standing*. Orthopedie Technik. 1999, Vol. 50. 506-515.
26. Yakimovich, T., Kofman, J. and Lemaire, E. D. *Design and evaluation of a stance-control knee-ankle-foot orthosis knee joint.* IEEE Transactions on Neural Systems and Rehabilitation Engineering. IEEE. 2006. Vol. 14. 361-369.
27. Nijenbanning, G. and Goudsmit, J. A**.** *Gravity operated locking hinge. US Pattern 20030153854.* 2003.
28. Fillaur, L. C. *Swing Phase Lock Manual.* Fillauer Companies, Inc. 2007.
29. Products: Fillauer. *Fillauer.* Fillauer Companies, Inc., November 17, 2009. Cited from http://www.fillauercompanies.com. 2009
30. Sclater, N. and Chironis, N. P. *Mechanism and Mechanical Devices sourcesbook.* New York: McGraw-Hill. 2001.
31. Naft, J. M., and Newman, W. S., *Orthosis knee joint. US Pattern 6517503* 2003.
32. Jonathan, S., Jennifer, J., Vanessa, P., Gerald, L., Gottlieb, J., Thomas S. and Daniel M. C. *Control of interjoint coordination during the swing phase of normal gait at different speeds.*. Journal of Neuro Engineering and Rehabilitation. 2007. Vol.4. 1-10
33. Robert, L.N. Cam Design and Manufacturing Handbook. 2nd edition. New York. Industrial Press, Inc, 2008.
34. M. R. Safizadeh, M. Hussein, M. S. Yaacob, M. Z. Md Zain, M. R. Abdullah, M. S. Che Kob and K. F. Samat, Kinematic Analysis of Powered Lower Limb Orthoses for Gait Rehabilitation of Hemiplegic and Hemiparetic

Patients, International Journal of Mathematical Models and Methods in Applied Sciences, Issue 3, Volume 5, pp: 490-498, 2011.

35. M.R. Safizadeh, M. Hussein, K. F. Samat, M.S. Che Kob, M.S. Yaacob and M.Z. Md Zain, Kinematic Analysis of an Assistive Robotic Leg for Hemiplegic and Hemiparetic Patients, NAUN Conference of Control (NCC'10), Puerto De La Cruz, Tenerife, Spain, November 30- December 2, 2010.
36. Gage J. *Gait Analysis in Cerebral Palsy*. London: Mac Keith Press. 1992.
37. Schneck, C. and Cuccurullo, S. *Physical Medicine and Rehabilitation Board Review*. New York: Demos Medical Publishing. 2004.
38. Orthotic Sandal Company LLC. How do Orthotics help prevent and heal injuries?. *Orthotic Sandal Company* . Retrieved January 13, 2011, from http://www.orthoticsandal.com/Injuries.html