Faculty of Mechanical and Manufacturing Engineering Technology

DESIGN AND ANALYSIS OF PASSIVE KNEE EXOSKELETON

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Bachelor of Manufacturing Engineering Technology (Product Design) with Honours

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DESIGN AND ANALYSIS OF PASSIVE KNEE EXOSKELETON

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A thesis submitted in fulfilment of the requirements for the Bachelor's Degree in Manufacturing Engineering Technology (Product Design) with Honours

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APPROVAL

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the Bachelor's Degree in Manufacturing Engineering Technology (Product Design) with Honours. The member of the supervisory is as follow:

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ABSTRACT

The objective of this project is to design and analyze a passive knee exoskeleton that is suitable for the industrial application. The scope of this project is only focused on the design of a knee exoskeleton that operates through a passive system such as spring. Spring is a passive element that able to store the wasted energy from the human body and release it when needed. Thus, the augmentation purpose of the passive knee exoskeleton achieved. The method to carry out this project started from the concept design followed the selection of the suitable concept through Weighted Rating Method. Next, the details design of the exoskeleton model and human body model were created by the SolidWorks and MakeHuman software. The dimensions of both models are based on the anthropometric measurements of Malaysian citizens. A man-machine model formed via the combination of the exoskeleton and human-body model is used for the kinematics analysis on the motion of squat lifting. A motion analysis is conducted to the passive knee exoskeleton and showed that the passive knee exoskeleton able to carry out the lifting more quickly and efficiently. The global response and local response on the spring from the exoskeleton model is studied with the linear static analysis by using SolidThinking software. The result showed that the critical component of the passive knee exoskeleton after applied load is the ball stud. Hence, parametric studies carried out on the ball stud from the aspect of material. Lastly, the design of the passive knee exoskeleton is optimised on the topology from the aspect of maximise the stiffness to weight.

ABSTRAK

Objektif projek ini adalah untuk merekabentuk dan menganalisis exoskeleton lutut bersifat pasif yang sesuai untuk aplikasi di industri. Skop projek ini hanya memberi tumpuan kepada reka bentuk exoskeleton lutut yang beroperasi melalui sistem pasif seperti spring. Spring adalah sejenis elemen pasif yang dapat menyimpan tenaga dari tubuh manusia dan melepaskannya apabila diperlukan. Oleh itu, exoskeleton lutut bersifat pasif yang bertujuan meningkatkan upaya manusia dapat dicapai. Kaedah untuk melaksanakan projek ini bermula dari reka bentuk konsep diikuti pemilihan konsep yang sesuai melalui *Weighted Rating Method*. Seterusnya, lukisan model exoskeleton dan model badan manusia dicipta dengan menggunakan perisian *SolidWorks* dan *MakeHuman*. Ukuran untuk kedua-dua model adalah berdasarkan pengukuran antropometrik penduduk Malaysia. Satu model yang dibentuk melalui kombinasi antara model exoskeleton dan tubuh manusia telah diberikan pergerakkan mengangkat barang secara mencangkung atas tujuan analisis kinematik. *Motion* analysis telah dijalankan kepada exoskeleton lutut and keputusan menunjukkan exoskeleton lutut dapat melakukan cangkung dengan cepat and berkesan. Tindak balas bersifat global dan bersifat tempatan pada spring dari model exoskeleton dikaji melalui *linear static analysis* dengan menggunakan perisian *SolidThinking*. Keputusan *linear static analysis* menunjukkan bahagian yang kritikal pada exoskeleton lutut adalah bahagian *ball stud*. Oleh itu, kajian-kajian parametrik dijalankan pada *ball stud* dari segi bahan-bahan. Akhir sekali, penambahbaikan topologi dilakukan pada reka bentuk exoskeleton lutut pasif.

DEDICATION

This researched study is dedicated to my beloved parents, my siblings and my friends who always motivate me to complete my researched study at Universiti Teknikal Malaysia Melaka (UTeM).

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LIST OF ABBRIVIATIONS AND SYMBOLS

3D	three dimensions
APL	Athletic Propulsion Labs
BLEEX	Berkeley Lower Extremity Exoskeleton
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CGA	Clinical Gait Analysis
cm	centimetre
DARPA	Defense Advanced Research Projects Agency
DOF	Degree of Freedom
eg	exampli gratia
EHPA	Exoskeletons for Human Performance Augmentation
EKSO	Ekso Bionics
EMG	Electromyography
EoT	Effect of Time
FEA	Finite Element Analysis
FFW	Future Force Warrior
FoS	Factor of Safety
FTK	Faculty of Engineering Technology
FYP	Final Year Project
HAL	Hybrid Assistive Limb
HEXAR	Hanyang Exoskeleton Assistive Robot
HULC	Human Universal Load Carrier
kg	kilogram
km/h	kilometre per hour
Max	maximum
mm/h	millimetre per hour
Min	minimum
MIT	Massachusetts Institute of Technology

NBA	National Basketball Association
Nm	Newton metre
SD	Standard Deviation
US	United States
UTeM	Universiti Teknikal Malaysia Melaka
VR	visual reality
WMSD	Work-related Musculoskeletal Disorders
WPS	Wearable Power Suit
%	percentage
/	or
°	degree

CHAPTER 1

INTRODUCTION

1.1. Background of Study

The extension of biological exoskeletons forms the concept of an exoskeleton type system. From the biological point of view, the exoskeleton is an external cover that used to protect or support the animal, for example, the shell of a crab. In addition, it acts as a surface to which muscles attach, water-tight barriers against dehydration and sensory interface with the environment. The metal armor that provides the knights with a hard shell or skin for protection can also be called as an exoskeleton to some extent. However, after scientists further expanded this idea, the exoskeleton now refers to "super suit" or system that able to expand or enhance human's physical ability. This system allows people to lift or carry heavy loads easily, run faster and jump higher. The exoskeleton that used in the military can provide the soldiers better protection and carries more weapons and equipment. This enables the soldiers more powerful than the "normal" people. The performance of man-machine systems has been greatly enhanced by the exoskeletons with the full use of human intelligence and machines. Table 1.1.1 shows an analogy between the exoskeleton and its biological concepts [1].

Table 1.1.1 The comparisons between the exoskeleton technology and biological concepts [1].

Function	Biological Exoskeleton	Exoskeleton Technology	Application
Support	Supporting the body of the invertebrates.	Supporting physically disabled patient or walking assistance.	Rehabilitation robotics or power amplifier.
Enhancement	Enhancing the power of animals	Strengthening the human operator.	Assistance equipment.
Protection	Protecting the animal's body.	Protecting the human operator.	Automatic armor for a soldier, rescue devices or safe manipulation for the radioactive materials in a nuclear plant.
Sensing and data fusion	Obtaining the information, acting the sensorium.	An interface of the human operator and the environment and making data fusion with information obtained by the human operator	Telerobotic, VR.

Exoskeletons can be classified as "active" or "passive" [2]. Active exoskeleton composed of one or more actuators, such as motors, hydraulic actuators, pneumatic muscles to increase the power of the human body. Instead of using an external power source, passive systems use materials, such as springs or dampers that able to store human motion energy and release it when needed. The exoskeleton is mainly used in the field of medical/rehabilitation. It's supporting role makes the weak, injured or disabled people able to perform various exercises in daily life, such as walking, stair ambulation, sitting and standing up, reaching out and grasping [3]. In addition, the exoskeleton is also designed for military use, to increase the soldier's ability or to carry the upper weight of heavy objects, and so on. The exoskeleton is a man-machine collaboration system that enhances the user's power in different of situations. The exoskeleton system uses a mechanical structure that combines with the exterior of the human body to improve the user's muscle strength.

Basically, the exoskeleton system can be categorized according to muscle strength supporting parts or based on the purpose of muscle strength support as shown in the Figure 1.1.1 below [1].

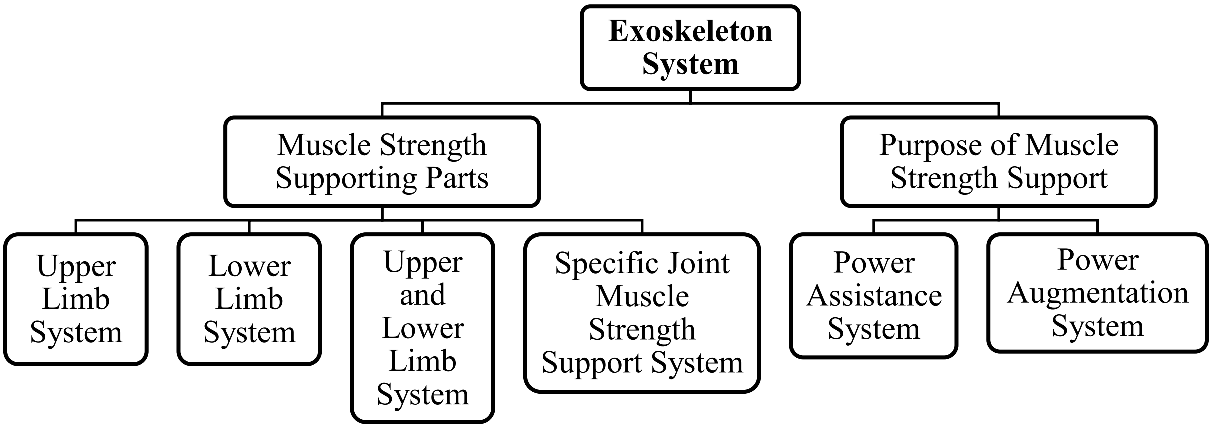

Figure 1.1.1 Classification of exoskeleton system.

The exoskeleton system that classified according to the intent of muscle strength support for can be divided into power assistance and power augmentation. Power assistance system normally use in the exoskeleton that gives aid to the aged, weak or disabled in their daily activities. It is an exoskeleton that assists the human body's power directly and provides user better strength. EKSO and HAL are two different exoskeletons that developed based on the power assistance system. Both of the exoskeletons bestead the user to stand and walk again by providing extra power and support to their muscle. Meantime, power augmentation system able to enlarge the strength of the user, enable the user to handle the task easily by themselves. The EHPA program launched by the DARPA has expedited the development of power augmentation exoskeleton. Hence, HULC, XOS, and HEXAR designed under the same goal, which is offloading the weight of carrying an object, enable the user mobile easily even with heavy loads.

Based on the muscle strength supporting parts, exoskeleton can be categorized into upper limb, lower limb, upper and lower limb and specific joint muscle strength support system. The lower limb exoskeletons involved in three major sectors: tread rehabilitation, locomotion aid, and human strength amplification. An exoskeleton that developed for gait rehabilitation will reduce the weighty trouble that faced by the therapist in the conventional physical therapy, provides a more effective therapy and more comprehensive training. Locomotion-aided exoskeleton enables the immobilized patient to restore the mobility such as stand up, walking, climbing a stair, sit down and so on. Human strength amplification exoskeleton shared the same purpose with the power augmentation exoskeleton that mentioned above. It aimed to promote the muscle capability of human being.

1.2. Problem Statements

Although modern industrial development tends to be automated and mechanized, however, work-related musculoskeletal diseases (WMSDs) still affect most of the industrial workers. Many workers' bodies still suffer from repetitive movements (63%) and awkward body postures such as lifting, carrying weights and trunk flexion and rotation [4], [5] during the materials handling. In WMSD, 30% of the diseases are located in the lower-limb areas [6]. Moreover, although full automation able to solve the problems of WMSD, but in some special conditions, this is not always feasible. For example, in a dynamic manufacturing or warehousing environment, high product mix and smaller order specifications require a high degree of flexibility. In this case, full automation is either not feasible or too expensive. Ever-changing products and tasks required a human being to observe, decide and take appropriate actions within minutes. As a result, workers are still needed in various production activities, such as assembly or material handling, thereby exposing themselves to the risk of WMSD. With the development of knee exoskeleton, problems that faced by the manual handling tasks could be solved. The major advantage of the exoskeleton over any type of robot system is that, in dynamic conditions, the user will fully profit from human's creativity and flexibility and there's no robot programming or teaching lesson is needed.

1.3. Objectives

This project is aimed to design and analyze a passive knee exoskeleton that is suitable for industrial application. The objectives of this study are:

i. To design a knee exoskeleton by using a passive element to reduce the risk of work-related musculoskeletal diseases (WMSDs) and enhance the strength augmentation of the industrial worker.
ii. To quantify the global and local responses of the passive knee exoskeleton.
iii. To obtain the optimized parametric data from the exoskeleton model.

1.4. Scope

i. This project will focus primarily on the design a knee exoskeleton that operates with a passive system.
ii. This passive knee exoskeleton will design for the augmentation for the industrial 's worker in lifting and have the capability to reduce the risk of the workers being exposed to WMSDs.
iii. The kinematic simulation will only conduct on the squat lifting motion.
iv. The payload of the passive knee exoskeleton is 60kg.
v. The output rate of the motion analysis is 100/s with the duration of 1s.
vi. The analysis that carried out to obtain the global response of gas spring is in the form of load versus displacement.
vii. The local response is determined by study the relationship of stress and strain in the critical region on the gas spring.
viii. The element size for the linear static analysis is 0.1m.
ix. The physical prototyping, manufacturing, costing and marketing of the passive knee exoskeleton will not be discussed in this project.

1.5. Organization

The organization of this project is as follows:

Chapter 2 reviews the previous researches or studies that have done on the trend of the passive exoskeleton, biomechanics of knee, the mechanism of passive exoskeleton and the prior art of passive knee exoskeleton.

Chapter 3 devotes to the approaches such as model CAD design via SolidWorks, concept selection with Weighted Rating Method, kinematics critical motion simulation using Blender software followed by inverse dynamics analysis and parametric study for the design optimization in Solidthinking software to achieve the objectives of the project.

Chapter 4 presents the detailed simulation studies for the kinematic simulation and inverse dynamic analysis that carried out on the passive knee exoskeleton model, human model, and man-machine model. The parametric studies and optimization of the passive knee exoskeleton design are also stated in this chapter.

Chapter 5 concludes the findings of this project and discuss the future study that can be carried out on this passive knee exoskeleton.

1.6. Gantt Chart

No	Task	Week																												
		PSM 1														PSM 2														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic selection																													
2	Journal research																													
3	Preparation of Chapter 1																													
4	Preparation of Chapter 2																													
5	Preparation of Chapter 3																													
6	Submission of progress form and turnitin report 1 (Draft)																													
7	Submission of comb-binded report, warning letter, turnitin report 1 (Final)																													
8	FYP 1 Presentation																													
9	Preparation of Chapter 4																													
10	Preparation of Chapter 5																													
11	Submission of progress form and turnitin report 2 (Draft)																													
12	Submission of comb-binded report, warning letter, turnitin report 2 (Final)																													
13	FYP 2 Presentation																													