Faculty of Mechanical and Manufacturing Engineering Technology

DESIGN AND ANALYSIS OF PASSIVE SHOULDER EXOSKELETON

Grace Ling Kian Hwai

Bachelor's Degree in Manufacturing Engineering Technology (Product Design) with Honours

2018

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GRACE LING KIAN HWAI

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

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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Sesi Pengajian: 2018/19

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DEDICATION

This researched study is dedicated to my beloved parents, my sister and my friends who always motivate me to complete my researched study at University Technical Malaysia Malacca (UTeM).

ABSTRACT

Exoskeleton system represents a human-robot cooperation system which attached externally to the human body to enhance the human's power. The existence of exoskeleton has a great impact on decreasing the rate of injuries in the industry especially the shoulder part. This is due to most of the operation in the industry required the upper limb movement, for example, lifting up the loads to a place that above the horizontal plane of the shoulder. However, these technologies have yet to make a significant impact or yet to be applied in industrial purpose due to the complex control requirements, the heaviness, and the prohibitive cost of the powered device. Thus, this paper focuses on the design of a passive shoulder exoskeleton mechanism for the flexion (90˚, 120˚, 150˚) of upper limb to eliminate the complex control requirement. As a result, gas spring is proposed as the mechanism implemented in the design as it has higher ability to against gravitational force and is more reliable than the conventional spring. The function of the device is optimized by relocating the gas spring to the side part of the device and the overall weight of the device is about 1.7kg which had achieved the ideal weight of less than 5kg to increase the overall performance. Furthermore, the analysis on the effects of the designed exoskeleton on the shoulder movement is studied from solidThinking. From the study, gas spring will accelerate more when force is applied showed the device exerted more force to act upon the force applied and thus helped in reducing the force acted on the shoulder part. The simulation test is also carried out to determine the critical stress region which in this study, the critical region is on the fillet region on Arm Length Holder – a part from the device. The purpose of carried out the simulation test is to optimize the part in future to extend the life span of the device. It is expected that the mechanism under development will aid in reducing the force applied on shoulder part to reduce the fatigue happened on shoulder part during lifting load in industrial.

ABSTRAK

Sistem *Exoskeleton* merupakan satu sistem kerjasama antara robot dan manusia dan ia dilekat secara luaran ke tubuh badan manusia untuk meningkatkan kuasa manusia. Kewujudan *exoskeleton* mengakibatkan kadar kecederaan dalam industri terutamanya pada bahagian bahu menurun secara mendadak. Hal ini disebabkan kebanyakan tugasan dalam industri memerlukan pergerakan bahagian atas tubuh badan, contohnya, mengangkat beban atas paras bahu. Walau bagaimanapun, teknologi ini masih belum memberi impak besar atau belum digunakan dalam tujuan perindustrian disebabkan oleh keperluan pengawalan yang kompleks, berat, dan kos yang tinggi. Oleh itu, tesis ini bertumpu kepada reka bentuk mekanisme *exoskeleton* bahu bersifat pasif yang bergerak secara *flexion* (90˚, 120˚, 150˚) untuk mengecualikan keperluan pengawalan yang kompleks. Hasilannya, *gas spring* telah dicadangkan dalam mereka bentuk peranti ini kerana ia mempunyai keupayaan untuk melawan daya graviti dan tahap kebolehpercayaan yang lebih tinggi daripada konvensional *spring*. Fungsi peranti dioptimumkan dengan memindahkan *gas spring* ke sisi peranti dan keberatan keseluruhan peranti adalah kira-kira 1.7kg telah mencapai keberatan *ideal* iaitu kurang daripada 5kg untuk meningkatkan prestasi keseluruhan. Tambahan pula, analisis mengenai kesan *exoskeleton* pada pergerakan bahu dikaji dalam *solidThinking*. Daripada kajian itu, daya yang diaplikasikan akan mempercepatkan pergerakan *gas spring*. Hal ini disebabkan peranti telah mengeluarkan kuasa berlebihan untuk bertindak atas daya yang diaplikasikan dan dengan itu membantu mengurangkan kesan negatif yang bertindak pada bahagian bahu. Ujian simulasi juga dijalankan untuk menentukan rantau tekanan kritikal. Dalam kajian ini, rantauan kritikal adalah pada rantauan *fillet* pada bahagian Pemegang Lengan Panjang iaitu salah satu bahagian daripada peranti. Tujuan menjalankan ujian simulasi ini adalah untuk mengoptimumkan bahagian tersebut supaya dapat menambahkan tempoh kebolehgunaan peranti tersebut. Akhirnya, berharap mekanisme ini dapat membantu mengurangkan tekanan dikenakan pada bahagian bahu supaya dapat mengurangkan keletihan ketika mengangkat beban di industri.

ACKNOWLEDGEMENT

First and foremost, I would like to thank God Almighty for giving me the strength, knowledge, ability and opportunity to undertake this final year project and to persevere and complete it on time. Thank Him to be the guidance of my way and give me strength when I am weak. Without His blessings, this achievement would not have been possible. All Glory to God!

Furthermore, I would like to take this opportunity to express my sincere gratitude to my supervisor, Dr. Ismail Bin Abu Shah from the Faculty of Engineering Technology, University Technical Malaysia Malacca (UTeM) for his guidance, supervision, suggestions and support towards the process of this final year project report.

Besides that, I would also like to send my gratitude to Mr. Hassan Bin Attan and Dr. Amir Hamzah Bin Abdul Rasid for evaluating my final year project. Valuable inputs suggested during the presentation of FYP 1 is used as idea and guidance to improve my final year project.

In addition, I would like to thank Faculty of Engineering Technology (FTK), University Technical Malaysia Malacca (UTeM), all the technicians, and staff in charged for giving a full support and allows me to utilize the facilities equipment's in which are available in laboratories.

Last but not least, I would like to send my greatest appreciation to my family, course mates, housemates, and friends especially my friends who undertaken the similar title of FYP, Ms. Chong Peh Han and Ms. Phoebe Hee Kar Cheng for their continual encouragement, recognition, and support over long months during the preparation of this project. We go through the up and down together, plan and discuss together, solve the problems together, and stay up late together. Without them, I will not able to complete this FYP on time. In sincerely, thank you for being my partner for this FYP.

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LIST OF ABBREVIATIONS

3D	3-Dimensional
CAD	Computer Aided Design
DoF	Degree of Freedom
ENH	Enhancement Purpose
FEA	Finite Element Analysis
FBE	Full Body Exoskeleton
ICR	Instantaneous Centre of Rotation
IND	Industrial Purpose
LLE	Lower Limb Exoskeleton
MED	Medical Purpose
PASS	Passive Actuation
ULE	Upper Limb Exoskeleton
USA	United States of America
UTeM	University of Malaysia Malacca

LIST OF SYMBOLS

Cc	Critical damping coefficient in Ns/m
k	Stiffness of oscillated body or the constant factor characteristic of the spring
m	Mass of body (gas spring) in kg

CHAPTER 1

INTRODUCTION

1.0 Introduction

Exoskeleton system represents a human-robot cooperation system which displayed in mechanical structure and attached externally to the human body to enhance the muscular power of the human operator. It enhances the human's power through the robot's artificial intelligence. Since the 1890s, the studies on exoskeleton are carried out rapidly by USA, Japan, Korea and Europe and the trend continues with various applications in various industries. [1]

1.1 Background of Study

Refer to Collins, 2015, exoskeleton is defined as the protective or supportive structure which covered the outside body of living things such as the thick cuticle of anthropoids [2]. In other words, exoskeleton can be defined as a mechatronic system that is wearable and enables direct transfer of mechanical power and exchange of information through a physical interface (Rocon, 2007).

The existence of exoskeleton can deal back to the late 19th and the early 20th century which researched for applications in various fields including military, medicine, rehabilitation, industry, and enhancement. The first concept of the exoskeleton was developed by N. Yagn [3] who proposed a kind of apparatus aided in walking, running and jumping. The revolution of the exoskeleton is continuously and the development of exoskeleton is as shown in Figure 1.1.

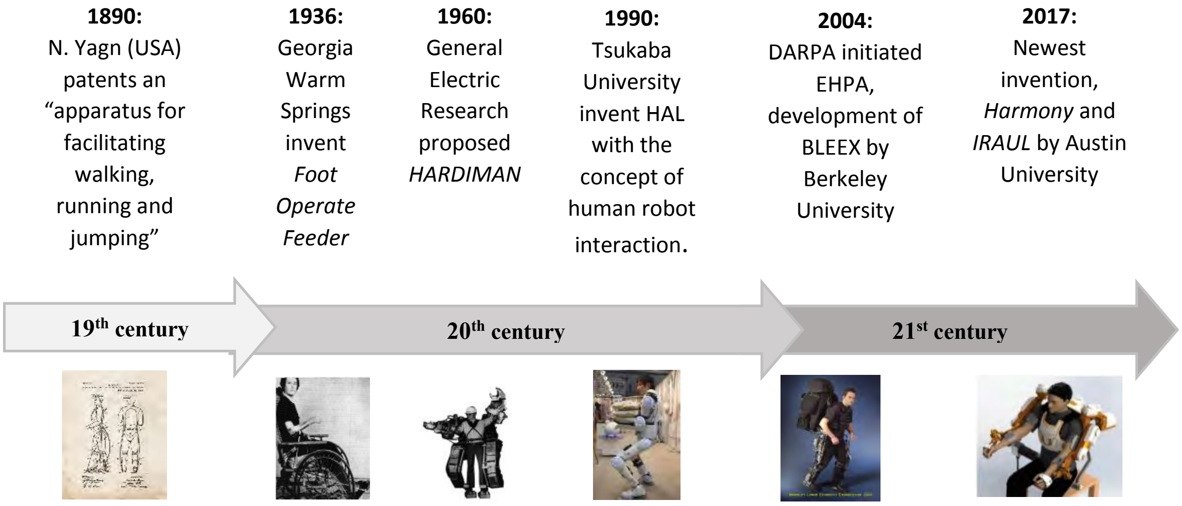

Figure 1.1 *The Development of Exoskeleton.*

The Exoskeleton development shows how's the wearable robot suit makes full use of the human intelligence and the power of the machine to greatly enhance the performance of the human-robot system in the different field. Table 1.1 explains some analogies between the exoskeleton in the man–machine system and its concept in biology.

Table 1.1 *The Comparison Between the Exoskeleton in Term of Technology and Biology.* [4]

Function	Biological Exoskeleton	Exoskeleton Technology	Application
Enhancement	Enhancing the power of living things	Strengthen the human operator	Assistance equipment
Protection	Protecting the living things' body	Protect the human operator	Automatic armour for the soldier, rescue devices or safe manipulation for the radioactive materials in the nuclear plant

Sensing and Data Fusion	Obtain the information, act at the sensorium	Interface of the human operator and the environment and making data fusion with information obtained by the human operator	Telerobotics, VR
Support	As a supportive system of the invertebrates	Support physically disabled patient or walking assistance	Rehabilitation robotics or power amplifier

Exoskeleton technology enhances, extends, complements human's capability. It also can substitute to replace the non-functional body part of human's body. According to [5], there are three major functions of the exoskeleton in the cooperation with the human: (1) Empowering robotic exoskeleton; (2) Orthotic robots; and (3) Prosthetic robots.

Empowering robotic exoskeletons is also known as extenders at the early age. From [6], this kind of exoskeleton enhances the human's hand power which breaks through the limit of human ability while human maintain as the main controller. The point is that the structure of exoskeleton can match perfectly with the anatomy of a human. Figure 1.11 shows the wearable empowering robotic exoskeleton.

Orthotic robots, which also can map with the human anatomy are purposely designed to restore lost or weak functions of the wearer body's part to function normally.

Prosthetic robots is designed in the electromechanical system which can replace the limbs after amputation. The function of robots is close to human's function due to the robotics technologies in terms of human-robot interaction (comprising sensing and control) and actuation. Figure 1.12 shows the different types of wearable orthotic and prosthetic robots.

Figure 1.11 *Wearable Robots (1): lower limb empowering robotic exoskeleton.*

Figure 1.12 *Wearable Robots (2): (top and bottom left) orthotic exoskeletons; (top and bottom right) prosthetic robot.*

1.2 Problem Statements

The high injuries rates in the industry are caused by applying a large force to carry out a specific task such as lifting a heavy load, equip and assembly processes by using only manpower without any assisting machine for a long period of time. The existence of exoskeleton has a great impact on decreasing the rate of injuries in industry. However, this technologies have yet to make a significant impact or yet to being applied for industrial purpose. This occurred due to the complex control requirements, the heaviness, and the prohibitive cost of a powered device. Therefore, this study is to design a passive shoulder exoskeleton which is also known as non-actuator wearable robots for the shoulder.

1.3 Objectives

The objectives of this study are:

- To establish a design mechanism for passive shoulder exoskeleton.
- To analyse the effects of exoskeleton on the shoulder movement.
- To carry out simulation test.
- To optimize the ergonomic design parameters.

1.4 Scope of Study

- The mechanism of passive shoulder exoskeleton (gas spring) with no active actuators used.
- Comparison of two passive actuators (spring and gas spring) to outcome a better exoskeleton design by weighted rating method.
- Identified the most suitable types and characteristics of component (gas spring) used in the design of passive shoulder exoskeleton.
- Use of S Type Load Cell to obtain the force acted on the shoulder part.
- Develop the 3D model using SolidWorks software.
- Suitable anthropometry data of Malaysian (male) with age 20 - 25, height 165cm - 180cm and 65kg - 80kg for the design of passive shoulder exoskeleton is obtained based on the reference on the journal.
- Human – machine interaction only focus on the shoulder movement at flexion posture for 90,120 and 150 degree.
- The analysis on the effects of force on the shoulder exoskeleton for flexion posture.
- The simulation of exoskeleton motion based on the shoulder motion in flexion posture using Inspire software (solidthinking).
- Simulation test of FEA in solidThinking software mainly focus on stress analysis on the shoulder exoskeleton design.
- Maximize the function of the design by determine the location of the component.
- The optimization of the design will not include in this study after the identification of maximum stress region on the design.

1.5 Structure of Study

The present work is articulated as follows.

- In the next chapter, Chapter 2, an exhaustive review on the development of passive shoulder exoskeleton, the kinematic and rotation of the shoulder, the comparison on the lifting force with and without exoskeleton and the components in order to design exoskeleton will be presented.
- In Chapter 3, a brief explanation on the methodology to design the exoskeleton included the design specification, develop of the conceptual design, method to obtain the data required (anthropometry data, force applied on shoulder, characteristic of gas spring, etc.), the design process, the method to carry out and study the human-robot interaction and lastly the simulation test on the highest stress region is included.
- In Chapter 4, it will included the presentation of the simulation result and the discussion on the result.
- In last chapter, Chapter 5, the conclusion of the overall study and the suggestion for future studies is written.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter will present a review of the mechanical solutions to be used in the passive exoskeleton. The first subsection will have a brief on the classification of the exoskeleton. The second will go through the trend of the passive exoskeleton, the third subsection will generally discuss the shoulder motion, the Degree of Freedom (DoF) in the shoulder joint and the force acted on the shoulder (with or without exoskeleton) during a different situation of carrying the load. Lastly, the components involved in designing a passive shoulder exoskeleton is discussed.

2.1 Exoskeleton Classification

Exoskeleton can be classified as shown in Figure 2.1, one of them is exoskeleton mechanism structures or mechanism architecture which can be branched into the anthropomorphic type (exoskeleton joint's rotation axis and human joint's rotation axis is align); the quasi-anthropomorphic type (exoskeleton and human joint function similarly); and the non-anthropomorphic type (exoskeleton and human joint is not aligned). Another exoskeleton mechanism: joint mechanism can be classified into active, passive and quasi-passive joints. Active joint need actuators but passive joint which need no actuators to function. The passive joint is lighter which contain energy-storing devices with elasticity or viscosity such as clutches, dampers, or springs as compared to an active joint which generally contains motor as the actuator to function. The third method of classification is supported part. Exoskeleton can be grouped into 3 major supported part which are lower limb exoskeleton, upper limb exoskeleton, and whole body exoskeleton. The more details on each classification will be discussed later in each subsection. [1]