

**DEVELOPMENT OF A CONTROLLER FOR AN EXOSKELETON ARM
MOVEMENT**

WAN MOHAMMED BADRUL AMIN BIN WAN ABDULLAH



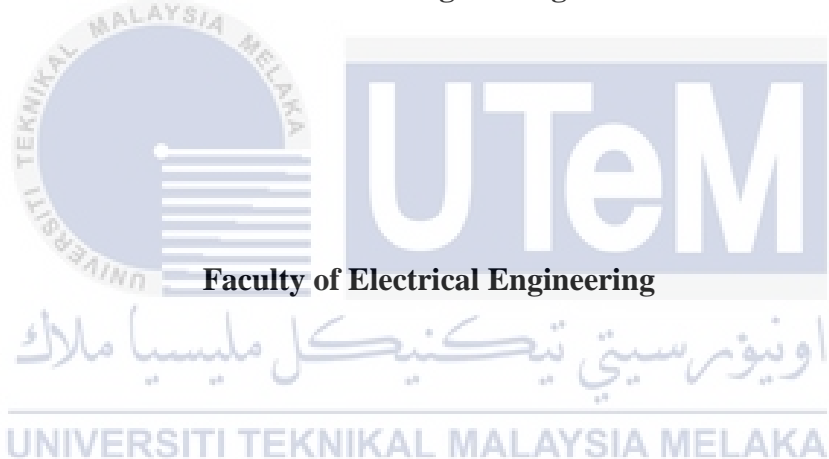
**BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

2021

**DEVELOPMENT OF A CONTROLLER FOR AN EXOSKELETON ARM
MOVEMENT**

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**A report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering with Honours**



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I hereby declare that this paper, entitled 'DEVELOPMENT OF A CONTROLLER FOR AN EXOSKELETON ARM MOVEMENT,' is the result of my own study, except as referenced above. The study has not been approved for any degree and is not submitted at the same time as an applicant for any other degree.

Signature



Name

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3 JULY 2021

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APPROVAL

I hereby declare that I have reviewed this study entitled 'DEVELOPMENT OF A CONTROLLER FOR AN EXOSKELETON ARM MOVEMENT' and that, in my view, this report is in partial accordance with the award of the Bachelor of Electrical Engineering with Honours.

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DEDICATIONS

To my beloved mother and father, who are always helping me to carry out my project and, thanks to them, I can finish the final year of my project.



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First and foremost, during my research to successfully complete the project for the final year, praise and appreciation to the Almighty God for His showers of blessings.

I would like to express my deep and sincere appreciation for giving me the opportunity to do this project and for providing invaluable guidance during this project to my supervisor, Dr. Hyreil Anuar Bin Haji Kasdirin. I was influenced deeply by his dynamism, vision, authenticity and motivation. He taught me the strategies for performing the study and presenting the test work as easily as possible. It was a great pleasure and honor, under his guidance, to work and learn. I am deeply grateful for what he has given me. I want to thank him, too, for his friendship, his empathy and his wonderful sense of humor. During the debate I had with him on research work and report preparation to his wife, family for their acceptance and patience, I extend my heartfelt thanks.

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Finally, my thanks go to all the individuals who have helped me directly or indirectly to finish the final year project. Their tips and suggestions are also useful. Unfortunately, it is not possible in this small room to list all of them. To all the members of my family, I am grateful.

ABSTRACT

The use of robotics had not yet been extensively studied in stroke patient rehabilitation. Stroke patients and people with disabilities had trouble performing their everyday operations without their fingertips. In order to recover from their illnesses, stroke patients often take a long time. In order to solve the problem, three objectives need to be achieved in this project which were to design the exoskeleton arm model using SolidWork software, to add a controller into the exoskeleton arm block diagram and to analyze the movement of the exoskeleton arm using the same degree of movement as real human arm. These ideas were still being commercialized since the system needs to be improved and upgraded to make it more accessible to impaired persons. To achieve these objectives, four things needed to be considered in the literature review which are hand design specification, mechanical design for hand exoskeleton device, PID controller and the tuning method of the PID controller. The designed of exoskeleton arm was based on a real arm which had two degree of freedom (DoF) such as shoulder joint and elbow joint. The exoskeleton arm model was designed using SolidWorks. Then, the design file will be extracted from SolidWorks into MATLAB-Simulink. The block diagram of exoskeleton arm model will be simulated using MATLAB-Simulink. The PID controller will be added into the exoskeleton block diagram in order to control the movement of the arm. The human arm movement was analyzed based on the output performance of the PID controller. The PID controller is tuned by using the MATLAB Autotuning method. The output result on based on the transient response which the exoskeleton arm was able to put its hand ups in stable condition such as a real human raising thier hand up. The future works for this project for this project are added more degree of freedom at the arm exoskeleton model, add load for the exoskeleton arm such as at wrist when the exoskeleton arm is moving and add another controller such Fuzzy Logic controller and do the comparison with PID controller and decide which one would produce a better result. Based on the software that been used which is MATLAB version 2015b, the project be be improved by using newer version MATLAB that may contains new improvements and features.

ABSTRAK

Penggunaan robotik belum banyak dipelajari dalam pemulihan pesakit strok. Pesakit strok dan orang kurang upaya menghadapi masalah untuk melakukan operasi seharian tanpa hujung jari mereka. Untuk pulih dari penyakitnya, pesakit strok sering memerlukan masa yang lama. Untuk menyelesaikan masalah tersebut, tiga objektif perlu dicapai dalam projek ini iaitu merancang model lengan exoskeleton menggunakan perisian SolidWork, menambahkan alat kawalan ke dalam rajah blok lengan exoskeleton dan menganalisis pergerakan lengan exoskeleton menggunakan yang sama tahap pergerakan sebagai lengan manusia yang sebenar. Idea-idea ini masih dikomersialkan kerana sistem ini perlu diperbaiki dan ditingkatkan untuk menjadikannya lebih mudah diakses oleh mereka yang cacat. Untuk mencapai objektif ini, empat perkara perlu dipertimbangkan dalam tinjauan literatur iaitu spesifikasi reka bentuk tangan, reka bentuk mekanikal untuk peranti exoskeleton tangan, pengawal PID dan kaedah penalaan pengawal PID. Reka bentuk lengan exoskeleton didasarkan pada lengan sebenar yang mempunyai dua darjah kebebasan (DoF) seperti sendi bahu dan sendi siku. Model lengan exoskeleton dirancang menggunakan SolidWorks. Kemudian, fail reka bentuk akan diekstrak dari SolidWorks ke dalam MATLAB-Simulink. Gambarajah blok model lengan exoskeleton akan disimulasikan menggunakan MATLAB-Simulink. Pengawal PID akan ditambahkan ke dalam rajah blok exoskeleton untuk mengawal pergerakan lengan. Pergerakan lengan manusia dianalisis berdasarkan prestasi output pengawal PID. Pengawal PID ditala dengan menggunakan kaedah MATLAB Autotuning. Hasilnya didasarkan pada tindak balas sementara yang mana lengan exoskeleton dapat meletakkan tangannya dalam keadaan stabil seperti manusia yang benar-benar mengangkat tangan mereka. Kerja masa depan untuk projek ini untuk projek ini ditambahkan lebih banyak tahap kebebasan pada model exoskeleton lengan, tambah beban untuk lengan exoskeleton seperti di pergelangan tangan ketika lengan exoskeleton bergerak dan tambahkan pengawal lain seperti pengawal Fuzzy Logic dan lakukan perbandingan dengan Pengawal PID dan tentukan mana yang akan menghasilkan hasil yang lebih baik. Berdasarkan perisian yang telah digunakan yaitu MATLAB versi 2015b, projek ini akan diperbaiki dengan menggunakan MATLAB versi yang lebih baru yang mungkin mengandungi peningkatan dan fitur baru.

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LIST OF SYMBOLS AND ABBREVIATIONS

DoF	-	Degree of Freedom
P	-	Propotional
I	-	Integral
D	-	Derivative
CVA	-	Cerebrovascular
MCP	-	Metacarpophalangeal
PIP	-	Proximal Interphalangeal
EEG	-	Electroencephalography



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CHAPTER 1

INTRODUCTION

1.1 Background

Stroke is basically the leading cause of morbidity and mortality, as well as the most common cause of injury. It is estimated that 40 percent of stroke patients with acute arm injury are either chronically or permanently affected, according to the study[1].

The purpose for this project is to develop an exoskeleton arm and its controller. For the developing of the exoskeleton arm model, SolidWorks is used to design the arm model part by part. Meanwhile, the controller will be develop using MATLAB-Simulink and will be insert into the exoskeleton arm model block diagram. The controller will be used to control the movement of arm and the transient response will be recorded.

1.2 Problem Statement

Basically, a handicap person is mostly unable to move their hands due to injury or something else. A control system with an exoskeleton arm as a designed model can perform the movement that has been set for their task. However, how the control system can perform their task that is comparable with actual human movement.

1.3 Motivation

A stroke happens when the blockage or bleeding of the blood vessels either interrupts the flow of blood to the brain or decreases it[2]. The brain does not obtain enough oxygen or nutrients as this occurs, and brain cells start to die. It's a medical emergency here. Some can lead to paralysis or death, while many strokes are treatable. Cerebrovascular injuries (CVA) or generally referred to as strokes have been a leading cause of serious disability over the past few decades, affecting 15 million people worldwide each year. Although patients with stroke can recover their motor functions through proper rehabilitation, traditional interdisciplinary stroke rehabilitation care is labor-intensive because it often includes manual one-on-one interaction with physiotherapists who support and motivate the patient through repetitive exercises. For stroke recovery, rehabilitation robots are increasingly becoming common because they can support, strengthen and further measure rehabilitation training for stroke patients.

One of the rehabilitation techniques for enhancing their movements due to paralysis due to stroke is the Exoskeleton hand model[3]. The therapy exoskeleton robot is increasingly being used in the implementation of rehabilitation training to support stroke patients. This exoskeleton hand robot rehabilitation system consists primarily of an exoskeleton hand robot, an EEG system, a motor control unit, several sensors and a workstation. And for the patients doing home rehabilitation training, the hand exoskeleton mechanism was compact, wearable and customizable. Up until now, after years of research and development, the exoskeleton rehabilitation hand robot had achieved some milestones, and robots that were studied by some institutions were primarily used in clinics and hospitals.

In order to compare the movement of exoskeleton arm and a real human arm, the degree of movement has been set at the joints which are shoulder and elbow.

1.4 Objectives

The objectives of this project are:

- a) To create an exoskeleton arm model by using a software called SolidWorks.
- b) To add a PID controller into the block diagram of exoskeleton arm model.
- c) To analyze the movement of exoskeleton arm model using the same degree as human arm.

1.5 Scope

There are a few aspects of the project that have been suggested to meet the specified purpose of the project. To achieve reliable results, this project includes studies of control systems and their implementation on robotic arms.

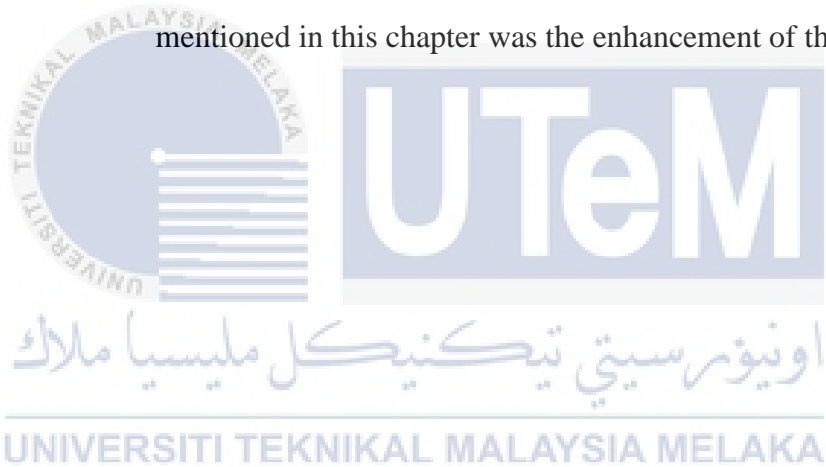
The scopes are:

- a) Create an exoskeleton arm model using SolidWorks 2018.
- b) Adding a PID controller into the block diagram of exoskeleton arm model using MATLAB-Simulink version 2015b.
- c) Prove the movement of exoskeleton arm model using the same degree of movement as a real human arm.

1.6 Organization of Thesis

As below, the organization of this study is illustrated,

- a) Chapter 2, Literature Review: The topic will cover the previous and current work or study in this chapter to gain an understanding and awareness of the progress of the project.
- b) Chapter 3, Methodology: The description of the entire project and the flow chart for the project are covered in this chapter.
- c) Chapter 4, Result and Discussion: This chapter shows the outcome of the design model simulation and addresses the findings that have been obtained.
- d) Chapter 5, Conclusion: This chapter concluded all project data and showed whether or not the targets were accomplished. Also mentioned in this chapter was the enhancement of this project.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is basically written with the support of the trusted data, such as article, journal and conference. The topic will be discussed in this chapter is the development of controller for an exoskeleton model. This chapter will be explained about the progress of the model's architecture and automation.

2.2 Hand Design Specifications

The most important linkage that needed improvement was the middle link (orange link in figure 1) which determined the distance between the MCP and PIP joints of all four fingers[4].

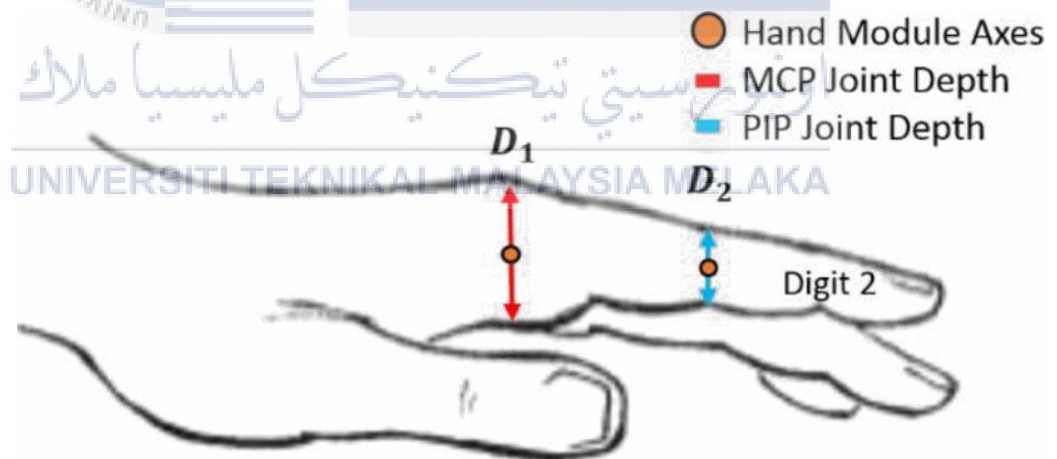


Figure 1: Side view of the hand display[4]

Denoted variable L in figure 2 and table 1, the new length range for this link was obtained from a single biomechanical study on cadavers. Unfortunately, this was the only source found with relevant information and the data collected was from a small population of 15 subjects[4]

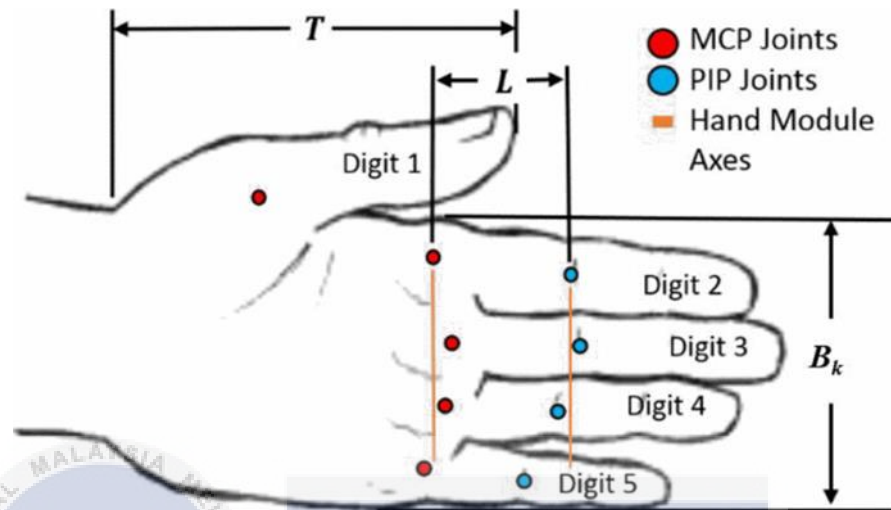


Figure 2: Top view of the hand depicting relevant joint locations[4]

Table 1: Hand and thumb dimension[4]

Measure	Mean \pm SD	5 th	50 th	95 th
L	48.74 \pm 5.77	30.80	48.74	66.60
D_1	30.22 \pm 2.79	26.41	30.22	34.80
D_2	18.54 \pm 1.78	15.75	18.54	21.34
B_k	78.65 \pm 7.16	66.75	78.65	90.52
T	93.22 \pm 12.45	72.77	93.22	113.7

*All dimensions in millimeters (mm).

2.3 Optimization Algorithm

A numerical optimization method determines the shape and dimensions of a mechanism capable of best replicating the recorded trajectory. Due to the complexity and non-differentiability of the objective function, a direct search optimization method was chosen for the optimization algorithm selection.

A collision between the finger and the mechanism during the use of the exoskeleton are avoided through the constrains implemented within the optimization process. The kinematic design of the tailored exoskeleton in this scenario has a maximum height of 30 mm from the finger, with the length dictated by the finger's diameter. Figure 3 reports the trajectories of the points A, B, C, D, E of the exoskeleton[5].

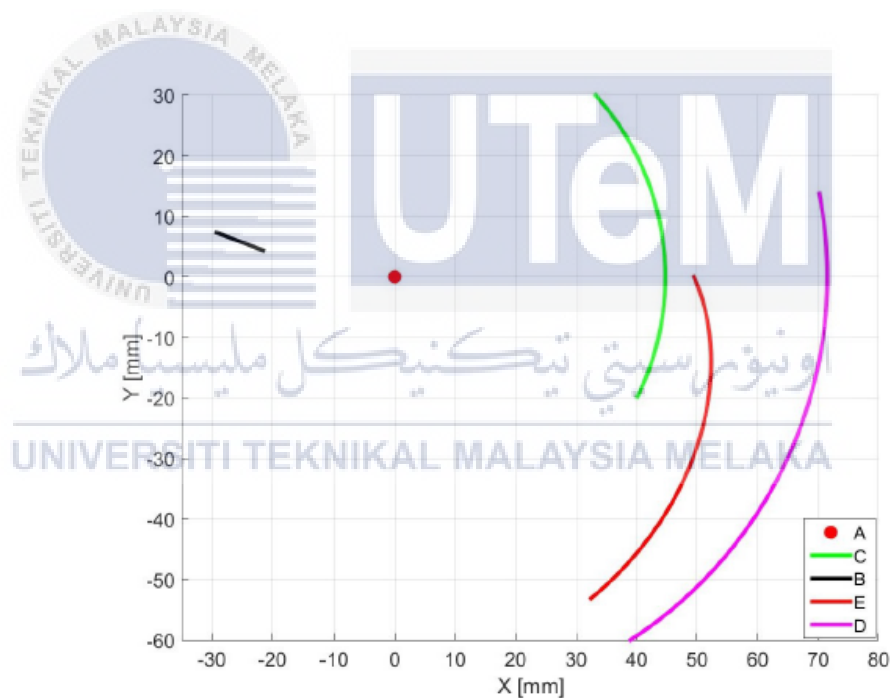


Figure 3: Trajectories of the points A, B, C, D, E of the exoskeleton[5]

2.4 Mechanical Design for Hand Exoskeleton Device

According to clinical study, patients' paralysis upper limbs are recovering from shoulder paralysis, followed by upper arm and finger function recovery. The active degree of the finger joint is frequently regarded by therapists as a recovery marker of whole-arm motion function. The active degree of the finger joint is frequently considered by therapists as a recovery indicator of whole-arm motion function in general. The upper limb exoskeleton rehabilitation equipment, on the other hand, is unable to acquire finger mobility. The hand exoskeleton is thus constructed using the ULERD. The virtual prototype is shown in figure 4 below [6].

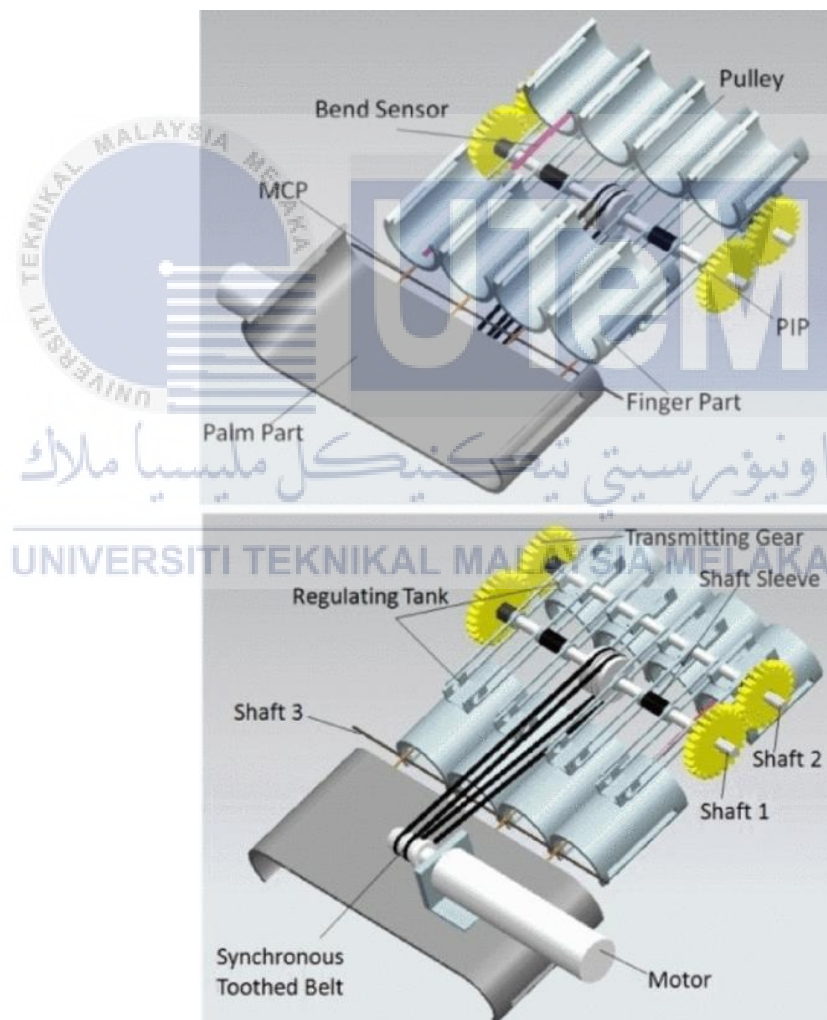


Figure 4: Drawing of the virtual prototype of hand[6]

2.5 Mechanical Design and Virtual Prototype Realization

There are currently two main modelling methods for robot simulation which are mathematical and solid models. The Lagrange method is used extensively in the mathematical model. It is possible to realise the solid model. Multibody cosimulation with SolidWorks, UG/NX, ADAMS, or Simscape, and the latter way is becoming increasingly prevalent as well as being widely accepted. The physiological structure of the human upper limb is depicted in figure 5, which indicates that the human upper limb has 9 degrees of freedom, two joints in the pectoral girdle and seven joints in the free upper limb[7].

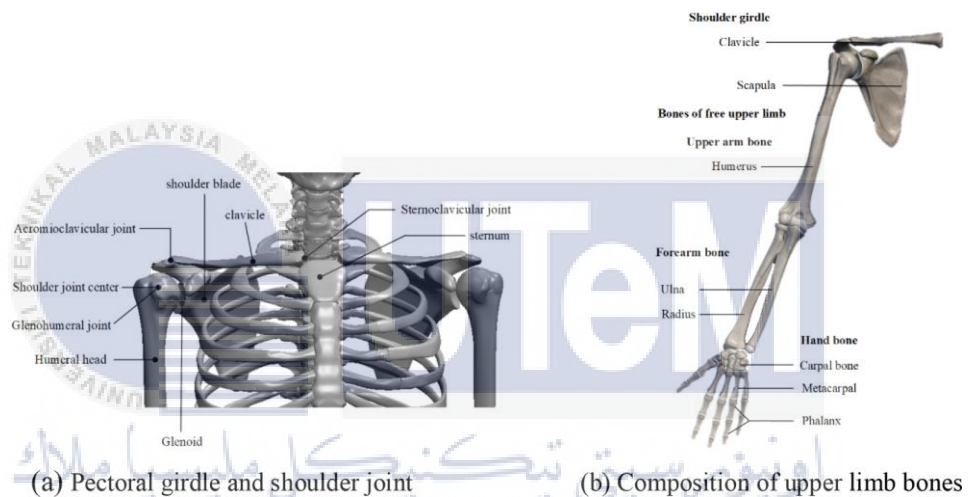


Figure 5: Human upper limb physiology with Anatomy 3D Atlas[7]

The mobility limits of each joint are listed in table 2 based on the physiological parameters of the human body. The movements of extension/flexion, adduction/abduction, and internal rotation/external rotation are represented by the notations E/F, A/A, and I/E, respectively[7].

Table 2: The DOF distribution and motion range($^{\circ}$)[7]

Num	Joint DOF	Physiological range	ADL range	Design range
1	Shoulder F/E	-180/60	-80/30	-120/60
2	Shoulder A/A	-50/180	-15/130	-50/145
3	Shoulder E/I	-90/90	-80/70	-90/80
4	Elbow E/F	-90/50	-90/50	-90/50
5	Forearm I/E	-80/85	-80/85	-80/80
6	Wrist A/A	-40/15	-30/10	-35/15
7	Wrist E/F	-80/90	-60/80	-80/80