# DESIGN AND DEVELOPMENT OF AN ELECTROMYOGRAPHY (EMG) BASED ACTIVE ELBOW ORTHOSIS WITH FEEDBACK CONTROL



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**RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MECHATRONICS ENGINEERING**

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**ORIGINAL LITERARY WORK DECLARATION**

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Name of Degree: Master of Mechatronics Engineering

Title of Research Report: ("Design and Development of an Electromyography (EMG) Based Active Elbow Orthosis With Feedback Control")

Field of Study: Prosthetics and Orthosis

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**DESIGN AND DEVELOPMENT OF AN ELECTROMYOGRAPHY (EMG) BASED ACTIVE ELBOW ORTHOSIS WITH FEEDBACK CONTROL**

## ABSTRACT

The project presents the design and development of an electromyography based active elbow orthosis for self-rehabilitation of post stroke patients or patients with elbow injuries. The elbow could lose its functionality as a result of multiple reasons however Humans depend on their elbow and the hand as a whole to carry out various activities of everyday life. Rehabilitation by physiotherapist is the traditional method to regain elbow functionality but it requires the patient to travel frequently to the hospital and the extra cost of consulting a physiotherapist. This gave rise to the need for developing an elbow orthosis which can be used for self-therapy, eliminating the cost and stress of visiting a physiotherapist. The active orthosis measures the patient's activity using Electromyography and the electrical signal obtained from this sensor is used to control the actuator that drives the orthosis. The orthosis is battery-powered with an active range of 60 – 140 degrees. The actuator for the orthosis generates a torque of 2.9Nm and the frame is made of light-weight thermoplastic polypropylene. The device was tested on five different subjects to determine the performance of the device in helping to flex and extend the patient's elbows. The range of movement of the joint when the subject was not wearing the orthosis and when the subject was wearing the orthosis was recorded using Kinovea software and the joint angle movement was thus calculated and compared. The analysis of the elbow orthosis using Kinovea software showed that the device is capable of helping in the flexion and extension of the human elbow through the normal ROM.

Keywords: Active elbow orthosis, Self-Rehabilitation, Electromyography

**REKA BENTUK DAN PEMBANGUNAN ELECTROMYOGRAPHY BERDASARKAN AKTIF ORTHOSIS DAN TINDAKAN RANSANGAN**

## ABSTRAK


Projek ini menerangkan ciri-ciri dan proses pembangunan sebuah electromyography berdasarkan siku aktif orthosis bagi proses pemulihan pesakit yang telah mengalami angin ahmar atau kecederaan pada bahagian siku. Bahagian siku yang mengalami kecederaan berisiko untuk tidak berfungsi dengan baik disebabkan pelbagai faktor. Walaubagaimanapun, manusia sememangnya bergantung kepada siku dan keseluruhan tangan untuk melakukan pelbagai aktiviti seharian. Proses pemulihan oleh ahli terapi Adalah kaedah tradisional yang digunakan untuk mengembalikan fungsi pada bahagian siku, namum kaedah ini memerlukan pesakit untuk berulang-alik ke hospital dan mengeluarkan belanja untuk sesi konsultasi bersama ahli terapi terbabit. Justeru, proses siku orthosis sangat diperlukan kerana mampu untuk mengurangkan kos dan juga tekanan berbanding kaedah pemulihan tradisional. Hal ini kerana pesakit boleh melakukan proses terapi sendiri.

Proses orthosis yang aktif mengukur kadar aktiviti pesakit menggunakan electromyography dan isyarat elektrik yang diperolehi daripada pengesan tersebut dan seterusnya digunakan untuk mengawal penggerak yang menggerakkan orthosis. Orthosis tersebut menggunakan dengan kadar aktif purata 60-140 darjah. Penggerak yang terdapat dalam orthosis menghasilkan tenaga putaran 2.9m dan bingkainya diperbuat daripada thermoplastik polypropylene yang ringan. Alat tersebut telah diuji pada lima subjek yang berbeza untuk menentukan keberkesanannya dalam melentur dan memanjangkan siku pesakit. Kadar purata pergerakan sendi apabila subjek tidak memakai orthosis dan apabila subjek memakainya telah direkodkan menggunakan aplikasi Kinovea. Pergerakan sudut sendi dikira dan dibandingkan. Analisa mengenai siku orthosis menggunakan aplikasi

kinovea menunjukkan bahawa alat tersebut mampu membantu dalam pelenturan dan pemanjangan siku manusia melalui ROM biasa.

Keywords: Active elbow orthosis, Self-Rehabilitation, Electromyography

**ACKNOWLEDGEMENTS**

"In the name of Allah, the Most Gracious and Most Merciful"

Alhamdulillah, through His Grace and Mercy I have successfully completed my Research project. I would hereby take this opportunity to thank all the individuals that were involved directly and indirectly in completing my project.

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May Allah s.w.t bless them all and accept all their contributions as an act of Ibadah.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| ABS | : | Acrylonitrile butadiene styrene |
| CAD | : | Computer Aided design |
| DOF | : | Degree of Freedom |
| EMG | : | Electromyography |
| ROM | : | Range of Motion |
| MACCEPA | : | Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator |
| MOSFET | : | Metal Oxide Semiconductor Field Effect Transistor |
| MMG | : | Mechanomyography |
| NEEM | : | NEUROExos-Elbow-Module |
| SEA | : | Series Elastic Actuator |

## LIST OF FORMULAE

$$T = F \times r \tag{3.1}$$

$$\sum F = 0 \tag{3.2}$$

$$\sum T = 0 \tag{3.3}$$

$$(B \times D1) - (G \times D2) - (W \times D3) \tag{3.4}$$

$$G = Weight\ of\ the\ humerus \tag{3.5}$$

## LIST OF APPENDICES

# CHAPTER 1: INTRODUCTION

## 1.1 Overview

Elbow orthosis are externally applied devices to the segments of the arm, particularly around the elbow to help improve or restore function or structural characteristics of affected muscles, joints and tendons.  Some types of elbow orthosis comprise braces, stabilizers, sprints, sleeves and straps. The primary function of the elbow orthosis is to provide low-load, prolonged flexion mobilization force to elbow joint, restrict full elbow extension or flexion or to restrict or prevent forearm rotation.

Electromyography (EMG) is a technique used to measure and record electrical signals that occur from the movement of the muscles. EMG translates electrical signals from the neurons which causes the muscles to contract into graphs, sounds or numerical values that can be easily interpreted. This signals can be used to control the movement of DC motors thereby controlling the movement of the elbow orthosis.

This project involves the development of an active elbow orthosis. The orthosis is automated by using the signals extracted from the EMG sensor as the input to the actuator which in turn moves the orthosis thereby flexing or extending the elbow.

## 1.2 Problem Statement

The main effector of the upper body is the arm. It allows for reaching, grasping and manipulation. Humans depend on the arm for carrying out multiple activities of daily life like eating, picking and placing. The arm consists of the wrist, elbow and shoulder. The loss of functionality of the elbow affects the whole arm thereby limiting the activities a person could perform. Patients with spinal cord injuries depend on the full range motion of the elbow for the movement of the wheelchair to adjust the sitting positions or bring their hand to the face. (Curt, Schwab, & Dietz, 2004)

The elbow could lose its functionality as a result of several reasons. It could be as a result of health problems for example trauma, congenital hand defects, or a disease. Extreme activities or exercises could equally strain the elbow thereby limiting the functionality of the elbow and hands. (Imm, 2014)

To regain elbow functionality, the patient has to go through rehabilitation. The rehabilitation is currently achieved with the use of a passive or static orthosis supervised by a physiotherapist. (Engen, 1976). The downside to these devices is that they passively flex and extend the arm without the patient making use of their muscle hence will not achieve the desired scar tissue breakdown.

Hence the requirement for the development of an active elbow orthosis, to help patients with elbow limitations regain full function of their elbow. The active elbow orthosis incorporates the concept of the passive device to help flex and extend their arms however the movement of the arm in this case would be initiated by the patient. The device uses a sensor system (Electromyography) in measuring the elbow muscular activity of the patient, an actuator in performing the required motion of the actuated part and a control system to control the actuator based on the movement of the patient, current position of the orthosis and other variables. (Březina & Jabloński, 2013). Since the elbow is automated, the need for a physiotherapist is eliminated, hence self-rehabilitation is achieved.

## 1.3 Objectives

i. To design and develop an active elbow orthosis.

ii. To implement electromyography (EMG) to automate the elbow orthosis.

## 1.4 Significance of the project

- To enable self-rehabilitation whereby the stroke patients or patients with elbow injury can exercise their elbows by themselves.

- To reduce or eliminate the cost of a physiotherapist.

- To assist stroke patients and patients with injured elbow to carry out the basic activities of daily life.

- Inexpensive and light weight design.

## 1.5 Scope of study

The scope covers the design of the elbow orthosis using solid works. It includes the development of the design into a solid model and the control of the DC motor movement using Arduino. It equally covers the implementation of EMG to detect the signals from the muscle of the patient which enables the movement of the DC motor in either flexion or extension, hence the automation of the elbow orthosis.

## 1.6 Report outline

This report consists of five chapters which describes the development of a smart elbow orthosis. It elaborates on how the smart elbow orthosis detects the signal from the muscle using electromyography and how the signals are transmitted to the motor to enable flexion and extension of the elbow.

Chapter 1 describes the general idea of this project, a brief definition of the elbow joint, elbow orthosis and electromyography, its problem statements and objectives. It also includes the significance of project, scope of study, methodology and the report outline.

Chapter 2 presents the overview of previous works done by other researchers regarding elbow orthosis and electromyography. It equally describes briefly the anatomy of the elbow joint, its bones, muscles and common injuries of the elbow.

Chapter 3 discusses the hardware development of the of the elbow orthosis which includes selection of components and the bill of materials. It equally explains the use of electromyography in extracting muscle signals from the human arm and using the signal as the input to the actuator to enable flexion and extension.

Chapter 4 analyses the design, the graphs and the result of the prototype of the elbow orthosis

Chapter 5 presents the conclusion, the limitation of study and recommendation for future work.

### 1.7 Methodology

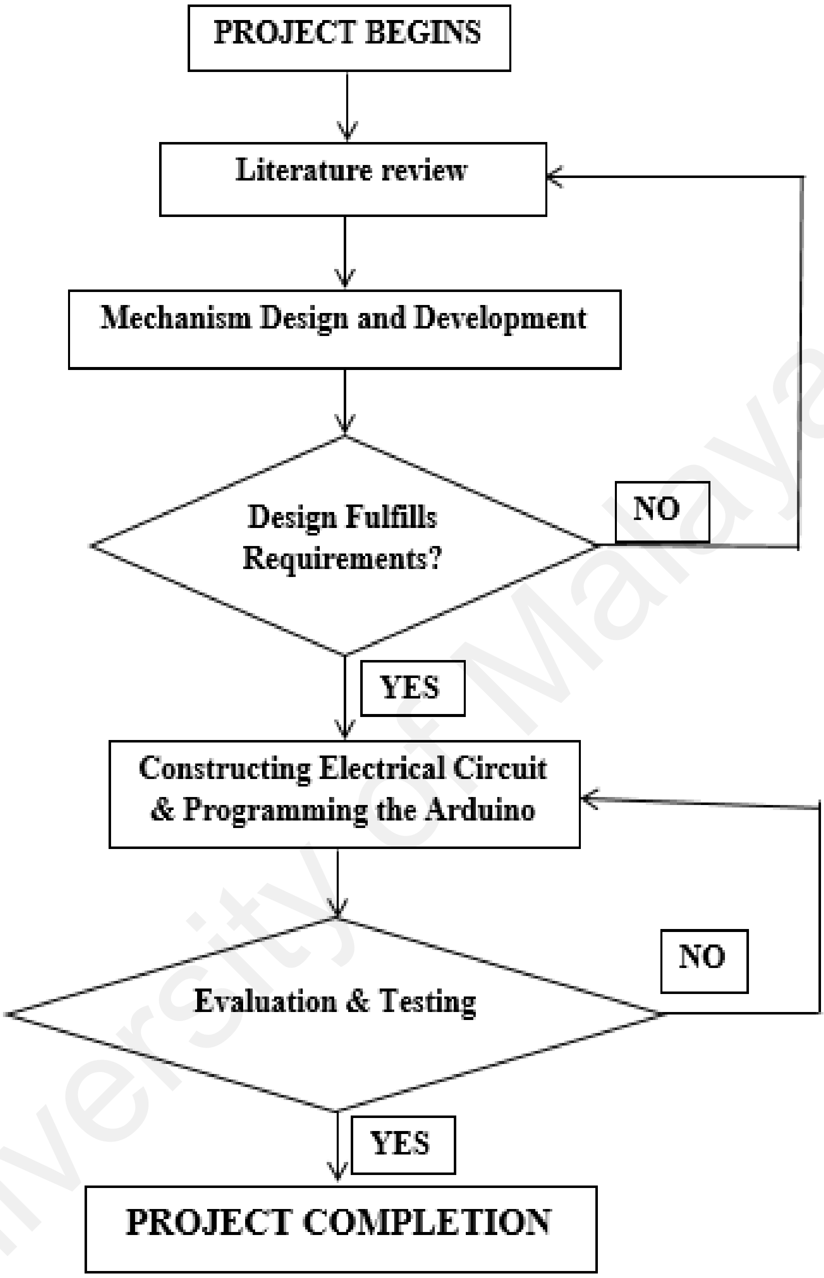


**Figure 1.1: Project Methodology**

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

The chapter entails the description of the anatomy of the human elbow with the review of previous approaches to the design of elbow orthosis.

The elbow joint is a hinge joint allowing for flexion and extension of the forearm with respect to the upper arm. (Jones, 2017). The joint allows for rotation of the forearm. The elbow joint occurs at the junction of the upper arm bone (humerus) and the lower arm bone (radius and ulna).

The three main ligaments of the elbow joint are the Medial Collateral Ligament, Lateral Collateral Ligament and the Annular Ligament while the largest of the muscles of the elbow joint are the biceps brachii, triceps brachii, brachialis, brachioradialis, pronator teres, extensor carpi radialis brevis. The muscles of the arm are responsible for enabling the joint to flex, extend, supinate and pronate. (O'rahilly, Muller, Carpenter, & Swenson, 2008).

The elbow joint is a common site for injuries since multiple muscles passes through the joint. The common injuries of the elbow joint are humeral fracture, elbow dislocation, ligament laxity, post-operative, osteoarthritis, radial and or ulnar Fracture, tendonitis, lateral epicondylitis (tennis elbow), medial epicondylitis (Golfer’s Elbow), fat pad injury. (Imm, 2014).

These injuries causes restriction in the movement of the elbow which could lead to overall loss of elbow functionality due to the inactivity of the muscle. The inactivity of the muscle could lead to fracture or increase in fat mass. To retain the muscle power, rehabilitation in form of physical exercise is necessary. This exercise, usually supervised by a physiotherapist involves the repeated flexion and extension of the elbow to build up the muscle strength thereby preventing inactivity of the muscle.

A smart device which uses a sensor system in measuring patient's activity, an actuator in performing the motion desired and a control system in controlling the actuator based on the activity of the patient is known as an active orthosis. Rehabilitation with the use of an active orthosis is similar the traditional rehabilitation process except that the physiotherapist is been replaced by the orthotic device. (Ripel, Krejsa, & Hrbáček, 2014)

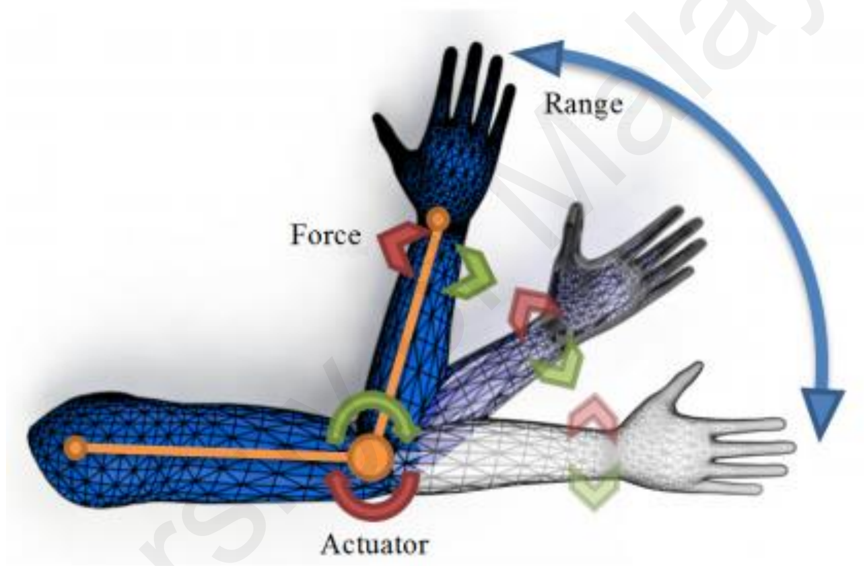


**Figure 2.1: Active orthosis scheme. (Ripel et al., 2014)**

This project presents the development of an active elbow orthosis which uses Electromyography to measure to measure the patient's activity. In the active orthosis scheme shown above, the feedback from the EMG sensor measuring the elbow activity is used to control the actuator.

## 2.2 The Elbow

The major function of the elbow is the addition of mobility of the hand in space by shortening/lengthening the arm or rotating the forearm and to provide control and stability for skilled hand motions and forceful upper extremity motions. The resting position of the elbow is full extension with full forearm supination and the closed pack position is $90^0$ of flexion with 50 of supination. The elbow joint occurs at the junction of three bones, the upper arm bone known as the humerus, the radius bone which is the bigger of the two forearm bones and the ulna. (Chai, 2004).

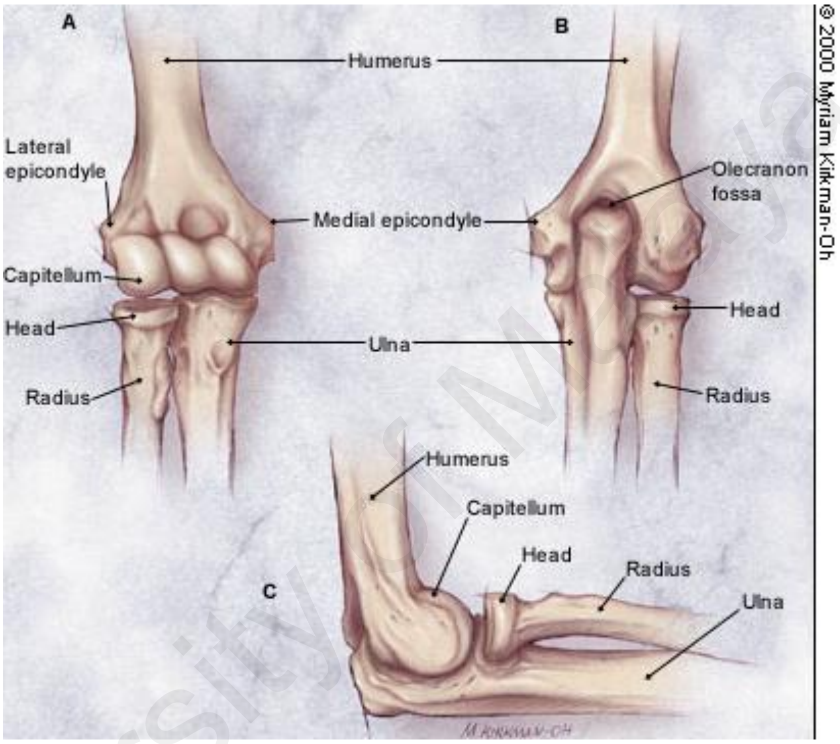


**Figure 2.2: Bones of the elbow. (A) Anterior view. (B) Posterior view. (C) Lateral view.**

The elbow consists of three joints. The first joint is the hinge joint with one degree of freedom which allows for flexion and extension of the elbow. It is called the humero-ulna joint because it is formed between the humerus and the ulna bones of the arm. The rest position of the humero-ulna joint is when the elbow is in $70^0$ of flexion and the forearm in $10^0$ of supination. The second joint is called the humero-radial joint because it is formed between the radius and the humerus bones of the arm. It is a ball and socket joint with two degrees of freedom. The rest position of the humero-radial joint is when the elbow is in full extension with forearm supination. It equally allows for flexion and extension as well as pronation and supination of the elbow. The third joint in the elbow is the proximal radio-ulna joint which is formed by the radius and the ulna bones of the arm. It is a pivot joint with one degree of freedom which enables the pronation and supination of the forearm. The rest position is when the elbow is in $70^0$ flexion and the forearm at $35^0$ supination. (Chai, 2004)

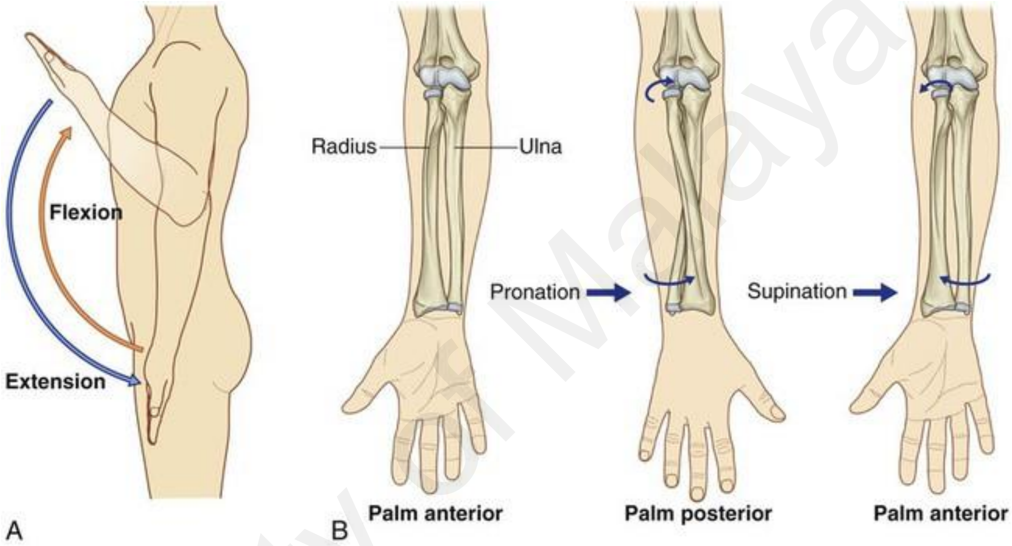


**Figure 2.3: Elbow movement. (Admin, 2015)**

The muscle of the elbow joint are responsible for enabling it to flex, extend, supinate and pronate. The largest of the muscles are the biceps brachii, triceps brachii, brachialis, brachioradialis, pronator teres, extensor carpi radialis brevis. The biceps brachii enables the flexing of the elbow joint and the supination of the forearm and the brachioradialis equally helps with the flexing of the elbow, pronation and supination. The triceps brachii is the main extensor of the elbow while the extensor carpi radialis brevis is the extensor of the wrist. The brachialis is the strongest elbow flexor when the palm is pronated and the pronator teres aid flexion of the elbow and pronation of the forearm. (Clinic, 2017)

Elbow flexion is simply the bending of the elbow joint by moving the forearm towards the upper arm resulting in a decrease of angle while elbow extension is the movement of the forearm away from the upper arm resulting in an increase of angle. The range of motion of elbow flexion is 0 – 1450 though hyperextension occurs especially in female. The functional range of motion is 300 – 1300 for push or/and pull actions.(Chai, 2004)

Pronation is the movement of the forearm so the palm faces the posterior i.e. faces down and supination is the movement of the forearm so the arm faces the anterior i.e. faces upwards. Full pronation and supination turns the forearm, wrist and hand at almost 180 degrees. Turning a screwdriver or turning or a key are examples of pronation and supination. They both occur at the hinge joint of the elbow known as the radioulnar joint. The end of the radius bone is rotated around the ulna by the pronator muscles from its position on the lateral side of the wrist to the medial side of the wrist during pronation. The muscles of the elbow rotate the radius bone in the opposite direction of the pronator muscles during supination. The axis of rotation during pronation and supination passes through the center of the radial head and the distal ulnar head. The range of motion is 0-$70^0$ pronation and 0- $85^0$ supination with a functional range of $50^0$ of pronation and $50^0$ of supination i.e. for opening door knob or opening of a can. (Chai, 2004)



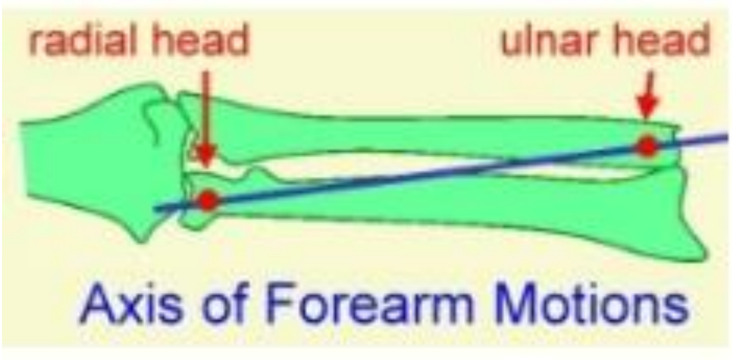


**Figure 2.4: Axis of forearm motion. (Chai, 2004)**

## 2.3 Range of Motion (ROM)

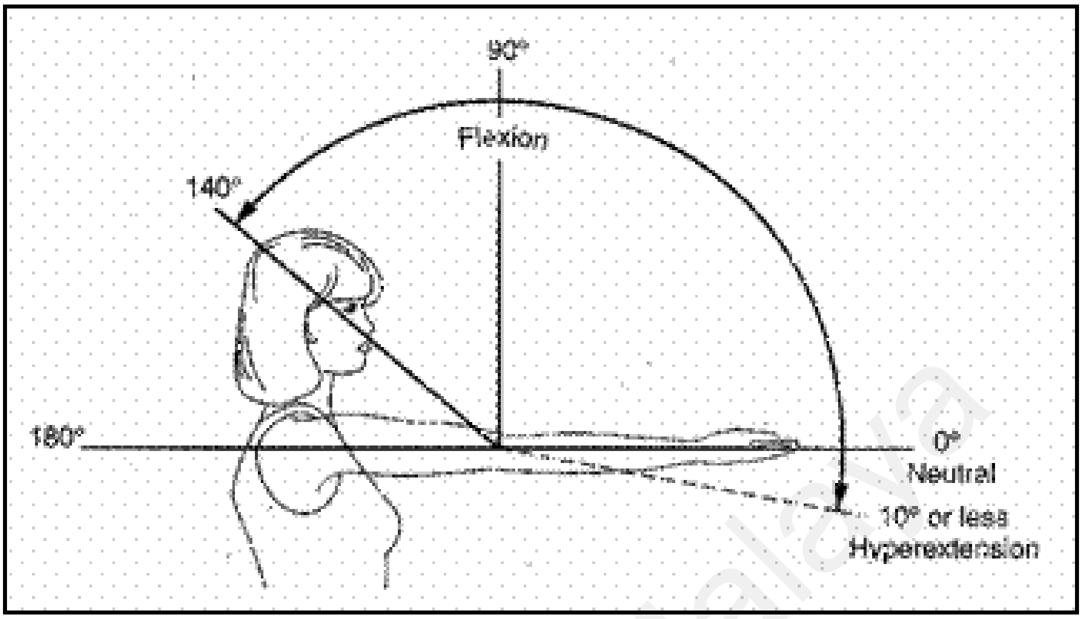


**Figure 2.5: Range of Motion of the Elbow. (Luttgens & Hamilton, 1997)**

The range of motion of a joint is the angle in which it moves from the anatomical position (zero degrees) to the extreme limit of segment motion in a particular direction. (Hall, 2003). It is usually measured in degrees using an instrument called goniometer. Range of motion test is traditionally performed in three different ways; active, passive and resistive range of motion. The active range of motion test is performed by the patient under their own power, the passive range of motion is performed by taking the patient through full ROM or up until the point of pain while the resistive range of motion is performed by the examiner resisting the athlete as they move through the motion. (Norkin & White, 2009). Normal ROM for the elbow is 140-150 degrees flexion, 0 degrees extension and 76-84 degrees pronation, 80 degrees supination. The functional ROM of the elbow is 30 – 130 degrees flexion and 50 degrees of pronation-supination. (Sardelli, Tashjian, & MacWilliams, 2011).

## 2.4 Common Elbow Injuries

Multiple muscles and ligament passing through the elbow joints makes the joint a common site for injuries. This injuries occur mostly during sports or recreational activities and as a result of accidental falls. The most common of the elbow injuries are acute injuries and elbow overuse. (Field & Savoie, 1998).

Overuse injuries occur when high stress is placed on a tissue or joint as a result of overdoing or repeating an activity. The high stress concentrated over the inner elbow over time causes injuries which could result into swelling behind the elbow (bursitis), series of micro tears in the connective tissue in or around the tendon (tennis elbow or golfer's elbow) or pinched nerves which usually occur with repeated motions. They are common in athletes that are subjected to repetitive elbow flexion-extension or pronation-supination of the wrist motion. (Maloney, Mohr, & El Attrache, 1999).

Unlike overuse injuries, acute elbow injuries occur as a result of a sudden impact or trauma. They are caused by a fall on the arm or contact collision during sports. They results in bone fractures, elbow dislocation, ligament sprains or tendon rupture. Elbow fracture is the break in one of the bones of the elbow usually requiring a surgery then an immobilization orthoses. Elbow dislocation occur as a result of the ulna and radius been forceful driven posterior to the humerus. (Physiopedia, 2010). Ligament sprain occurs as a result of damage to the medial collateral ligament (MCL) of the elbow which be as a result of overuse, impact injury or accident. Elbow hyperextension injury occurs as a result of over-straightening (bending the elbow backwards in the wrong direction) of the elbow which damages the ligaments and structures of the elbow.

Most injuries require three stages of tissue healing. The inflammatory stage, proliferative stage and the scar maturation. The inflammatory stage lasts around one week. During this stage, rest is more important than any form of exercise. Immobilization orthoses are used for protecting, supporting and resting the injured part. The second stage, proliferative stage begins after a few days and could last for a few weeks. During this stage, mobilization orthoses which takes advantage of tissue's elasticity and responsiveness to external stress are useful for facilitating tissue growth. Active exercises using mobilization orthoses occur during the scar maturation stage. (Physiopedia, 2010)

## 2.5 Orthosis

Orthosis are devices applied externally for modification of the functional characteristics of the neuro-muscular-skeletal system. (Bowker, Condie, Bader, & Pratt, 1993). The common goals of orthosis are to stabilize weak or paralyzed segments or joints, support damaged or diseased segments or joint, limit or augment motion across joints, control abnormal or spastic movements and unload distal segments. (Hsu, Michael, & Fisk, 2008).

All orthosis apply forces to the body. (Edelstein & Bruckner, 2002). The benefit of the force applied may be to resist or assist motion, transfer force, or protect a body part. Orthosis used to resist motion are used for controlling excessive or unwanted motion and to maintain a particular body alignment. For example, a wrist-hand orthosis used for minimizing ulnar deviation in a patient with rheumatoid arthritis, a knee ankle foot orthosis uses to stabilize the knee in a patient with quadriceps paralysis.


**Figure 2.6: Knee ankle foot orthosis. (trbsorthosis.com)**

Orthosis used to assist motion provide mechanical assistance of weak or paralyzed muscles to enable the patient to perform a specific function. For example, a wrist-hand orthosis may link the wrist extension to flex the fingers in a paralyzed hand. (Edelstein & Bruckner, 2002)

**Figure 2.7: Wrist-hand orthosis: Cock-up splint. (ibnsinamedical.com)**

Orthosis can also be used to transfer forces from one portion of the body to another. For example, a foot orthosis that shifts load from a heel spur to the forefoot. It absorbs the shock at the heel contact and transfers the load to the forefoot. (Edelstein & Bruckner, 2002)


**Figure 2.8: Internal heel orthosis (fadavis.com)**

Some orthosis are used to protect body areas and preventing deformity or injury. For example, the newly grafted skin of a patient with burns need to be shielded from secondary trauma. The wrist-hand-stabilizer below is used by patients with burns who are vulnerable to flexion contractures. (Edelstein & Bruckner, 2002)

**Figure 2.9: Wrist-hand-stabilizer (plasticsurgerykey.com)**

### 2.5.1 Classification of orthoses

Orthoses can be classified into static, dynamic, and progressive orthoses based on the goal or intent of its design.

Static orthoses are the most common and they allow no motion across the joint or segment involved. Hence the primary goal of static orthoses is stabilization. They are thought to be resting, or positional orthoses used for positioning or holding. They can be used to facilitate dynamic functions, for example, blocking one joint to encourage the movement of the other.(Riggs, Lyden, Chung, & Murphy, 2011)

Dynamic orthoses allow motion across the joint or segment involved. They generate a mobilizing force on a targeted tissue which results in a passive assisted ROM. (Fess & Phillips, 1987; Glasgow, Tooth, Fleming, & Peters, 2011). The controlled mobilizing force is applied via a dynamic assist in form of rubber bands, springs, neoprene or wrapped elastic cord.

Progressive orthoses are those with diverse biomechanical functions as the disability progress or changes. It is designed to accommodate improvement or deterioration of the disease. They are similar to dynamic orthoses except that they use non-elastic components like screws, hinges, turnbuckles or non-elastic tape to deliver the mobilizing force. (Sueoka & DeTemple, 2011)

Orthoses can equally be classified as therapeutic or functional. Therapeutic orthoses are those which involve the use of force to improve the patient's motor skills i.e. to strengthen the muscle, while functional orthosis are those which helps the patient regain lost learnt skills such as those required for daily life activities or work-related skills. (Placidi, 2007)

## 2.6 Elbow orthosis

The objective of elbow orthosis ranges from provision of stability to the elbow, allowing mobility of the elbow, biomechanical alignment control of the elbow, pressure redistribution in the elbow, external force restriction to the elbow, excessive movements limitation of the elbow, elbow protection and shock absorption. There has been a string of noteworthy research efforts in the field of elbow orthoses. The following though not a complete list presents a snapshot of the field

Vanderniepen, Van Ham, Van Damme, and Lefeber (2008) developed a powered elbow orthosis for orthopedic rehabilitation using Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator (MACCEPA) actuators. A MACCEPA actuator is a bidirectional rotational actuator with mechanically adaptable compliance consisting of a spring and two electric drives. It was developed using MACCEPA actuators to ensure inherent compliance thereby providing safety. The orthosis design is wearable, light hence portable allowing for frequent and longer training sessions. Mechanical stops were added to the device to avoid over extension of the elbow. The orthosis is powered with a Maxon gearbox, electric drive and a worm gear, allowing a maximum torque of 10Nm and an overall weight of 1.1kg.

**Figure 2.10: Prototype of the powered elbow orthosis**

NEEM (NEUROExos-Elbow-Module), a portable wearable robotic elbow exoskeleton using Series Elastic Actuation (SEA) for the mobilization of paretic or spastic elbow condition was developed. (Cempini et al., 2013; Vitiello et al., 2016). The low level control system of the orthosis provides two different therapy protocols, the torque control and the joint position control to achieve basic physical rehabilitation process. NEEM can supply a joint torque of 30N-m with a spring stiffness of 100 N.m.rad-1, a value comparable to that of the human elbow. (Abe & Yamada, 2003). It has a double shell structure with a 4-DoF passive alignment mechanism and a one active DOF with remote cable-driven actuation.

**Figure 2.11: NEUROExos Elbow Module**

A 1-DOF bimanual wearable robotic device with Master-Slave configuration to train elbow movement in flexion and extension was developed in (Herrnstadt, Alavi, Randhawa, Boyd, & Menon, 2015). The orthoses combines position and force sensors with the implementation of control loops which can be operated for both passive and active training. Any movement or resistance made by the master (non-hemi paretic arm) causes an equal movement or resistance of the slave (hemi paretic arm).


**Figure 2.12: Bimanual wearable robotic device**

An active orthosis which provides assisted movement to the injured elbow by reacting to the patient's muscular activity was developed in (Ripel & Krejsa, 2012). The orthosis uses a tensometric gauge attached to the frame to measure the patient's effort to move the elbow. The actuator in turn moves the orthosis through the joint in the desired direction.

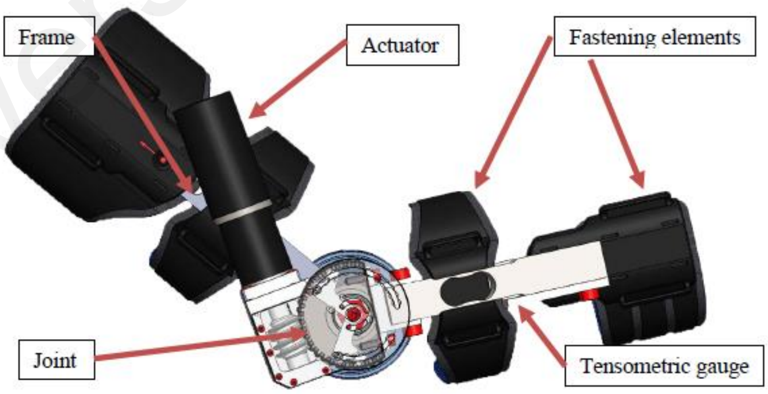


**Figure 2.13: Mechanical design of the Active orthosis**

(Pylatiuk et al., 2009) integrated electromyography, functional electrical stimulation and a fluidic actuator in his development of a lightweight elbow orthosis for treatment of patients suffering from paraplegia. The problem with this approach is that functional electrical stimulation causes the muscle redundancy instead of causing voluntary contraction of the muscle.(Faller, Nogueira Neto, Button, & Nohama, 2009)

**Figure 2.14: Mechanical design of the hybrid orthosis**

## 2.7 Actuator Control

Measuring the patient’s activity is the key input for the orthoses system. Many methods based on several principles exists for the measurement of muscle activity. Strain gauge measures strain and converts it into a change in electrical resistance. Strain is the result of external force applied to a body in form of the displacement and deformation that occur. The actuator control is based on the feedback from the strain gauge.

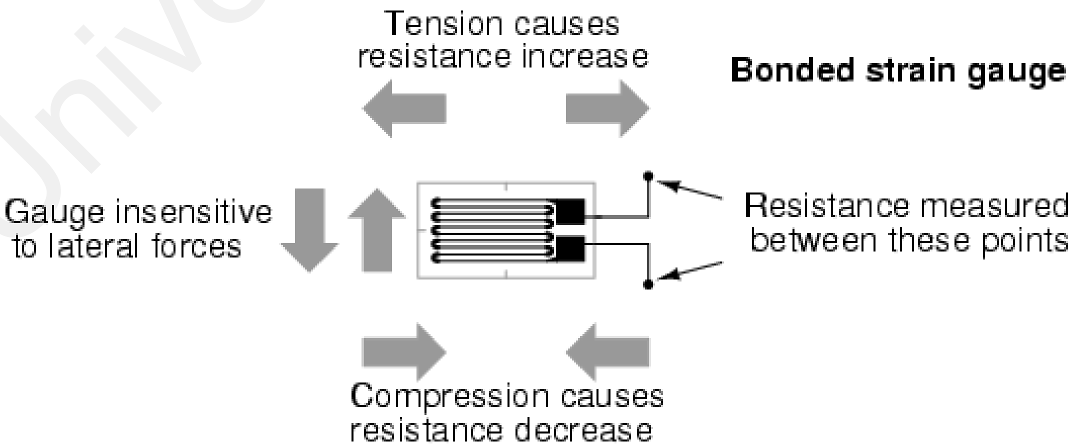


**Figure 2.15: Mechanism of Strain gauge Sensing**

Electromyography (EMG) measures muscle response or electrical activity (voltage) in response to a nerve's stimulation of the muscle. The electrical activity is usually measured and recorded using three surface electrodes, a negative, positive and ground. The electrodes are placed about 1cm apart on top of the muscles that needs to be monitored. The signal from the EMG sensor needs to be converted from analog to digital so as to be understood and used the signal in controller coding. The force exerted by the muscles in real time is represented by the voltage measured.

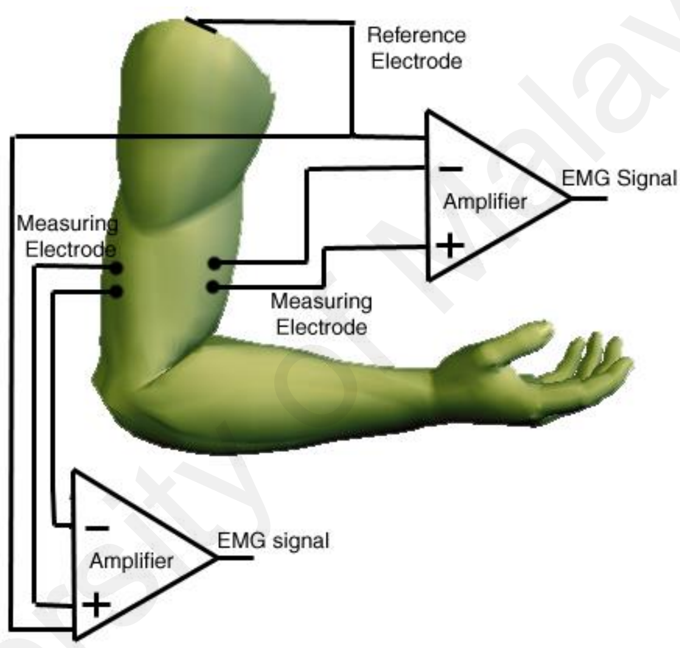


**Figure 2.16: Mechanism of Electromyography sensing**

Mechanomyography (MMG) measures mechanical signal that appears when a muscle is contracted using an accelerometer or microphone placed on the skin. The signal is characterized by low frequency distribution below 100Hz. The vibration of the muscle during activation creates pressure waves that can be detected on the skin's surface by accelerometers, piezo-electric contact sensors, condenser microphone or a laser distance sensor. (Watakabe, Itoh, Mita, & Akataki, 1998)

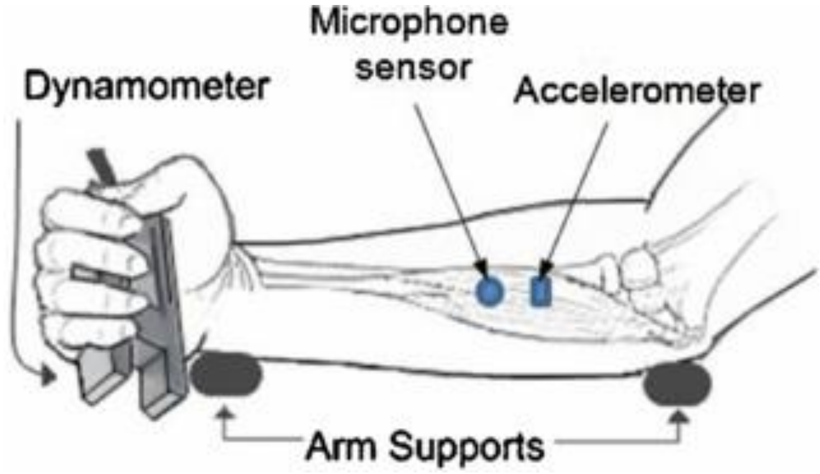


**Figure 2.17: Mechanism of MMG Sensing**

The MMG has a higher signal-to-noise ratio compared to the EMG. Thus can be used to monitor muscle activity from deeper muscles without using invasive measurement techniques. (Beck et al., 2006). It does not suffer any interference from the electrical stimulation device while the muscle signal is being collected. (Faller et al., 2009). However EMG is chosen for this project due to its vast popularity and deep knowledge of the sensing procedure.

# CHAPTER 3: METHODOLOGY

## 3.1 Introduction

This chapter details the mechanical design and the electrical design of the elbow orthosis. It focuses on the hardware design, biomechanics of the elbow, device functionality, the details of components selection and the bill of materials. It equally discusses the software design including the electrical circuits.

### 3.1.1 Gantt Chart

The Gantt chart (refer to appendix) shows how the project planning was organized and carried out. Research (literature review and component selection) required some amount of time because the project methodology and the proper components have carefully and rightly selected. The orthosis design and developed was done in about four weeks followed by the circuit design and programming which was accomplished in another four weeks as well. The orthosis was then tested, evaluated and then the report writing began in December.

## 3.2 Functionality

The main function of this elbow orthosis is to enable the patient exercise their elbows without the need of a physiotherapist. The arm is designed to move over the normal range of motion of the elbow both in flexion and extension. The device exercises the elbow by enabling flexing and extension the forearm at varying angles for a required period of time. The flexing and extending of the arm is solely based on the output from the electromyography sensor. It also provides other functions like supporting the forearm and allowing the patient to lock their elbow at any desired angle for an extended period of time.

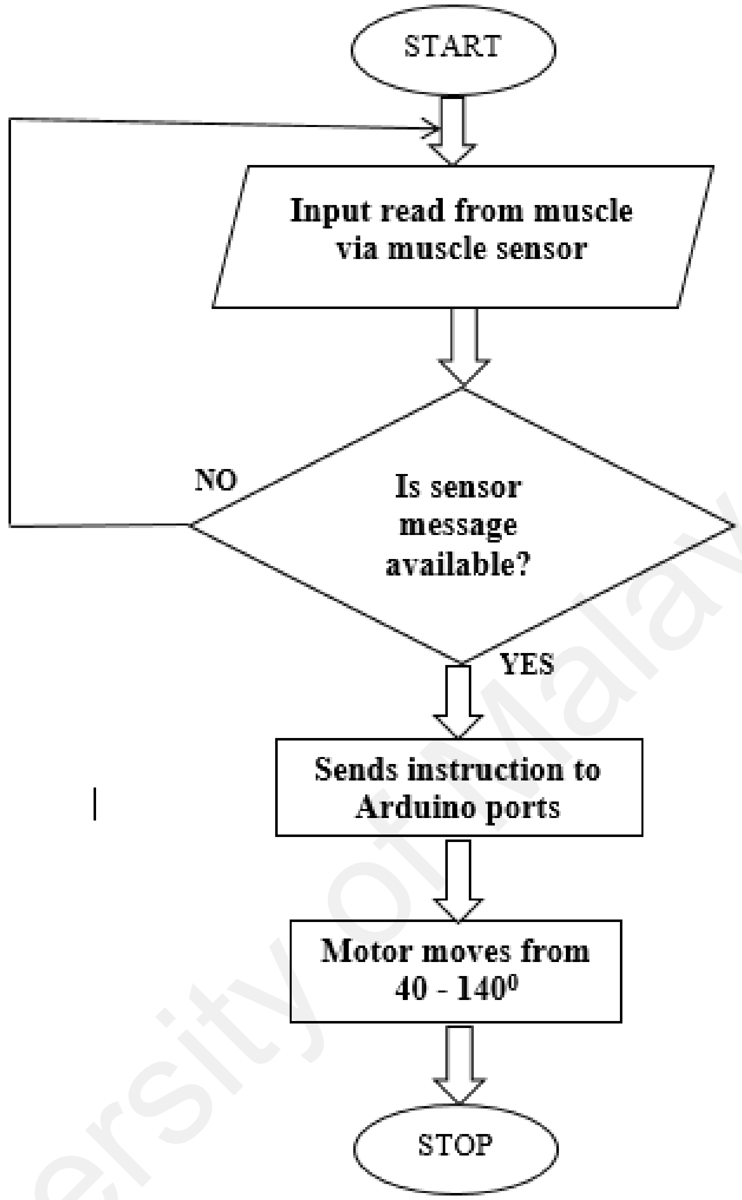


**Figure 3.1: Flow chart of elbow orthosis system**

The orthosis in its off state positions locks the forearm at any desired angle suitable for performing day to day tasks to improve the quality of life of the patient. In its on state, the electromyography sensor obtains electrical signal from the muscle when flexed. These signals are sent to the DC motor which has been programmed to flex and extend the forearm at varying angles for a predefined period of time. This action is repetitive until the orthosis is switched off and the patient can lock the device at any desired angle.

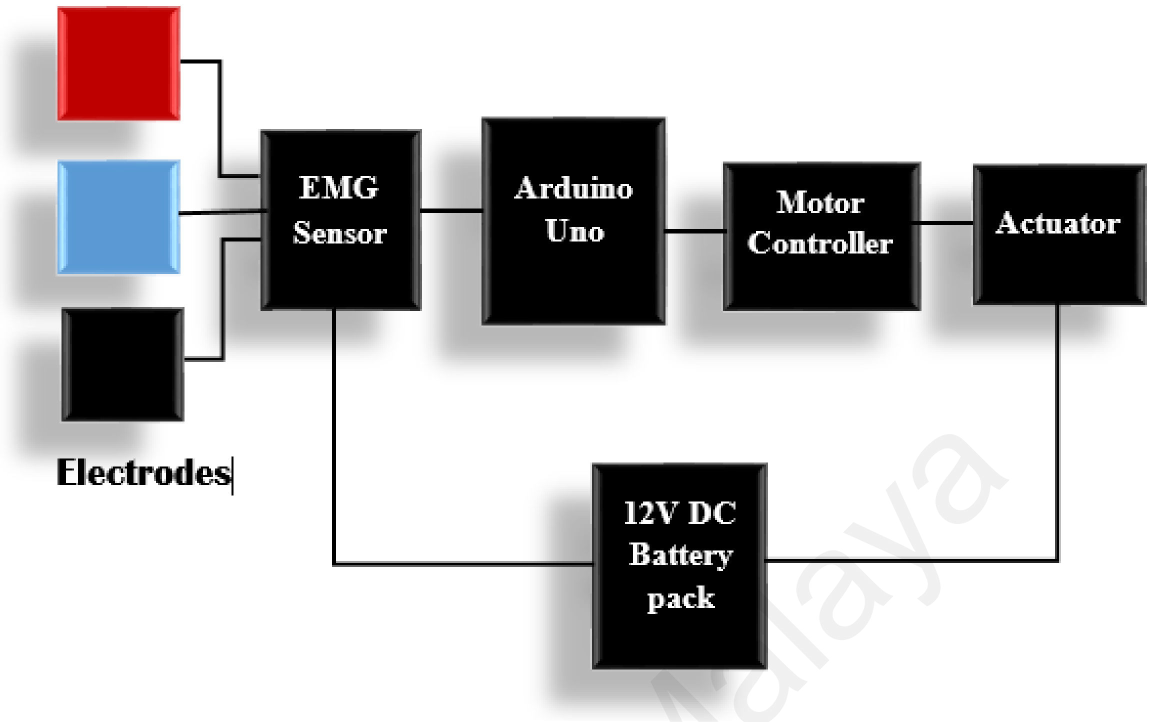


**Figure 3.2: Block Diagram of Elbow orthosis**

## 3.3 Mechanical Design

The design is made up of two shells, one part supporting the upper arm and another supporting the lower arm linked together by two hinges.

### 3.3.1 The Frame

The frame consists of shells designed to support the lower arm without restricting any of its movement. The design is light weight thereby keeping most of the weight off the injured shoulder of the patient. The shells of the orthosis was developed using thermoplastic polypropylene.

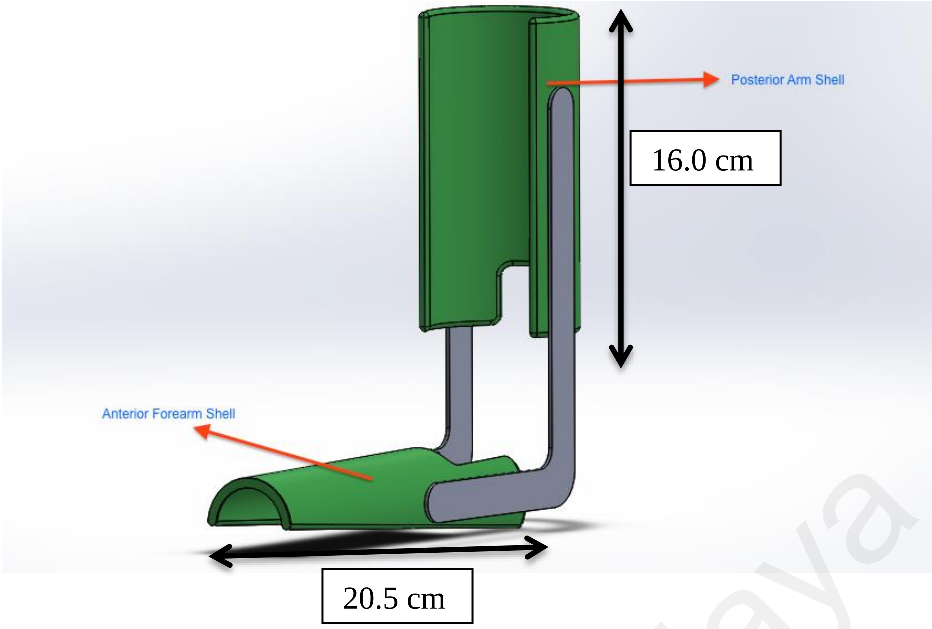


**Figure 3.3: CAD Design of the Elbow Orthosis**

A thermoplastic is a plastic polymer which is moldable when heated above a specific temperature and solidifies upon cooling. There are multiple types of thermoplastic materials including ABS thermoplastic and polyethylene thermoplastic polymer. Acrylonitrile butadiene styrene (ABS) is known for its light weight, high impact resistance, safety and mechanical toughness. Polypropylene thermoplastic polymer is equally known for its lightweight, toughness, high density and high resistance to temperature changes.(plastics, 2017). However polypropylene thermoplastic was selected because it was a cheaper option.

### 3.3.2 The Joint

The mechanical joint of the elbow orthosis consist of a hinge and a DC motor attached to it. A hinge joint allows one degree of movement and the DC motor actuates and allow for flexion and extension of the elbow joint. The hinge joint can move the elbow over normal range of elbow movement.

**Figure 3.4: CAD Design of the Hinge Jointjoin**

## 3.4 Elbow Biomechanics

The elbow has two degrees of freedom because it is capable of flexion and extension as well as pronation and supination. However it is mostly considered as a simple hinge joint with one degree of freedom because of the congruity at the ulnohumeral articulation and surrounding soft tissue. (Morrey & Sanchez-Sotelo, 2009). It is important to know the relationship between forces acting through the biceps muscle to generate an idea of the force required by the prosthesis to sustain.

$$T = F \times r \tag{3.1}$$

Where

T= torque (Nm)

F = Force (N)

r = moment arm (m)

Torque is the measure of the extent to which a force can cause rotation in an object. Force is any influence that causes a free body to undergo acceleration. The muscles of the body are responsible for creating torques which moves the limbs. A muscle contracts by pulling on its point of attachment along a line of action. A line of action is the imaginary line that the force pulls or pushes along. Moment arm is the perpendicular distance from the line of action to the centre of joint rotation. It represents the mechanical transformation between the muscle and the joint. (van der Helm, 2000)

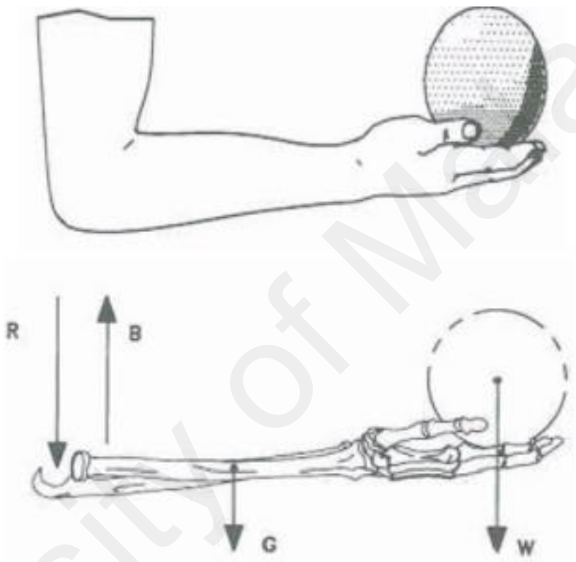


**Figure 3.5 Free body diagram of the forearm holding a ball (Artati, Van der Smagt, Krüger, & Baena)**

The free body diagram above was used to analyse the effects created by the forces and moments acting on the elbow joint. It is assumed that the forearm is rigidly fixed and R stands for the forces acting between the ulna and the humerus that is the joint reaction force, B stands for the force acting through the biceps and G is the forearm weight acting vertically downwards. The force in the biceps can be calculated by taking moments about the elbow bearing in mind that the joint reaction force has a moment arm of zero hence it creates no moment about the joint axis.

$$\sum F = 0 \tag{3.2}$$

$$\sum T = 0 \tag{3.3}$$

$$(B \times D1) - (G \times D2) - (W \times D3) \tag{3.4}$$

$Where$

$D1, D2, D3 = perpendicular\ measured\ distances\ from\ the\ elbow\ joint$

$$G = Weight\ of\ the\ humerus \tag{3.5}$$

$$Sum\ of\ moments\ in\ 'y\ direction = 0 = -R + B - G - W$$

The moment in the y-axis direction can be calculated using the force through the biceps keeping in mind that the sum of the sum of the moment is equal to zero. Since B, G and W are known, R can be calculated. (Lucas, Cooke, & Friis, 1999)

## 3.5 Components Selection

The main components used in the design of the elbow orthosis are the Power window motor, motor driver, thermoplastic polypropylene, Arduino Uno, 12V battery pack and the Muscle sensor.

### 3.5.1 Thermoplastic polypropylene

This is used as the frame of the elbow orthosis. Polypropylene was chosen because it can be manufactured through different methods and used in multiple applications. It is low cost, readily available, light weight with good fatigue resistance and impact strength. (Mechanisms, 2016)

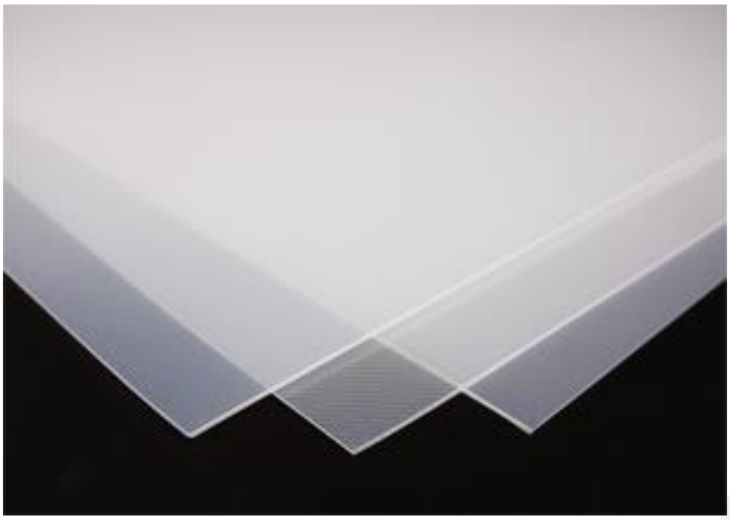

**Figure 3.6: Polypropylene sheets**

### 3.5.2 Arduino Uno

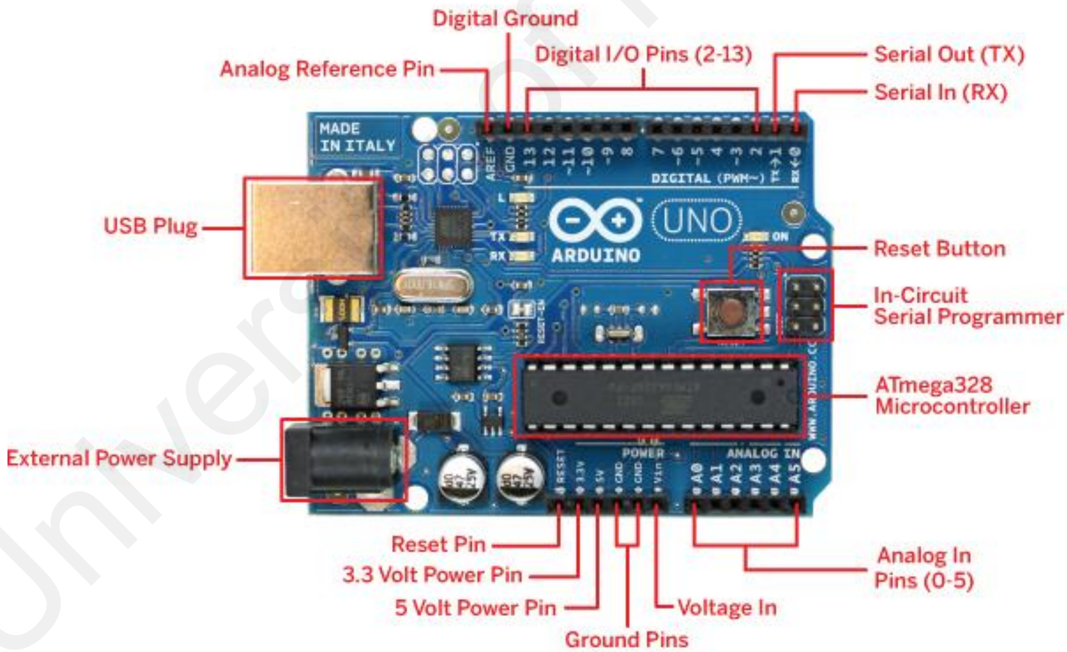


**Figure 3.7: Arduino Uno (MrLndr, 2011)**

A microcontroller allows a programmer to gain direct access to hardware from a higher-level language (than assembly), often based on C or C++. Arduino was selected for this project because it is the most popular and easiest to use microcontroller. It can be programmed with a USB cable and can also send and receive serial data through this connection. The standard Arduino packages offer rows of female headers for sticking wires into.

### 3.5.3 Power window motor

The functional range of elbow movement is between 30 degrees and 130 degrees and the elbow joint requires a maximum moment of 5.8Nm to carry out various activities of daily life. However only a moment of about 3.1Nm is required by the elbow joint to hold the forearm at 90 degrees against gravity (Murray & Johnson, 2004). Hence an elbow orthosis should allow for this range of elbow movement and a torque higher than 6Nm.

**Figure 3.8: Power window motor (lazada.com.my)**

Several actuation techniques are available for the actuation of the orthosis. Some are the Series Elastic Actuator (SEA), Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator (MACCEPA), Pneumatic Artificial Muscles and so on. A metallic gear servo motor would have been the best choice due to its robust mechanical construction, containing a brushed motor, gearbox, motor controller and a feedback mechanism that allows to set the motor's angular position. However a servo motor which provides the required torque for the elbow orthosis is very expensive thereby defeating one of the significance of the project. As a result, a power window motor was chosen because of its high torque and affordable price compared to that of a DC motor. A power window motor runs for a very long time without overheating and it can be paired with a potentiometer to provide the precision required.

### 3.5.4 Motor Driver

The L298N motor driver is an H-bridge which can be used to control the speed and direction of motors with an Arduino. It can control motors of voltage between 5 to 35V DC at up to 2A peak with a heavy duty heat sink. It contains four switching elements, transistors or MOSFETs, with the motor at the centre forming an H-like configuration. The rotation direction of the motor is changed by changing the direction of the current flow.

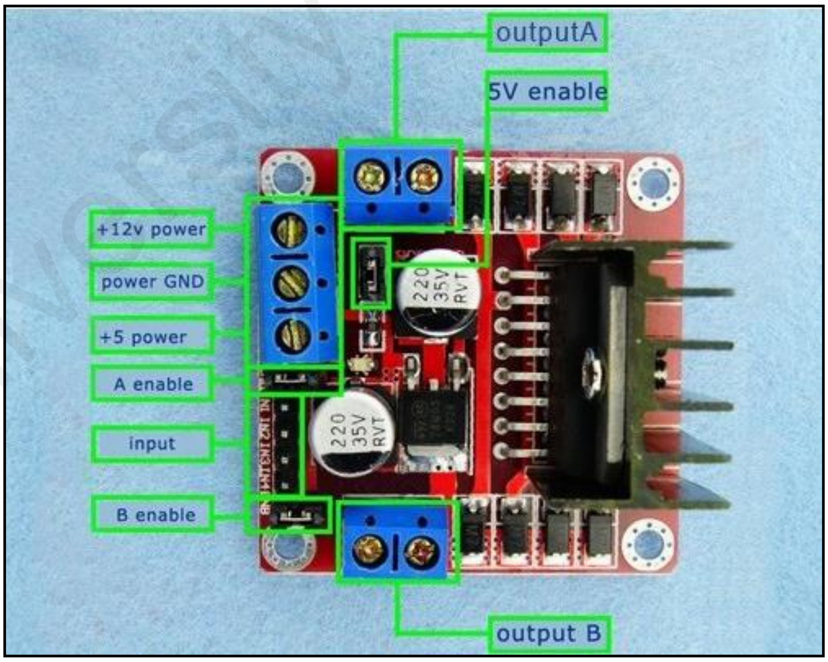


Figure 3.9: L298N Motor Driver (Amazon.com)

### 3.5.5 Muscle sensor

Measuring the patient's activity is the key input for the orthoses system. Many methods like the Strain gauge, MMG and EMG exists for the measurement of muscle activity. EMG was however chosen for this project due to its vast popularity and deep knowledge of the sensing procedure. The muscle sensor was chosen for this project because it is Arduino powered which allows for easier integration with the microcontroller. This muscle sensor does not output raw EMG signal, rather it output filtered and rectified electrical activity of the muscle and gives the output in volts. It allows to add the sensor pads directly to the board hence getting rid of excess cables.

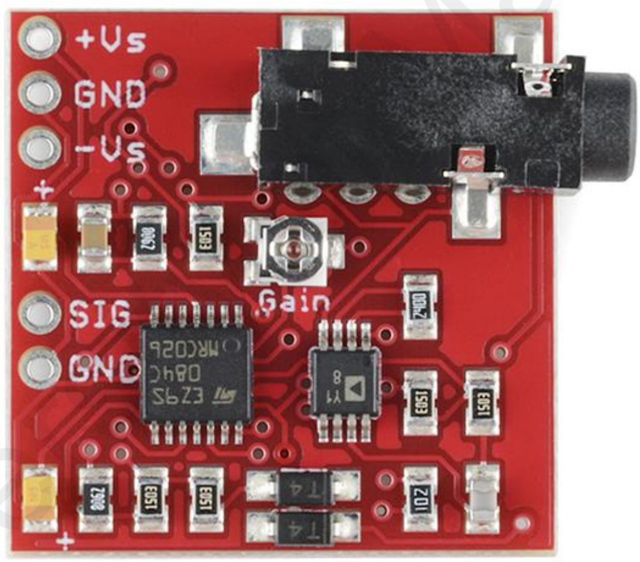


**Figure 3.10: Muscle sensor (Sparkfun.com)**

### 3.5.6 Power Source

The power window motor used in this project was designed to operate at operate at 12 volts and 5A no-load current. The Lithium polymer (LiPo) battery 11.1V is a light weight battery capable of powering the high voltage DC motor. However it is very expensive and requires a very costly charger. Another option is using 10x1.2V AA batteries but the combination of the batteries cannot supply the required current to power the high current

DC motor. Hence a 12V lead acid battery pack was chosen though it is heavy, it is strong enough to power the motor. For commercialization, LiPo or Lithium Iron Phosphate (LiFePO4) would be used.


**Figure 3.11: 12V Lead Acid Battery (lazada.com.my)**

### 3.6 Bill of Materials

Table 3.1 shows the specification, quantity and the price estimation of the main components to be used for the project.

**Table 3.1: Bill of Materials**

| Material | Specification | Quantity | Price |
|---|---|---|---|
| Power Window Motor + Motor Shield | • Voltage Rating: 12VDC<br>• No load Speed: 85 ± 15RPM<br>• Rated Speed: 60 ± 15RPM<br>• Current (No Load): <5A<br>• Rated Current (Load): <15A<br>• Stall Current: <28A at 12V | 1 | Rm60 |

| | | | |
|---|---|---|---|
| | • Rated Torque: 30Kg.cm (2.9N.m)<br>• Stall Torque (Locked): 100 ± 15Kg.cm (~10N.m) | | |
| Arduino Uno | • Operating Voltage: 5V<br>• Digital I/O Pins: 14<br>• PWM Digital I/O Pins: 6<br>• Analog Input Pins: 6<br>• DC Current per I/O Pin: 40 mA<br>•DC Current for 3.3V Pin: 50 mA<br>• ATmega328P | 1 | Rm40 |
| Muscle sensor | • Small Form Factor<br>• Specially Designed For Microcontrollers<br>• Adjustable Gain<br>• 3.5mm Connector<br>• Breadboard Compatible<br>• Power supply voltage: min. +-3.5V<br>• 1.0" x 1.0" | 1 | Rm280 |
| Thermoplastic | • Thermoplastic acrylic and polyvinyl chloride | 1 | Rm 40 |

| | | | |
|---|---|---|---|
| | • Length: 300mm/11.8"<br>• Width: 200mm<br>• Thickness: 1mm | | |
| Ratchet hinge | • Iron material<br>• 16mm thickness<br>• 125mm barrel length<br>• 105 degrees range | 2 | Rm10 |
| Power Supply | Voltage: 12V<br>Capacity: 7.0Ah<br>Size: 150mm x 63mm x 94 mm<br>Weight: ~2.324kg | 1 | Rm60 |
| Velcro Straps | 20mm x 180mm (7") L x 3 pcs. | | Rm 10 |
| Total | | | Rm500 |

## 3.7 Electrical Design

Basically the entire circuit consists of hooking up the power window motor, the electrodes and the muscle sensor to a ground, power, and signal wire. The ground wires all combine and go to both the black (-) wire of the battery and one of the ground inputs on the Arduino. The power lines all go to the red (+) wire of the battery. The signal wire goes into one of the digital Arduino pins: 3, 5, 6, or 9

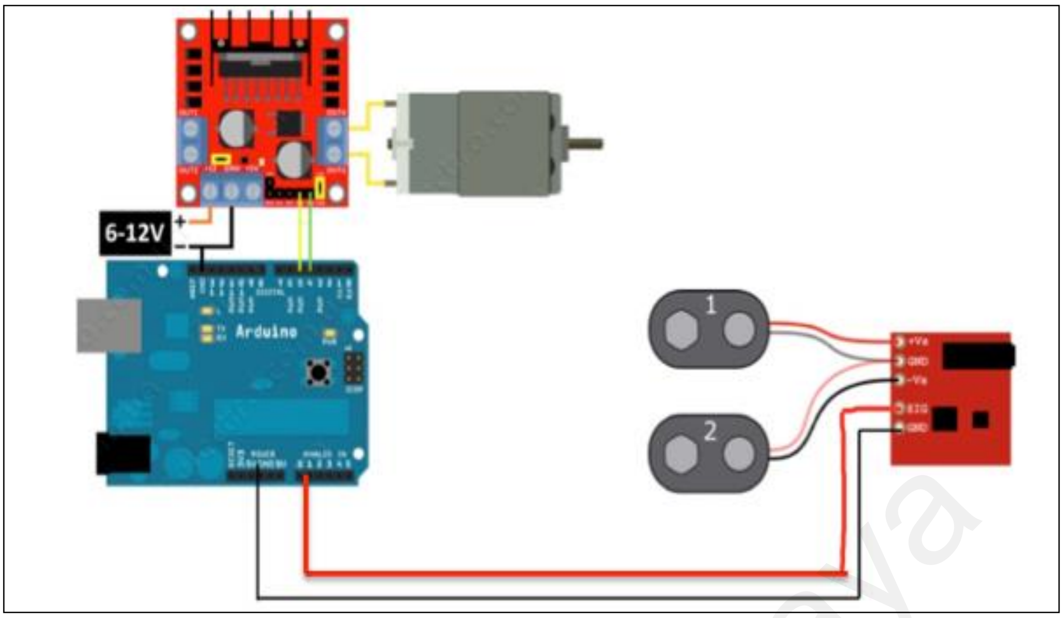


**Figure 3.12: Circuit connection**

Basically the entire circuit consists of hooking up the power window motor, the electrodes and the muscle sensor to a ground, power, and signal wire. The ground wires all combine and go to both the black (-) wire of the battery and one of the ground inputs on the arduino. The power lines all go to the red (+) wire of the battery. The signal wire goes into one of the digital Arduino pins: 3, 5, 6, or 9

## 3.8 Subjects of the Experiment

Five subjects with no conditions especially at the elbow region would be chosen to undergo the experiment to determine the performance of the device in helping to flex and extend their elbows through the normal human range of motion. Subjects with no elbow or arm conditions were chosen because we need to observe if the device built can mimic the normal elbow range of motion for flexion and extension.

The first stage of the testing would be for the subjects to flex and extend their elbows without the elbow orthosis worn on. The subject's normal range of motion for flexion and extension would be measured using a goniometer. The orthosis is then mounted on their arms and the electrodes placed on the selected muscle. The subjects would then try to flex their elbows and the electrical signal detected from the muscle sensor would serve as the input to the actuator which moves in a manner that flexes and extends the elbow. The range of motion would then be recorded and compared with normal ROM of the subject previously measured. The results would then be analysed using Kinovea software as it compares side by side the normal ROM without the elbow orthosis worn and the ROM when the orthosis is been worn.

The table below shows the criteria used to choose the subjects for the experiment. The subjects that fulfils the criteria would be chosen to undergo the testing procedure of the developed elbow orthosis. This study was approved by University Malaya Medical Centre ethics committee under the reference number 829.15

**Table 3.2 Selection Criteria**

| **Criteria** | **Justification** |
|---|---|
| Gender | 3 females and 2 males |
| Age | Age gap of 20 years to 45years |
| Elbow Joint range of motion | Can fulfil normal flexion and extension ranging from 0 – 140 degrees. |
| Strength of the muscle (Oxford Grading Scale) | The strength of the muscle should be able to allow for full range of motion against gravity |
| Health Condition | No chronic health condition |
| Orthotic History | No history of orthosis use |
| Elbow-Flexion Contracture Condition | Higher than 30 degrees |

## 3.9 Kinovea

The method used to measure angles and for assessing joint position in space is known as Goniometry. (Nordin & Frankel, 2001). A goniometer is a tool mostly used to measure an angles in the musculoskeletal system. It can also be defined as a tool that allows an object to be rotated to a precise angular position. It is used in medicine or rehabilitation for recording range of motions of a joint in the patient's body for tracking the patient's progress in a rehabilitation program.(Milanese et al., 2014). The goniometer is mostly suitable and usually easy to use for one degree of freedom joints. However it is very difficult to use for measuring range of motions with multiple degrees of freedom.


**Figure 3.13: International Goniometer (www.ncmedical.com)**

Multiple approaches to measuring angular positions of the human body extremities has been demonstrated in the literature. The most popular approach requires the use of an accelerometer. The downside is the requirement of extra devices to aid the measurement and the need for knowledge about data acquisition.(Dejnabadi et al., 2006).

Another approach requires the use of Wii Remote infrared sensors using a table for setting the origin and a glove. The infrared LEDs are used for registering the movement which is captured using the infrared camera of the WII Remote. (Attygalle et al., 2008). The measurements proposed in the literature generally requires the use of devices which are costly. The ideal measurement approach should not require the use extra sensors or gadgets and most importantly, it should be easy to use.

Kinovea is a free software used to analyse videos mostly in the field of medicine and sport. It is used for analysing, comparing and evaluating movement of patients or athletes. It is capable of measuring distance, speed, line length and the data obtained can easily be exported to an Excel file or video formats or images for analysis depending on the need of the experiment.(Guzmán-Valdivia et al., 2013). Unlike the other approaches to angle measurements, Kinovea is easy to use, free and does not require extra sensors or gadgets for analysis of the body extremeties. Hence the software was chosen to be used to measure, observe and analyse the elbow movement.

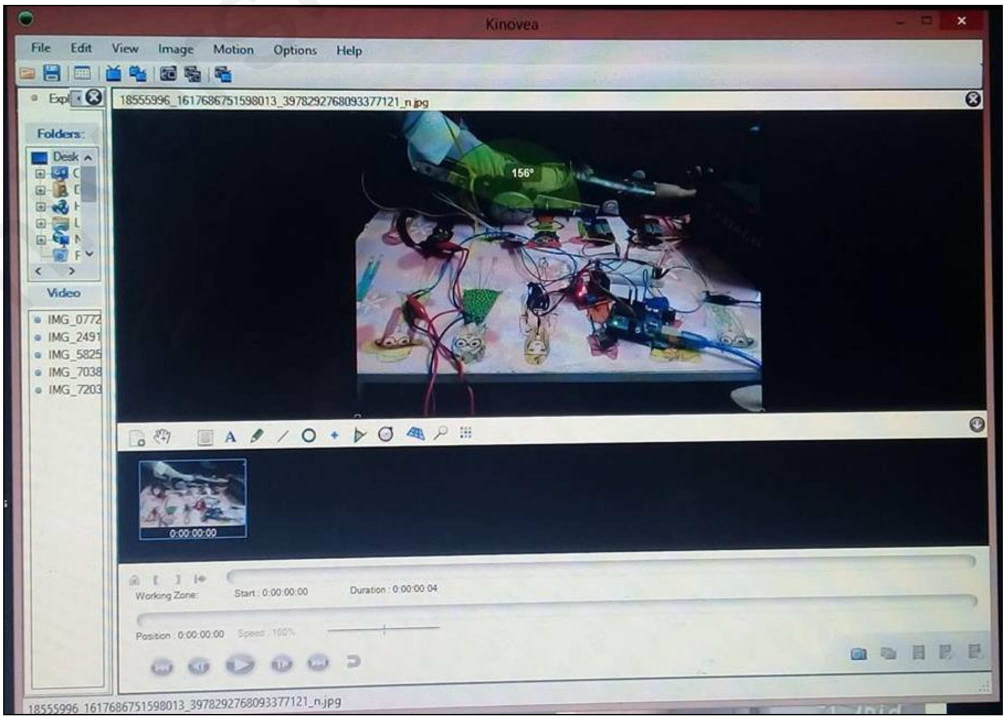


**Figure 3.14: Kinovea Software**

Kinovea works by detecting and analysing videos using position markers for measuring the angular positions of the body extremities. The video to be analysed would be captured using webcam, then position markers would be added for the analysis of the video. Angular positions of the elbow are obtained from the video and then exported to an excel sheet for analysis.

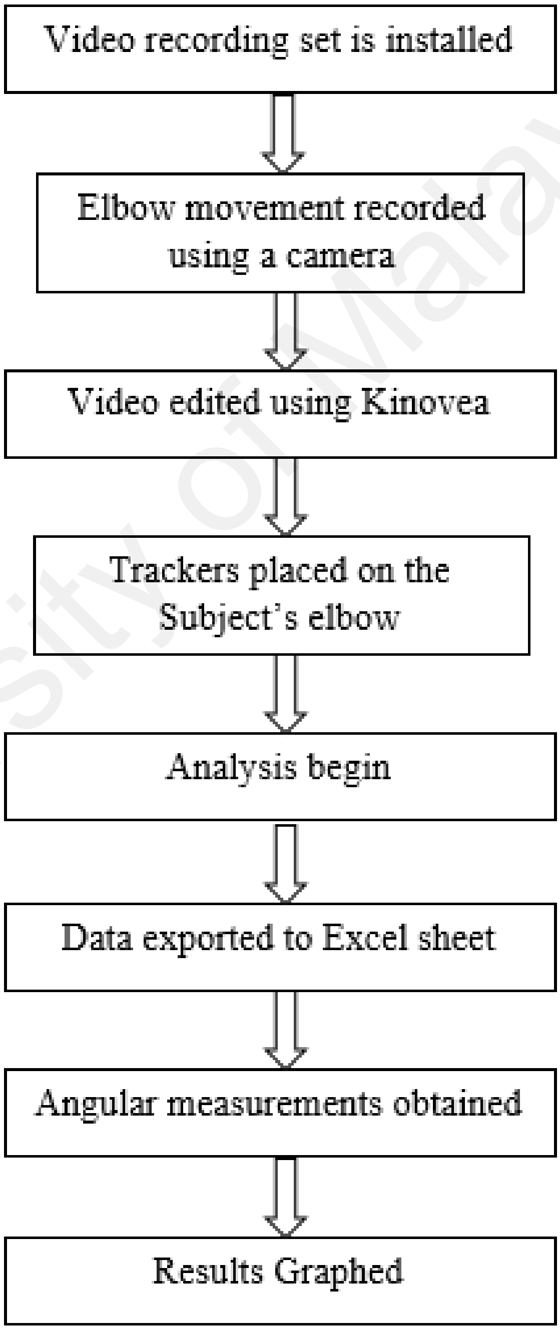


**Figure 3.15: Analysis Block Diagram Using Kinovea**

# CHAPTER 4: RESULTS AND DISCUSSION

The Active elbow orthosis having the mechanical and electrical design described in the previous chapters was built and tested for different hardware and software specifications. The design weighs about 1.5kg with a posterior forearm shell of length of 16cm and anterior forearm shell of 20.5cm.

## 4.1 Experimental Setup of the Active Elbow Orthosis

The pictures below show the hardware of the active elbow orthosis prototype. The orthosis has two shells, one covering the forearm part of the arm, the anterior region, while the other covers the posterior region of the arm connected together by a hinge. The shells were made with Thermoplastic polypropylene. The hinge functions as the elbow joint allowing for one degree of freedom movement, flexion and extension of the elbow. The Velcro straps helps to keep the orthosis in a fixed position when worn.


**Figure 4.1: Elbow Orthosis Frame**

The DC motor attached to the hinge joint in figure 4.2 below actuates the elbow orthosis. The electrical circuit controlled by the Arduino microcontroller includes the connection of the 12V DC power supply, the L298N motor shield and the muscle sensor to the elbow orthosis. The power window motor has a torque of 2.9N.m which is capable of moving the forearm for flexion-extension movement.

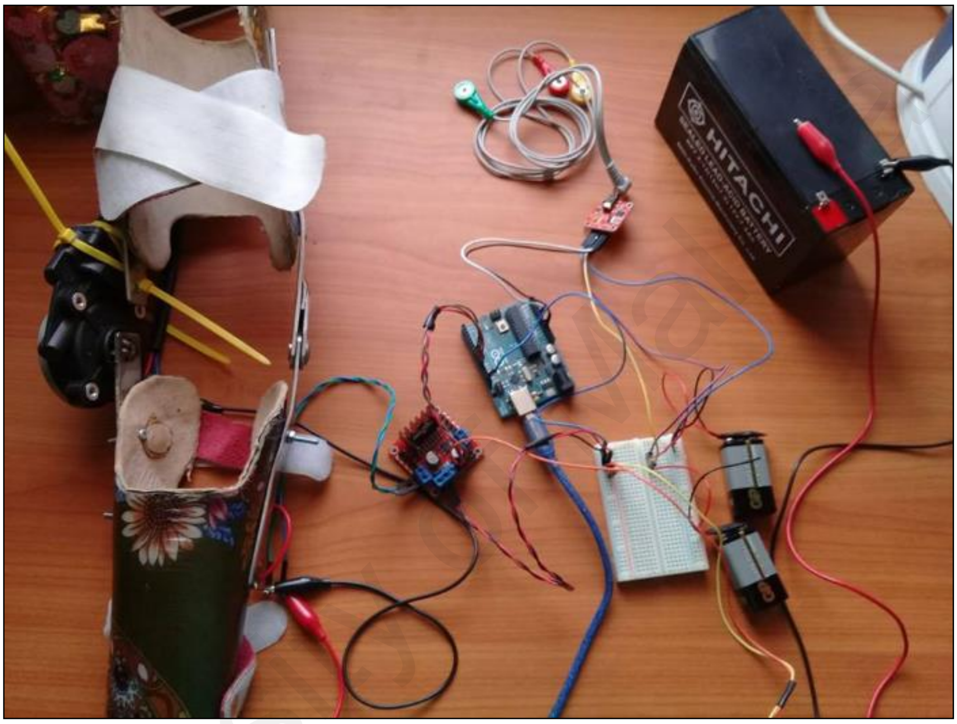


**Figure 4.2: Setup of the Active Elbow Orthosis**

The EMG sensors are placed on the bicep and triceps muscle because they are responsible for flexion and extension of the forearm. When the circuit is on, the muscle sensor reads input from the biceps and triceps muscle and sends the information to the microcontroller. In the absence of an input, the orthosis remains in the neutral or locked position. However if there’s an input to the muscle sensor, the microcontroller processes this input and sends an output to the DC motor. The DC motor then moves in a direction that flexes and extends the forearm and the cycle is repeated until the system is switched off.

### 4.2 DC Motor Control with Muscle Sensor

Figure 4.3 depicts the signal obtained from the muscle sensor when the muscle is at rest and when muscle activity is detected. The muscle sensor outputs muscle activity when it is at rest and during contraction. The muscle sensor used measures the rectified filtered electrical activity which is in voltage. This signal serves as the control signal for the DC motor. When the muscle is at rest, no signal would be sent to the motor, however when any muscle activity is been detected, the DC motor responds to this signal by flexing or extending the elbow.

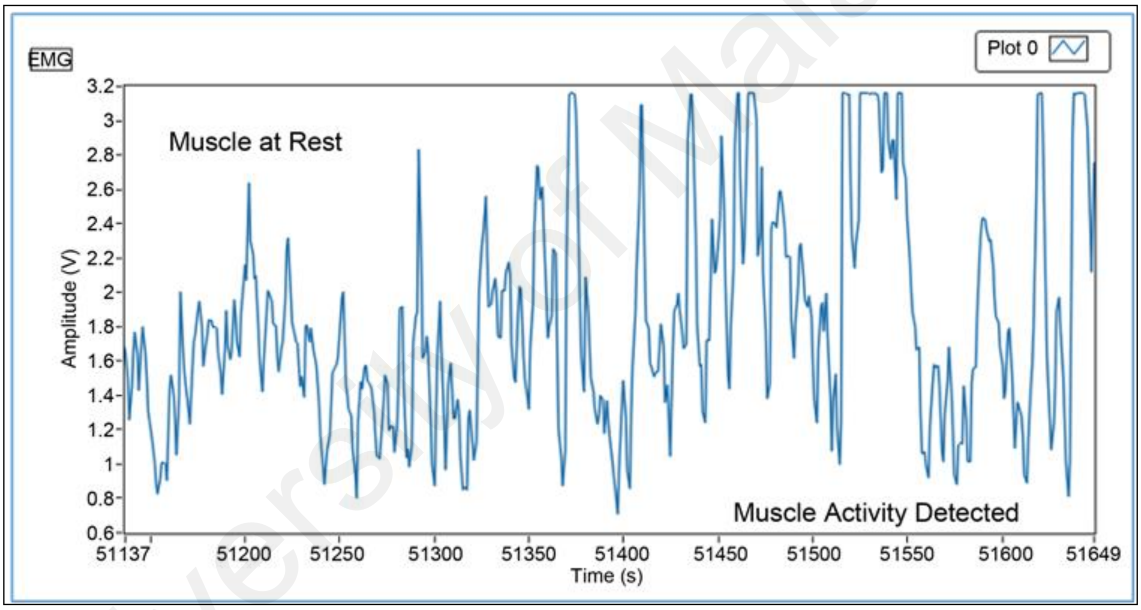


**Figure 4.3: Muscle Signal**

### 4.3 Biomechanical Analysis Using Kinovea

The elbow orthosis was analysed using Kinovea to determine whether the device can help in the flexion and extension of the human elbow through the normal ROM. The ROM of the joint when the subject was not wearing the orthosis and when the subject was wearing the orthosis was recorded using the software and the joint angle movement was thus calculated and compared.

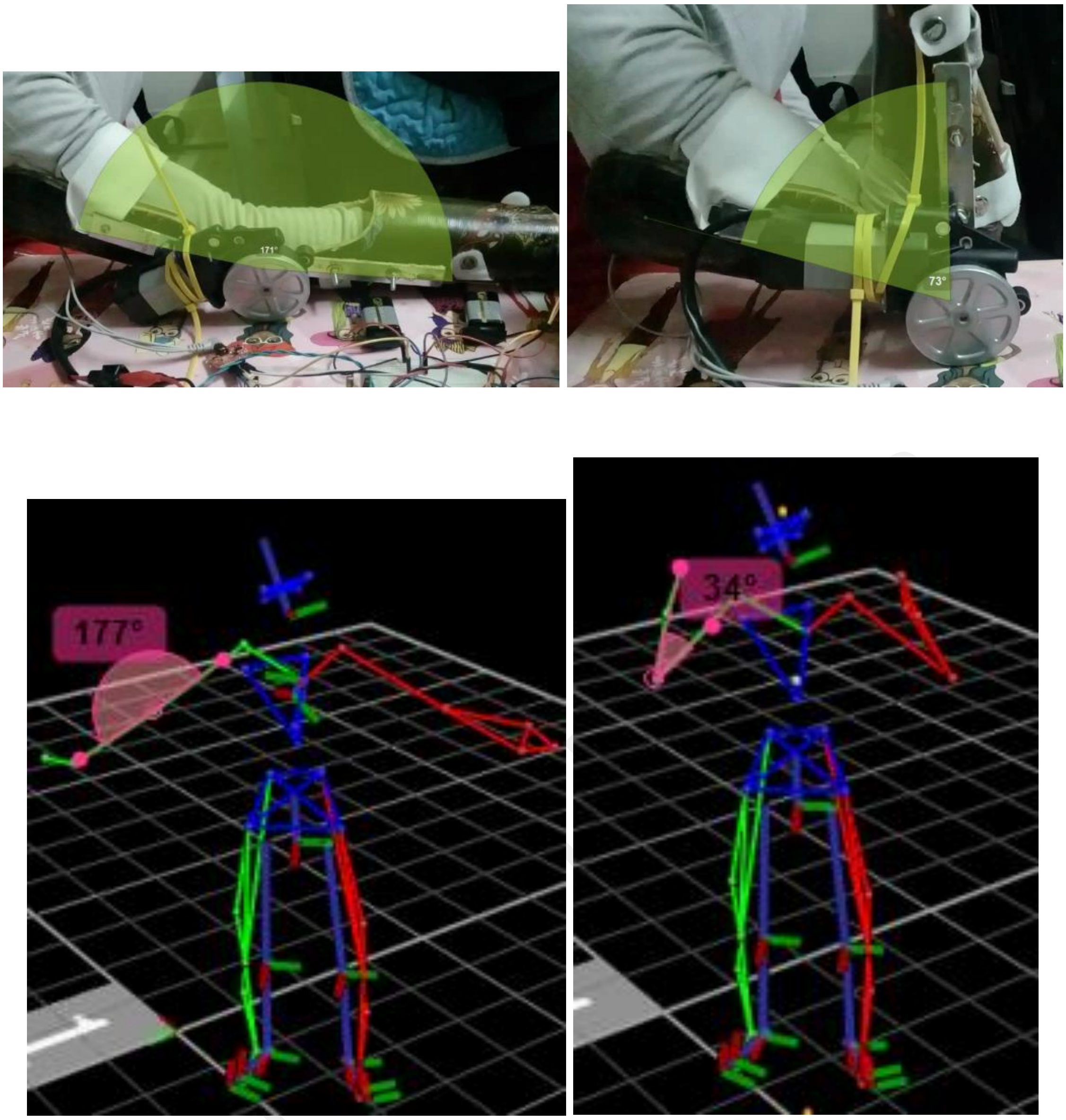


**Figure 4.4: Biomechanical Analysis**

The accurate measurement of the arm is required before the Kinovea software can be used. Hence the distance between each of the limbs of the human body was measured. The distance between the shoulder and the elbow is 18.5cm and the distance between the elbow and the wrist is 20.5cm. The angular measurement of elbow in flexion and extension with respect to the origin was equally measured as seen in figure 4.4 above. The elbow covered $34^0$ degrees in flexion and $177^0$ degrees in extension.

Table 4.1 below shows the result obtained from the application of Kinovea. It presents the maximum flexion angles of the elbow joint for the five subjects used for testing the performance of the elbow orthosis. The second column of the table shows the maximum flexion angles when the elbow orthosis is not worn while the third column shows when maximum flexion angles when the orthosis is worn. The percentage difference, which is the error of the elbow orthosis is calculated in the fourth column. The data from Table 4.1 was plotted in a graph as seen in figure 4.5 below.

The average maximum flexion angle of the elbow joint obtained is 140.8 degrees while the normal range of motion for the elbow is 140 – 150 degrees flexion. (Sardelli et al., 2011). This shows that the subjects chosen on an average falls within the normal range of elbow flexion movement. However only subject 2 and subject 5 falls within the normal range. Subject 1, subject 3 and subject 4 falls below the normal range of flexion movement with a few degrees.

**Table 1.1 Maximum Flexion Angle of Elbow Joint**

| Subject | The maximum flexion angle of the elbow joint (degree) | | Percentage difference (%) |
|---|---|---|---|
| | Without Elbow Orthosis | With Elbow Orthosis | |
| Subject 1 | 136 | 107 | 21.3 |
| Subject 2 | 146 | 96 | 34.2 |
| Subject 3 | 137 | 100 | 27.0 |
| Subject 4 | 135 | 106 | 21.5 |
| Subject 5 | 150 | 95 | 36.7 |
| Average | 140.8 | 100.8 | 28.14 |

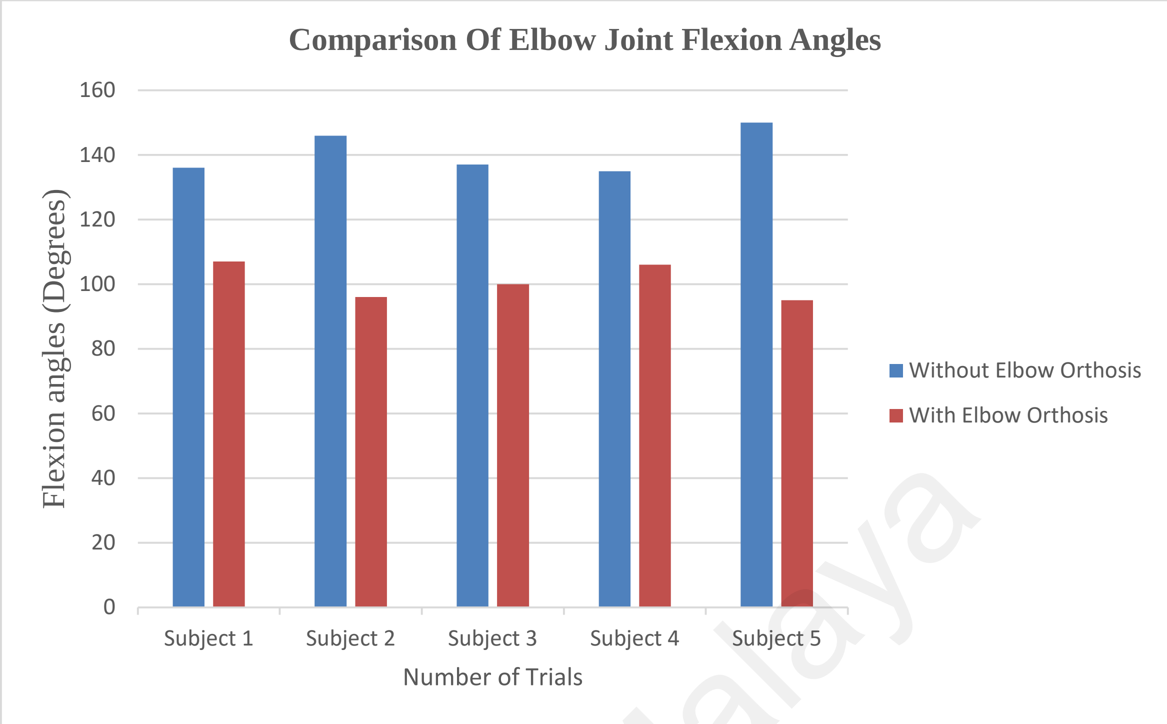


**Figure 1.5: Flexion Angle of Elbow Joint**

When the orthosis is worn, it was obtained from the result that all the subjects were not able to accomplish their normal flexion. Subject 1 falls short with 21.3 degrees while subject 2 falls short of normal flexion with 34.2 degrees. Subject 3 fell short with 27.0 degrees, subject 4 with 21.5 degrees and subject 5 with 36.7 degrees. The highest error obtained was from subject 5 and the average error was 28.14 degrees.

The average error shows that the elbow orthosis does not fully assist in covering the normal elbow flexion range of motion. This could be as a result of the torque provided by the DC motor not been sufficient enough to lift the arm. It could equally be that the design does not suit all the subjects because only one orthosis was designed and tested on five different subjects. Whereas five different orthosis should have been custom made for the five different subjects.

**Table 1.2 Maximum Extension Angle of the Elbow Joint**

| Subjects | The maximum angle extension of the elbow joint | | Percentage Difference (%) |
|---|---|---|---|
| | Without Elbow Orthosis | With Elbow Orthosis | |
| Subject 1 | 3 | 9 | 3.3 |
| Subject 2 | 2 | 15 | 7.2 |
| Subject 3 | 4 | 19 | 8.3 |
| Subject 4 | 3 | 17 | 7.7 |
| Subject 5 | 7 | 18 | 6.1 |
| Average | 3.8 | 15.6 | 6.5 |

Table 4.2 above displays the result obtained from the Kinovea software. It presents the maximum extension angles of the elbow joint of the five subjects used for testing the performance of the elbow orthosis. The second column of the table shows the maximum extension angles when the elbow orthosis is not worn while the third column shows when maximum extension angles when the orthosis is worn. The percentage difference, which is the error of the elbow orthosis is calculated in the fourth column. The data from Table 4.2 was plotted in a graph as seen in figure 4.6 below.

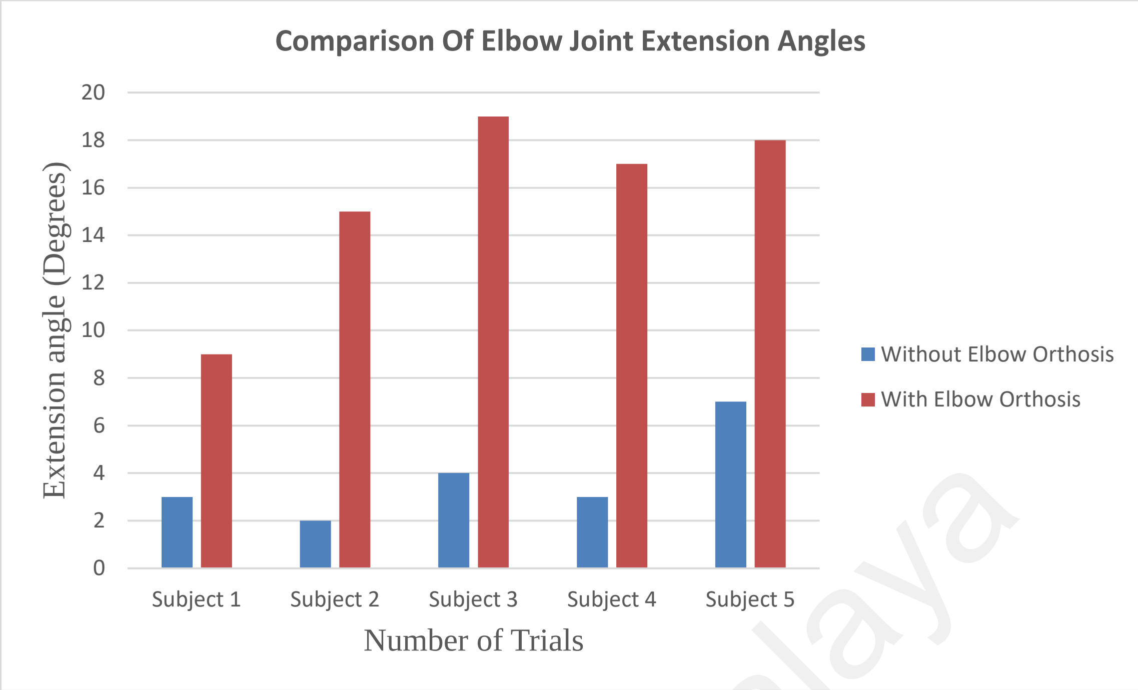


Figure 4.6: Elbow Joint Extension Angle

From the results, it can be seen that the average maximum extension angle of the elbow joint obtained from the subject is $7^0$ degrees while the normal range of motion for the elbow is $0^0$ - $5^0$ degrees extension. (Sardelli et al., 2011). This shows that the subjects chosen on an average falls within the normal range of elbow extension movement. Subjects 1, 2, 3 and 4 falls within the normal range of elbow extension however Subject 5 falls below the normal range with $2^0$ degrees.

The subjects were not able to accomplish their normal extension when the orthosis was worn. Subject 1 falls short with $3.3^0$ degrees while subject 2 falls short of normal flexion with $7.2^0$ degrees. Subject 3 fell short with $8.3^0$ degrees, subject 4 with $7.7^0$ degrees and subject 5 with $6.1^0$ degrees. The highest error obtained was from subject 3 and the average error was $6.5^0$ degrees.

The normal range of movement for extension is 0 – 5 degrees. The result displayed in the table shows that the elbow orthosis is capable of almost mimicking full extension.

The orthosis could have fully mimicked the range of motion for extension if the orthosis was custom designed for each of the subjects and a motor generating higher torque is used.

The active human ROM is from 40 degrees to 140 degrees. The result shows that the elbow orthosis moves through these active range. Hence the orthosis can be used to help patients with post stroke conditions having weak arms especially at the elbow region to regain their elbow active ROM thus the device can be used for self-rehabilitation.

# CHAPTER 5: CONCLUSION AND FUTURE WORK

## 5.1 Conclusion

An active elbow orthosis which detects signal from the muscle using electromyography has been developed. The mechanical design, method of sensing and actuation and the analysis of the results have been presented. The aim of the project which was to design and develop an active elbow orthosis and to implement electromyography (EMG) in the orthosis has been achieved. However the third objective which was to implement feedback control in the elbow orthosis was not achieved. The analysis of the elbow orthosis using Kinovea software showed that it is capable of helping in the flexion and extension of the human elbow through the normal ROM.

## 5.2 Limitation and Recommendation

The orthosis in this project was actuated with a motor capable of a moment of 2.9N.m. However the elbow joint requires a maximum moment of 5.8Nm to carry out various activities of daily life hence a motor capable of a higher torque should be used.

The orthosis was powered with a 12V lead acid rechargeable battery. This battery is heavy which makes the orthosis not portable. A Lipo battery or a LiFePO4 battery should be used to make the orthosis portable.

A feedback control was to be implemented in the orthosis to make the orthosis more accurate and automatically correct for flexion-extension angle errors. However due to time-constraint, it wasn’t implemented hence should be applied in future work.

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APPENDIX A: GANTT CHART

| Tasks | | | Months | | |
|---|---|---|---|---|---|
| | July | August | Sept. | Oct. | Nov. | Dec. |
| Literature review | | | | | | |
| Mechanical design | | | | | | |
| Electrical design | | | | | | |
| Coding, Testing | | | | | | |
| Evaluation | | | | | | |
| Report writing and presentation | | | | | | |

APPENDIX B: PROGRAM CODE

```
int enA = 10;
int in1 = 9;
int in2 = 8;
void setup() {
 // set all the motor control pins to outputs
 pinMode(enA, OUTPUT);
 pinMode(in1, OUTPUT);
 pinMode(in2, OUTPUT);}
void Sweep() {
 // this function will run the motors in both directions at a fixed speed
 // turn on motor A
 digitalWrite(in1, LOW);
 digitalWrite(in2, HIGH);
 // set speed to 200 out of possible range 0~255
 analogWrite(enA, 200);
 delay(2000);
 // now change motor directions
 digitalWrite(in1, HIGH);
 digitalWrite(in2, LOW);
 delay(2000);
 // now turn off motors
 digitalWrite(in1, LOW);
 digitalWrite(in2, LOW); }
void loop()
{
 Sweep();
 delay(2000);
}
```

```
// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // print out the value you read:
  Serial.println(sensorValue);
  delay(1);        // delay in between reads for stability
}
```