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Development of a Tele-Physiotherapy Device to Remedy Elbow Joint with Mobile App Support

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by

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Development of a Tele-Physiotherapy Device to Remedy Elbow Joint with Mobile App Support

Abstract

The aim of this thesis was to develop a wearable tele-physiotherapy device that addresses the remote elbow joint rehabilitation. The developed device consists of a wearable exoskeleton equipped with servo motor, joint angle sensor, EMG sensor, battery and Wi-Fi module. By connecting with the Android mobile application, it enables real-time monitoring of EMG data and programming of personalized exercise programs. The device offers convenience and comfort to patients by eliminating the need for face-to-face physiotherapy sessions and aims to reduce treatment costs and treatment time.

The development process started with the design of the exoskeleton structure, then the necessary electronic hardware and sensors selected and placed on the device. In the second stage, the embedded system software of the Stm32 processor developed. The embedded system on the device should be able to control the servo motor, sensors and connect to the android phone and share the sensor data and exercise program information. In the last stage, a mobile application developed to connect the physiotherapy device from the phone. Thanks to the developed IOT mobile software, the patient's training programs can be controlled, loaded onto the device, and the patient's condition can be shared with the doctor.

In this thesis the development process of a wearable tele-physiotherapy device with an IOT (internet of things) feature is presented. The device is capable of data collection/processing, physiotherapy programs made by doctors via online, and healing status tracking to fasten healing process while reducing risk of suffering from pain. The validity of the proposed device is carried out by long term real life testing.

Future work involves further improvement of the device and software for comfortable use and functionality.

Keywords: Electronics, EMG, IOT, orthosis, physiotherapy automation, prosthesis

Dirsek Eklemini İyileştirmeye Yönelik Tele-Fizyoterapi Cihazı Geliştirilmesi

Öz

Bu tezin amacı, uzaktan dirsek eklemi rehabilitasyonunu ele alan giyilebilir bir tele-fizyoterapi cihazı geliştirmektir. Geliştirilen cihaz servo motor, eklem açı sensörü, EMG sensörü, batarya ve Wi-Fi modülü ile donatılmış giyilebilir bir dış iskeletten oluşmaktadır. Geliştirilen mobil uygulamaya bağlanarak EMG verilerinin gerçek zamanlı izlenmesini ve kişiye özel egzersiz programlarının programları oluşturulabilmesini sağlar. Cihaz, yüz yüze fizyoterapi seanslarına olan ihtiyacı ortadan kaldırarak hastalara kolaylık ve rahatlık sunuyor ayrıca tedavi masraflarını ve tedavi süresini düşürmeyi hedefliyor.

Geliştirme sürecine, dış iskelet yapısının tasarlanması ile başlandı, ardından gerekli elektronik donanım ve sensörler seçilerek cihaza yerleştirildi. ikinci aşamada Stm32 işlemcisinin gömülü sistem yazılımı geliştirildi. Cihaz üzerindeki gömülü sistem, servo motoru, sensörleri kontrol edebilmeli ve telefona bağlanıp sensör verilerini ve egzersiz programlarını bilgisini paylaşabilmelidir. Son aşamada ise fizyoterapi cihazına telefondan bağlanmak için bir mobil uygulama geliştirilmiştir. Geliştirilen IoT mobil yazılım sayesinde hastanın eğitim programları kontrol edilebilmekte, cihaza yüklenebilmekte ve hastanın durumu doktor ile paylaşılabilmektedir.

Bu tezde IoT (nesnelerin interneti) özelliğine sahip giyilebilir bir tele-fizyoterapi cihazının geliştirme süreci sunulmaktadır. Geliştirilen cihaz, veri toplama/işleme, doktorlar tarafından çevrimiçi olarak yapılan özel fizyoterapi programlarını alıp uygulama ve yanlış egzersize bağlı ağrıdan muzdarip olma riskini azaltırken iyileşme sürecini hızlandırmak için iyileşme durumu izleme kabiliyetine sahiptir. Önerilen cihazın geçerliliği, uzun süreli gerçek hayat testleri ile gerçekleştirilebilir.

Gelecekteki çalışmalar, rahat kullanım ve işlevsellik için cihazın ve yazılımın daha da geliştirilmesini içerir.

Anahtar Kelimeler: Elektronik, EMG, IOT, ortez, fizyoterapi otomasyonu, protez

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List of Abbreviations

ADC	Analog to Digital Conversion
EMG	Electromyography
IoT	Internet of Things
Li-Ion	Lithium-Ion
Li-Po	Lithium-Polymer
MCU	Micro Controller Unit
MPa	Megapascal
SoC	System on Chip

List of Symbols

A	Ampers
F	Force [N]
d	Distance [Meter]
r	Diameter
m	Mass [kg]
w	Weight [kg]
°	Degrees
π	The Constant Pi Number (3,14)
θ	Elbow Angle [Degrees]

Chapter 1

Introduction

Elbow joint injuries are a common health problem that can happen to people for various reasons such as sports activities, work accidents and traffic accidents. In such a case, patients should receive physiotherapy. Traditional physiotherapy methods may encounter time and access limitations, and the difficulties in patient follow-up and rehabilitation process can prolong the physiotherapy process. For example, during the COVID19 pandemic, the limitations of health services and the precautions taken have created significant disadvantages in the treatment and physiotherapy processes of elbow joint injuries. It was difficult for the patients to reach the hospital and their doctors for physiotherapy, and there were problems in planning appointments and physiotherapy sessions. In addition, problems arose in the motivation and follow-up of patients.

1.1 Elbow Joint Injuries

Arm joint injuries can be generalized into 2 types. These are logical injuries like stroke and physical injuries like tendon breaks. Elbow joint injuries can result from diverse causes, including traumatic events, overuse, repetitive motions, sports-related activities, workplace accidents, and medical conditions. Acute injuries often involve sudden and forceful impacts, such as falls, direct blows, or dislocations. Chronic injuries, on the other hand, develop gradually over time due to repetitive stress on the joint or underlying medical conditions, such as tendinitis or arthritis. Elbow joint injuries can lead to various complications and functional impairments. One common issue is the development of elbow contractures, which can restrict the range of motion and cause pain and stiffness (Hildebrand et al., 2004). Elbow contractures are often treated by excision of the joint capsule, but the underlying changes in the joint capsule after trauma are not well understood.

Every year, 15 million people worldwide suffer a stroke, and it is the leading cause of motor disabilities. More than 85 percent of the patients survive, but only 10 percent recover completely (Benjamin et al., 2017). The rest must deal with disability in the upper or lower limb, cognitive disabilities or other types of after stroke conditions. Victims of the stroke can get help relearning skills they have lost or new techniques of performing tasks to compensate for lost abilities through Occupational Therapy. Physical Therapy can also help stroke victims by reducing muscle spasticity and pain with improved range of motion in the impaired joints.

Another complication that can arise from elbow injuries is myositis ossificans (MO), which is the abnormal formation of bone within muscle tissue. MO is a rare complication, especially in children, but it can occur after trauma and excessive rehabilitation exercise (Cao et al., 2021). A case report by Cao et al. (2021) described a case of MO in an 8-year-old girl who underwent surgery for a lateral humeral condyle fracture. The bony mass appeared around the elbow due to wrong exercise methods during rehabilitation (Cao et al., 2021).

In addition to these complications, the elbow joint is also susceptible to other injuries, such as lateral epicondylitis and valgus extension overload (Ellenbecker et al., 2012).

1.2 Elbow Joint Physiotherapy

Physical therapy and rehabilitation play a crucial role in improving the range of motion and overall functional outcomes in patients with elbow injuries. The elbow joint plays a significant role in throwing motions, and maximal strength developed by the flexor and extensor muscles of the elbow has been shown to be related to ball velocity in sports such as volleyball and tennis (Forthomme et al., 2005). Rehabilitation exercises, such as eccentric external rotation strengthening, are important for restoring function and preventing further injuries in the elbow joint. Physical therapy and rehabilitation can help improve the range of motion and overall functional outcomes in patients with posttraumatic contractures (Gocevska et al., 2022). A study by Gocevska et al., 2022 highlighted the importance of kinesitherapy and functional therapy in combination with other physical procedures for the treatment of posttraumatic contractures in children. Most effective rehabilitation is specific to the patients needs and sufficiently high intensity with duration to truly retain the nerves and muscles which are involved (Huang et al., 2009) (Kwakkel et al., 1997).

But the limitations start here on available resources such as the number of trained physiotherapists while the number of patients increase day by day, particularly as population age. The U.S. Census Bureau estimates that the number of Americans aged 65 or over, whom according to stroke research studies are at greater risk of suffering a stroke, will double by 2050 (He et al., 2016). Interest in the physiotherapy field is growing, physical medicine and rehabilitation projects and the current physiotherapy shortage will increase significantly in the upcoming decades.

Clinical study done at 66 patients shows the effect of physiotherapy on tennis elbow disease, shows progressive exercises bring about increased and faster recovery in patients with tennis elbow (Moneet & Ankit, 2002).

Loss of muscle mass accompanies periods of bed rest and limb immobility in humans and requires rehabilitation exercise to effectively restore mass and function. During rehabilitation, exercise-induced myogenesis may be partially responsible for the recovery of muscle mass (Marimuthu et al., 2011).

Rapid and sustained exercise based suppression of myostatin mRNA expression, that precedes gain in muscle mass, points to this, along with other myogenic proteins, as being potential regulators of muscle regeneration during physiotherapy rehabilitation in humans. Diagrammatic representation can be seen on Figure 1.1. Reduced muscle activity is associated with loss of muscle mass in aging. It is a common feature of bone fracture, surgery, ICU admission, and disease.

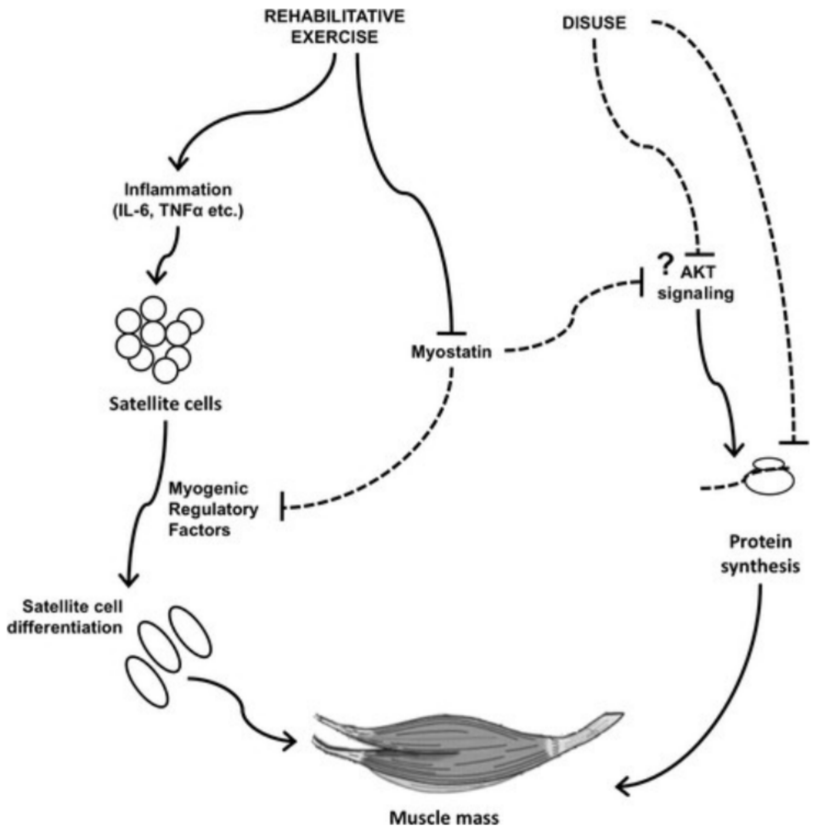


Figure 1.1 Diagrammatic representation of the main mechanisms responsible for regulating skeletal muscle mass

It is recognized that muscle mass loss can negatively impact the ability to perform daily tasks, increase the incidence of future injury, prolong the period of physiotherapy rehabilitation (Marimuthu et al., 2011).

The rehabilitation programme should be built around progressive agility and trunk stabilization exercises, as these exercises seem to yield better outcomes for injured skeletal muscle than programmes based exclusively on stretching and strengthening of the injured muscle (Järvinen et al., 2007).

One of the diseases affecting the muscles is Osteoarthritis (OA) is the most common form of arthritis, affecting millions of people worldwide. It occurs when the protective cartilage that cushions the ends of the bones wears down over time. Although OA can damage any joint, it commonly affects joints 2 in your hands, knees, hips and spine. Muscle strength, endurance, and speed were 50 Percent less in OA patients. After physiotherapy rehabilitation, there was a significant increase in strength (35 Percent), endurance (35 Percent), and speed (50 Percent). Healing in muscle function was associated with decreased dependency, difficulty, and pain. The average increase in measured parameters was 25 Percent after four months of physiotherapy rehabilitation. Improvements sustained for eight months after physiotherapy rehabilitation. The muscle rehabilitation program was designed specifically to improve muscle function (Fisher et al., 1991).

The myoelectrical activity is found to be increasing during the physiotherapy exercise which can be explained with increased rate of firing in muscle motor units (Enoka, 1988). To observe changes in the myoelectrical activity of muscles used in Physiotherapy exercises, the transition lower frequencies of the surface EMG signals due to low pass effect of tissues must be acknowledged (Lindstrom et al., 1977).

The square root (RMS) of the average power of the EMG signal increases as muscle motor unit recruitment and firing density of units are increased (Petrofsky, 1979).

To activate motor units with higher threshold without need for bigger load to be used during the physiotherapy exercise, muscles need to develop fatigue levels sufficient to activate those fibers. By developing fatigues in muscle and recruiting motor units with higher threshold it is possible to obtain muscle hypertrophy to promote better muscle growth (Marcotte et al., 2015).

1.3 Surface Electromyography (EMG)

Surface electromyography (EMG) is a non-invasive technique used to measure the electrical activity of muscles. EMG is a valuable measurement method since it can work from the surface of the skin, it is used in sports, biomechanics, rehabilitation and physiotherapy.

EMG electrodes are adhesive patches with conductive gel for pickup electrical activity through the skin. EMG device amplifies the electrical signals and processes the signals to make it meaningful.

Since EMG measures electrical activity from the surface, it may not show deep muscle activity accurately. In that case other measurement tools can be used, like MRI to visualize or invasive methods (Woods & Bigland-Ritchie, 1983).

1.4 Relations of Surface EMG and Muscle Rehabilitation

EMG measurements can be used on diagnosis as it shows muscle function and activation patterns. It helps identify muscle imbalances, weakness or other patient's symptoms. EMG data can be used as biofeedback, which shows real-time visual feedback about muscle activity. In physiotherapy EMG is used to monitor muscle activity during rehabilitation exercise to ensure correct muscle activation and optimize the healing process. It can also be used to postoperative rehabilitation EMG can guide timing and progression of exercises helping patients to protect healing tissues and optimize the recovery process (Frank et al., 1999).

For investigating muscle fatigue, the surface electromyographic power spectrum is preferred. Surface EMG able to make observations of electrical properties of muscle during Physiotherapy exercise and observation of muscle frequency analysis regarding the action potential of muscles is a well researched topic (Gibson & Edwards, 1985).

Muscles adapts to exercise training and EMG is widely used to observe the time needed for adaptation and muscle response to training. The neural adaptation to Physiotherapy exercise is directly evident in EMG studies (Felici, 2006).

1.5 Wearable Physiotherapy Devices

Wearable physiotherapy devices show a modern approach to rehabilitation and physiotherapy that gained increased interest in recent years. Smart watches, fitness trackers, motion sensors revolutionized the healthcare industry. In physiotherapy, wearable devices can provide real time feedback, monitor patient progress and track patient condition during rehabilitation. Sensors on modern wearable devices allow for continuous monitoring of users movement patterns, joint angles, muscle activity, EMG and ECG data which can be valuable data for both patients and doctors.

For the elbow joint physiotherapy elbow brace or supports are in wide use. As an example, wearable lower-limb exoskeletons are emerging as a revolutionary technology for robotic walking rehabilitation. 87 Clinical studies analyzed focusing on device technology (e.g., actuators, sensors, structure) and clinical aspects (e.g., training protocol, outcome measures, patient impairments), and make available the database with all the compiled information. The results of the literature survey shows that wearable exoskeletons have high potential for applications including early rehabilitation, promoting physical exercise, and carrying out daily living activities both at home and the community. For non-ambulatory patients it means improved mobility and independence with wearable exoskeletons. Also, it may reduce secondary health conditions related to sedentariness, with all the advantages that this entails (Rodríguez-Fernández et al., 2021).

The CLEVERarm study is one of an exoskeleton-based rehabilitation device for curing stroke related arm diseases by utilizing robotic systems. CLEVERarm planned to use it for upper-limb rehabilitation and design it as an eight DoF arm exoskeleton. Its structure is compact and lightweight by using 3D printed parts with material selection of carbon fiber. CLEVERarm needs clinical tests but studies like this show how much potential this topic has (Soltani-Zarrin et al., 2017).

1.6 Wearable Physiotherapy Devices on Market

1.6.1 MyoPro by Myomo Inc

MyoPro is a limp orthosis designed to support and assist patients with neuromuscular conditions that affect function of their arm and hand, including stroke, spinal cord injury and brachial plexus injury. It uses EMG sensors to detect patients' intended muscle movement and uses motors to assist movement in real-time (Myomo Inc.).

1.6.2 EksoBionics EVO

Evo is an upper limb exoskeleton product from a Russian company. It is designed to assist patients with upper limb motor impairments. Evo provides personalized assistance to the elbow and shoulder which enables patients to perform daily activities and rehabilitation exercises. It utilizes sensor technology and algorithms to detect the patient's intention of movement, providing motorized support during rehabilitation exercises and activities of daily living (Ekso Bionics).

1.6.3 Ironhand and Carbonhand by Bioservo Technologies

Ironhand is a robotic exoskeleton glove that can assist patients with reduced handgrip strength, but it also includes elbow support. It can also be used in work environments where workers need high gripping powers. Carbonhand is a more daily solution, for lower need of support and lightweight applications (Bioservo Inc.).

1.6.4 NEUROExos Elbow Module

The NEUROExos elbow module is part of a modular exoskeleton system. It targets the elbow joint and provides active assistance and resistance for rehabilitation and physiotherapy purposes. This exoskeleton aims to improve motor units recovery and promote functional independence (Vitiello et al., 2013).

1.6.5 ExoAtlet Company

ExoAtlet is a medical physiotherapy exoskeleton developer company that has a very common usage area and functionality of ExoAtlet exoskeletons has been accepted by 16 clinical studies, 24 clinics and over 700 patients. ExoAtlet provides wearable exoskeletons, also known as, recovery devices for children and adults, and assistive robotic tools for industry workers and older people. These products will be more involved in people's lives in the near future (Exoatlet).

1.6.6 SmartWatches

Smart watches are getting more and more common day by day. Most of the new smartwatches have advanced sensors that track exercise and body condition. According to statista, in 2023 210.2 million people use smart watches, which shows people care about their exercise, sports, heart rate and ECG tracking and happy to wear that type of devices in a fashionable way (Statista Research Department, 2023).

1.7 Elbow Joint Physiotherapy Exercises

1.7.1 Elbow Flexion and Extension (Elbow Bend)

Elbow flexion brings the hand closer to the shoulder by bending the elbow joint, vice versa elbow extension moving the hand away from shoulder by straightening the elbow joint. These movements work the muscles in the anterior and posterior of the upper arm and also muscles around the elbow joint. Such as biceps, triceps, brachialis (Stasinopoulos et al., 2005).

1.7.2 Biceps Curls

This is one of most known exercise, biceps muscle is the main target of this exercise. The movement of the arm focused on bending the elbow while holding weight and bringing weight closer to the shoulder (Donaldson et al., 2014).

1.7.3 Elbow Rotations

This exercise involves circular movements with the forearm. Several muscles responsible for stabilizing and controlling the motion of the elbow joint. Biceps, triceps, brachialis, pronator teres and supinator, brachioradialis and anconeus. This exercise is a good example of physiotherapy specific exercise because there is no additional weight involved. Therefore, the main aim of this exercise is improving mobility, flexibility and stability. This exercise also helps warm up and strengthen the elbow muscles and reduce the risk of injuries in more intense exercise sessions (Stasinopoulos et al., 2005).

1.7.4 Triceps Extension

Weight or force applied on the arm to make opening the arm harder with straightening the elbow. As an example, overhead cable pulling, straightening the elbow to open arms. This exercise mainly focuses on triceps muscle (Donaldson et al., 2014).

1.7.5 Pronation and Supination

Bending elbow 90 degree angle, rotating forearm palm down and palm up while grabbing weight in the hands. This exercise focuses on rotational movements of the forearm. Pronator teres, pronator quadratus, brachii, supinator muscles involved in this exercise. These muscles work together for pronation and supination movements. These movements are needed for daily needs like turning door knobs, using screwdrivers and performing other everyday tasks that include twisting motions (Stasinopoulos et al., 2005).

1.7.6 Example Training Program

Patients' elbow and wrist should warm up by starting with the wrist turn movement and activating the ligaments and muscles in and around the elbow. This movement is performed by turning the palm 180 degrees, facing up and down, without any load. The palm is brought to a position parallel to the ground, facing down, and it is held this way for 5 seconds. Then, it is turned 180 degrees with the palm facing up, waited for another 5 seconds, and this movement is repeated 15 times. This movement exercises the muscles around the elbow and wrist and can be done in later stages of the rehabilitation exercise depending on the patient's condition. The anatomical visual of the movement and the muscle groups used are shown in Figure 1.2.

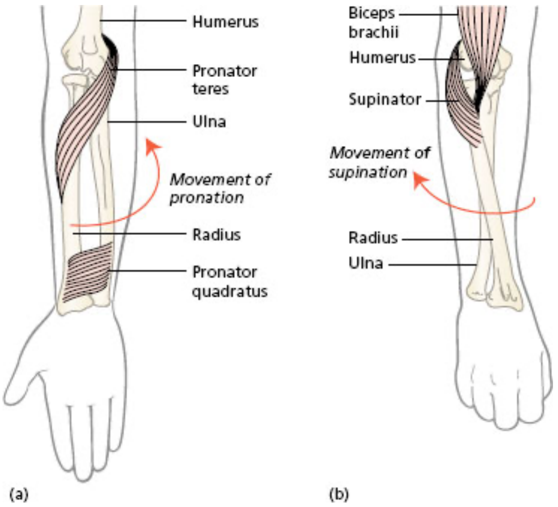


Figure 1.2 Wrist turn anatomic view

Passive flexion exercise is performed as the second movement. This movement is very similar to the Elbow Bend movement, but it is performed by passively applying pressure without any load. The elbow is placed on a towel placed on a table to provide a soft and flat surface. The patient's hand is stretched by applying pressure with the patient's other arm or with the help of the developed orthosis, so that it rests on the shoulder, and waits for 1 minute while applying pressure. This movement is repeated 10 times (Fort Worth Hand Center.).

The rehabilitation program continues with Elbow Bend Flexion. While the patient is standing, one arm is released straight and extended downwards, then slowly lifted up to the shoulder with a light weight and waited in this position for 15 seconds. This movement is repeated 10 times. This exercise can be performed with the correct speed and number of repetitions thanks to the developed orthosis, the patient can receive support from the orthosis, and the patient's recovery process can be monitored by examining EMG data (Orthopedic Associates of Hartford, 2020).

In the next program, the Elbow Bend movement is performed again, but this time the exercise is performed as Extension. Using the developed orthosis while standing, the patient tries to open his arm to resist the orthosis. The developed orthosis works like a rubber band which works against the patient's arm and thus helps in performing extension exercises. Monitoring of the patient's condition and correct execution of the exercise movement is ensured by the developed orthosis. This movement is repeated 10 times and 3 sets a day are performed depending on the patient's condition. The muscle groups used in Elbow Bend movements are shown in Figure 1.3.

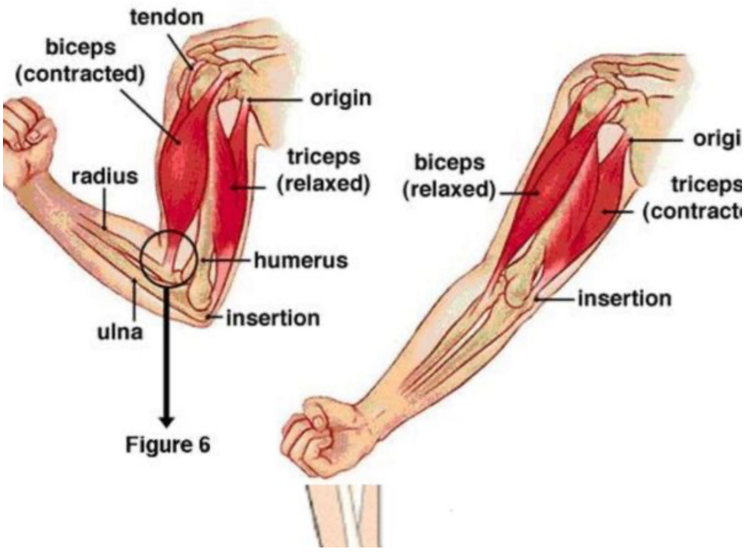


Figure 1.3 Elbow bend working muscles (Duncan Sports Physical Therapy, 2017)

Finally, the Supination/Pronation movement is performed, very similar to the Wrist Turn movement using active weight. In this movement, the patient extends his arm flat on a towel on the table and slowly turns his wrist approximately 90 degrees to the right and left, using a hammer-like weight in his hand. This movement is repeated 10 times and 1-3 sets are performed per day depending on the patient's condition. Support or difficulty can be provided to the elbow during the exercise with the help of an axis and motor added to the developed orthosis so that this movement can be performed using an orthosis. In this way, the patient can make the movement correctly and the patient's condition can be monitored in detail.

Example muscle groups that can be exercised with the developed orthosis are shown in Figure 1.2 and Figure 1.3. Clinical experiments conducted in the Review of articulated elbow orthotics for joint stiffness rehabilitation and Static Progressive Orthoses for Elbow Contracture: A Systematic Review studies showed that rehabilitation exercises performed with orthoses were more beneficial than old-style exercises. It has been observed that it provides support in more efficient and precise treatment of target muscle groups and accelerates the treatment process, while also helping the patient return to normal life (Cavalcanti et al., 2022; Chen et al., 2017).

1.8 Electronics in Robotic Physiotherapy Devices

1.8.1 Electric Motors

1.8.1.1 Brushless Motors

Brushless motors have 3 groups of coils on the inside of the motor, which is settled to the mounting. On the external side, it contains multiple magnets mounted to the cylindrical outer cover that is appended to the turning shaft. Hence, the coils are fixed and there is no need for brushes. Brushless motors turn a lot quicker and use less power at the same speed relative to DC motors. Unlike DC motors, they don’t lose power in the brush-transition, so it is a lot more productive. The Kv rating in a motor demonstrates how various RPMs (Revolutions per minute) the motor will do per volt. The higher the kV rating is, quicker the motor rotates at a steady voltage but with the lower torque (Droneybee).

A motor driver, called the electronic speed controller or (ESC) is needed for using brushless motors which is what controls the brushless motor with 3 phase AC according to the ESC control signal, which comes from MCU. It is responsible for controlling the rate of power delivery to the motor and few other features: coil control timings, beeping etc. Another requirement is Brushless motors and ESCs need at least 8 Volt (Gong & Verstraete, 2017).

1.8.1.2 Stepper Motors

Stepper Motors type of Brushless DC motors, with increased number of coils, magnetic poles which results in extremely high precision. High precision machines like CNC cutters use step motors to move the machine's axis. As a downside, step motors are the largest and heaviest among others.

Just like standart brushless DC motors, step motors needed a special driver board. Direction and pulse signal is needed to rotate the step motors shaft. Generally, Step motors turn one complete revolution with 200 steps/pulses which equals to 1.8 degrees per pulse. Stepper motor drivers need 12 Volts to work stable (Aranjo et al., 2012).

1.8.1.3 Servo Motors

Servo motors consist of coreless or micro size dc motors and a few gears to increase torque and provide precise out shaft angle. Precise and high torque movements are the main pros of using servo motors. The out shaft of the servo motor can be moved a total of 90, 180 or 360 degrees depending on the model. Limited out shaft angle is a downside among others.

Unlike other types of motors Servo motors include motor drives in itself. Which means less weight and less electronics space. Also, servo motors can work stable with 5 Volts. Internal driver needs a motor angle signal from the MCU and constantly tries to remain in the wanted angle. Driver uses closed loop control for this. Position of the out shaft continuously monitored by the driver and compared to signal from MCU, and it makes required movements to compensate and ensure the motor shaft is in the wanted position (Wada et al., 2009).

1.8.2 Batteries

1.8.2.1 LiPo Batteries

LiPo batteries are produced as thin rectangle shaped, wrapped in aluminum. Puncture and drop resistance are main concerns as if the chemicals in the LiPo battery contacts with air, it catches fire or explodes. Lighter than Li-ion batteries. Instant and continuous discharge current is way higher than Li-ion batteries. Continuous discharge current of lipos varies between 30 A to 400 A (Kwon et al., 2006).

1.8.2.2 Li-ion Batteries

18650 Li-ion batteries are shaped just like regular AA batteries but bigger and more powerful. Li-ion batteries have better power density than Li-Po. Metal frame protects it from droppings and punctures, but still if that happens it will catch on fire or explode. 18650 batteries Used on heavy duty applications like Drills and electric cars (TESLA). One more upside is Li-ion batteries are Cheaper. Continuous discharge current between 5A to 30A (Spielbauer et al., 2022).

1.8.3 Microcontrollers

1.8.3.1 MicroChip Atmel/PIC

Microchip Technology Inc. is one of most known microcontroller producer in the world. Peripheral Interface Controller in short “PIC” Microcontrollers vary in options such as 8 to 32 bit architectures, peripherals, features etc. PIC is widely used in industrial automation, consumer electronics, automotive applications, medical devices and more.

Atmel Microcontrollers also known as AVR microcontroller family. AVR stands for "Alf and Vegard's RISC," name taken from microcontroller architecture. Atmel’s ATtiny and ATmega series gained extreme reputation by the use of them in Arduino boards. AVR microcontrollers are used in various applications just like PIC microcontrollers, ranging from hobbyist projects and DIY electronics to industrial automation and embedded systems (Slade et al., 2011).

1.8.3.2 STM32

STM32 microcontroller family produced by STMicroelectronics. ARM Cortex processor cores used with additional peripherals. STM series microcontrollers are generally used on Industrial applications rather than hobbyist because STM32 programming requires professionality in embedded electronics. STM is known for their robustness, versatility, industrial capability and stability. STM family has a rich ecosystem and variety of features to offer users such as, Memory options, low power modes, industrial temperature range, peripherals and communication features (Brown, 2016).

1.8.3.3 ESP32

ESP32 is developed by Espressif Systems. ESP32 is the successor of ESP8266 Microcontroller. ESP Microcontroller series generally used on the Internet of Things (IoT) applications due to its wireless communication capabilities and very high processing capabilities. ESP32 has a very powerful dual core 240 MHz processor, since it has Bluetooth BLE, Wifi, Flash memory and SRAM on the board in addition to GPIOs it is known as System on chip (SoC).

Another upside, the ESP32 can be programmed using the Arduino IDE or MicroPython, which can shorten the elapsed time during development of the prototype (Maier et al., 2017).

1.9 Aim of The Thesis

The aim of the thesis is to overcome the limitations of traditional physiotherapy methods and to offer a more accessible, effective and personalized method in elbow joint rehabilitation. The developed device eliminates travel and accessibility difficulties by enabling patients to access rehabilitation services at home and remote health centers. In addition, monitoring, feedback and personalized exercise programs enable patients to do the right physiotherapy exercises, increase their motivation and offer an effective rehabilitation process. In this way, the tele-physiotherapy device aims to achieve more effective results by overcoming the limitations of traditional methods while increasing the comfort level of the patients.

Chapter 2

Proposed Design

2.1 Mechanic Design and Structure

Designed Tele-physiotherapy device's main aim is that the patient can have physiotherapy in the flexion and extension axis of the arm and elbow joint. The elbow joint is considered a 2-DOF joint that can be seen at Figure 2.1.

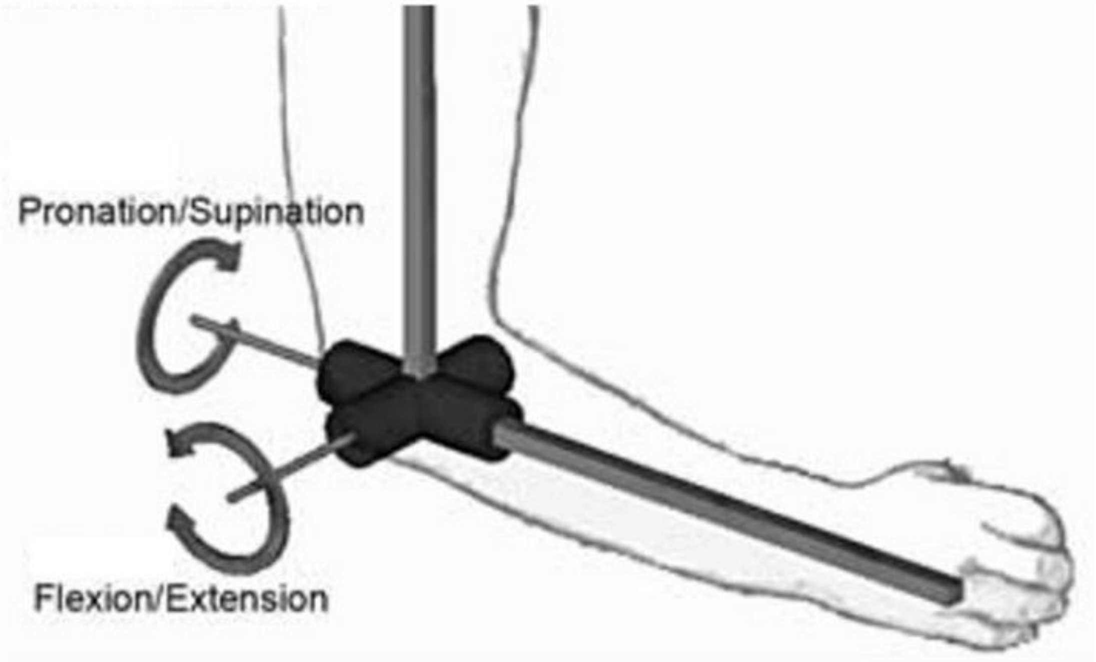


Figure 2.1: DoF of elbow joint

In order to achieve these movements, the servo motor was selected and placed at the shoulder level of the ROM orthosis. By pulling a rope attached to the end of the ROM orthosis by the servo, it was aimed to move the orthosis upwards, which was inspired by human tendons, that is, to make the arm-elbow joint flexion. A semi-circular piece is mounted on the servo motor, sacrificing torque to increase the distance in arm movement. At a 5V servo motor's torque is 10 kg-cm, with the help of the semicircular disc which has 5 cm which reduces torque to 2 kg, but the distance is increased. Effective torque increased by placing the connection.

$$2 * \pi * r \ = \ 2 * 3.14 \ * \ 5 \ = 31.4 \, is \, perimeter \tag{2.1}$$

By using formula 2*π*r, in equation (2.1) new perimeter to wind the rope is 31,4 cm since the servo motor cannot turn 360 degrees but 180 degrees so the usable new distance is 15.7 cm. As human tendon-like design is used to increase effective torque, the triangle formula can be applied to calculate arm movement. When the arm is fully flexed the angle is 180 degrees, both of ROM orthosis arms are 30 cm in length. From the calculation, the rope's length must be 60cm. If the servo motor winds the rope by rotation 180 degrees, the rope's length is 44.3 cm by using the triangle formulation again for a new triangle with sides of 35x30x44.3 cm, angle is 85 degrees. So, the achieved delta movement angle is more than 95 degrees which is enough for physiotherapy.

With this setup used servo motor capable of 10kg/cm with 5cm diameter disc motor support calculation is on equation (2.2).

$$Motor \ Support \ = \frac{10 \ kg/cm}{5cm} = \ 2kg \tag{2.2}$$

Using Tele-physiotherapy devices have various advantages but there is a chance that these devices may result in harmful effects if used wrong. So, a designed device must have some safety features. Hand, elbow, joints, arm and even shoulder anatomy must be well understanded as the developed device can affect all of these. Developed physiotherapy device must have limits for upper and lower extremities, maximum angle of flexion and extension in accordance with human anatomy. The maximum force that can be applied by the device should be limited in accordance with the human anatomy as can be seen on Figure 2.2. (Ertaş, 2010).

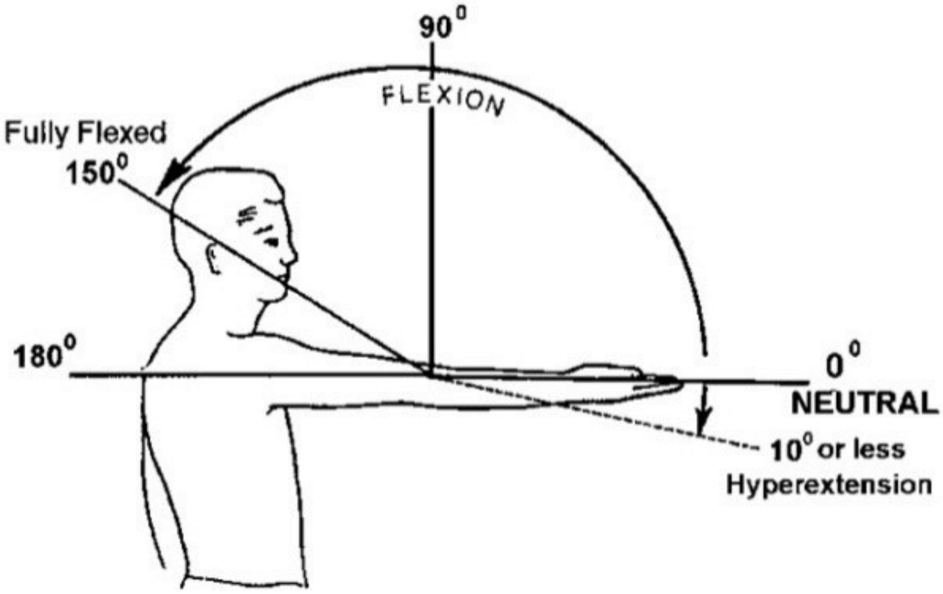


Figure 2.2: Expected range of motion

Extension – 0°, although some may possess more, such as 5° of hyperextension. Flexion – 140-150°. Supination and Pronation – 80-90°. The isometric strength of both elbow flexion and extension is maximum at 90°, which are 62,90 N and 63,30 N, respectively (SSharma et al., 2021).

2.1.1 Structure

Aluminum Exoskeleton structure used as a base system. This exoskeleton can be wearable with 4 straps attached to the user's arm. Electronics sensors and motors are placed on this structure. Elbow Rom Orthosis normally used for conservative treatment in elbow dislocations, rehabilitation in elbow contracture, orthotic treatment in medial lateral epicondyle fractures, post-prosthesis protection, protection and rehabilitation in elbow fractures, and post-operative protection and rehabilitation in elbow ligament injuries. Angle limiter is used when it is necessary to keep the elbow fixed at a certain angle or within a certain range of two angles (Variteks Inc.).

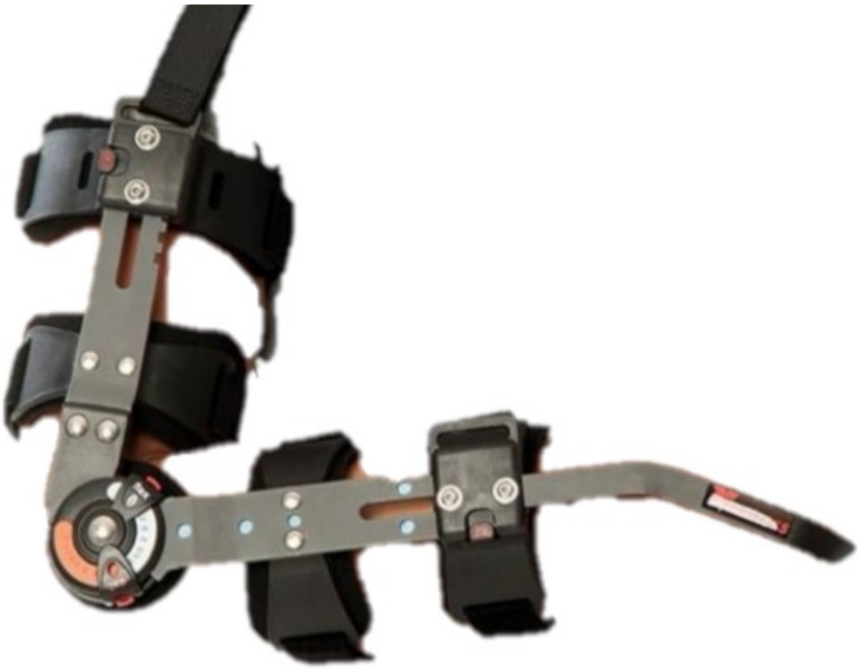


Figure 2.3: Variteks rom orthosis

Variteks Brand chosen because this product made from metal, durable and strong to handle motor forces, universal size for anyone with adjustable straps, easily accessible, had a few screw holes to mount electronics and motor, and built-in angle limiter that can be seen on Figure 2.3. Mechanical adjustable angle limits are useful to ensure patients arm movement stays within the limited range. Also, it provides additional safety for a few cases like the user can't handle, give up on lifting or any fault that can happen on the exoskeleton electronics.

2.1.2 Mechanic Design

Currently used systems were examined. An orthopedically robust and reliable design was chosen. Electronic servo motor is placed at shoulder level, so that it will not add weight to the movement of the arm and will not make the movements difficult, and the motor's effective torque also increases within this situation. Electronic's weight approximately 100 grams and can be placed on the structure between elbow joint and shoulder, near the servo motor. 18650 battery is 50 gr, ESP32 is 15 gr, pcb board, Step up regulator, ECG sensors, Sockets etc takes a total of 40 gr.

Five different 3D parts designed in Fusion 360 for the developed prototype. Two parts needed to place a potentiometer on the joint to use it as an angle sensor. One part designed to hold the servo motor in place as can be seen on Figure 2.4.

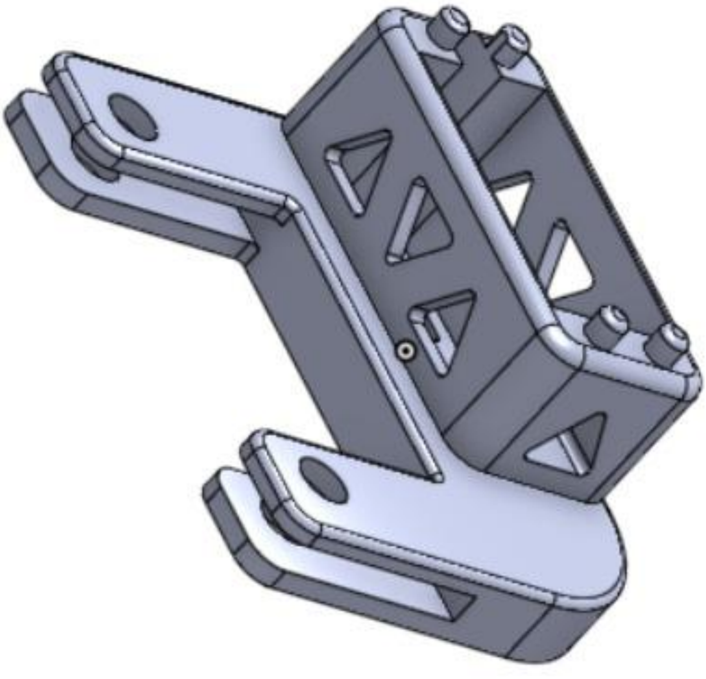


Figure 2.4: 3D Design of servo motor holder

Design inspired by human anatomy so servo motor placed near the shoulder. Servo motor rotates the other designed part, a semicircular disc, which is connected to a string. Strings other end connected to the another designed part which placed the hand side of the orthosis in this way torque is increased. When the disc winds the string on itself, the string pulls the orthoses from the front side,this makes users arm upwards.

Designed parts produced with a 3D printer as it is the fastest and cheapest way to build a prototype. High infill rate and PLA material used. Prototype can be seen on Figure 2.5.

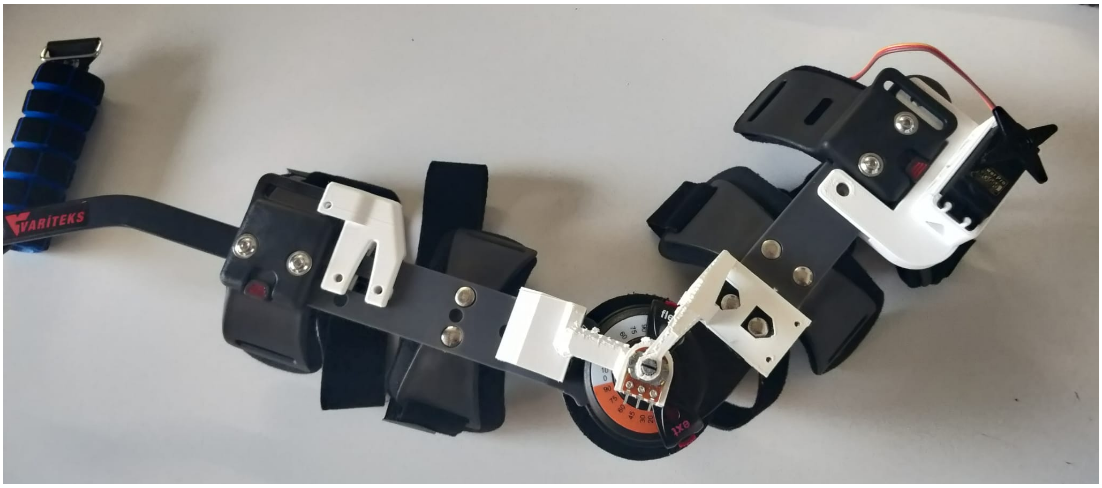


Figure 2.5: Developed tele-physiotherapy device

2.2 Mechanic Calculations and Analysis

Mechanical calculations were made on the second movement of the sample exercise program, which was the type of movement that would be most helpful to the user in daily life with the developed device. This movement is called Biceps Curl, and it is one of the exercises in which the developed device is used most efficiently. In this movement, the Biceps muscle is a muscle that connects from the upper part of the forearm to the part of the lower arm close to the elbow and is the main muscle responsible for lifting the arm up. When the function of this muscle is handled by the developed device, both the load on this muscle and the load on the elbow are reduced and the patient's comfort in daily life is ensured.

2.2.1 Biceps Curl Mechanics

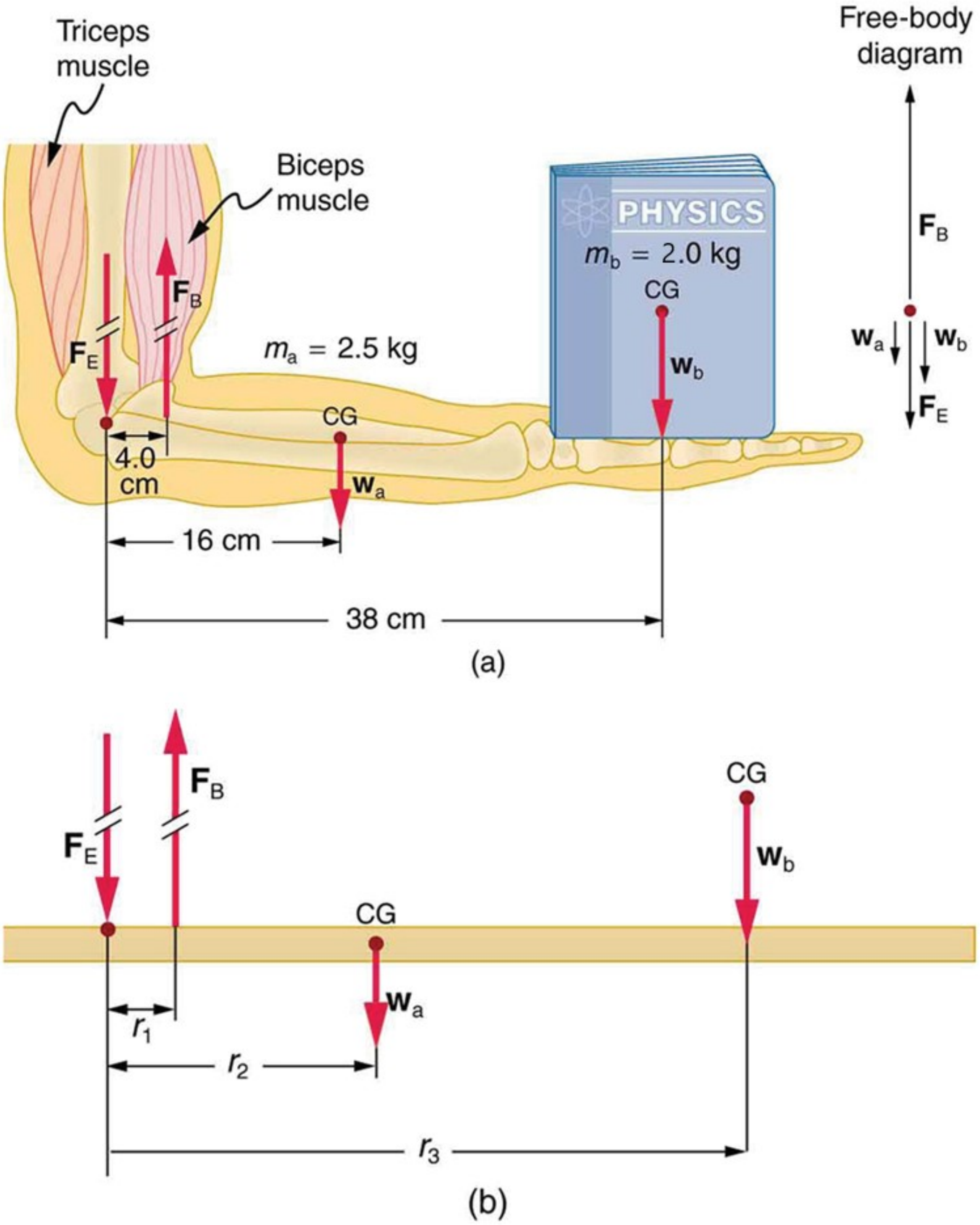


Figure 2.6: Forces on elbow joint

From Figure 2.6 there are four forces acting on the forearm and its load. The magnitude of the force of the biceps is FB; that of the elbow joint is FE; that of the weights of the forearm is wa, and its load is wb. choose the pivot to be at the elbow, then the torque due to FE is zero, and the only unknown becomes FB (Lumen Learning.).

The torques created by the weights are clockwise relative to the pivot, while the torque created by the biceps is counterclockwise like in equation (2.3);

$$r_2 * w_a + r_3 * w_b = r_1 * F_B \tag{2.3}$$

Note that sin θ = 1 for all forces, since θ = 90º for all forces. This equation (2.4) can easily be solved for FB in terms of known quantities;

$$FB = \frac{r_2 * w_a + r_3 * w_b}{r_1} \tag{2.4}$$

For the example above with known values in equation (2.5);

$$FB = \frac{0.16\ m * 2.5\ kg * 9.80\ m/s^2 + 0.38\ m * 2.0\ kg * 9.80 m/s^2}{0.04\ m} = 284N \tag{2.5}$$

Since this calculation is for θ = 90º.

Where;

FB is force of biceps muscle,

r1 = 4 cm is distance from Elbow joint to Biceps muscle Ulna bone connection distance,

r2 = 16 cm distance of Center Gravity of Ulna and Radius Bones,

r3 = 38 cm is complete forearm length,

Wa = Bones weight,

Wb = Weight of carried mass,

F weight is the weight of carried items in hand.

2.2.2 Developed Orthosis Mechanics

There are two main differences between biceps and orthosis. First r1 is longer as can be seen on Figure 2.7 so power of the servo motor is used way more effectively. Second Motor movement and power is more limited than biceps.

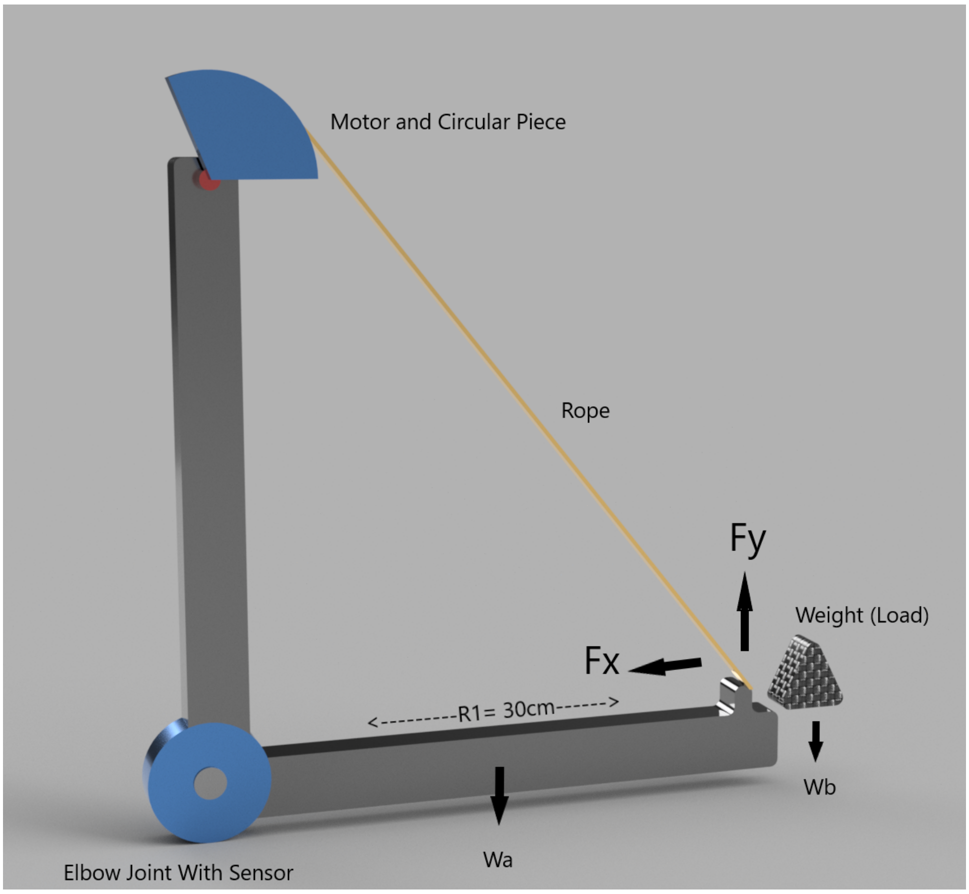


Figure 2.7: Developed orthosis 3D model

Calculation for developed orthosis in equation (2.6);

$$F_O = \frac{r_2 * w_a + r_3 * w_b}{r_1} \tag{2.6}$$

Where the F_O is Force of Orthosis

New r_1 value = 30 cm

New w_a is = 2,7 kg, as orthosis will add additional weight.

Others stay the same. Calculations are in the equation (2.7).

$$\theta = 45^{\circ} so, Sin(45) = 0.7$$

$$F_O = \frac{0.16\ m * 2.7\ kg * 9.80\ m/s^2 + 0.38\ m * 2.0\ kg * 9.80 m/s^2}{0.3\ m * sin(45)}) = 55N \tag{2.7}$$

$$\frac{284N}{55N} = 5.2$$

So that connection method of the motor to the forearm is increasing efficiency of required force by nearly 5.2 times for 2 kg additional weightlifting. Calculations change for other degrees of lifting.

Orthosis rope angle calculated from triangle rule. For 2 kg load Equation (2.8) is;

$$F_O = \frac{0.16\ m * 2.7\ kg * 9.80\ m/s^2 + 0.38\ m * 2.0\ kg * 9.80 m/s^2}{0.3\ m * sin(Rope\ Angle)}) = ?\,N \tag{2.8}$$

This equation (2.8) is used to calculate required force. Since the orthoses have 90 degree movement, calculation done for 60 to 150 degree elbow joint movement as the most of the rehabilitation exercises are within this range (Doheny et al., 2008).

For the calculate required force, rope angle should be calculated first with this equation (2.9);

$$Rope\ Angle = (180 - Arm\ Angle)/2\ for\ 60^{\circ}\ to\ 150^{\circ} \tag{2.9}$$

Results of this calculation showed on Figure 2.8 and Figure 2.9 with the 4th order curve fitting algorithm. Figure 2.8 shows that rope angle increases by keeping the forearm closer to the shoulder. This causes the pull force vector (Fy) to raise as the sine component of pull force raises. Few examples of results given at Table 2.1.

Table 2.1 Example result of orthoses force equation

Elbow Angle (Degree)	Rope Angle (Degree)	Required Force (Nm)
60	60	45
85	48	53
110	35	68
135	23	102
150	15	151

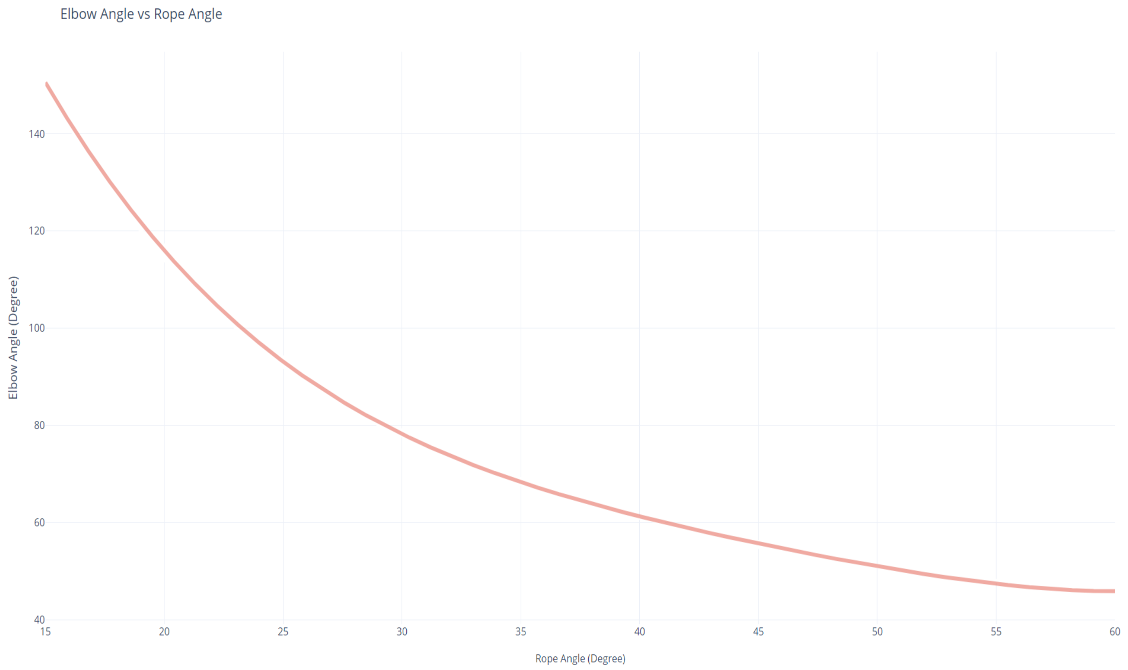


Figure 2.8 Elbow angle versus rope angle

Finally, equation of required force to lift 2 kg load with orthoses results showed on the and Figure 2.9 with 4th order curve fitting algorithm.

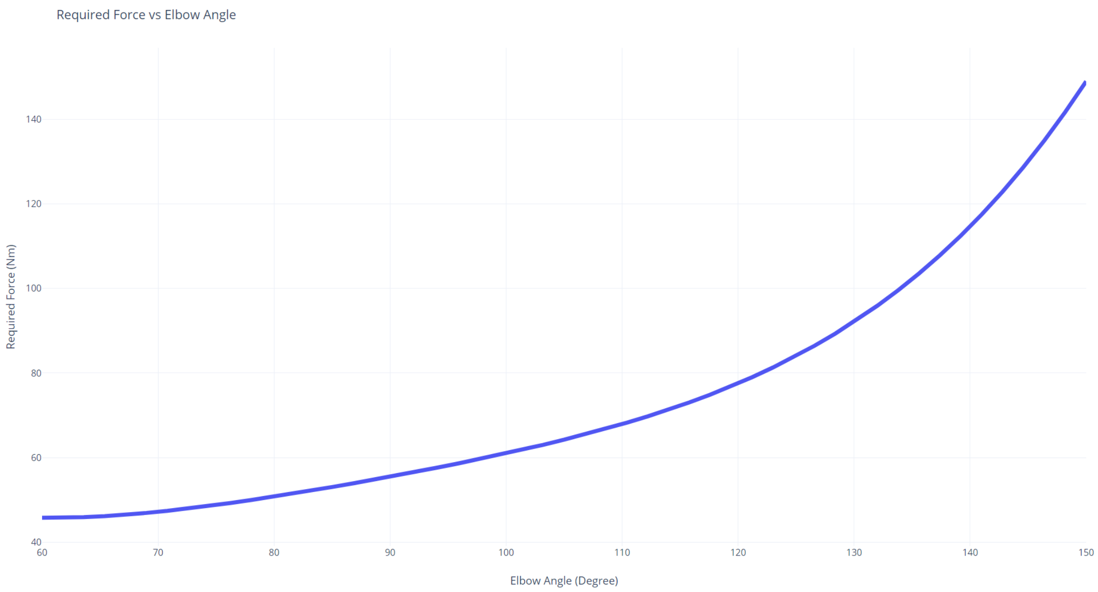


Figure 2.9 Required force versus elbow angle

From these results, orthoses help a lot when the forearm is closer to the shoulder because the pull force vector will rise as the rope angle increases.

2.2.3 Static Analysis of Parts

SimScale was used to calculate the strength of the designed parts. Von Mises stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials. Analyzes were made using this method and choosing ABS material. ABS is a common material used in nearly every sector which involves plastics. ABS has low weight (1.01 – 1.20 g/cc density) and high tensile strength (>20MPa) (MatWeb.).

According to the test results, the most sensitive part and the part exposed to the most load was the part to which the rope resting on the forearm was attached. Visual representation of the test can be seen on Figure 2.10 and Figure 2.11.

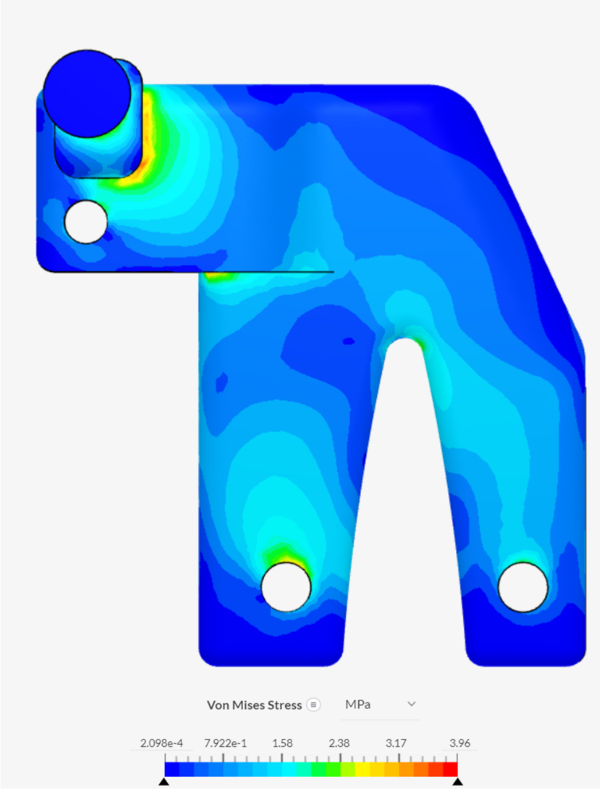


Figure 2.10: Forearm part analysis

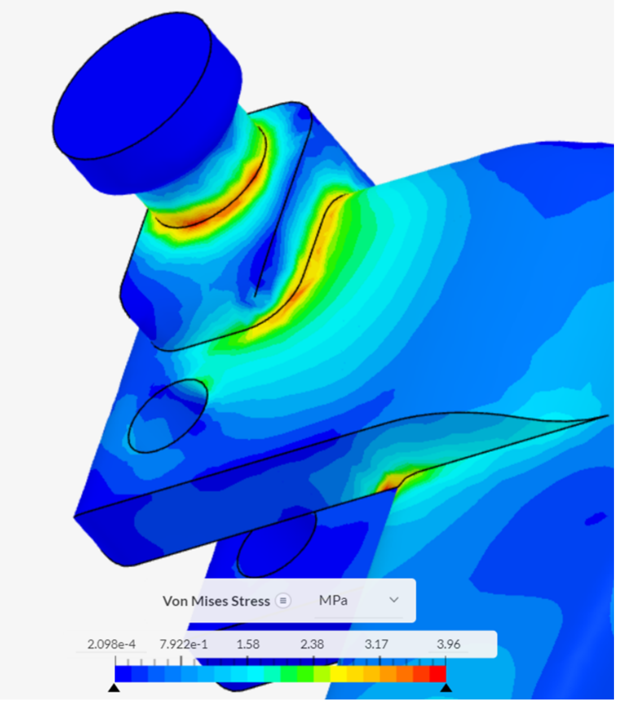


Figure 2.11: Forearm part analysis weak point

One of the reasons for this is that the rope is constantly pulled from different angles and the neck part to which the rope is attached is thinner than the other parts of the system. Since the semicircular piece with a diameter of 5cm connected to the motor limits the power of the motor to 2kg, the load on the piece cannot exceed 2kg (19.6 N). The test was performed using two vertical and horizontal vectors with a force of 20 N at the same time, and it was observed that the part would remain intact. However, this part may be revised in the future to eliminate weak points. For example, the shaft to which the rope is attached can be thickened and supported on both sides.

2.3 Electronic Design

2.3.1 Sensors

Physiotherapy devices, like any other biomedical device, uses sensor technologies to monitor and measure data and sometimes in real-time. Modern sensor technologies play a vital role for developing biomedical devices. By the new sensors and developed technology precise measuring and real-time data monitoring.

2.3.1.1 Electromyography (EMG) Sensors

EMG sensors are used to analyze the voluntary and involuntary electrical signals produced by the muscles. With the developing sensor technology, emg sensors began to be attached to mobile devices. Miniature EMG sensors collect electrical signals through a few potential difference electrodes and reference electrodes attached to the patient's skin. These received electrical signals pass through a signal processing layer that works as a filter and amplifier. In this way, the interpreted signals can be interpreted by the doctor in real time.

A 3-electrode EMG sensor is used in the developed tele-physiotherapy device. Electrical signals in the muscles are measured by the EMG sensor, then the sensor values read by the MCU are transferred to the phone wirelessly via Wi-Fi or Bluetooth, so that they can be followed and interpreted by the doctor. It can be used for various benefits such as the track patient's muscle control ability, monitoring motor units and optimizing exercises. EMG Sensor tested on the researcher himself as that can be seen on Figure 2.12. EMG signal tests results can be seen on results section.

Figure 2.12: EMG Sensor tests

AD8232 Chip selected as an EMG sensor front end. AD8232 is widely used on ECG applications therefore it is capable of reading uVolts’s from human skin precisely. Setting the chip with 3 electrode configuration, adjusting high pass filters and setting gain is needed to obtain meaningful data readings. Sensor creates Analog signal and this signal is directly connected to ESP32’s 12 bit ADC pin (Bravo-Zanoguera et al., 2020). AD8232 Chip internal block diagram can be seen on Figure 2.13.

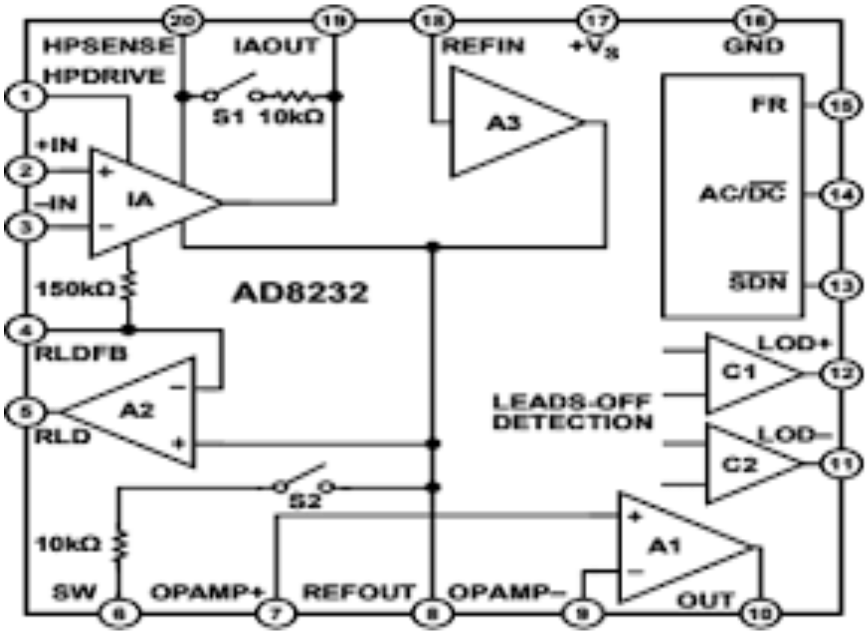


Figure 2.13: EMG Sensor functional block diagram (Bravo-Zanoguera et al., 2020)

2.3.1.2 Joint Angle Sensor

Elbow joint is the main topic of the developed device, so monitoring the elbow joint angle is crucial. Since this sensor is crucial for the developed device, it needs to be long lasting, high accuracy, cost effective, simple and reliable, so as a sensor a potentiometer placed exactly on the joint axis. When joint angle changes resistance of the sensor changes accordingly. Analog voltage measured from the sensor and this data processed to become joint angle. To do this the sensor needs calibration, on every startup of the device there is very quick calibration by setting angle 0 and 90 degree, after that device can calculate the elbow joint angle correctly.

Elbow joint angle information can be used to determine if the patient makes exercises correctly, exercise sets and repeats, track patients movements, track maximum and minimum joint angles of the patient. With the addition of EMG sensor data, the developed device can detect the patient's intention to open or close their arm and can support the patient's movement with the motors. Figure 2.14 shows a sensor mounted on orthosis while Figure 2.15 shows 3d design of these parts.

Figure 2.14: Elbow joint angle sensor holder

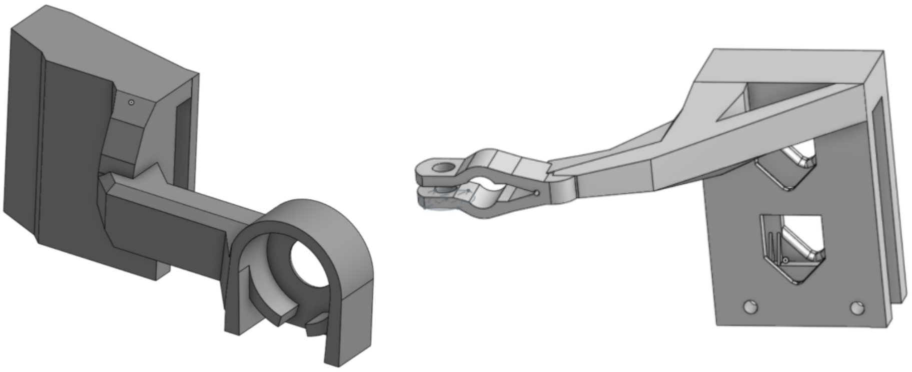


Figure 2.15: 3D Design of joint angle sensor holder

2.3.2 Microcontroller Unit (MCU)

The ESP32 MCU is a widely used System on Chip (SoC) made by Espressif Systems. ESP32 has exceptional features and it is a cost effective solution for Internet of Things (IoT)and embedded systems. Since ESP32 is SoC, the need for additional components is very low, the circuit diagram can be seen in Figure 2.16. ESP32 has a dual-core processor with clock rate up to 240 MHz which makes multitasking and real-time processing easier. Like other advanced MCU's ESP32 has digital and analog Inputs/Outputs, SPI, I2C and UART which can be used to use a range of sensors, motors and actuators etc. In addition to these ESP32 has built-in Wi-Fi and Bluetooth. ESP32 also has hardware accelerated encryption and cryptographic algorithms which can be used for the IoT data security. Its computational power, wide range of peripherals and wireless capabilities make ESP32 MCU best for this thesis topic, Tele-Physiotherapy device with IoT features.

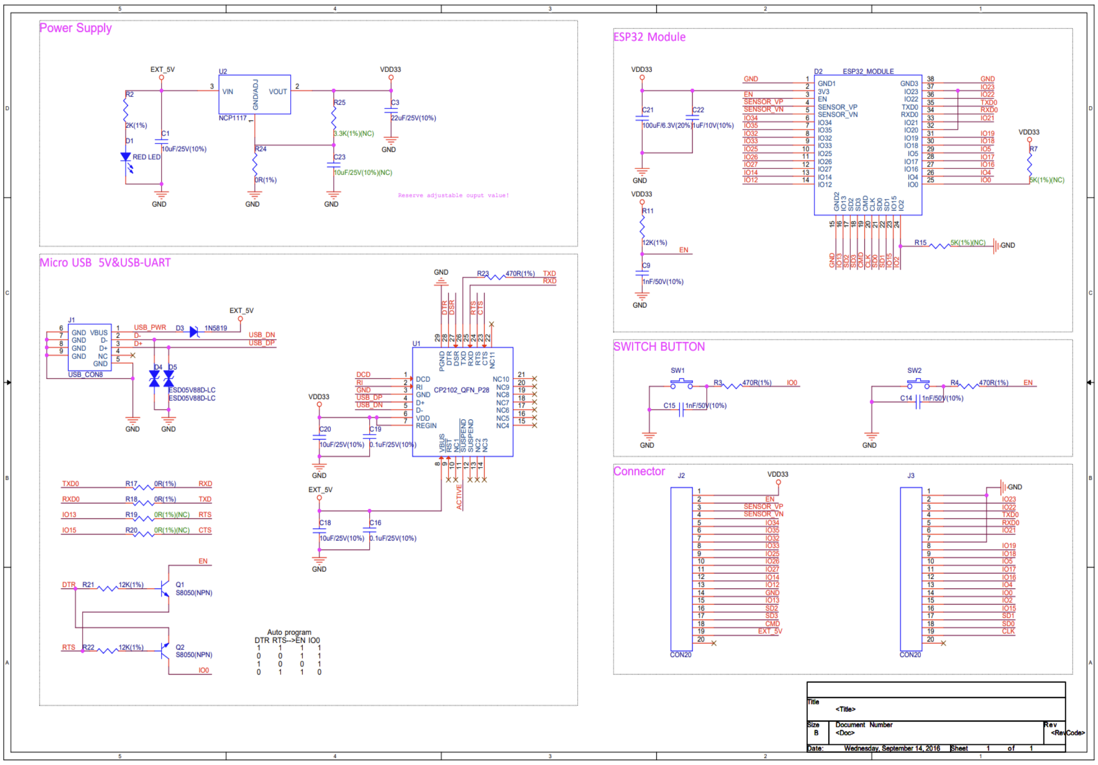


Figure 2.16: ESP32 Circuit diagram (Espressif Inc.)

2.4 Servo Motor

Servo is chosen for this application. Tower Pro MG995 is a selected servo motor with a built-in feedback and driver circuit which ensured the lightweight and compact design. Built-in motor driver circuit had precise movement ability and feedback circuit kept the servo motor angle always at required angle with the closed loop feedback system. Servo Motors requires continuous signal total signal length with the deadzone is 20 mS. Control signal is in the range of 1000 uS and 2000uS. So, a 1000 uS signal means telling the driver to keep the Servo motor angle at 0 Degrees, 1500 uS means 90 Degrees and 2000 uS means 180 Degrees as well. The motor has a high torque to support arm movement. When powered with 5 Volt motor torque is higher than 10 kg-cm. For high torque and precise applications, selected servo motor has metal final drive gear instead of plastic. Technical Specifications of MG995 Servo Motor can be seen on Table 2.2. (Tower Pro Inc.).

Table 2.2 Servo motor specifications

Torque:	4.8V: 138.9 oz-in (10.00 kg-cm)Ss
Speed:	4.8V: 0.20 sec / 60°
Weight:	55.0 gr
Gear Type:	Final Gear Metal, Internal Gears Plastic
Rotation Range:	180°

Additionally, a 3D designed and printed disc is used to increase the distance the rope is wound but reduce the motor torque, which can be seen in Figure 2.17.

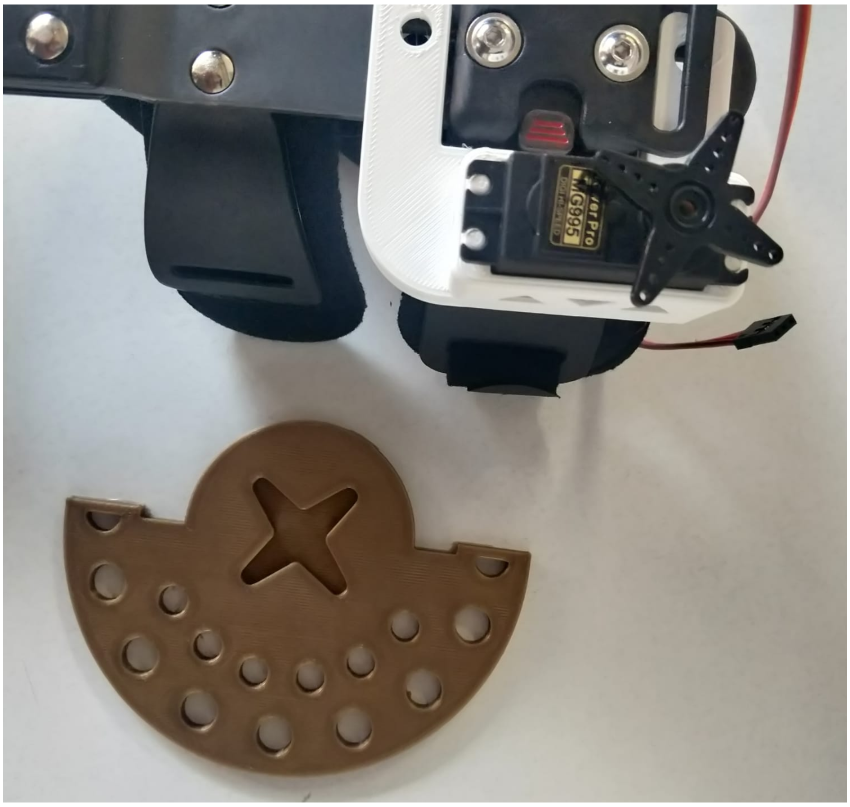


Figure 2.17: Servo motor assembly and semicircular disc

2.5 Battery

18650 3.7V 2500 mAh Li-ion battery is chosen for the project. This type of battery has a durable metal outer shell, can supply instantly high currents which is useful for the servo motor and has a high capacity. Voltage of one 18650 battery varies between 3.7V to 4.2V depending on the state of the charge. To achieve higher servo motor torque, Step Up Regulator used. The Regulator's output can be changed with a trimpot and that is directly changing the servo motor’s torque. Tests done at 5 volt output. 3D printed 18650 Li-ion battery holder with TP4056 charger can be seen on Figure 2.18.


Figure 2.18: 18650 Battery with charger

2.6 Embedded Software

Developed tele-physiotherapy device is aimed to be open source. In this way researchers easily use developed tele-physiotherapy devices to achieve better results and some clinical experiments. By using this open-source base device and software researchers can develop tele-physiotherapy devices for other joints and limbs. Even people who cannot afford the device can make their own.

Since the ESP32 supports Arduino IDE, it is used to develop embedded system software. Analog inputs used to measure joint angle sensors output and EMG sensor output. Since ESP32 has a 12-bit analog, EMG sensor reading and the joint angle sensor reading with very high precision. Flow chart representation shown on Figure 2.19.

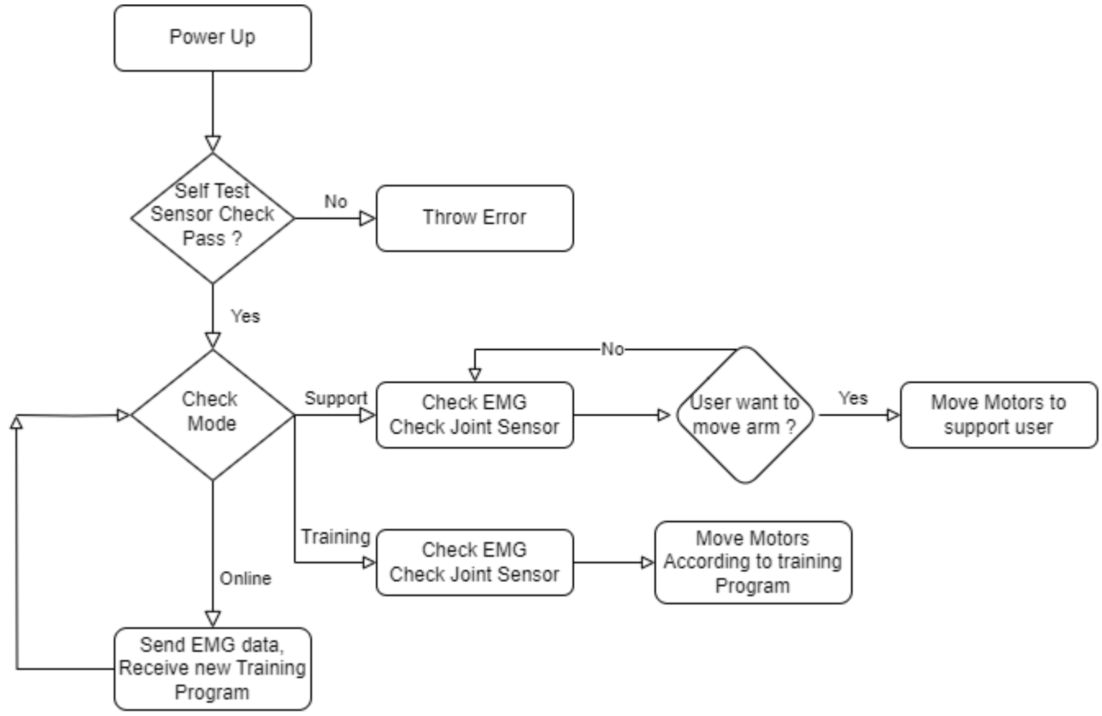


Figure 2.19: Embedded system flow chart

2.7 Electronic Circuit

Selected electronic parts were collected on an electronic circuit. Communication was established and microcontroller software was installed. The voltage between 3.7 – 4.2 provided by the 18650 Li-Ion battery was increased to a constant 5 Volts with the XL6009 Step Up converter. In this way, the servo motor and ESP32 were powered by 5 volts. AD8232 EMG-ECG circuit, EMG output and probe outputs were connected to the Analog inputs of ESP32. The Elbow joint angle sensor was connected to the ADC of ESP32 and supplied with 3.3 Volts. The circuit diagram can be seen in Figure 2.20. The circuit was implemented on pertinax. A simple PCB circuit was designed as a concept design, it can be seen in Figure 2.21.

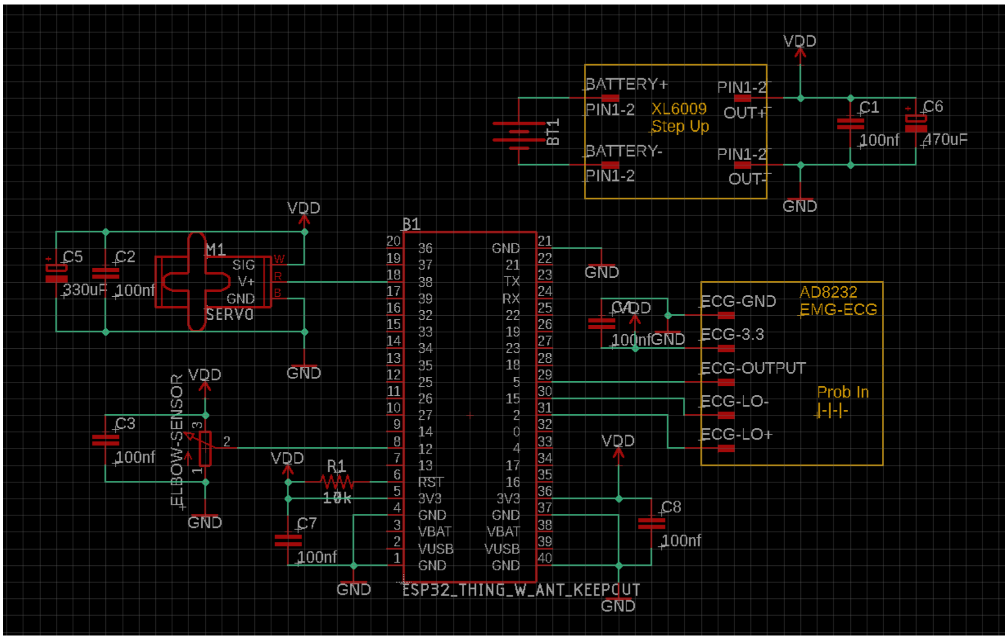


Figure 2.20: Electronic scheme

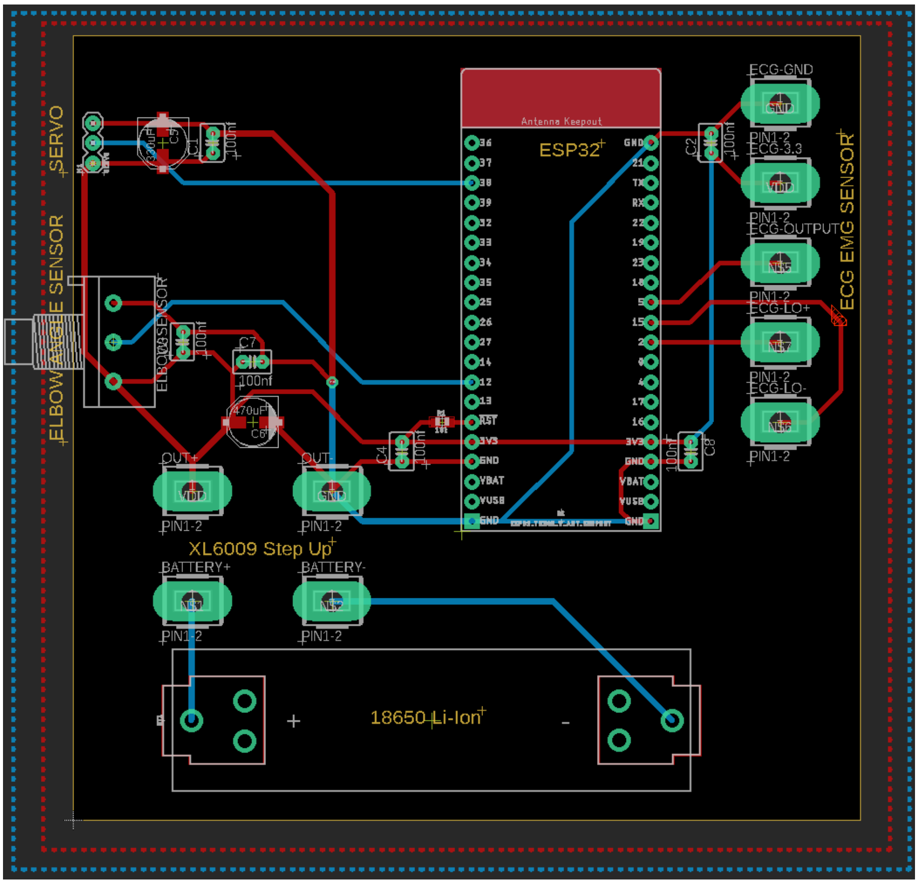
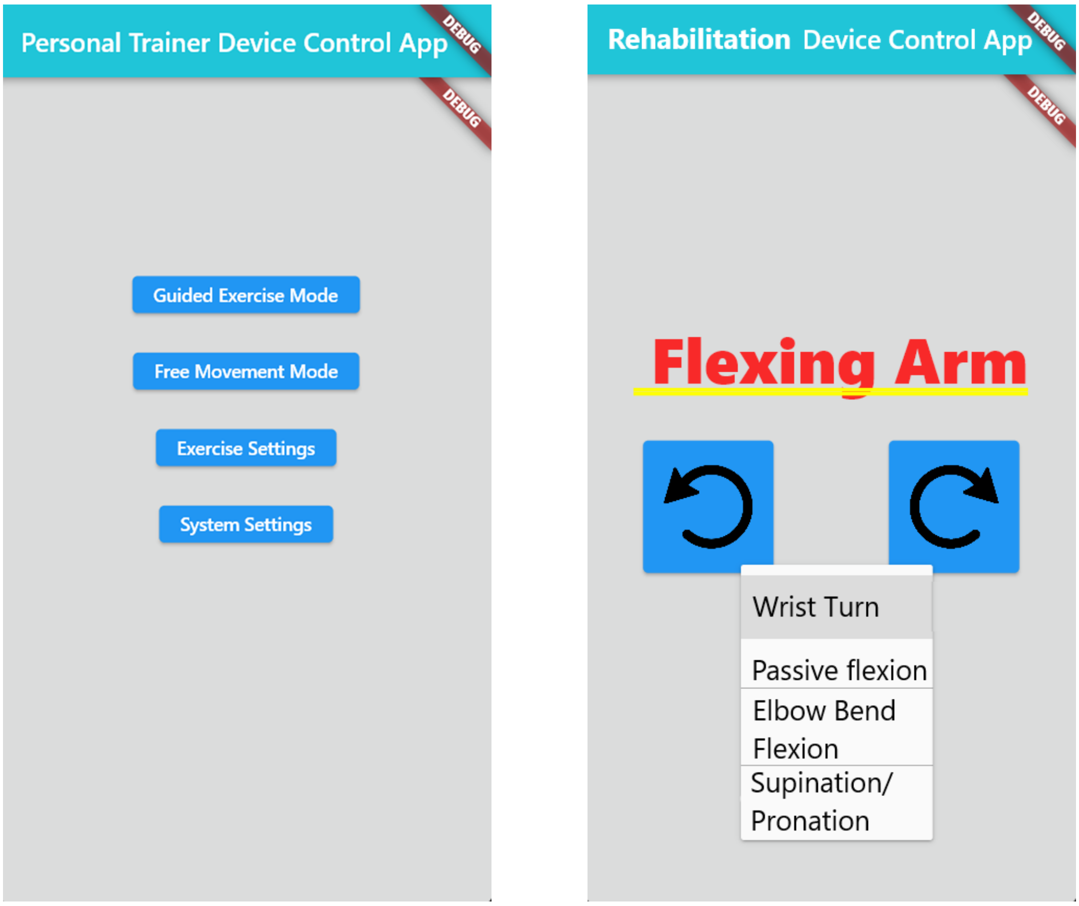


Figure 2.21: Concept PCB design

2.8 IOT Software

Android application can be developed using Flutter. Flutter is an open-source framework by Google. With Flutter it is possible to make this application for both android and ios devices (Tashildar et al., 2020). It will provide ease of use thanks to the sample codes that allow use with Bluetooth and USB OTG. With this application, the arm exercises programme can be transferred from the doctor to the patient and to the embedded system in the device. The collected EMG data will also be transmitted to the doctor. Example visuals of android applications can be seen on Figure 2.22a and Figure 2.22b.



(a)

(b)

Figure 2.22: Android program visuals, (a) Menu screen, (b) Exercise screen

Chapter 3

Results and Discussion

Trials started with the EMG sensor. It was tested whether the EMG sensor could receive signals from the biceps muscles clearly and accurately. An attempt was made to obtain meaningful data from the EMG sensor results and the trigger level was determined, thus making the orthosis commandable. Then, mechanical orthosis tests began. Since the rotation distance of the motor was limited, a semicircular part was added to enable 90-degree arm movement. In order not to reduce the force applied by the engine, the turning distance was limited to 90 degrees and the semicircle size was regulated. In the final stage, the device was completed by establishing a wireless connection between the Android software and the orthosis, and testing began.

During the tests, it was seen that the electric motor of the device needed to be strengthened, and the points that needed to be improved in order for the device to move beyond the prototype level and become suitable for clinical tests were determined. These are: Improving the electric motor, improving the pulley system and thus reducing power loss. Adding an artificial intelligence-supported application for interpretation of EMG signals.

Assist mode works when there is certain feedback on the patient to move the arm, EMG sensor can sense it, MCU can decide what the user wants and move motors according to that user's wish. But the device hesitates when there is little signal like the user just wants a little movement. Good EMG reading and bad EMG reading can be seen on figure 3.1 and figure 3.2 respectively.

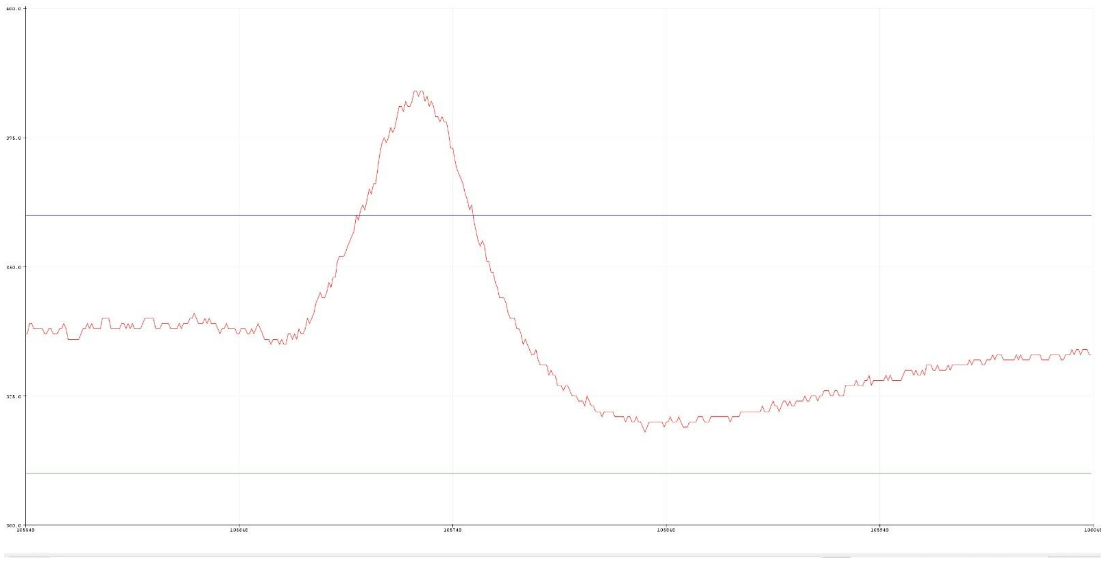


Figure 3.1: Good example of EMG reading

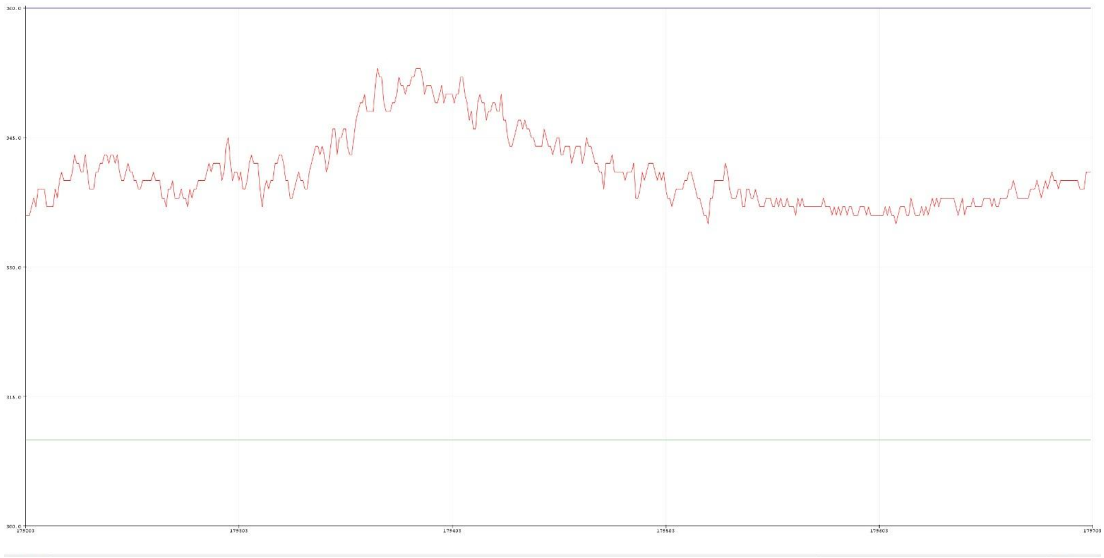


Figure 3.2: Bad example of EMG reading

In figure 3.1 EMG reading easily passes the trigger threshold, but EMG reading on figure 3.2 EMG reading shows there is a rise other than noise, but it is not enough to pass the threshold point and looks like a noise on the signal.

The developed device was found to work smoothly in the experimental environment. Thanks to the orthosis developed for the movement in the patient's elbow joint, the support of the motor weighing approximately 10 kg was added.

MyoPro orthosis works with a similar logic to the orthosis developed in this thesis. However, MyoPro aims to read the user's own wishes through brain signals and move the orthosis according to these signals, rather than to implement the exercise programs given online by the doctor. For this reason, exercise programs given by the doctor cannot be transferred to the device and the effectiveness of these programs cannot be measured.

Another study, EksoEvo, is a passive arm orthosis that receives support from the waist and does not offer motor support. The purpose of EksoEvo, which does not contain any electronics, is to passively support the user's arms in an upward direction. In this way, it aims to minimize work-related injuries. Since it provides passive support, it is not suitable for use in the rehabilitation process and cannot provide support during exercise, and it cannot read the patient's EMG data.

Ironhand and Carbonhand offer an additional grip force of 16 N per user's fingers. This support is made to support the user's hand, arm and wrist in areas such as holding devices and lifting loads in the industrial environment. The same system can support disabled and weakened patients to grasp devices and heavy loads. The combination of the orthosis developed as the subject of this thesis and the Carbonhand project can create a very useful arm exoskeleton. In this case, the patient will be able to easily grasp and hold hand tools and heavy loads thanks to the Carbonhand product and will be able to lift and carry the grasped objects with support with the developed orthosis.

ExoAtlet Company produces professional level leg exoskeletons and helps patients with injuries during their treatment processes. Clinical tests have been carried out and the benefits of this product in use have been proven. However, this product can be used by a person in charge with the help of a tablet and a control device. For this reason, it cannot be used in the patient's daily life or at home.

Factors such as the electric motors, electronic circuits and plastic injection parts used in end-user products such as ExoAtlet and MyoPro, among other developed devices, have shown that the ideas in this theme are applicable and useful in real life. The project, which is the subject of this thesis, can be put on the market after a revision for the end user and the completion of clinical tests, and it can be predicted that it will make people's lives easier.

There are no other devices developed that enable the patient to perform the correct exercises prescribed by the doctor at home without needing assistance. The device aimed to be developed in this thesis is planned to be used not only during exercise but also in the daily life of the patient and to make his life easier. At the same time, the patient's recovery process will be monitored by the device.

Chapter 4

Conclusion

From the test done on dolls, Manuel mode of the device works without hesitation, motor can precisely move the to the desired position, movement speed can be set on the software. Wanted arm angle or movements can be set on the phone application.

The Developed device can execute the therapy program, perform premade movements saved on the device's memory or directly accept inputs from the phone application. Set and trial numbers can be set on the phone application. EMG data recorded continuously while in therapy or exercise program to send it to the doctor to follow-up of the healing progress.

From the tests done and reviewing articles it is clear that EMG is a reliable method to measure muscle fatigue and Physiotherapy exercise to fatigue is successful in healing muscle and creating muscle hypertrophy. To create physiotherapy exercise programs more data needs to be collected with EMG sensors during physiotherapy exercise. Current arm exoskeleton design is for three arm muscles: biceps, brachialis and triceps. The benefits of developing and automating the system were identified.

Chapter 5

Future Works

Further study is needed on the electronics side. To reduce signal noise and create precision control on the motor to both facilitate and complicate. With exoskeleton models designed to support other limbs and joints it is possible to make physiotherapy rehabilitation on different muscle groups.

To solve EMG reading noise problem further research needed for faster and reliable movement support assist, better EMG sensor and motion prediction AI can be used to improve response of the exoskeleton support. Another topic that needed further research is due to the current mechanical design, the exercise hardening mode only works in one direction. System with GT2 belt, pulleys and belt tensioner may work for this issue.

To measure effectiveness of the device on patients' healing progress, clinical study is needed. With the test to be performed on volunteers, the deficiencies of the device can be determined and improved by considering factors such as muscle development, ease of use, recovery time and user satisfaction. Data such as the rate of recovery and quality of physical therapy obtained in the tests can be compared to the treatment performed by a physical therapist face-to-face with a patient.

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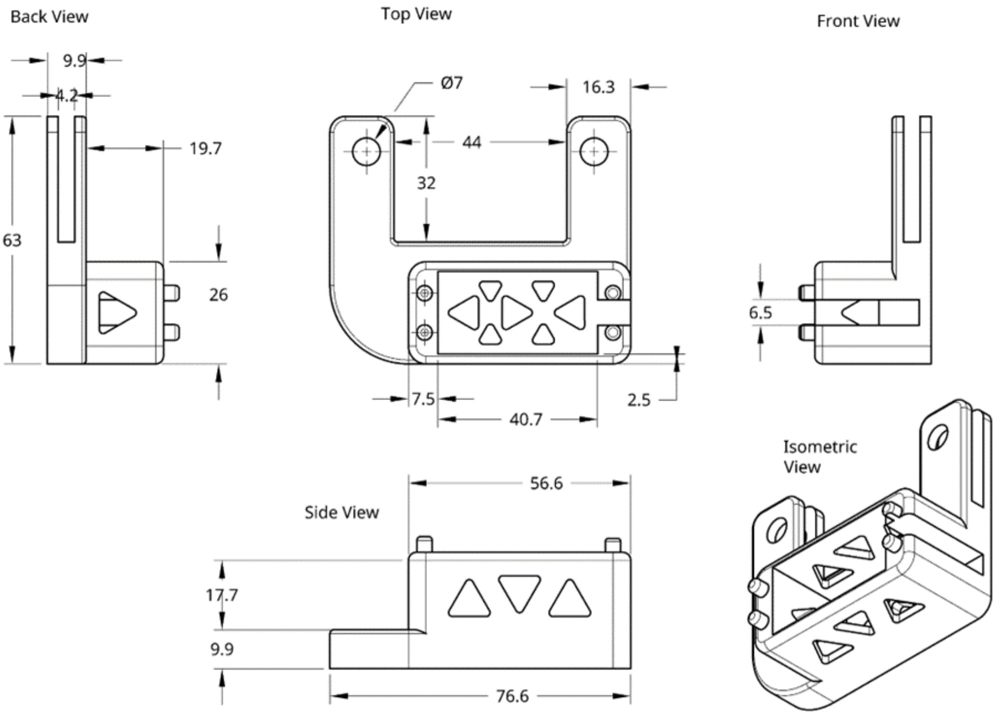
Appendices

Appendix A

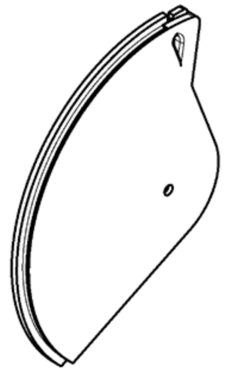
Technical Drawings of Parts

Motor Housing

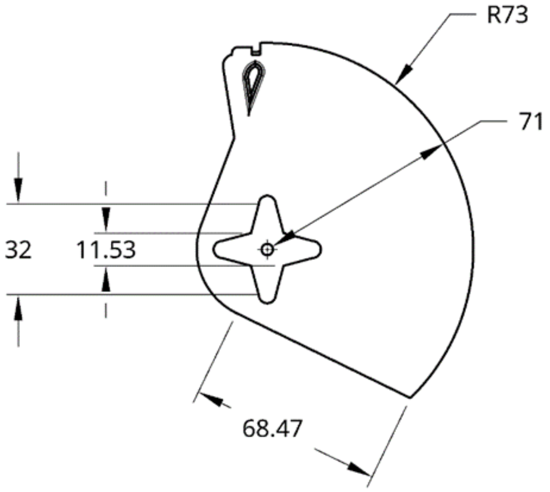


Moving Arm

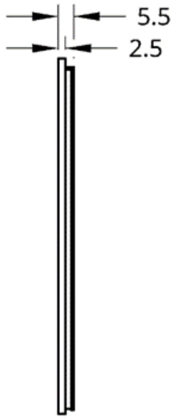
Isometric View



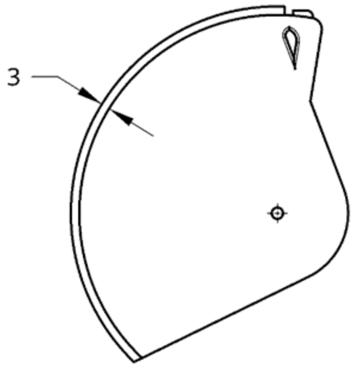
Back View



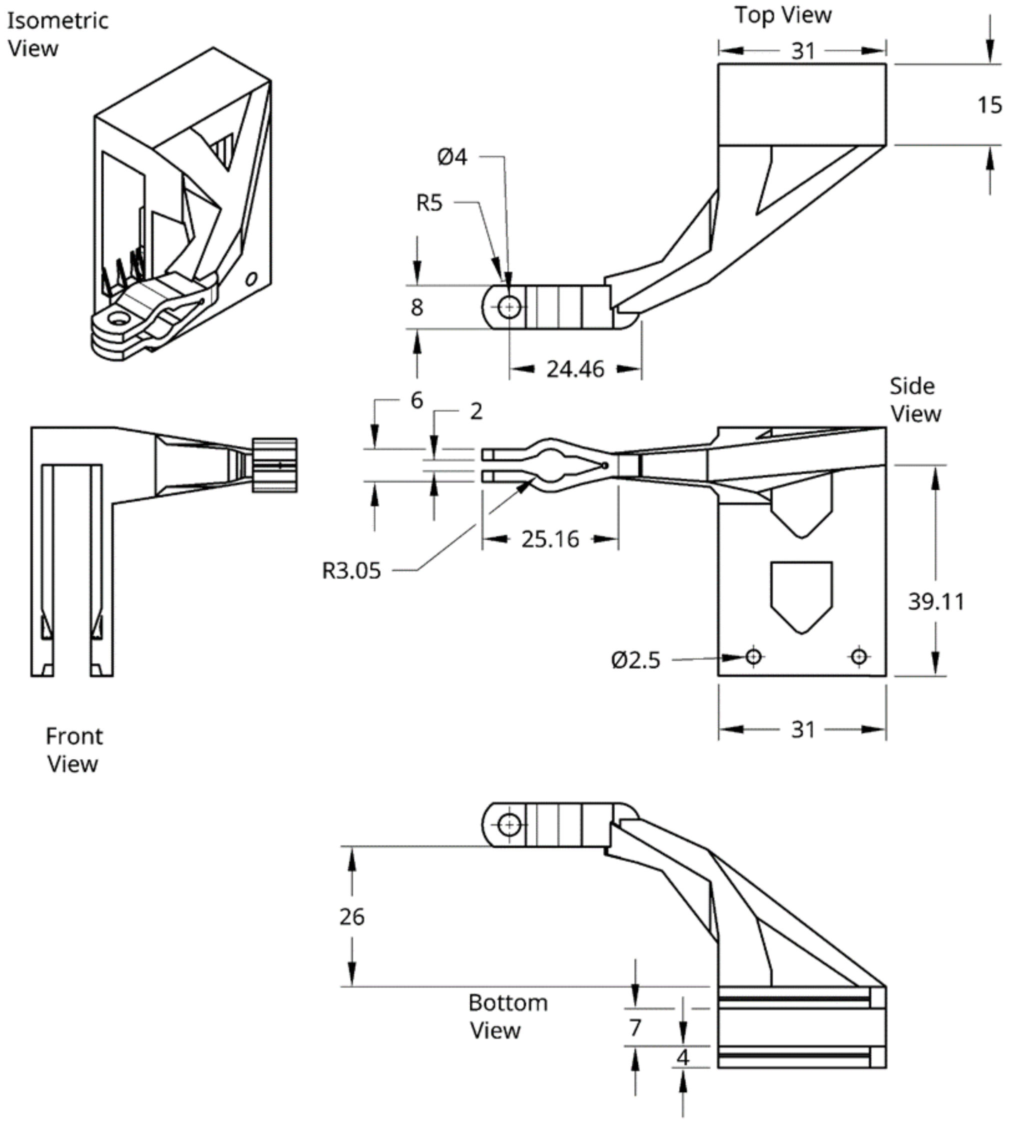
side View



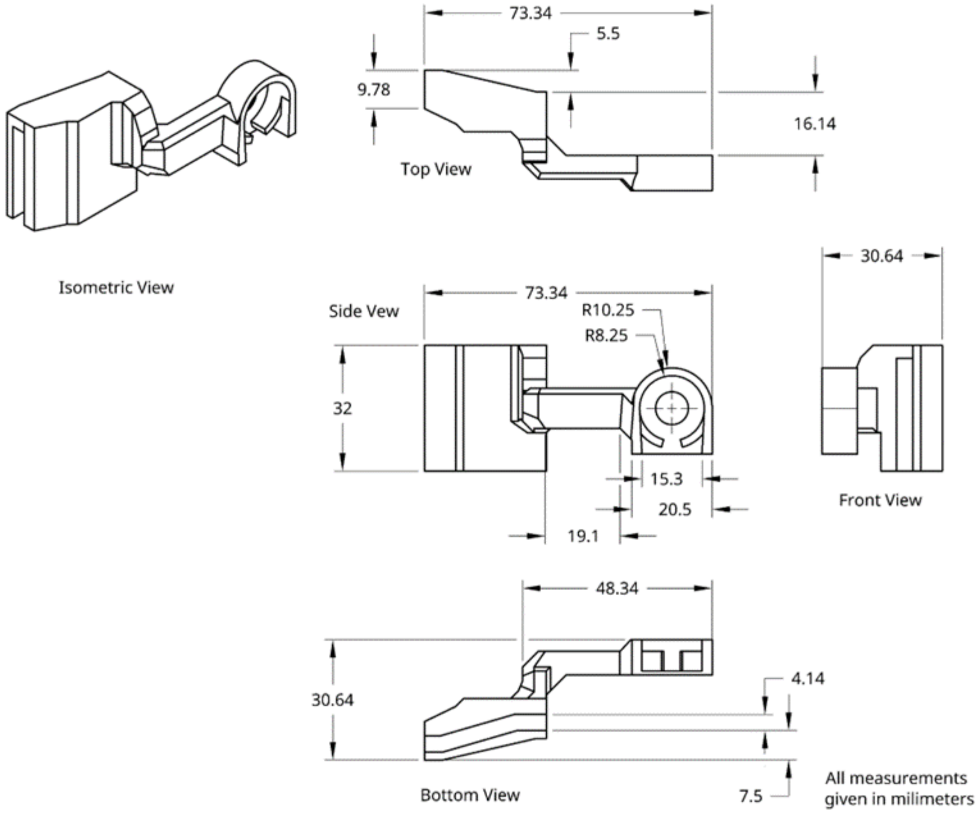
Front View



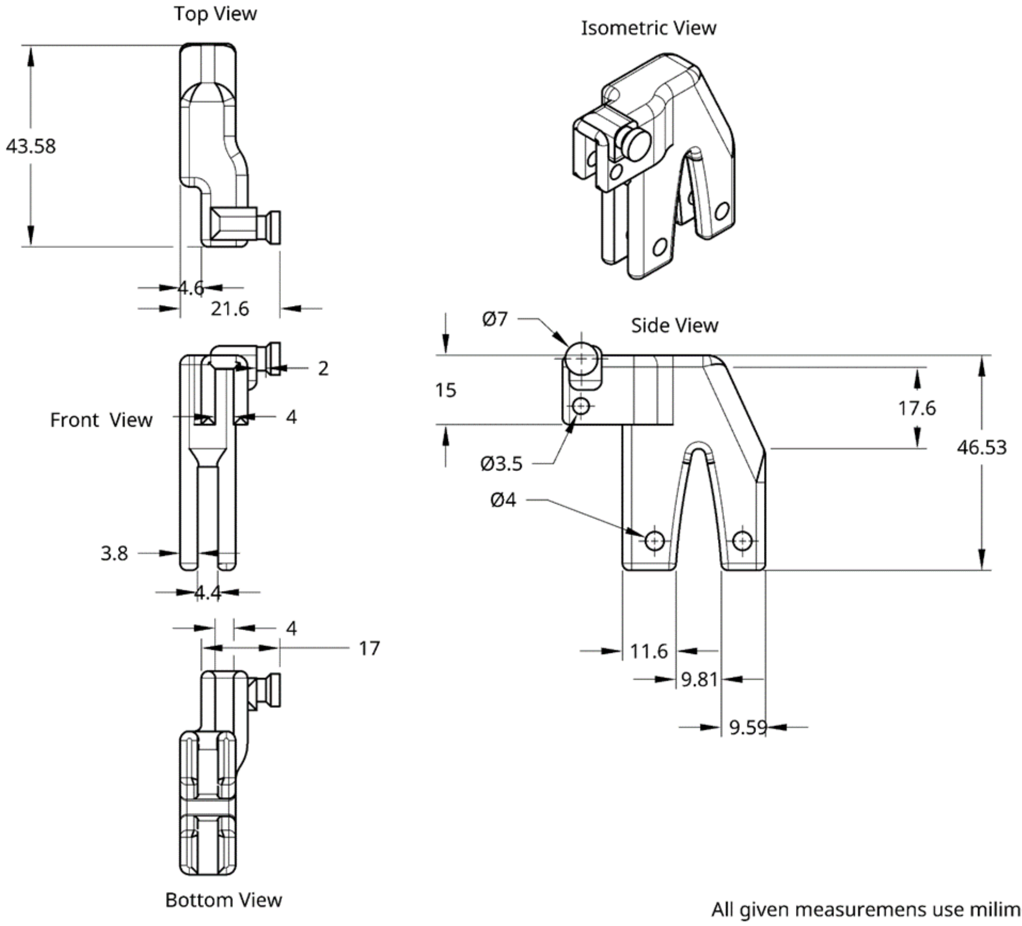
Moving End of Rotary Encoder Holder



Stationary End of Rotary Encoder Holder



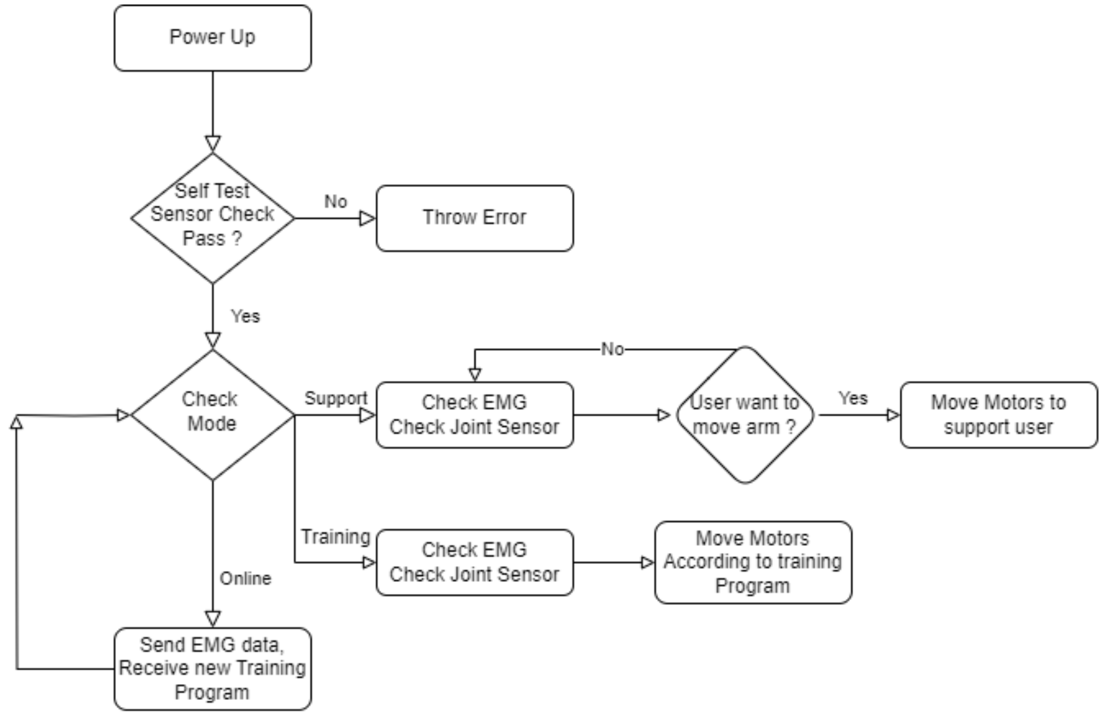
Cable Connector End Piece



All given measuremens use milimeters

Appendix B

Embedded Code Diagram



Appendix C

Publications from the Thesis

Journal Articles

1. Sarpay, A. Journal of Intelligent Systems with Applications (2022), Design of a Tele-Physiotherapy Device to Remedy Elbow Joint (e-ISSN 2667-6893).

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Publications (if any):

1. Sarpay, A., Arslan, O., Yalçın, İ., 5. International Conference on Medical Devices (ICMD'2022), The Relationship Between Vascular Occlusion and Gender in the Likelihood of Developing Heart Disease.
2. Arslan, O., Sarpay, A., Yalçın, İ., 5. International Conference on Medical Devices (ICMD'2022), Relation of Age, Blood Sugar and Blood Cholesterol Levels with Heart Diseases .
3. Sarpay, A. Journal of Intelligent Systems with Applications (2022), Design of a Tele-Physiotherapy Device to Remedy Elbow Joint (e-ISSN 2667-6893).