Smart sensor for wrist movements

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ABSTRACT

The aim of this thesis was to develop a way to evaluate the mobility of the wrist or hand after an injury.

To do this a prototype of a compression glove with added conductive silicone was made. A tensile test was done first to test linearity between resistance and elongation. Thereafter this was implemented on the prototype. The silicone, Elastosil LR3162 showed good proprieties for the purpose when stretching the fabric. The results showed linear behavior and also a large indication when changing the resistance .

Wearing the prototype glove and bending the hand will stretch the silicone. When bending it is thus possible to measure the change in resistance. The readings can thereafter be converted to angular displacement from a given starting position.

The final goal is to further develop this idea and send the readings with a bluetooth device to an application in the patients mobile phone.

This project is delimited to evaluate Elastosil as a suitable material, to develop a simple prototype, and to suggest how to proceed.

ACKNOWLEDGEMENTS

I would like to thank my friends and family for the support throughout my studies.

A huge gratitude to my supervisor Ingrid Svensson for all the help and support during this whole time. Thank you also Magnus Tägil, assistant supervisor for your help. The institution of biomedical engineering deserves a great gratitude as well. I got a lot of help throughout this project, from controlling the machine at the tensile tests to dealing with several difficulties with the measurement setups and programs. I really want to thank all the people that have been involved in my project.

Thank you!

CONTENTS

CONTENTS

1

INTRODUCTION

The aim of this project was to develop a way to improve the rehabilitation after a hand or wrist injury. To do this a 'glove' was developed, where the angular displacement of the wrist from a given starting position could be measured. With a bluetooth device this signal should be sent to an application in the patients phone. Both the patient and the doctor should have access to the app to follow the rehabilitation. The application should show the maximum angle the patient can fulfill every day/week and it should also be possible to design an exercise program that suits the patient.

Instead of just evaluating the injury at the return visits to the hospital this technique would help both the patient and the doctor to follow the recovery on a daily basis.

To measure the angles an electric conductive silicone was painted in strings on a compression glove. The silicone used was Elastosil LR3162, manufactured by the German company 'Wacker'. The relation between resistance and elongation was tested in a tensile test. It showed linear behavior, thus from a measured resistance the elongation can be calculated, and this elongation can be converted into angles. To obtain the angles the hand was videotaped simultaneously as performing the different measurements

Similar gloves that measure mobility of the hand can be found today. Most of these gloves are very expensive and ungainly. Part of the goal with our model was to make it small and simple. In this thesis the prototype with Elastosil were compared to Cyberglove, a well established sensor-based glove.

Studies performed The Swedish School of Textiles, University of Borås were a major inspiration to this thesis. They develop so called smart textiles, where the idea is to use a textile for facilitating and improving measurements using a wearable fabric.

1.1 OBJECTIVES

- Evaluate Elastosil LR3162 and find out if it is a suitable material.

- Make a prototype

- Suggest future work

1.2 APPROACH/METHODOLOGY

The master thesis will be divided in the following steps

- Literature study about the anatomy of the hand, the hand and wrist function, and the most common injuries.

- Obtaining supplies. (Elastosil, compression glove)

- Tensile test in a MTS machine to measure the relation between resistance and elongation

- Making the prototype

- Tests on the prototype

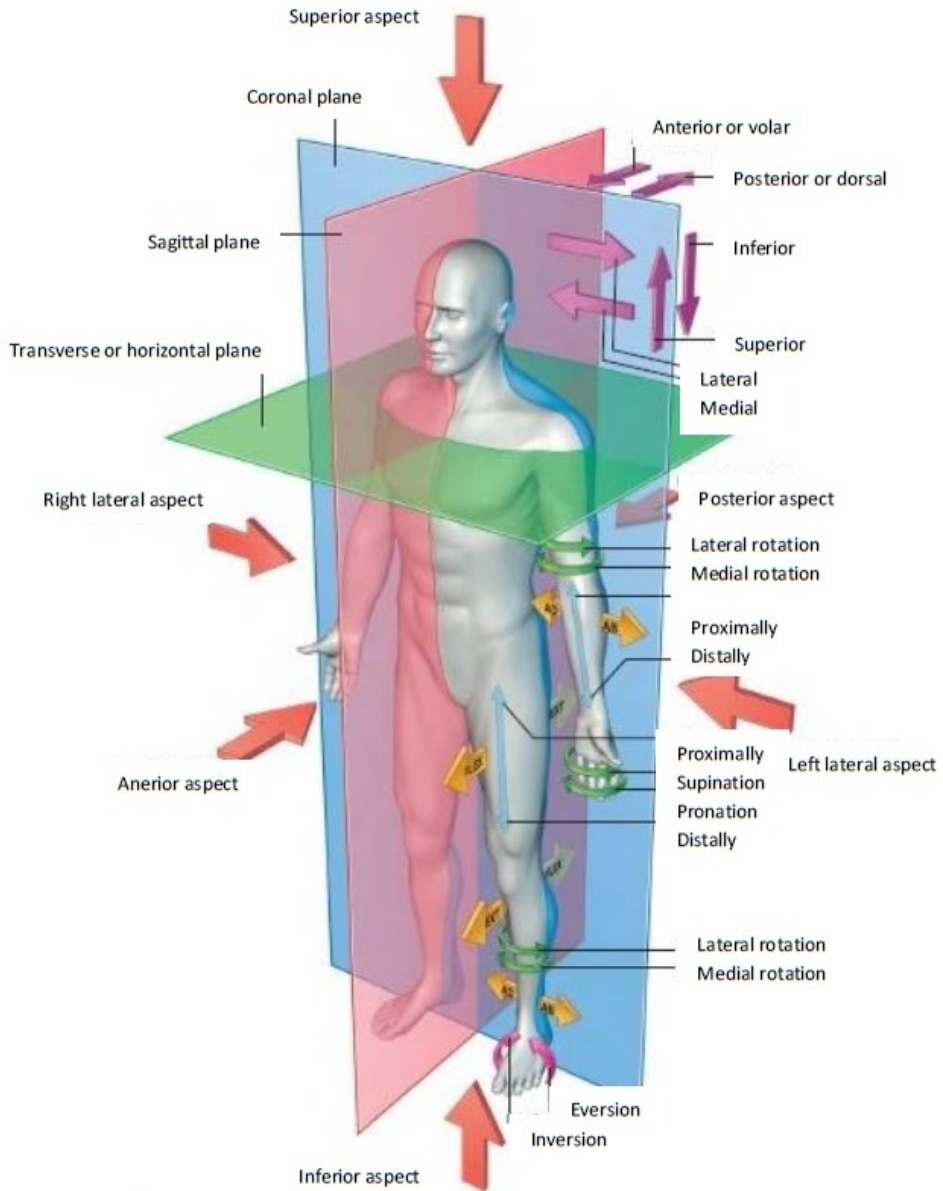- Analyzing and evaluating the properties and functionality

Figure 1: Terminology used to describe anatomy [4].

2

ANATOMY OF THE HAND AND WRIST

The human hand is very complex and can perform very fine movements. It enables us to many types of functions, from grasping small things with the finger tips to powerful grasp patterns or to provide the whole body with support.

The collection of bones and soft tissues that connects the forearm to the hand is called wrist or carpus. It consists of multiple bones, joints, ligaments and muscles. The ability to grasp, flex and extend the fingers are affected by the current position of the wrist.

The within-the hand manipulation between the fingers and the thumb helps us to understand and explore small object, and perform all the fine movements we are able to do.

The hand is also the final link in a mechanical chain of levers starting at the shoulders. The combination of mobility and stability of the shoulder, elbow, and wrist and their capacity to move in different planes result in a very wide range of movement [1].

2.1 BONES

The wrist is made up of eight small bones, or carpals, which are divided into the proximal and distal rows. see 7.4. The carpals in the distal row are called trapezium, trapezoid, capititate and hamate, and articulates with the metacarpals. The proximal row is more mobile than the distal. The carpals are called scahphoid, lunate,triquetrum and pisiform. The proximal row articulates with the radius and ulna in the forearm.

Further, the hand consists of five metacarpals, numbered from one to five starting from the thumb. Connected to the metacarpals are the five fingers, where the thumb consists of two parts- the proximal phalanx and the distal phalanx. The other four fingers are made up of three bones, proximal, middle and distal phalanx. see figure 2 [2].
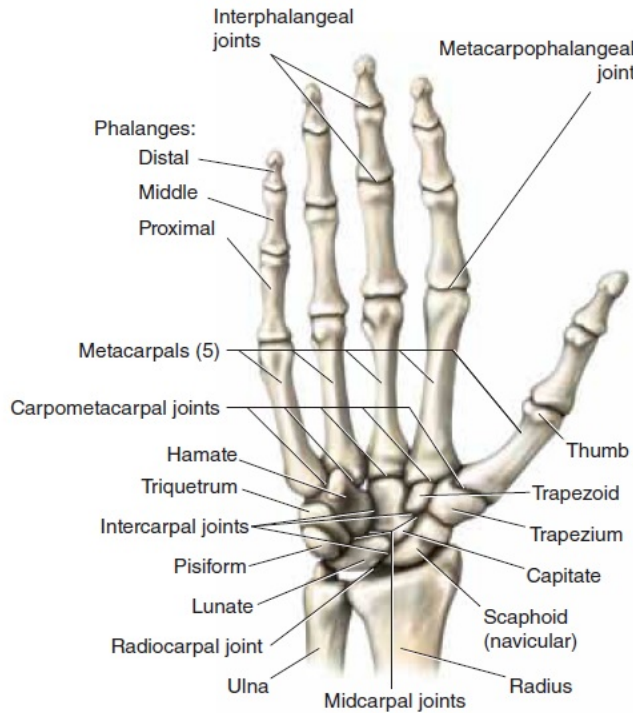

Figure 2: Bones and joints of the hand and wrist [2].

2.2 JOINTS

The bones are connected to each other with joints. Between the forearm and the proximal row of carpals are the radiocarpals. The midcarpals are found between the proximal carpals and the distal carpals. The five joints between distal carpals and the metaphalanges are called car-

pometacarpals. The fingers contain the metacarpophalangeal joints and the interphalangeal joints, see figure 2[2].

2.3 LIGAMENTS

The wrist contains five main ligaments. The ligament between the radius and ulna, and the proximal carpal row are called the capsular ligament.

Between the end of radius and the proximal row of the carpal bones is the dorsal radiocarpal ligament. The volar radiocarpal ligament is situated between the proximal row of the carpals and the anterior surface of the radius and its styloid process.

There are two collateral ligaments. The radial collateral ligament goes between the scaphoid and the styloid process of the radius, and the ulnar collateral ligament goes between the styloid process of the ulna and the pisiform and triquetrum bones.

In addition there are the intercarpal ligaments. These ligaments connect the intercarpal joints between the carpal bones in three different ways. There is the connection between the joints in the proximal row, the connection between the distal row and finally the connection of the joints between the proximal and distal row.

Between the carpometacarpal joints are the dorsal, volar, interosseus and carpal carpometacarpal ligaments.

The ligaments between the joints in the thumb are different from the rest of the fingers, with a structure of loose capular carpometacarpal ligaments. This is found from the trapezium and the proximal part of the metacarpal in the thumb.

There are two more ligaments, the flexor retinacula on the dorsal side of the hand and on the volar side extensor retinacula are found. Both ligaments are found over the carpal bones on one side each of the hand. Between the carpal bones and the extensor retinaculum pass the extensor tendons of the hand and wrist. The gap between the carpal bones and the flexor retincula is larger and forms a bridge called the carpal tunnel, where the flexor muscle tendons pass [2].
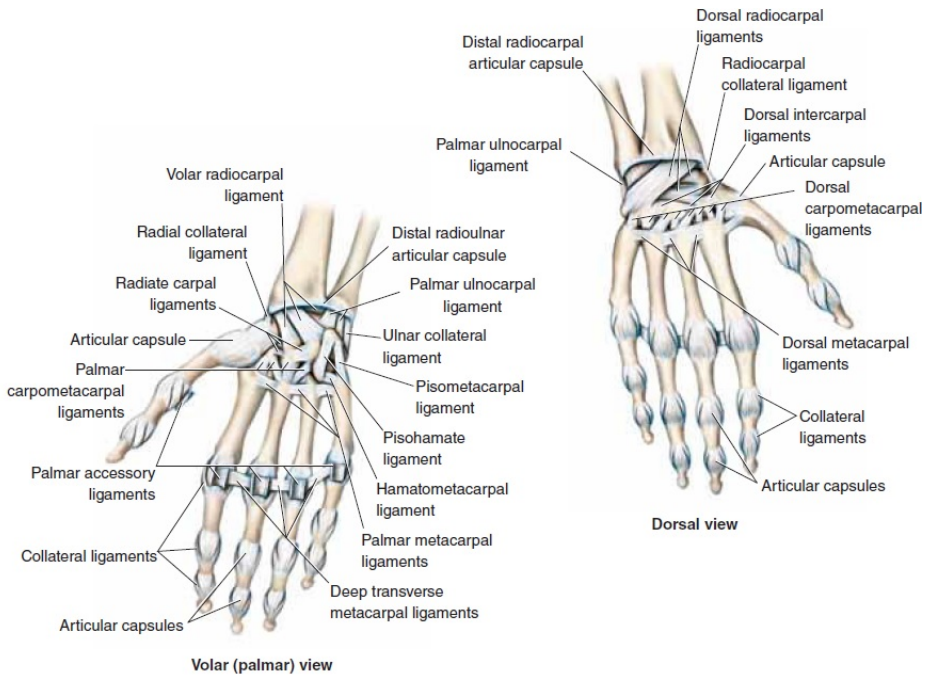
Figure 3: Ligaments of the hand and wrist [2].

2.4 MUSCLES OF THE WRIST

The ability of bending the wrist is due to two large muscle groups called the flexors and extensors. These muscles originates on the arm, quite far from the hand and attaches within the hand.

There are three big muscles which all flexes the wrist. There is the flexor carpi ulnaris, which motion is deviation from ulnar. Flexor carpi radialis is the radial deviation of the hand. Among the flexor muscle group is also palmaris longus, where contraction of the muscle results in flexion of the wrist

There are additional muscles that flexes the wrist. One is flexor digitorum superficialis which flexes the wrist, metacarpophalangeal, and interphalangeal joints.

Included within the deep layer muscles are the flexor digitum pro-fundus, which flexes the wrist, metatacarpophalangeal and the interpha-langeal joints.

Among the extensor muscles are the extensor carpi radialis longus and brevis, and extensor carpi ulinaris and brevis. These muscles gives the radial respective ulnar deviation of the hand.

There is extensor digitorium which extends the wrist, metacarpopha-langeal, and interphalangeal joints.

There is also digiti minimi which extends the wrist and the joints of the little finger.

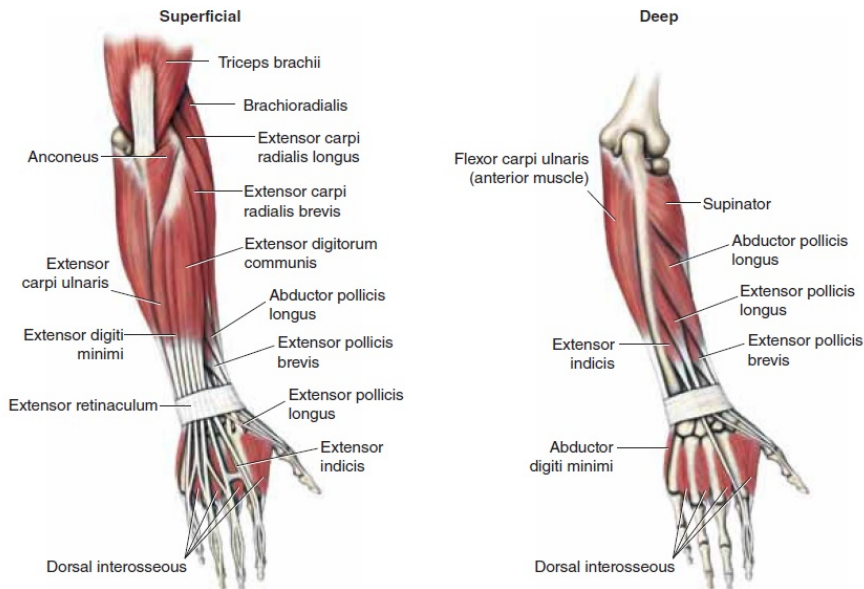Part of the deep layer extensor muscles are the extendor indicis which extends the wrist and thumb [1], [3].

Figure 4: Muscles of the hand, wrist and arm, posterior view [2].

2.5 MUSCLES OF THE HAND

Many of the muscles in the hand and wrist originate from other parts of the arm. These muscles are called extrinsic muscles, whereas muscles within the hand are called intrinsic muscles.

2.5.1 *Extrinsic muscles*

The extrinsic muscles that attaches in the wrist or hand originates from either the forearm or humeral segments. The extrinsic muscles act mainly as flexion and extension of the wrist, but also radial and ulnar flexion, finger abduction and adduction, as well as thumb movements. These muscles are described in more detail in section 2.4 and 2.6 [2], [3] .

2.5.2 *Intrinsic muscles*

Three of the instinsic muscles are known as the hypothenar eminense. They are called the abductor digiti minimi, the flexor digiti minimi brevis, and the opponens digiti minimi.

Abductor digiti minimi abduct and assist with flexion on the metacarpal joint of the little finger, and is found from the pisiform bone to the proximal phalanx of the little finger.

Flexor digiti minimi assists in flexion of the metacarpal joint of the little finger. This muscle is found between the hamate bone to the metacarpal and the proximal phalanx of the little finger.

Opponens digiti minimi assists with abduction and flexion of the metacarpal of the little finger. This muscle give the ability to bring the thumb and little finger toward each other. This muscle starts on the hamate bone and ends on the metacarpal and the proximal phalanx bone of the little finger.

There are several muscles involved in the in the four other finger joints. These muscle groups are called the dorsal and palmar (volar)interossei and the lumbricales.

First, the four dorsal interossei, which originate on the metacarpal bones that insert in the proximal phalanix of each fingers.

On the palmar side of the hand are three palmar interoessi muscles which run between the second, fourth and fifth metacarpal bones, where two of them attaches the phalanix.

Deep within the hand the four lumbricales muscles are found. These muscles helps with the flexion of the metacarpophalangeal joint and the extension of the proximal interphalangeal joint and the distal interphalangeal joint. The lumbricales run between the flexor digitorum profundus and the tendons of the extensor digitorumcommunis in the area of the proximal phalanges [1], [2].

2.6 MUSCLES OF THE THUMB

There are many muscles that are involved in the movement of the thumb. These muscles are also usually divided into the extrinsic and intrinsic group, where similarly, the extrinsic muscles originates from the forearm whereas the intrinsic originates and inserts within the hand. Almost all these muscles includes the word pollicis, from the latin word pollex for thumb [1], [2].

2.6.1 *Extrinsic muscles*

Extensor pollicis longus extends the thumb, more precicely the metacarpophalangeal and interphalangeal joints. It also help the arm and wrist with radial deviation and supination. It inserts on the distal phalanx of the thumb and originates on the ulna.

There is also a muslce called flexor pollicis longus, with the same inserting point but with an originating point from the radius. It help in the flexion movement of the wrist, and also flexion of the metacarpophalangeal and interphalangeal joints.

Origination from radius and inserting in the proximal phalanx of the thumb, extensor pollicis brevis is found. This muscle extends the metacarpophalangeal joint and also help in the the radial deviation.

Abductor pollicis longus assists with the radial deviation and flexion of the wrist, and also abduction of the thumb. It originates from the ulna and inserts in the proximal metacarpal bone [1], [2] .

2.6.2 Intrinsic muscles

There are four intrinsic muscles that assists in moving he thumb. They are called abductor pollicis brevis, adductor pollicis, which as assists in abduction repesktive adduction of the thumb.

Another muscle adducting the thumb is Opponens pollicis.

The last intrinsic muscle is the flexor pollicis brevis which helps flexing the metacarpophalangeal joint of the thumb [1], [2].
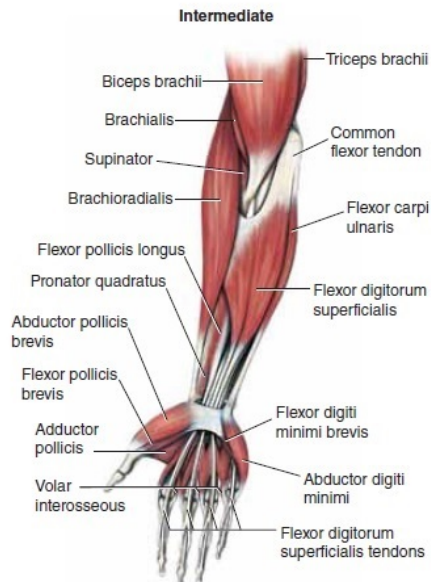

Figure 5: Muscles of the hand, wrist and arm, anterior view [2].
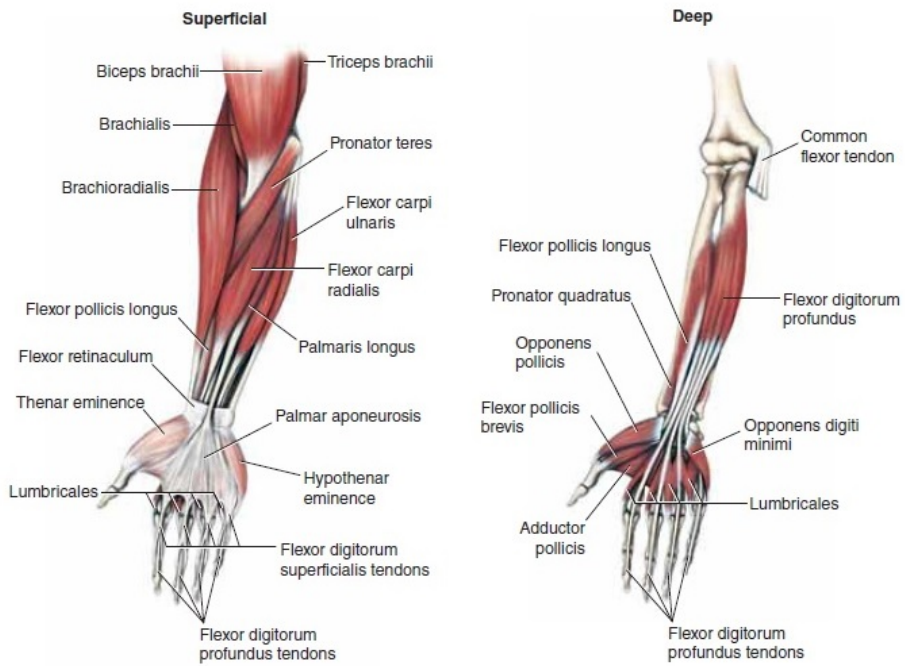
Figure 6: Muscles of the hand, wrist and arm, anterior view [2].

2.7 OTHER ANATOMY

The intrinsic muscles form the thenar eminence, which is a tissue- full part of he hand situated proximal to the thumb.

The abductor pollicis longus together with the tendons of the extensor pollicis brevis form a depression over the scaphiod bone as the pass the wrist. This depression is called the anatomical snuffbox.

Between the carpal bones and the extensor retinaculum pass the extensor tendons of the hand and wrist. The gap between the carpal bones and the flexor retincula is larger and forms a bridge called the carpal tunnel, where the flexor muscle tendons pass [1], [2] .

3

WRIST AND HAND MOTION

3.1 MOTION OF THE WRIST

The hand and wrist are very mobile and can move and rotate in many different ways. It is therefore difficult to calculate the absolute center of rotation. Usually when modelling the center is placed in the head of the capitate, with the flexion extension axis orientated from radial to ulnar styloid process and the radius ulnar deviation axis is orientated orthogonal to the flexion extension axis. This is obviously a very simple kinematic model of wrist movements considering the complex carpal motions.

With this model in consideration, the wrist moves mainly in two planes. Flexion and extension in the sagital plane, and radial-ulnar deviation in the frontal plane, see figure 6. The wrist can move in a circumduction way, which means it can move in a combination of the fundamental movement of a bi- or triaxal joint. Due to many joints next to the wrist, a slight decrease in angular movement does not interfere with most of the daily activities [2].

3.1.1 *Flexion and Extension*

The range of motion varies a lot between people, but in average from 65°to 80°of flexion an 55°to 75 °of extension. Flexion range is larger at the radiocarpal joint whereas extension range is greater in the midcarpal joint. Flexion and extension are mainly limited by antagonistic muscles,
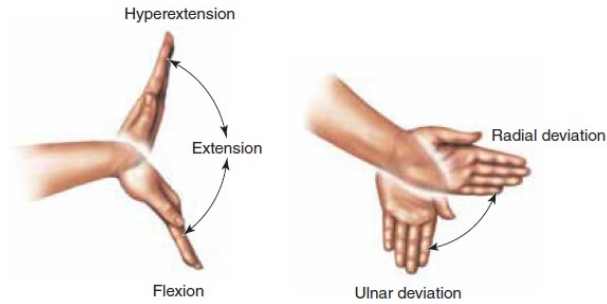
Figure 7: Movement of the wrist [2].

therefore the range of flexion is slightly reduced when flexing the fingers because of increased tension in the extensors. The dorsal and palmar ligaments are only fully stretched when the joints are forced to the limits [1], [4] .

3.1.2 *Radial and ulnar deviation*

Similarly, the range of motion for the ulnar deviation is approximately 50 °to 60 °for the whole movement from radial to ulnar. The radial deviation is 15°to 20°, and the ulnar deviation is 35 °to 20°

When moving in one direction, the distal carpal row follow the same way as the fingers whereas the proximal row slide in the other direction, this opposite movement is larger when moving the hand in the ulnar direction.

Both radial and ulnar deviation occurs mainly in the midcarpal joint.

The palmar intrinsic ligament and the radioulnate and ulnolunate ligaments form a double V system that stabilize the radial-ulnar deviation [1].

3.1.3 *Dart Thrower's Motion*

Another well studied movement is the Dart thrower's motion, which is the movement you perform when throwing a dart, i e. the motion from radial extension to to ulnar flexion. During the DTM motion the carpal row forms a stable base for fine motor control and force demands, for example throwing a ball or swinging an axe [1].

3.1.4 *Forearm Pronation and Supination*

The forearm pronation and supination is the movement where the forearm rotates from the the palm of the hand facing backward, to facing forward. see figure 6. During this movement, the radius rotates around the ulnar bone. The range of motion is approximately 160°, where around 75° of pronation and 85° of supination. This movement does not occur in the wrist directly but is important for the hand and wrist function [1].
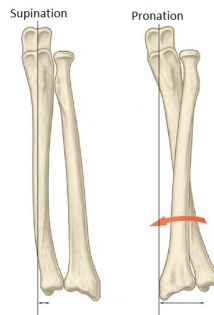
Figure 8: Supination and pronation [4].

3.2 HAND-WRIST INTERACTION

The position the wrist affects the ability to grasp and the ability to move the fingers. When moving the wrist in different positions, the tendons digital flexor is altered. This creates varying forces in the fingers which affect the ability to grasp. Extending the wrist slightly will make full

flexion of the fingers possible, i.e. making a fist. Flexion the wrist slightly will instead make it possible for full finger extension since the position of the wrist creates tension in the digital extensor tendons, which then automatically opens the hand, see figure 8 [1].
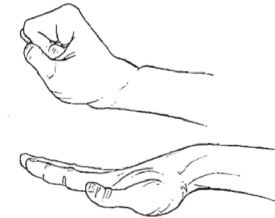

Figure 9: top: A slight extension bottom: Slight flexion [1].

It has been shown that the optimal wrist position that maximizes grip strength is 35 °of extension and 7 °of ulnar deviation [1].

4

INJURIES

Injuries of the wrist are very common. The most common injuries are different kind of fractures or ligament injuries. The treatment and rehabilitation vary from different types of injuries [11].

4.1 FRACTURES

A fracture on the wrist is the most commonly treated fracture in health care. In Sweden approximately 20-25000 wrist fractures are registered every year [10].

Fractures extending into the wrist region are called intra-articular fracture. The fractures that don't extend all the way are called extra-articular fracture. If the bone is broken in more than one place the fracture is called comminuted fracture. A fracture that also result in breaking the skin is called an open fracture. In this case medical attention is usually needed immediately to avoid infection [12].

4.1.1 *Types of fractures*

What is usually referred to as a broken wrist is actually called a distal radius fracture, or Colle's fracture. The most common way to fracture this bone is falling forward onto an outstretched arm. Among old people this is very common due to osteoporosis, especially among older women with a weaker bone structure. It is also common for children, younger

people and athletes due to higher activity which increases the risk of falling.

There are many other types of wrist fractures apart from Colle's. There is Smith's fracture which is also on the distal radius. Smith's fracture is sometimes called reverse Colle's fracture. Unlike Colle's you fall onto a flexed wrist or on the dorsal forearm. The fracture will be placed volarly, whereas Colle's fracture appears on the dorsal side of the wrist.

The most frequently injured carpal bone is the scaphoid bone. The fracture is called Scaphoid fracture. This occurs typically when falling and hyper extending the wrist or with direct axial compression. It usually causes pain and swelling in the base of the thumb.

Figure 10: To the left: scaphoid fracture, to the right distal radius fracture.(picture by Case courtesy of Dr Mohammad Taghi Niknejad, Radiopaedia.org).

Another type of fracture is Barton's fracture which is a fracture dislocated of the radiocarpal joint. This is caused when falling on a extended and pronated wrist. It can be either dorsal or volar depending on the fall. Usually intrinsic treatment with pins and plates is needed here.

Fractures can occur on either the ulnar or radial styloid. The radial styloid fracture is also called the Chaffeur's fracture. Usually it is caused by compression of the scapoid bone in the styloid process of the distal radius. The name comes from the injury many chauffeurs got earlier when they were hand cranking to start the car and the car backfired.

The crank caused a force in the drivers palm which resulted in a styloid fracture.

Among children there is also the Greenstick fracture which occurs in soft bone. Aging makes the bone harder and more brittle, therefore this fracture usually only occurs among children under an age of 8. During the accident the bone usually bend and break, often the fracture is not easy to discover on an x-ray [12], [16].

4.1.2 *Bone healing*

Bone has the ability to remodel, by size, shape and structure, to adapt to the mechanical loading put on. This involves bone cells, with bone resorption by the osteoclasts and bone formation by the osteoblasts. The current bone mass is determined by a balance between this resorption and formation [5]. According to Wolffs law, loads exerted on bone promotes bone formation. Physical exercise will also increase the loading on the bone while inactivity will have a negative effect on the bone mass. For example, bed rest will reduce the bone mass with approximately 1 % a week [1].

Since the bone remodels it is very important that the bone is put back in the right position after an injury to heal correct, and also that the person exercises to get back the strength and size.

4.1.3 *Treatment*

Depending on the injury the treatment varies. If it is just a crack, just resting and a bandage around the wrist is usually enough. If the bone is broken the injury is treated with a plaster cast for several weeks.

Sometimes the bones is displaced in the accident. To correct this it is sometimes enough to put it back on place and put a plaster cast around the wrist, but sometimes in more difficult cases surgery is necessary. The bone pieces is then put back in the right place using metal pins, either extrinsic in a supportive plate /disc or intrinsic, where metal plate is implanted in the wrist. Sometimes a combination of the intrinsic and

extrinsic method is used. A surgery like this can take several months, up to over half a year to heal [11], [12].

4.1.4 *Rehabilitation after injury/Recovery*

When the injury is stable and the fracture has healed the plaster cast and/or external metal plate is removed. The bone will still be weak for another couple of weeks or months depending on the accident. At first the hand is usually very stiff, swollen and moving the wrist hurts. To get back the strength and get rid of the stiffness and the swelling the patient has to exercise the wrist to obtain proper recovery. Usually the patient get some kind of training program from the doctor or a physiotherapist [10].

4.2 LIGAMENT INJURIES

Ligament injuries are also common in the hand and wrist.

4.2.1 *TFCC*

TFCC stands for Triangular FibroCartilage Complex. This is the collection of ligaments and cartilaginous structure that stabilize the rotation of the wrist. An injury usually occurs directly when falling onto the arm or hand, but it is also common that an earlier injury recurs. Due to poor blood supply, these kind of injuries heal poorly and can thus result in chronic pain.

A TFCC injury usually gives pain in certain rotary movements, with or without a load. The patient perceive the wrist as weaker and unstable, sometimes with a clicking sound when moving in a specific direction. Sometimes the injury is treated with just a plaster cast for a couple of weeks but it is common that surgery is needed. During an operation, the blood flow is stopped, and to regain the stability in the wrist the ligament is attached to the bone. After the operation a plaster cast is

put on the wrist and one has to rest for a couple of weeks and thereafter rehabilitation, recovery and training remains [4], [15].

4.3 CARPAL TUNNEL SYNDROME

Carpal tunnel syndrome is refereed to as the pain or reduced mobility in the carpal area of the wrist. There are tendons, blood vessels and nerves that passes the carpal tunnel. Inflammation, overuse or injury of those tissues can cause swelling, which causes pain in this area [2].

5

EQUIPMENT/MATERIAL

5.1 ELASTOSIL

Elastosil LR3162 is a conductive silicone, where the LR stands for liquid rubber. It was chosen because of its good mechanical and electrical properties. Elastosil contains two components, A and B which are mixed at a ratio of 1:1. The curing time is 8 hours [13].

5.1.1 *Properties*

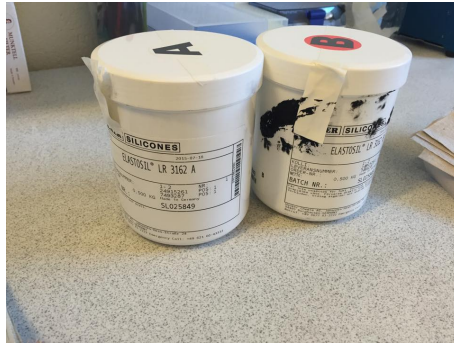| Characteristics	Value
Hardness shore A	53
Appearance	Black
Elongation at break	400%
Tensile strength	5.5 N/mm^2
Density at 23°	1,12g/cm^3
Tear strength	18N/mm
Rebound elasticity	54%
Volume resistivity	11 Ωcm

Figure 11: Elastosil A and B.

5.1.2 *Silicones*

Silicones are made up of quartz sand, a material that exists in nature in almost unlimited quantities. Silicones that are not cured yet contain polymers of different chain length. These rubber silicones always contains a main silicone oxygen chain and an organic group that might be methyl, vinyl, phenyl or other. Its properties depends on the organic group and the chains chemical structure. Silicones in common use are classified as solid- or liquid silicone rubber depending on which organic groups are present.
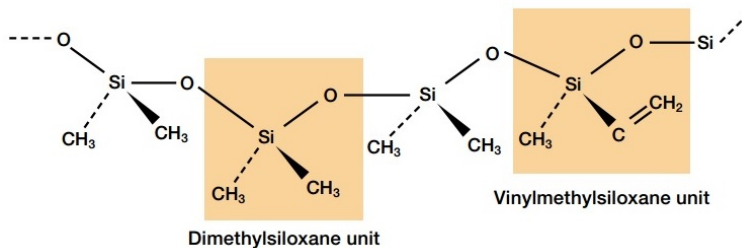

Figure 12: Chemical structure [13].

A silicone liquid rubber has better flow properties than the solid version. It is made up of shorter chains i.e has a lower molecular weight.

29

Liquid silicone rubber is addition-curing which means two parts are needed to initiate the cure. Component A contains platinum catalyst and component B contains crosslinker. A crosslinker converts the raw rubber to a cured, mechanically stable product.

Apart from the polymers, the uncured silicone rubber usually contains crosslinkers, fillers and sometimes additives

Fillers are used to strengthen the elastic silicone network. The composition and quantity of the filler influences the properties of the rubber. The most frequently used fillers are pyrogenic silica,precipitated silica, carbon black or quartz.

Additives are stabilizers or colorants. The essential properties are determined by the silicone polymer, thus additives are not always necessary. The silicone rubber is transparent, i.e in Elastosil LR3126 a black colourant is used.

During the addition curing process in the platinum catalysation the Si-H groups in the crosslinker reacts with the organic group and forms a three-dimensional network [13].
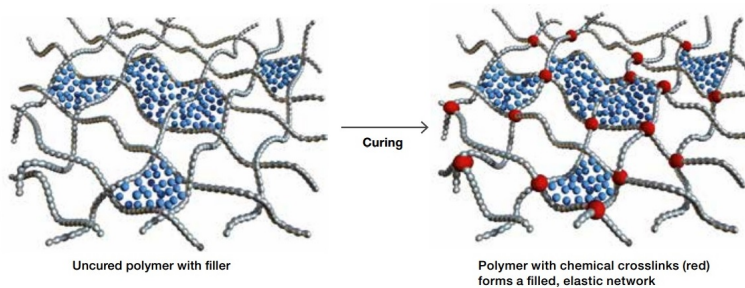

Figure 13: Curing [13].

5.2 CYBERGLOVE

Cyberglove is a wearable glove that uses a bend-sensing technology that transfer the movements of the hand to real-time digital joint-angle data. It is made up of 18 sensors. It has two flexion-extension sensors on each fin-

ger, four abduction sensors, and also sensors measuring thumb crossover, palm arch, wrist flexion, and wrist abduction. The glove can be used for many different things. For example, digital prototype evaluation, virtual reality biomechanics and animation [9].

Figure 14: Cyberglove [9].

5.3 DARTFISH

Dartfish is a program where you can capture, analyze, code, enrich, share and monetize video content. It is used to analyze movements and techniques in sports, rehabilitation etc [14].
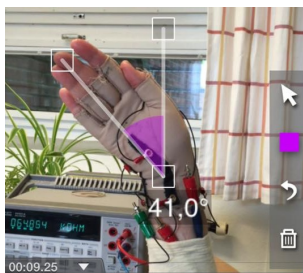

Figure 15: Angular displacement measured with Dartfish

6

MEASURING STRAIN AND RESISTANCE

6.1 RESISTANCE

Electrical resistance is measure of the opposition of a electric current passing through a conductor. All materials apart from superconductors have a resistance. It is usually designated as R and the SI unit is ohm (Ω)

If the crossection A is homogeneous, the resistance is proportional to its length L and can be calculated as equation 1, where ρ is the resistivity for the material.

$$R = \rho \frac{L}{A} \tag{1}$$

The change in resistance in Elastosil LR3162 is due to the presence of carbon black particles. In a neutral state, the carbon particles are contacted tightly to each other and distributed uniformly. When stretching, the particles will be slightly separated, and some of them wont have contact with other particles. This causes the conductive path to be narrower and thus the resistance will increase [7].

6.2 ELONGATION

Strain (elongation) is unit-less measure how much of an object that is deformed i.e percentage of initial state. It can take both negative and positive numbers depending on if the object is exposed to tension or compression. Strain is usually designated as ϵ.

There are different ways to measure strain. For $\epsilon > 1$ true strain or logarithmic strain is usually used . The elongation can be calculated by integrating equation 2 as shown in equation 3 [5].

$$d\epsilon = \frac{dL}{L} \tag{2}$$

$$\epsilon = \int_{L_0}^{L} \frac{dL}{L} = lnL - lnL_0 = ln\frac{L}{L_0} \tag{3}$$

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METHOD

7.1 MAKING THE PROTOTYPE

Elastosil was ordered from the German company 'Wacker'. To obtain the right composition, component A and B were mixed at a ratio of 1:1. This mix were thereafter painted in four stripes, approximately 1 cm wide on an elastic compression glove, see figure 15. The lines were painted where the hand achieves the greatest elongation in flexion-extension and radial-ulnar deviation. The painted gloves were then left in a fume hood overnight to cure.

The compression glove is from Catell AB. It contains 85 % nylon and 15 % spandex. The model is with open fingertips and compression class 1 (15-25 mmHg).

To measure the resistance, wires were attached to the glove. The wires were attached with push buttons at first, but due to glitches the attachment was changed to staples and eyelet terminals.

7.2 MTS MACHINE, TENSILE TEST

Two tensile tests were made in a MTS machine, which is a tensile test machine from the company MTS. The machine moves apart with a constant velocity of 1 mm/s, thereafter with same velocity back to the initial position. The two tests were performed with a couple of minutes between each other. A one cm wide stripe was cut out from one of the prototypes. The cloth was attached to the machine with 7.4 cm between fixing points

Figure 16: Top left: Pre painted compression glove, top right: painting the glove, bottom: Overnight curing in a fume.

and stretched to a total length of 8.4 cm every measurement. At the same time the resistance was measured using an external multimeter linked with a GPIB cable to Labview to obtain the data files.

7.2.1 *Measurement methods*

7.2.1.1 *Sensitivity*

The change in resistance divided by the elongation is defined as the sensitivity of a strain sensor. It provides information of the overall sensing property [7].
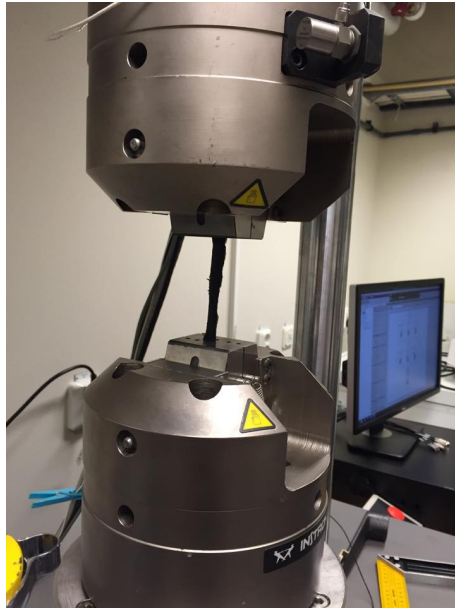
Figure 17: Tensile test in MTS.

7.2.1.2 *Hysteresis*

Hysteresis error is the deviation of the output at a point of the input signal when it is approached from the opposite direction. For this thesis the hysteresis before stretch and after release is relevant [7].

7.3 MEASURING ON THE GLOVE

To measure the movements of the hand the glove had two measuring points on each stripe. The resistance in flexion and extension were measured at the same time using two multimeters. The same setup was used for radial and ulnar deviation. The movements were performed in cycles. Simultaneously the movements were filmed with Dartview to pick out the angles. The purpose was to examine if the magnitudes of the different curves of resistance change correspond to a matching curve for

the angular displacement, and also to investigate if the cycles are easy to distinguish.

7.4 LABVIEW SETUP
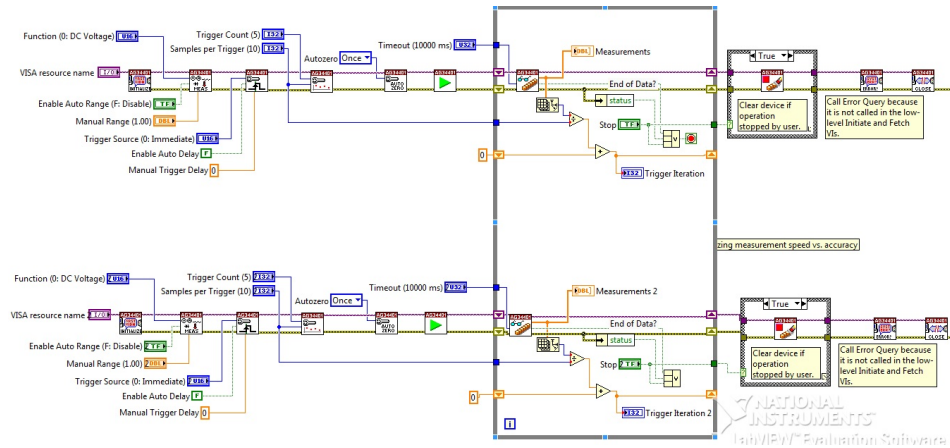
Labview setup to get the measurements to a data file.
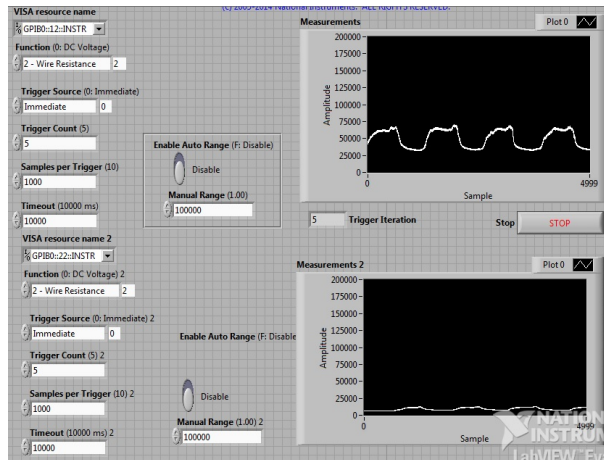

Figure 18: Labview setup.

Figure 19: Labview setup for the glove with Elastosil.

7.5 CYBERGLOVE

To compare the method with Elastosil Cyperglove were used. Flexion-extension and radial-ulnar deviation movements were plotted and analysed with Labview.

7.6 CONVERTING TO ANGLES

The change in resistance from 0 % to maximum stretch should correspond to the angular displacement from starting position to maximal displacement. To convert, the measurements were scaled to the angles from the videos.

RESULTS

8.1 TENSILE TEST WITH MTS

Two tensile tests were done to show linearity between the resistance and elongation.
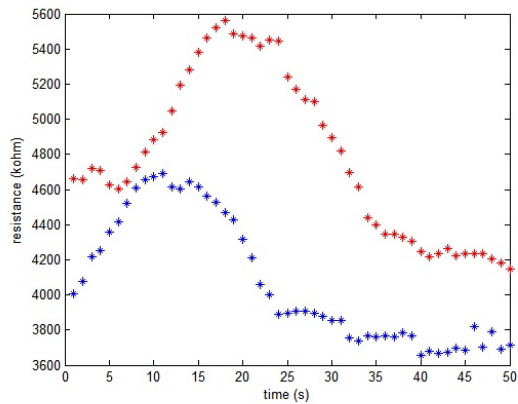
8.1.1 *Resistance as a function of time*

Figure 20: The resistance as a function of time. Red line is in the first tensile test, blue line is the second tensile test.

8.1.2 *Resistance as a function of elongation*
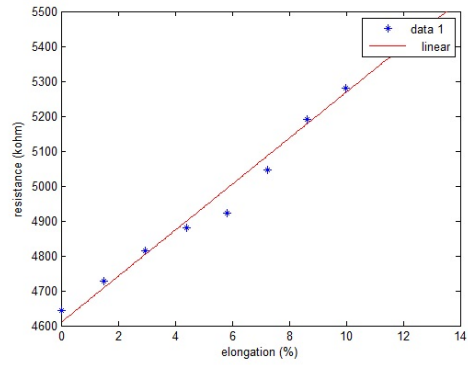

Figure 21: Stretching in test 1. Red line y=61.872x+4616.7.
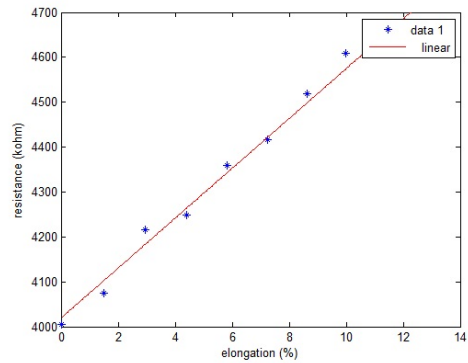

Figure 22: Stretching in test 2. Red line y=51.993x+4026.5.

8.1.3 *Resistance change in % as a function of Elongation in %*
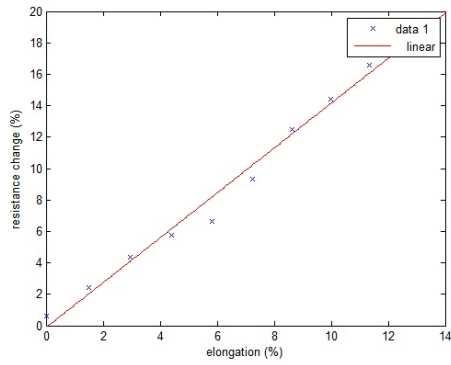

Figure 23: Stretching in test 1. Red line y=1.4277x-0.0012081.
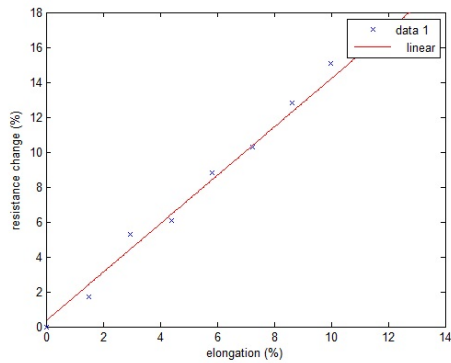

Figure 24: Stretching in test 2. Red line 1.386x+0.0033711.

41

8.1.4 *Hysteresis. Resistance as a function of elongation*
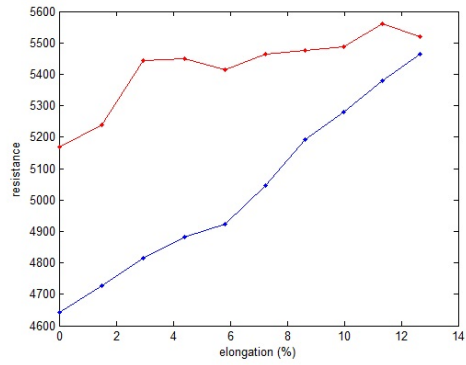
Figure 25: Hysteresis test 1. Blue line is stretch, red line is release.
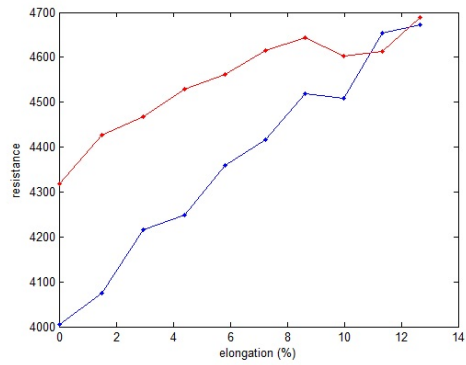
Figure 26: Hysteresis test 2. Blue line is stretch, red line is release.

8.2 MEASURING ON THE GLOVE

Flexion-extension and radial-ulnar deviation were performed in cycles to examine the properties on the glove prototype.
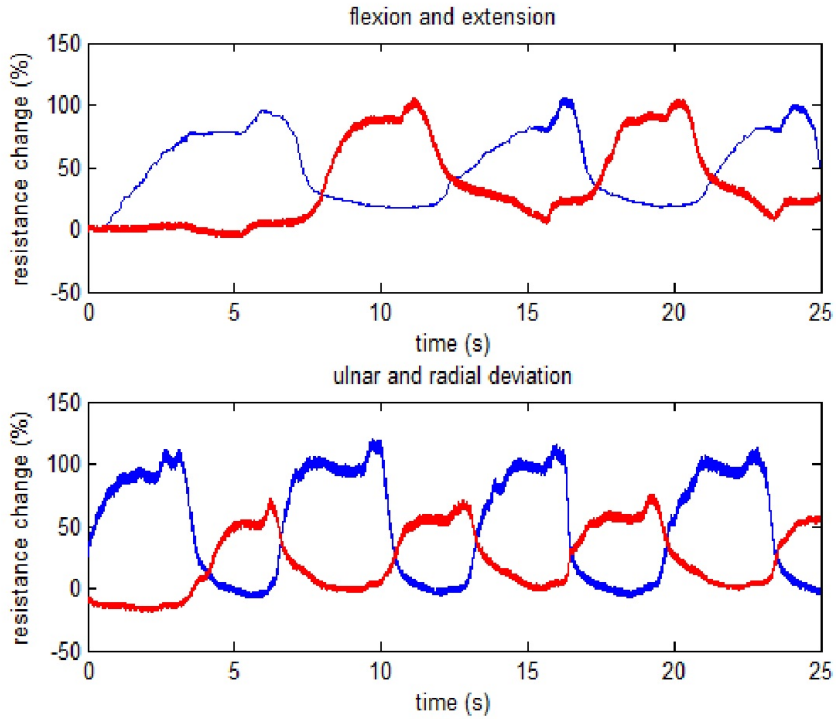
Figure 27: Top: Blue line is flexion, red line is extension. Both movements are shown in the same plot. Bottom: Blue line is ulnar deviation, red line is radial deviation. Both movements are shown in the same plot.

The green dashed lines in figure 27 show the angular displacement from the video from Dartfish. Due to incomparable magnitudes of the change in resistance and the angles every movement is scaled individually. The plot is mainly for showing how the resistance measurements follow the angular displacement from the video in Dartfish.
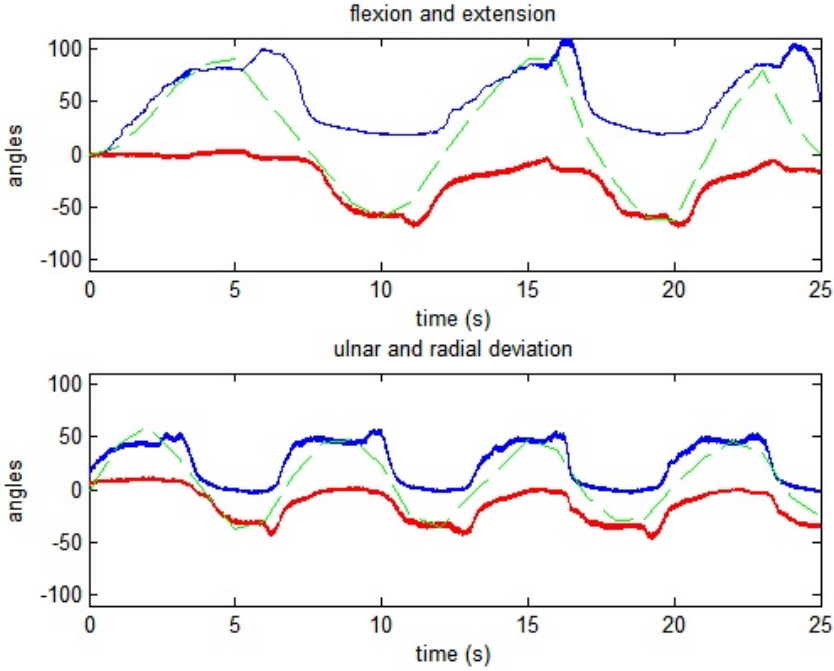
Figure 28: Top: blue line is flexion, red line is extension and green line is the angular value. Bottom: blue line is ulnar deviation, red line is radial deviation and green line is the angular value.

8.3 CYBERGLOVE

One cycle of flexion and one of radial ulnar deviation with cyberglove to compare the curve to the curve with Elastosil.
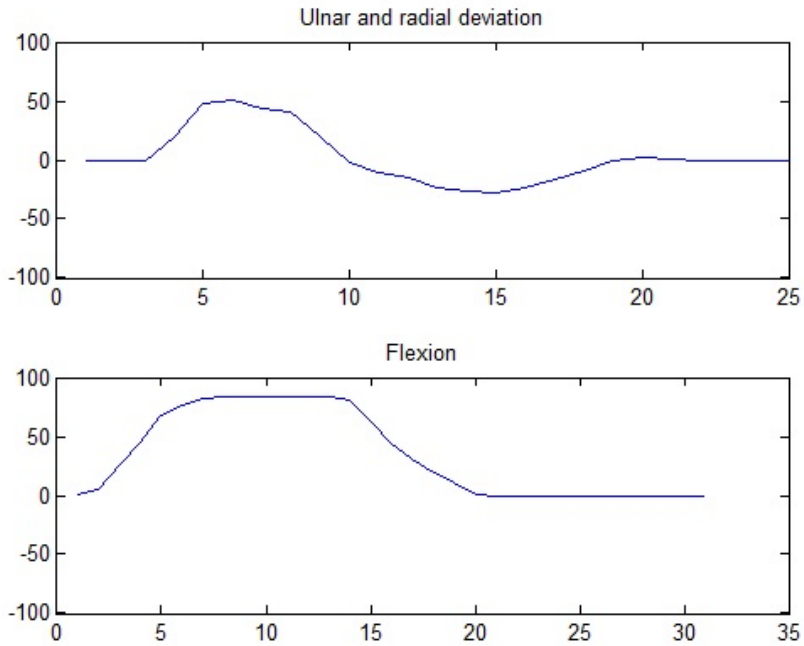

Figure 29: Top: Ulnar and radial movement using cyberglove. Bottom: Flexion movement using cyberglove.

9

CONCLUSION AND DISCUSSION

The conclusion of this project is that Elastosil has good properties for measuring the change in resistance as a result of elongation. The signal changes significantly already in a slight increase of elongation. The measured resistance is of a magnitude of kΩ, as are the change in resistance, i.e quite large. This makes it easy distinguish a decrease or increase. Early in the recovery the wrist might not be able to fulfill any large movements, but the glove has to be able to register the maximal angle, and register cycles of movements for the training programs. The results show that it would definitely work for counting cycles, but as it is now it is not accurate enough to pick out the maximal angle.

Hysteresis is a problem, thus the movement probably has to be re calibrated after every cycle or at least after every use. There also seems to be an overshoot after returning to initial state which not should be mistaken for another movement, nor the maximal angle.

Due to limited time the application was not possible to proceed with, but the goal is that the signal with angles should be sent with a bluetooth signal to the application. From there this signal should be further developed with exercise programs made up by doctors or physiotherapists.

Another thing that has to be changed is the size of the measuring equipment. In this thesis the resistance was measured with a multimeter and connected to Labview on a computer with a GPIB cable. To produce a simple usable model, the resistance has to be measured in another way, small enough to fit on the wrist. The bluetooth device should also be small to fit on the wrist.

With a complete model, the next step would be to try this glove on a group of patients and follow their rehabilitation and evaluate the patients experiences. A big advantage with this method is that it is cheap. If the glove can be developed as planned it is also very wearable and usable.

9.1 TESTS

All measurements were made on the fabric of a compression glove with painted silicone on the surface. The silicone was very viscous and it was a bit tricky to paint the lines of silicone exactly the same, and uniformly thick everywhere. This might of course affect the results, and it can differ some depending on which stripe is measured.

The results from the tensile tests in the MTS machine show that the resistance seems to be proportional to the elongation. However the resistance decreases below the initial state as shown in figure 19. The initial resistance is thus significantly lower in the second tensile test. The decrease back to initial state is also a bit slower and not as linear.

Figure 20 and 21 shows the resistance as a function of the elongation. The graphs clearly shows linear behavior in both cases, although the slopes differs with approximately 66 kΩ increase per percentage elongation for the first test and 56 kΩ increase per percentage elongation for the second test.

Due to different initial resistance the percentage difference in resistance were plotted as a function of elongation. The result is shown in figure 22 and 23. The data points exhibit linear behavior with the slope very similar in both tests around 1.4 percentage resistance change per 1 percent change elongation.

For a more accurate result the experiment should also have more data points, either set the displacement velocity of the MTS machine lower or have the multimeter sample the resistance more often. To get a more proper results this measurements could also have been done with repeated attempts. With the same stripe the decrease in initial resistance could have been analyzed further. Both after several tests directly after each other, but also to do the test again on the same stripe after a longer

time period. More attempts with different stripes, cut in the same size should probably give a more accurate result.

The initial resistance decreases from around 4600 Ω to 4000 Ω from the first to second experiment, which is a decrease of 13 %. A similar test was done by Li Guo, Lena Berglin, and Heikki Mattila [7] The resistance decreased after time there as well but not as much as in our experiment. Instead they get a 10 % decrease after two weeks.

Despite this, the results exhibit good linear behavior when stretching the fabric. Hence it was decided to not redo the experiment and instead proceed with the measurements on the prototype.

The motions on the glove are very easy to distinguish. Training programs in the application, where cycles are counted should be very easy to be able to perform. The magnitude varies a bit on the different painted stripes. For example flexion should be larger then extension, but it was not. Both radial and ulnar deviation should also be smaller than flexion and extension but this was not the case here.

In the results ulnar deviation is quite large. When doing the measurements the initial resistance was around 6-10 kΩexcept ulnar deviation where the initial condition was around 45 kΩ. The attachment seemed to be on a seam of the glove and just slightly outside the stripe, which maybe can explain the large difference in initial resistance.

At first the measuring points were attached at the same distance as in the tensile test 7.4 cm, but the first measurements with push buttons were a bit loose which resulted in very noisy and misleading plots. The new attachment of the wires had therefore to be put back on new places, therefore the distance between the measuring points vary slightly between the stripes. This can have affected the measurements, because a larger distance will increase the resistance.

Due to that the lines might not be equally thick, and the measuring points differs up to one cm, it is probably not possible to find a formula that directly converts the resistance to angles sufficient for all four measurements at the same time. Nevertheless it might be possible with more exact methods to produce the prototype.

The slopes when stretching the fabric for every individual movement are very similar which indicates that with more accurate and exact mea-

suring methods it should result in a more similar behavior and thus it might be possible to have a common formula to convert the resistance to angles.

There is an overshoot in all the movements when turning to move back to initial position. In picture 26 one can also see a slight dip when turning in the opposite direction. This extra peak should probably be filtered so it is not mistaken for the maximal angle. When looking at the video it is not possible to see any movement that should lead to those peaks. However, it it still possible that it is an effect from testing on a person.

Another important aspect is that the 'glove' has to fit the hand and not slip due to the hands movements. In that case the measurements will be strongly affected and the the values for elongation would be very wrong.

9.2 FUTURE WORK

The application can of course be further developed with individual training programs and other features.

The glove itself could also be much more developed. An example is to put senors or material that respond to pressure on the fingertips to measure finger mobility, and evaluate the strength in the fingers during rehabilitation. Elastosil could also be painted onto additional places to measure other movements. Every finger could be painted and thereby make it possible to measure every movement. Instead of having all kinds of measurement on the same glove, the gloves could of course be designed for different purpose. For example one for wrist injuries, another one for finger injuries etc, or a combination. One issue is that the Elstosil silicone is very thick and viscous, otherwise it might be possible to cover the whole glove with silicone and add resistance meters on relevant places.

The principal used in this thesis can be used to follow motion in other joints system in the body for rehabilitation purpose. The application should be calibrated after which body part and injury, and the training program too.

Apart from in rehabilitation purpose, this technique with a conductive silicone and measure the resistance can be utilized much more than it

is today, for example it should be possible to use for different bending measurements for example in robotics, modelling, construction models.

The future part with the application to use for evaluating the recovery on a daily basis and to use for a training program could be much more developed than it is today and really be a helpful tool for both the patient and the doctor.

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