Simultaneous and proportional control of reaching and grasping

P7 Masterproject - Autumn 2017

Gruppe 17gr7404

Abstract

Nulla in ipsum. Praesent eros nulla, congue vitae, euismod ut, commodo a, wisi. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Aenean nonummy magna non leo. Sed felis erat, ullamcorper in, dictum non, ultricies ut, lectus. Proin vel arcu a odio lobortis euismod. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin ut est. Aliquam odio. Pellentesque massa turpis, cursus eu, euismod nec, tempor congue, nulla. Duis viverra gravida mauris. Cras tincidunt. Curabitur eros ligula, varius ut, pulvinar in, cursus faucibus, augue.

17gr6407

Forord

This project Morbi luctus, wisi viverra faucibus pretium, nibh est placerat odio, nec commodo wisi enim eget quam. Quisque libero justo, consectetuer a, feugiat vitae, porttitor eu, libero. Suspendisse sed mauris vitae elit sollicitudin malesuada. Maecenas ultricies eros sit amet ante. Ut venenatis velit. Maecenas sed mi eget dui varius euismod. Phasellus aliquet volutpat odio. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Pellentesque sit amet pede ac sem eleifend consectetuer. Nullam elementum, urna vel imperdiet sodales, elit ipsum pharetra ligula, ac pretium ante justo a nulla. Curabitur tristique arcu eu metus. Vestibulum lectus. Proin mauris. Proin eu nunc eu urna hendrerit faucibus. Aliquam auctor, pede consequat laoreet varius, eros tellus scelerisque quam, pellentesque hendrerit ipsum dolor sed augue. Nulla nec lacus.

Indhold

Del I

Postanalysis

0.1 Anatomy of the lower arm

In this paper/project there will be a focus on the lower arm only, since the MYOBAND will only be used to measure EMG signals from this part of the body. The anatomy of the lower human arm will briefly be described in this section along with a description of relation between lower arm muscles and hand movements for selected gestures.

The lower human arm is designed to give humans a manoeuvrability and dexterity with which we can coordinate and execute complicated and precise hand and finger movements with ease. This skill is achieved through the use of several muscles which intertwine and make synergies to perform all the different gestures our hands are able to make [**jiang2009**] [**avella2006**]. The lower arm contains around 20 individual muscles separated in an outer, middle and inner layer. These muscles are used to rotate the forearm and hand, flex and extend the hand at the wrist as well as adduction and abduction, of both the wrist and fingers. The muscles control extension and flexion of the fingers at each separate joint and the movements of the thumb.
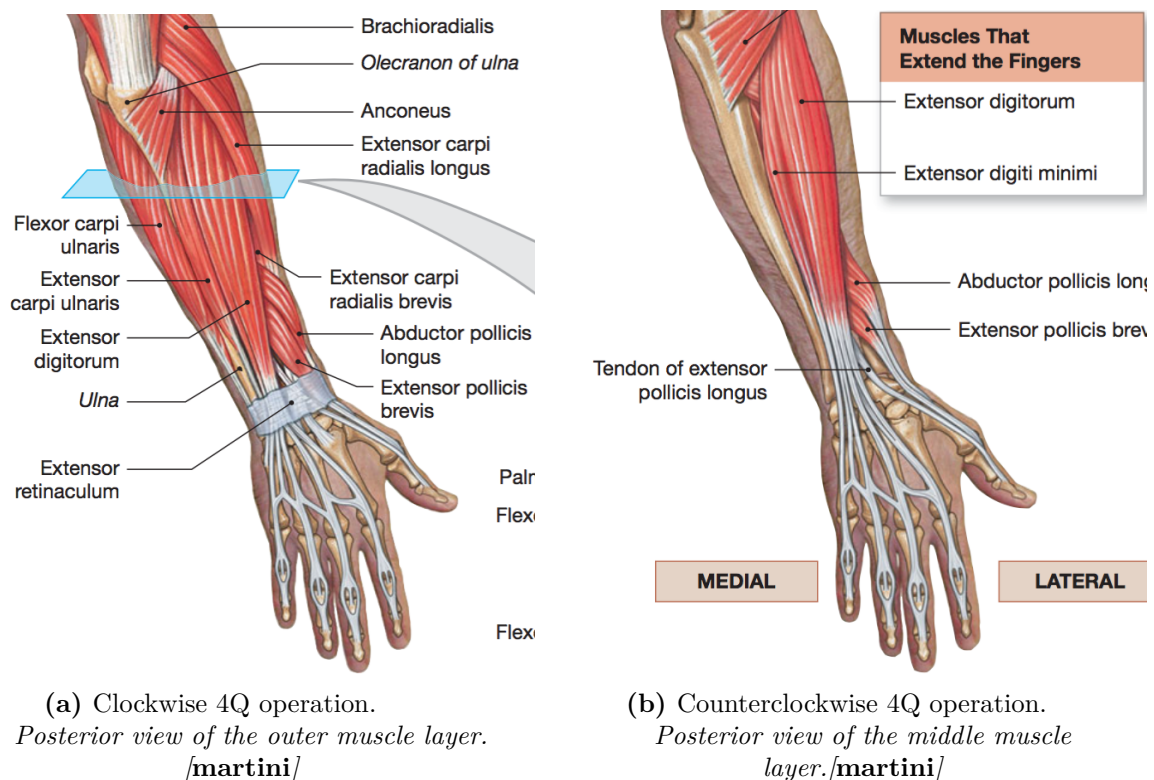

(a) Clockwise 4Q operation.
Posterior view of the outer muscle layer.
[**martini**]

(b) Counterclockwise 4Q operation.
Posterior view of the middle muscle layer.[**martini**]

Figur 1: Muscles and muscle layers of the forearm.

The aim for this paper/project is to translate pronation and supination of the wrist along with extension and flexion fingers via EMG signals to control a robotic arm. Therefore, only selected muscles will be relevant to further investigate. Muscles involved with pronation of the wrist includes the pronator quadratus and pronator teres muscles. The

pronator quadratus muscle is located near the wrist and is fixated on the distal portions of both ulna and radius, from where is forms a wide band across the gab of the two bones. The pronator teres is located near the elbow, where it originates from the medial distal part of humerus and the medial lateral part of ulna, to reach across the anterior part of the forearm and fixate to the midlateral surface of radius. There is only one muscle involved in the process of supination of the forearm, the supinator. The supinator muscle sits opposite the pronator teres muscle near the elbow, where it originates from the lateral distal part of humerus and the lateral proximal part of ulna and fixate on the anterolateral surface of radius. These three are the only muscles responsible for pronation and supination of the forearm. Therein exists a problem in detecting viable EMG signals to properly detect pronation and supination gestures, since the muscles involved does not extend through the forearm as most other muscles in the forearm.

Extension and flexion of the fingers include most of the muscles in the lower arm. Most of these muscles extend throughout the whole forearm as most of them originates from the lateral surfaces of humerus or the proximal portions of ulna and radius, and extends towards the wrist and fingers to fixate on the metacarpal bones in the wrist and through tendons fixate on the different phalanges bones of the fingers and thumb. See 2 and 3 for a detailed overview of each muscles origin, insertion and action it performs.

ACTION AT THE HAND				
Flexors Flexor carpi radialis	Medial epicondyle of humerus	Bases of second and third metacarpal bones	Flexion and abduction at wrist	Median nerve (C_6–C_7)
Flexor carpi ulnaris	Medial epicondyle of humerus; adjacent medial surface of olecranon and anteromedial portion of ulna	Pisiform, hamate, and base of fifth metacarpal bone	Flexion and adduction at wrist	Ulnar nerve (C_7–T_1)
Palmaris longus	Medial epicondyle of humerus	Palmar aponeurosis and flexor retinaculum	Flexion at wrist	Median nerve (C_6–C_7)
Extensors Extensor carpi radialis longus	Lateral supracondylar ridge of humerus	Base of second metacarpal bone	Extension and abduction at wrist	Radial nerve (C_6–C_7)
Extensor carpi radialis brevis	Lateral epicondyle of humerus	Base of third metacarpal bone	Extension and abduction at wrist	Radial nerve (C_6–C_7)
Extensor carpi ulnaris	Lateral epicondyle of humerus; adjacent dorsal surface of ulna	Base of fifth metacarpal bone	Extension and adduction at wrist	Deep radial nerve (C_6–C_8)

Figur 2: Table of the muscles in the forearm involved with movements of the wrist. [**martini**]

Muscle	Origin	Insertion	Action	Innervation
Abductor pollicis longus	Proximal dorsal surfaces of ulna and radius	Lateral margin of first metacarpal bone	Abduction at joints of thumb and wrist	Deep radial nerve (C_6–C_7)
Extensor digitorum	Lateral epicondyle of humerus	Posterior surfaces of the phalanges, fingers 2–5	Extension at finger joints and wrist	Deep radial nerve (C_6–C_8)
Extensor pollicis brevis	Shaft of radius distal to origin of abductor pollicis longus	Base of proximal phalanx of thumb	Extension at joints of thumb; abduction at wrist	Deep radial nerve (C_6–C_7)
Extensor pollicis longus	Posterior and lateral surfaces of ulna and interosseous membrane	Base of distal phalanx of thumb	Extension at joints of thumb; abduction at wrist	Deep radial nerve (C_6–C_8)
Extensor indicis	Posterior surface of ulna and interosseous membrane	Posterior surface of phalanges of index finger (2), with tendon of extensor digitorum	Extension and adduction at joints of index finger	Deep radial nerve (C_6–C_8)
Extensor digiti minimi	Via extensor tendon to lateral epicondyle of humerus and from intermuscular septa	Posterior surface of proximal phalanx of little finger (5)	Extension at joints of little finger	Deep radial nerve (C_6–C_8)
Flexor digitorum superficialis	Medial epicondyle of humerus; adjacent anterior surfaces of ulna and radius	Midlateral surfaces of middle phalanges of fingers 2–5	Flexion at proximal interphalangeal, metacarpophalangeal, and wrist joints	Median nerve (C_7–T_1)
Flexor digitorum profundus	Medial and posterior surfaces of ulna, medial surface of coronoid process, and interosseous membrane	Bases of distal phalanges of fingers 2–5	Flexion at distal interphalangeal joints and, to a lesser degree, proximal interphalangeal joints and wrist	Palmar interosseous nerve, from median nerve, and ulnar nerve (C_8–T_1)
Flexor pollicis longus	Anterior shaft of radius, interosseous membrane	Base of distal phalanx of thumb	Flexion at joints of thumb	Median nerve (C_8–T_1)

Figur 3: Tabel of muscles in the forearm involved with movements of the wrist and fingers. [**martini**]

0.2   What do we measure with EMG?

The electric potential detected with an electromyography is an action potential causing the muscle to contract. Certain mechanisms are involved for this to happen. The motor unit of the muscle needs to be activated alongside with its associated alpha motor system,

which is the lower motor neuron, its axon, and the muscle fibers the motor unit innervates. The muscle fiber is an excitable cell with a resting potential of between -90mV and -70mV. A threshold of approximately -55mV needs to be reached for an action potential to be generated. The sarcolemma, the membrane covering the muscle fibers, has sodium and potassium ion channels that maintains the resting potential, depolarize the muscle fiber if the threshold is exceeded or repolarize the muscle fiber.

The lower motor axon is branching out so that it can attach to the muscle fiber at the motor end-plate and create neuromuscular synapses. The action potential traveling down the axon reaches the synapses and releases ACh. ACh raises the permeability of the cell membrane where sodium ions influx and causes the membrane to depolarize. Calcium ions are released and binds with troponin and exposes the active sites on the thin filaments which allows the muscle to contract. The action potential travels along the whole muscle fiber through t-tubuluses. This happens in both directions from the motor end-plate to the tendentious attachment. When the peak of the depolarization of about 30mV is reached a rapid efflux of potassium ions causes the muscle fiber to repolarize and reach its resting potential again.

Depending on the force that needs to be applied for a given task more or less motor units are activated and therefore more or less muscle fibers are contracted. The bigger the force the more motor units are activated. Furthermore, the number muscle fibers per motor unit varies between muscles in the human anatomy. The finer the movement the higher the innervation, e.g. the extraocular muscle has the highest innervation of 3:1 and the gastrocnemius muscles has one of 2000:1.

(Something about how the innervation is in certain muscles of the forearm)

0.3   Some stuff and such stuff and other stuff too

The following section will contain an explanation of the two main components when acquiring EMG signals, including different electrode designs and the most common pre-processing methods used in EMG acquisition.

0.3.1   Electrode function and selection

When performing EMG the electrodes act as a transducer by converting the differences in ion distribution on the skin surface caused by ion exchange under muscle activity, into an electric current. Electrodes used to aquire EMG signals comes both with and without gel covered surfaces, where the the Myo Band employs dry electrodes. Using dry electrodes will often be more practical in use, while the gel covered electrodes will aquire more exact readings of the signals. [**lee2008** , **cram2012**]

The most commonly used electrodes for EMG are made of disposable silver-impregnated plastic, and in order to keep the electric potential on the skin surface stable and reduce

impedance between the surfaces, they are often covered in a silver chloride gel. Using dry electrodes will result in a higher surface impedance, which means that the signal contains more noise compared to a gel covered electrode.[**cram2012**]

0.3.2   Preprocessing of EMG

In order to achieve a higher signal to noise ratio (SNR) it is common practice to implement some preprocessing methods, including input impedance, differential amplification and filtering. The raw EMG signals has to be preprocessed due to them sensible to noise elements from the surroundings, since the range of the signal is in the order of millivolts to microvolts.[**cram2012**]

Input impedance is determined by a simple rule in order to avoid defeating the common mode rejection of the EMG amplifier. The rule states that the input impedance of the EMG amplifier has to be between 10 and 100 times higher than the impedance of the skin-electrode interface.[**cram2012**]

Differential amplification is used in EMG in order to amplify the original signal and remove common signals from two or more electrodes, in order to avoid common noise from more electrodes in the amplified signal. The amplifier has a build in gain as well, which determines the final strength of the signal, and both of these features are implemented in order to avoid the SNR.[**cram2012**]

Basic filtering should be implemented in order to avoid electrical noise (50 or 60 Hz). This filter would be implemented as a notch filter, in order to reject the electrical noise and achieve a higher SNR. Furthermore the filtering should include a bandpass filter with a bandwith chosen depending on where the EMG is performed. This is done in order to make sure the final signal doesn't contain irrelevant high and low frequencies.[**cram2012**]

0.4   Myo band arm

Myo band arm is a gesture interactive system developed by Thalmic Labs capable of identifying the movement of hands and arms in order to interact and control different electronic devices.
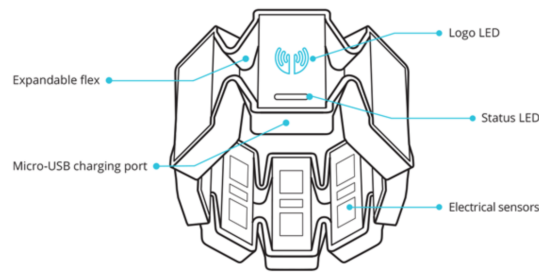
Figur 4: Main components of the Myo armband. []

The main components of the Myo armband illustrated in the figure 4 are:

- The logo LED gives information about the sync state. The LED is solid when you perform the Sync Gesture successfully and the Myo armband is synced to your arm. The LED pulses when the armband is not synced.

- The status LED shows the state of the Myo armband. When it lights up in blue once the Myo armband is connected to a device.

- The USB charging port allows to charge the Myo armband battery.

The systems counts with sizing clips, these small pieces give a tighter grip which is more appropriated for smaller arms.

This wearable physical device (arm band positioned in the upper forearm) counts with eight medical grade stainless steel electromyogram (EMG) sensors, responsible of recognizing and performing each gesture. In addition, it has nine axis inertial measurement unit (IMU) which enable the detection of arm movement. IMU includes a three axis gyroscope, a three axis accelerometer and a three axis magnetometer. An inertial measurement unit is an electronic device that provides information concerning position and orientation for navigation and stabilization purposes. The magnetometer has the property of measuring magnetism. (something about the actual data the myoband provides). The accelerometer measures the physical acceleration experienced by an object, where the object in this case is the body part of the placement of the myoband. It gives information about the acceleration expericed relative to free fall and expresses this in g-force. One g-force being when the accelerometer is at rest on the Earth's surface. That is since all points on the surface of the Earth is accelerating upwards relative to an object in free fall near the surface. For the g-force to change from one g-force the accelerometer must be exposed to motion. The gyroscope has the property of ... (It is equipped with an ARM Cortex-M4 microprocessor of low consumption.)

Figur 5: Hand gestures detected by proprietary EMG muscle sensors. []

It offers five pre-defined gestures as showed in the figure 5, it provides haptic feedback through short, medium or long vibrations to correct moves or activate the system.

The Myo armband is capable of pulling sEMG data at a sample rate of 200Hz while the remaining data (accelerometer, gyroscope and magnetometer) is pulled at a sample rate of 50HZ. The recorded signals can be sent to other devices using Bluetooth 4.0

Myo band arm supplies two kinds of data:

- Spatial data, provides information about the orientation and movement of the user's arm. There are two types of spatial data:
    - Orientation
    - Acceleration

- Gestural data which gives information about the user's position of their hands.

0.5   JACO^2 robotic arm

In this section a briefly description of the JACO^2 robotic arm will be given. It is a 6 DOF robotic arm with a three fingered hand developed by Kinova Robotics. Its lightweight ($4.4kg$) makes this machine specially indicated for use in assistive and collaborative applications. It is design to help people with upper body disabilities in order to gain more autonomy in ordinary daily tasks.

Figur 6: . []

The JACO^2 is a serial manipulator, which means that this kind of robotic arms are designed as a series of links connected by motor-actuated joints that extend from a base to an end-effector. Any movement in a joint affects all the following joints and links in the chain. The arm can be controlled with the help of a joystick, it can be programmed in C++, using an SDK provided by the manufacturer.

The control of the JACO^2 arm can be Angular and Cartesian. In Angular control each actuator moves separately. Cartesian robots called Gantry robots as well, are mechatronic devices which make linear movements in three axes, perpendicularly oriented to each other. It allows eight movements:

- Three translations

- Three rotations of the wrist

- Two movements of the fingers (*open/close*)

0.6   Preprocessing of Data

this is [?]

0.7 Feature extraction methods

The EMG data recorded by the Myo band contains a lot of both useful and useless data. In order to extract the features which can be used to differ between the movements performed by the wearer, different feature extraction methods can be implemented. In addition to highlighting important features within the signal, the implementation of feature extraction will be useful when it comes to removing unwanted signal features caused by noise sources such as the powergrid and movement of the electrodes. [**phiny2012**]

When analyzing EMG signals there will be three different signal components to be extracted, which are the frequency and time domains, as well as the time-scale representation. Frequency domain features require a Furrier transformation of the signal, which requires more processing than the direct extraction of time domain features. [**phiny2012**]

The time domain features are performed directly on the raw EMG signal, and these feature extraction methods are often used both for research and practices since they often require very little processing compared to frequency domain features, as the signal do not need to be transformed to the frequency domain before feature extraction. Time domain features are mainly focused on the amplitude of the signal, which means they have a disadvantage if the signal differs in amplitude. [**phiny2012**]

0.7.1 Choice of feature extraction methods

Choice of features will be based upon reviews of different methods, where the method will be chosen based on it's performance in the low frequence area and the processing time for the feature to be extracted. This is a result of the Myo band limiting the recordable signal to 100 Hz and the intend of being able to control the JACO arm in real-time, where a long processing time would cause a delay between hand movement and movement of the JACO arm.

This study will only implement time domain features, due to the low sampling rate of the Myo band, which means that an implementation of frequency domain features will not be useful, as the signal does not contain a lot of information in that domain. The feature chosen in this study will be the logarithmic variance of the signal, based on a previous study by [**hahne2014**], where they find that this feature is useful for methods based on the numerical range of the features. [**hahne2014**] finds that the cross-validation performance improves significantly with the use of linear regression combined with logarithmic variance, compared to combining the linear regression with variance alone. [**hahne2014**].

0.8 Regression methods

Regression methods are widely used is statistics as a method to determine relationship between variables. It can be used to extract relations to predict future developments or tendencies in a given data set. It is also a commonly used method to evaluate EMG signals

to determine different parameters.

The most basic form of regression is linear regression, which is a test for linear dependency between two variables. In simple linear regression it is investigated how one, dependent variable, is related to another, independent variable. The term *simple* denotes that only two variables are being considered simultaneously. Performing simple linear regression finds the correlation between the tested variables, and is expressed by the correlation coefficient. This coefficient describes how the two variables relate to each other by how the development of one variable is dependent on the the other. Thus a positive correlation represent that a change in one variable will resolve in a similar change in the other variable as well. On the contrary, a negative correlation imply that change in one variable will resolve in an opposite change in the other variable. If no correlation is present between the two variables no change in either variable will resolve in change in the other, and it can therefore be determined that the two variables has no relation to each other. [**zar2009**] The simple correlation coefficient is calculated as: [**zar2009**]

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \tag{1}$$

Furthermore a coefficient of determination can be calculated to express how much of the variability of the dependent variable is accounted for when regressing upon the independent variable. This coefficient is denoted r^2 and can be calculated by simply squaring the correlation coefficient (r). Both r and r^2 can be used to determine the strength of the relationship between the two tested variables. [**zar2009**]

A variant of the linear regression is the multiple linear regression, which can be used in cases where the relationship between three or more variables is wished to be investigated. Here it is considered that one of the variables are dependent on two or more independent variables. Multiple linear regression can be used in cases where two or more variables are expected to have a linear correlation to a dependent variable and it is wished to find which of the independent variables who has the biggest influence on the dependent variable, so to say the highest correlation coefficient. Since multiple linear regression is based upon simple linear regression, it is modelled after the equation for simple linear regression known to all: [**zar2009**]

$$Y_i = \alpha + \beta X_i \tag{2}$$

However, as Y can be dependent on more than one other variable at times, another can be added to the equation: [**zar2009**]

$$Y_i = \alpha + \beta_1 X_1 i + \beta_2 X_2 i \tag{3}$$

When three variables are present in the equation, the visual representation of the regression is in the 3rd dimension, and will no longer be presented as a line in 2D, but as a plane

in 3D. Having more than three variables will resolve in a regression in the m-dimension, where m is the number of variables. This plane of regression is called the hyperplane. However, regression is not a perfect fit to every sample point, and thus the equation for three or more variables is only complete when the error is also calculated: [**zar2009**]

$$Y_i = \alpha + \beta_1 X_1 i + \beta_2 X_2 i + \epsilon_i \tag{4}$$

, where the sum of the error (ϵ) is zero and is assumed to be normally distributed.

There exist ofcourse cases where the relationship between more than three variables is wished to be investigated. In such cases, each new variable can be added to the equation, and the final can be expressed in a summed up equation: [**zar2009**]

$$Y_j = \alpha + \sum_{i=1}^{m} \beta_j X_i j + \epsilon_j \tag{5}$$

, where m is the number of variables. There exist no limit to the number of variables which can be tested, however there should always be at least two observations more than the number of variables, so that $n \geq m + 2$. Otherwise multiple linear regression is not possible. [**zar2009**]