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BIOENG-390

Availability of sEMG controlled prosthetic arm components

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1. Introduction

1.1. Motivation

The recent progress made in the biomedical data analysis and prothesis development domains heralds hope and better conditions for people suffering from upper limb amputation. Protheses have been existing for a long time and current technologies can bring them to a stage that enhances an amputee's life. To understand the different elements of the prosthesis it is important to distinguish and explain the respective steps and mechanisms of upper limb prosthetic hands. This text mainly aims at sEMG controlled prostheses and more particularly concerns freely available techniques and tools that can allow the development of low-cost devices. More than 1.6 million amputees were referenced in 2005 in the United States of America, and this number is expected double by the year 2050[1,2]. Losing a limb strongly changes the life of the amputee and of its family. Most of the amputations are due to a trauma occurring at an age between 15 and 45 years. An amputation has many consequences; amputees may not be able to continue their prior work life, which can cause financial trouble. Hence, it raises the difficulty to obtain a prothesis that can allow them to get back a semblance of their previous life.

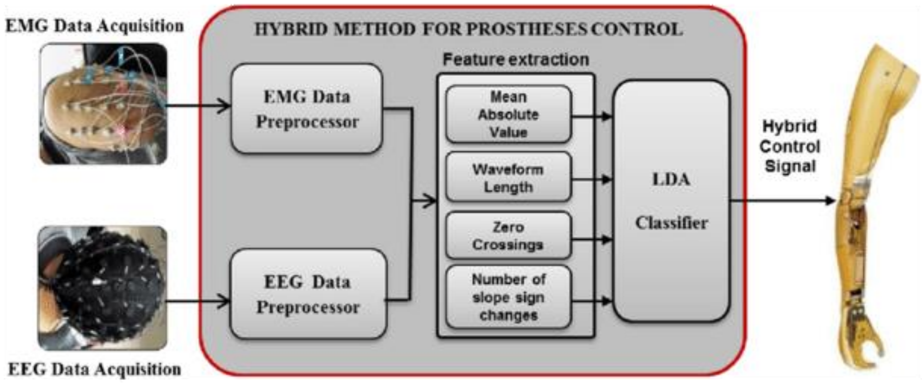

Figure 1. Steps in the creation of an sEMG controlled prothesis (Figure taken from[3]).

To correctly control a prosthetic hand the first step is to get a signal from the patient on the control. Surface electrodes on the skin are most frequently used. The sensors record a signal from the person who wants to move its hand and transmit it to a controller that analyzes the data. For this second step, often a software tool is required for the control that is based on analysis of the signals. It analyzes the data transmitted by the sensors and then sends a signal to the prosthesis to execute movement on the prosthetic hand, based also on the exact capabilities of the hand. In this last step, the type of hand prosthesis plays a major role. Prostheses can be bought from a few commercial companies specialized in this area (such as Otto Bock[4] or Touch Bionics[5]) or they can also be created by research groups as research prototypes. Many hand prosthesis descriptions are available and can be used free of charge, now often with 3D models to print the pieces directly. Such 3D models have been developed extensively, as researchers can often not afford the high prices of commercial prostheses. The components of many prostheses can be printed by 3D-printers and this procedure only requires cabling and mechanical assembling in a next step. Professional prostheses have prices ranging from $25,000 up to $75,000 but with the models being published free of charge and 3D-printing with reduced prices some prostheses can be built for as little as $500[6].

The price of commercial devices is a major challenge for amputees for several reasons. First of all, the cost of a prosthesis is not always covered by insurance companies making the prostheses unaffordable for many amputees. Second, many amputees live in countries suffering from war or civil war and therefore poverty. Finally, caused by war or by other events, there are many children who lost a limb. Since children are still growing, the prosthesis needs to be changed nearly every year making it financially even more difficult[6].

1.2. Objectives

With the current hardware and software tools at our disposition, researchers have an easier task to enhance the amputee's life by crafting a self-made prosthesis. The main objective of this text is to create an inventory of the existing and available prostheses and techniques or tools that can be reused by researchers. An indirect aim is also to make the subject more popular in order to allow individuals, NGOs (Non-Governmental Organizations), or humanitarian projects to help those who suffer from an upper limb amputation[6].
The methodology used is described, a scientific background of the technologies behind prostheses is presented. The different parts constituting the prostheses are presented with their particularities and prices as well as what is currently available or still a research prototype. The final goal is to have an overview of the components to understand the main concepts concerning this field and to help being able to assemble a prosthetic hand with affordable materials.

1.3. Background

1.3.1. Data measurement using electrodes

The document focuses on EMG-powered prostheses even though various other models exist, such as body-powered prostheses or purely cosmetic prostheses without any advanced control.

General aspect:

To actuate a muscle a synaptic input from motor neurons is required. A signal will flow through the nerves to multiple muscle fibers causing them to contract at the same time. The action potential occurring when the membrane potential of a specific cell location rapidly rises and falls can be measured. The muscles situated inside the arm generate an electrical impulse. Electrodes are capable of detecting this electric impulse which is a mix of signals of what happens inside the muscles. The fat tissue insulates so it may possibly reduce the quality of the signal. The data are then transmitted for an analysis. The objective here is focused on the electric muscle activity and not directly the nerve activity that is much lower in value[7].

Many of the muscles needed for the motions of the hand are present in the forearm, hence many movements can theoretically be reproduced using electromyography on the forearm with the residual muscles. The thumb movements are possible but more complicated, as the muscles are not present in amputees. The more residual muscles are missing the weaker are the muscles signals thus they are harder to detect[8].

It is the first step in the prosthesis activation and has a crucial role because it represents the person's will to move its hand and execute a specific movement. Different electrodes are currently available on the market, but some companies do not give prices for them unless concretely making an order such as the bebionic from Ottobock US[9]. Brains Robotics are planning to sell a prosthetic hand for around $3k-5k to compete against similar devices that can cost between $40'000 and $60'000[10,11]. The main challenge is the price of the electrodes. For creating an affordable prosthesis, it is important to find cheap control devices that are still precise. Electrodes on the market and in development will be reviewed to give an overview of the available ones[8].

Electroencephalography:

Electroencephalography is a field which concerns the recording and analysis of the electroencephalogram (EEG). The EEG is a technology which records electric signals generated by the brain cells during cooperating actions. To be precise, it records the time of extracellular field potentials. To measure these signals electrodes are placed on the scalp or directly on the cortex.
Different rhythms can be distinguished in the signals such as the delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (above 30 Hz). According to the rhythms obtained an analysis can be done to guess the movement induced[7].
The method is typically noninvasive, although invasive electrodes are sometimes used such as in intracranial EEG[12–14].

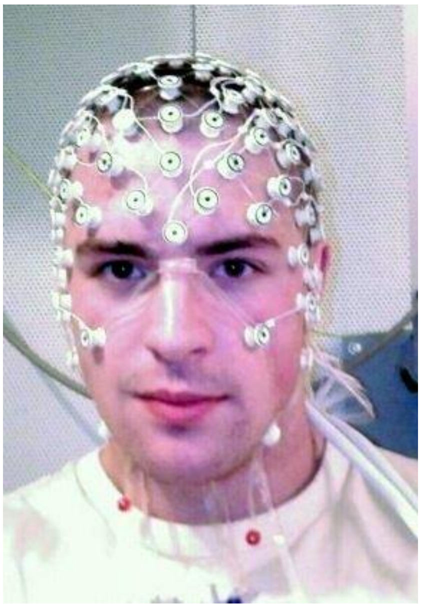

Figure 2. An EEG recording setup[15].

The EEG result is a graph representing the activity of the neurons within the brain, it is often used in the medical field to diagnose epilepsy which causes abnormalities in EEG readings. It can also be utilized to diagnose sleep disorder, depth of anesthesia, coma, encephalopathies, and brain death[12–14].

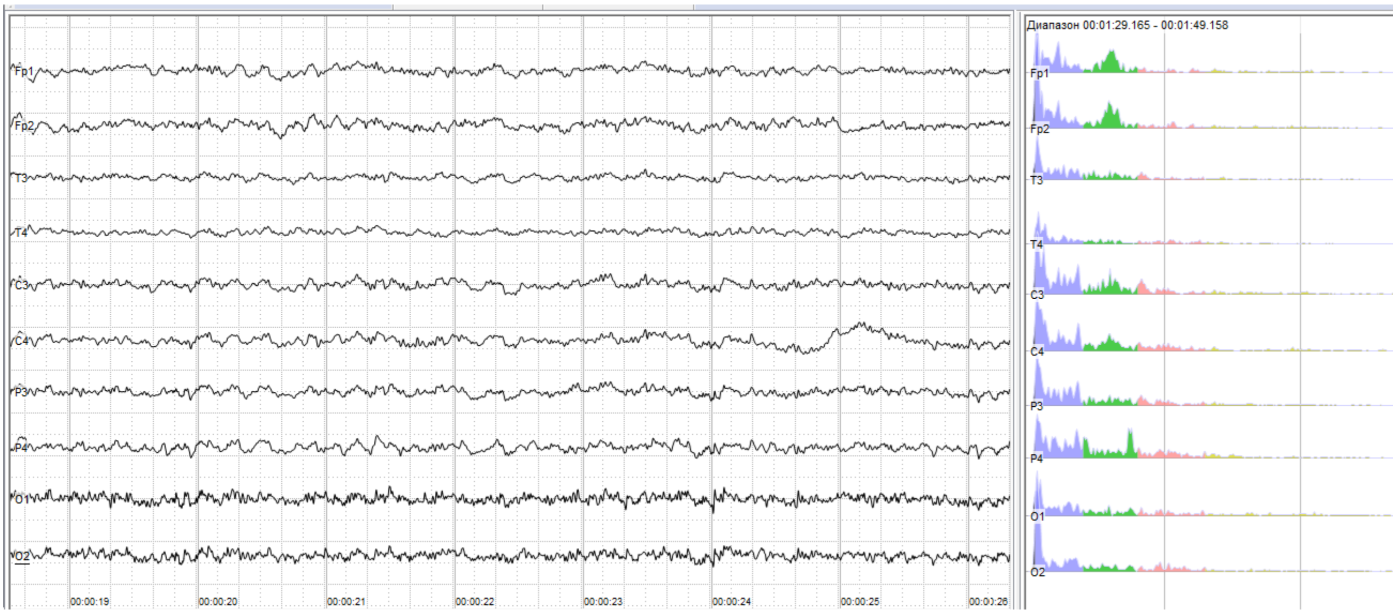

Figure 3. EEG of a human at rest[16].

Electromyography (EMG):

Electromyography is a technology recording and evaluating the electric activity produced by skeletal muscles. The EMG is performed using an electromyograph that produces an electromyogram. The device detects electrical potential of the muscle cells usually on the skin of the persons, when muscles are actuated in an electrical or neurological way. The signals can then be analyzed. EMG is often used for gesture recognition and in the prosthetics domain recognizing the movement induced allows to transmit the information to the prosthetic hand to execute it. Electromyography can be performed with electrodes directly on the skin, called surface electromyography (*sEMG*). It can also be executed by directly implanting electrodes on the muscles, so invasively. This method is invasive and can provoke a rejection or lead to infections[6,17–20].

Figure 4. Myo bracelet on a stump[21,22].

Figure 5. sEMG electrodes placed on a stump[21,22].

The signal recorded from the surface electromyography must then be transferred to a device in order to treat the signals and extract meaningful actions. With the current technologies Bluetooth and WiFi can be used with a mobile processing device (e.g. a smartphone), for example. In order to improve battery durability, low power standard can be used such as Bluetooth Low Energy (BLE) and Low Power Wifi (LpWiFi)[23].

Shoulder controller and mechanical hand:

The control of upper limb prostheses using shoulder movements was used for a long time [24,25,6]. It was used by amputees after conflicts such as the civil war in the USA and had a very rudimentary way of working. The prosthesis was linked with the shoulder by cables and the user had to use the chin or its sane hand to adjust the prosthetic hand with it. The method was improved over the years and now shoulder controllers possess sensors that can react to shoulder movement and forces. The person can then use the shoulder movement and strength to induce hand motion[24,25,6].

Figure 6. An example of a cosmetic prosthetic hand[26].

Data acquisition protocol:

The data acquisition protocol is an important key to the comprehension of data measurement for research. The data differs according to many criteria. First, intact subjects or trans-radial amputated are separated. Gender, age, height, weight, laterality all have an impact as well[23,25]. For the amputees the date, type and reason of the amputation, remaining forearm percentage, information about the use of the prosthetic hand, type and degree of phantom limb sensation and the DASH (Disability of the Arm, Shoulder and Hand) score are taken into consideration.
The signal passes through several processing steps before being classified. The data undergo synchronization, relabeling, and filtering. They are then available on repositories for later use such as research on movement classification[17].

1.3.2. Data analysis

General aspects:

To perform the correct movement the input data must be analyzed precisely in order to induce the appropriate motion. Therefore, the data analysis using a specific software plays a major role. Different algorithms are required to process the data and give a result allowing movements. They also must be trained with a database to get improved.

To resume the main parts of this aspect, there is a first step where the software extracts the features, meaning various characteristics coming from the sEMG that allow for movement classification, so that are discriminative. The patients need a certain amount of training to correctly move the prosthesis because they must be able to provide constant and coherent signals for the specific movement targeted[17,27]. Depending on the amount of machine learning used, this training can be more or less hard for the patients.

1.3.3. Data and tools available for research

It is important to train algorithms that recognize the movements because the range of the electrical signals may vary. Therefore, training allows a good classification and a better control over the prosthesis. The datasets of sEMG recordings are distributed with details of their acquisition setup because each criterion has an impact on the electrical signals. Therefore, they contain a detailed procedure and specifications about the subjects and the way the data were acquire[28].

1.3.4. Prostheses

Models for printing prostheses in 3D

The models of several prosthetic hands can be obtained on the Internet. Not every pattern is free of charge. In addition, the 3D printing allows modifications and adjustments of these patterns so they can be reworked according specific requirements. They are accessible on several websites[29,30]:

- MakerBot’s Thingiverse is a community oriented on the design in order to discover, create and share 3D printable things. This open platform allows anyone to use and/or alter any design. Many different templates are available and the creators are often attentive to any question[30].
- Instructables is a community sharing designs in various domains such as wood craft or 3D printed prosthetic hands. Different designs are available, and the assembly route is often very detailed even with some explanations about the software to analyze the data and how to measure them[29].

Components of prosthetic hands

General aspects:

Current upper limb hand prostheses are produced in a wide panel of materials and conceptions. They have very different prices. The externally powered prosthetic hand can cost from $25,000 up to $75,000 but the recent large-scale availability of 3D-printing allows to decrease prices.
3D printing enables to make the product in one part, meaning no assembly is necessary. Complex geometries can be created and the designs are modifiable at ease allowing a cheap and rapid pathway from the idea to the conception. There are a few disadvantages such as the maximum size that is possible with standard printers and the accuracy that is affected by the parameters. Basic and important characteristics for the materials are lightness, strength, and cost. The materials must then pass a stress analysis. For example, out of the three materials Plexiglas, Nylon 6, and Nylon 66 the Nylon 6 proved to be the most suitable by its different characteristics and capacity to resist to the stress analysis. Therefore not every material can be used such as Plexiglas and Nylon 66[31].
Prostheses can be crafted using the 3D-printing with low prices as low as $500[6].

Weight:

The weight of a prosthetic hand can vary strongly. It obviously depends on the part it is replacing, if it is a full arm it will be heavier than only a hand prosthesis. Each prosthesis has its own weight according to the materials used. The weight varies from 132g up to 960g[6], there are nevertheless lighter and heavier devices. The DLR German Space Agency[32] researched hands with applications in prosthetics which weighed up to 2.2 kg[32–34].The lightest one was developed by M. Groenewegen and the heaviest is the Roboarm from Unlimited Tomorrow weighting 2 kg. The weight is actually an important parameter since the prosthesis is attached to a socket linked to the stump.

3D printing:

There are various 3D printing techniques that can also be used for the prostheses. The hands can be crafted by using powder or liquid and UV laser or UV light. There are a few techniques possible such as selective laser sintering (SLS) technology, selective stereolithography apparatus (SLA) technology, and polyjet printing. Fused deposition modelling (FDM) technology can also be used, it uses a continuous filament to print the pieces for the prosthetic hand[6].

Material:

The components themselves vary accordingly to the techniques. FDM, which is the most common one, can use acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). There are also different materials available such as nylon or polystyrene, it depends on the techniques used. The motors, if used, also has a broad price range. They allow a correct motion of the hand; some hands may have a motor per finger for good accuracy and control[6].

Price:

As explained before, the prices for prosthetic hands vary in a large range. Some prostheses state the low price of $5 referring to the cost of the material used by the 3D printer, but to create the entire hand with the motors and cables the price raises up to $500. Some companies work on prostheses which can be sold for $1000. For example, the You Bionic and Open Bionics are working on a prosthesis which could be sold for $3000[6].

Mechanics

General aspects:

There are 3 types of prostheses. Prostheses of the hand that suits for a partial hand amputation. The prostheses including the forearm are used for an amputation below the elbow. Third, an upper arm prosthesis corresponds to people amputated above the elbow.
The prostheses can be activated by several methods. There are usually two types, passive prostheses that require an external force to adjust the grasp, for example using the non-amputated hand, and active ones. Active prostheses mechanisms can be triggered by the body, so are called body powered, or by an external source of energy. The externally powered prostheses are commonly electrically powered but they can be powered by pressurized air as well[6,24,25].

Control system:

To control the prostheses many tools are available. It can be by using the thumb, the wrist, the elbow, a should harness, the voice, the electroencephalography (EEG), or the electromyography (EMG)[6].

Force distribution:

When grasping an object, the force can get distributed in three different ways. First, the force can be equally distributed over the fingers. Second, it can be distributed along the fingers by a mechanical linkage system allowing an adaptive grasp and the possibility to keep applying a force with the free fingers while some are blocked by an object. Finally, the force can be independent on each finger if these ones have a motor. It allows an adaptive grasp and a larger panel of grasp types[6,35,36].

Flexors and extensors:

To grasp object the prosthesis needs to move the fingers using flexors and extensors. The flexor allows to close the hand. Many use voluntary closing devices, meaning the natural position is open, when no force is present. When activated, the hand closes. Cables or non-elastic bands are used to close the hand. Flexion of the wrist or elbow induce a closing grasp assured by the cables or cords attached to the end of the fingers. Mechanical solutions without cables nor cords are also used. The mechanical linkages can be controlled by motors or even compressed air.
To extend the hand the prostheses usually use elasticity which open the hand automatically. Elastic cords, bands, and elasticity of the finger joints assure this role. Compliant mechanisms are elastic finger joints. The prostheses using these compliant mechanisms have fingers made from one piece with rigid phalanges and flexible joints. Some prostheses have cables, cords, or mechanical linkages which are attached to motors[6].

Kinematic aspect:

The prosthetic hands can perform different movements and grasps depending on their build. The number of joints, the degrees of freedom, the number of actuators, the joints motion range and grasp types all have an impact on the kinematic specifications of the prosthesis[6,35,36].

Most of the prosthetic hands have more degrees of freedom than actuators due to the link between the phalanges in the fingers. There are usually 3 phalanges connected via cables, cords or any other as explained before. The cable from each finger is then attached to a shared linkage assuring the fingers move at the same time. The externally powered prostheses have motors connected to each fingers allowing a separate control of each one[6,35,36].

Each human finger has four joints as shown in the figure 1. the distal interphalangeal joint (DIP), the proximal interphalangeal joint (PIP), the metacarpophalangeal joint (MCP), and the carpometacarpal joint (CMC). The thumb itself has only 3 joints, the DIP is replaced by the interphalangeal joint (IP). The prosthetic hands do not have the CMC joint[6,35,36].

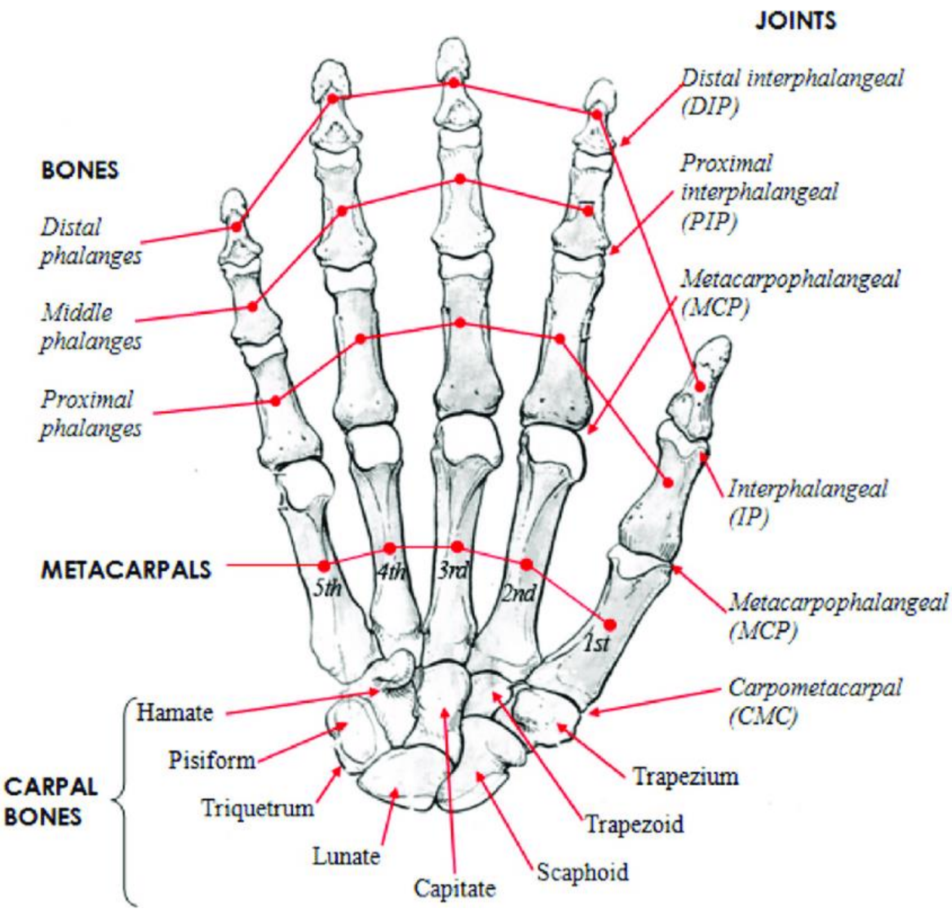

Figure 7. Human hand with the its joints named[37]. (Figure taken from[37]).

Daily life grasps:

The prostheses must have different types of grasp to assure daily life basic functions. They also need to perform an adaptive grasp to adapt to the shape of the objects they are holding. There can be a force distribution between the fingers to assure some fingers can apply force while some others are blocked. The prostheses which have motors on each finger can control them separately. An air pressure actuated hand can perform the grip by controlling the pressure in the fingers using valves. Some have a smart mechanism which distributes the force[6,35,36].

Taxonomy of hand movements:

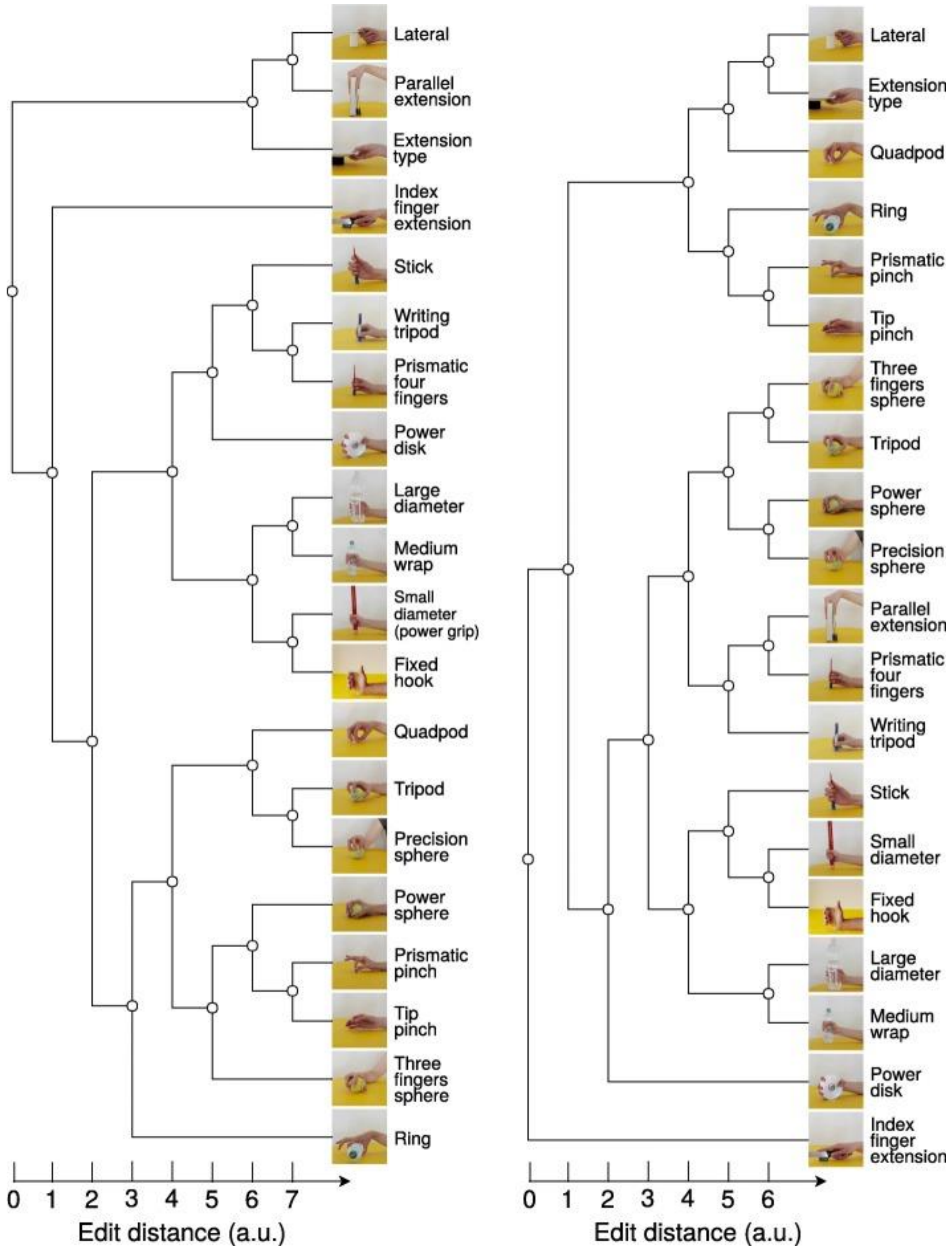

Figure 8. Muscular and kinematic taxonomies of hand grasps[38].

This is a hierarchical organization of hand movements. This picture allows to have an overall comprehension of the different motions doable and that can be tried to be done using a prosthetic hand.

2. Methodology

To start the writing of the article it was necessary to get more information about the parts of the prostheses that were to be included into this text. Manfredo Atzori, senior researcher in HES-SO Valais in Sierre, recommended me an article about 3D-printed upper limb prostheses[6]. It is an article that explains the different parts of the prostheses and makes a review of 58 that which are available or in development[6].
Many details about the prostheses were given. The next step was to get more information about the other components such as the data recording with sEMG electrodes, accelerometers and other sources, the software to analyze the data and the motors to induce the movement. For this article only prostheses working with sEMG will be listed since this is likely the most comfortable and least invasive method to get an input.

Google Scholar was used to search for scientific papers, starting with the data recording. Several papers about sEMG, EEG and shoulder prosthesis were found using this web application. The exact words used for the search were: Electroencephalography, Electromyography, Prosthetic hand[12–14,16–18,23,39,40].
PubMed is a website indexing more than 30 million articles of the biomedical literature and allowing to search in them. It was also used with the same words as before.

Mr. Atzori proposed a few universities and platforms to find information about electrodes. Northwestern University, the University of Alberta, Arduino and a Chinese alternative to the Myo bracelet were the first sources that were checked. I also read articles the team in Sierre published to fully understand the concepts[17,21,22,27,38,41].
The electrodes were often in still under development and since I wanted to present some that can already be purchased, I also looked for commercial ones using the Google search engine.

I then searched for different software tools to analyze the data. In order to do so, Mr. Atzori gave me a few tracks to follow such as BioPatRec, and alternatives in Python that are available on GitHub.

The algorithms of the software must be trained with a database to increase accuracy of the movement recognition.

Looking at the prostheses allows to get information about material and potential web pages to order them. There are also procedures to create them. This part led me to websites that can be used to purchase the parts.

3. Results

3.1. sEMG Electrodes

In this article only sEMG electrodes is presented. Therefore, only different electrodes which can detect muscle electric field will be presented.

The company Advancer Technologies[42] provide sEMG sensors with a reasonable price. The company makes a MyoWare Muscle Sensor which can be used to get the input needed for the prosthesis, the cost of this device is $37.99.

Single channel EMG boards that are already set up allow an easy use with microcontrollers such as Arduino[43]. Several instructions can be find on how to use it[43]. The advantage of these electrodes is that they already possess a processor which can be used.

These different EMG electrodes already contains acceleration captors which are used in addition to the electrical signal of the muscle for a better accuracy and therefore a greater motion triggering.

3.2. Data analysis and Control

To analyze the data obtained from the sEMG a software is needed to extract the features, classify the potential corresponding to the different movements. Here are a few examples.

BioPatRec:

BioPatRec is an online platform which is used widely for testing and development of algorithms that can be applied to control prostheses. The code source has data structures using modules that can be changed. The software is programmed in MATLAB[44].

A startup guide is available which explains the pathway to follow to setup a workplace, to treat the raw signals and extract the signal features, running patter recognition, controlling the virtual reality environment, recording signals.

Beowulf-EMG-Classification:

PyoManager library get used to collect EMG data from the Myo. This software can only be used for gesture recognition, which is then split into the three tasks data collection, training, and prediction. The software was programmed in python[45].

EMG-SVM-Classifier:

This project is an EMG Classifier aiming at the acquisition of EMG signals, processing and classification using a support vector machine to control a virtual prosthetic hand. The software was programmed in python[46].

Machine learning EMG hand movements classification system:

This classifier uses a binary system dividing into two classes the data obtained. The required system states if the patient is doing lateral or palmar motion based on certain features of the EMG. The software was programmed in python[39].

Parallel Window feature extraction PaWFE:

This code available on GitHub allows to work on parallel windows for a fast signal feature extraction. It allows an impressive reduction of the computational time up to 20 times the original one. This MATLAB code is publicly available and supports different time domain and frequency features, nevertheless it requires a strong setup as described on the web page[41,47].

3.3. Data base available

NinaPro and NinaWeb

The NinaWeb is the web interface of NinaPro, of ProHand and of PaWFE. The ProHand is a robotic prosthetic hand controlled with machine learning. The PaWFE is a signal feature extraction using parallel time windows to shorten the computational time. The NinaPro is a free and open multimodal database destined for the research on robotic and prosthetic hands.
The website[48] includes electromyography, kinematic, inertial, eye tracking, visual, clinical and neurological data. Different datasets are described and available to train the software wanted.

A first MeganePro dataset[48] 1 is available, the acquisition protocol consists of static and dynamic movements. The data contain surface Electromyography (sEMG), Accelerometry, Gaze, Video in first person of the scene.

The second MeganePro dataset[49] 2 has a different acquisition protocol, for the amputees it is a motor imagery of the phantom limb and of the intact hand. The data are Surface Electromyography (sEMG), Accelerometry, Gaze, video of scene in the participant's first-person perspective.

The MeganePro dataset[50] 4 has the same data types as the second dataset presented. The acquisition protocol is however different. For amputees there were two tasks demanding motor imagery of the phantom limb and motor execution of the phantom limb requiring movements of the stump. For the first task there was also motor imagery and motor execution of the intact hand.

3.4. Prostheses

Many templates are available for the prosthesis. They can then be constructed using a 3D-printer. The templates are available on websites[29,30].
The different components required are presented. The 3D printing step also describes the material and gives the files for the printing. The websites available to get the parts are also given. The SP Robotic Works company[51] provides pieces and even motors to allow the motion of the prosthetic hand.

Compliant Prosthetic Hand with Sensorimotor Control and Sensory Feedback for Upper Limb Amputees

This prosthetic hand available on Instructables by Kyung Yun is an sEMG controlled hand which can be built under $550. The components can be 3D printed and assembled with a few componenrts that are described.
It can control 5 different grasps, the Pinch, power, three-jaw chuck, key and open. They are all based on EMG pattern recognition. Pressure sensors implanted in the silicone structure of the fingers allow a control of the pressure. Electrotactile stimulation is also implemented, the pressure sensors can deliver a stimulation, which allows the user to get the feeling when they are in contact with an object[52].

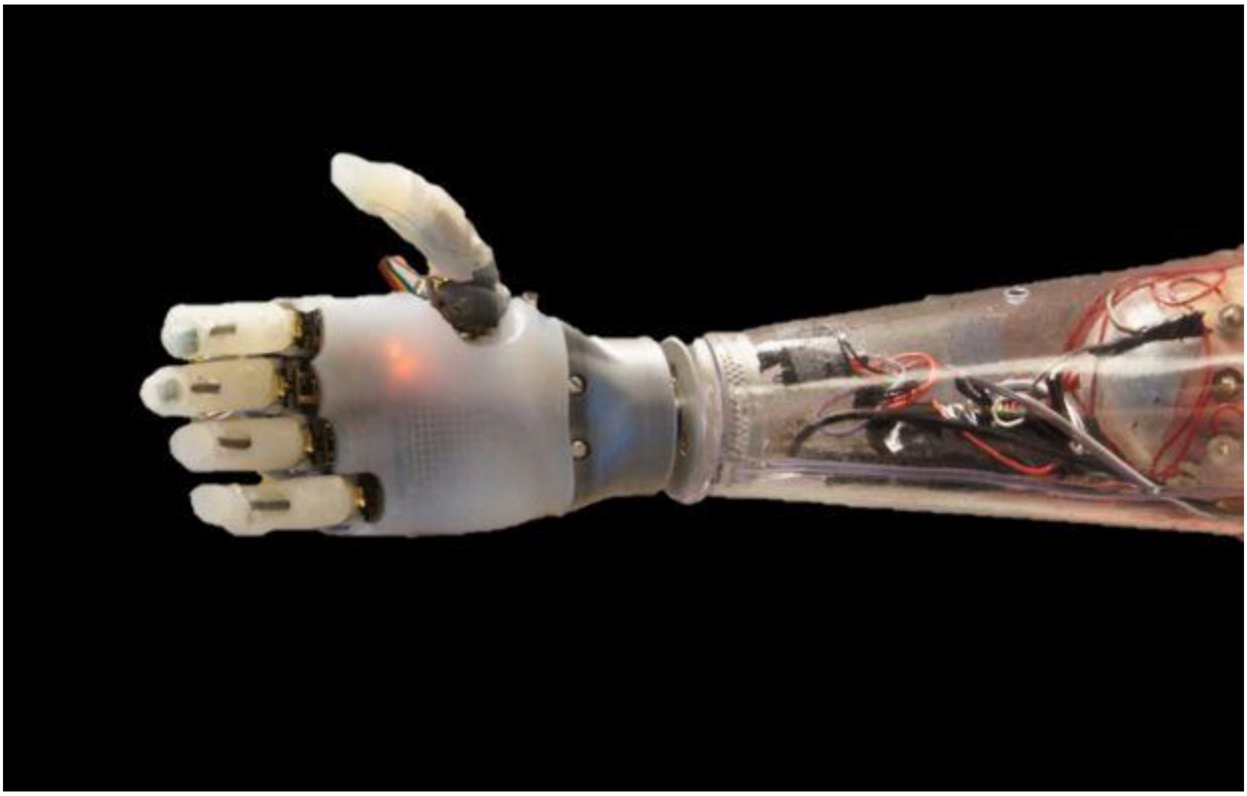

Figure 9. The prosthetic hand (attachable to the elbow/lower arm)[52].

The crafting of this arm is very detailed and can be of course modified according to the person.
The codes for the EMG signals and the control interface on the prosthesis are all available.

Tact: Low-cost, Advanced Prosthetic Hand

This is a low-cost, open source, prosthetic hand available on Instructables by Patrick S. It can be built for $250 including the components for the 3D printing and the myoelectric control. It can perform various grasps such as pinch, three-jaw chuck, power grip[53].
The crafting of this hand is detailed and straight-forward, the myoelectric control is however not explained. Single channel EMG boards that are already set up allow an easy use with microcontrollers such as Arduino[43]. Several instructions can be find on how to use it[54].

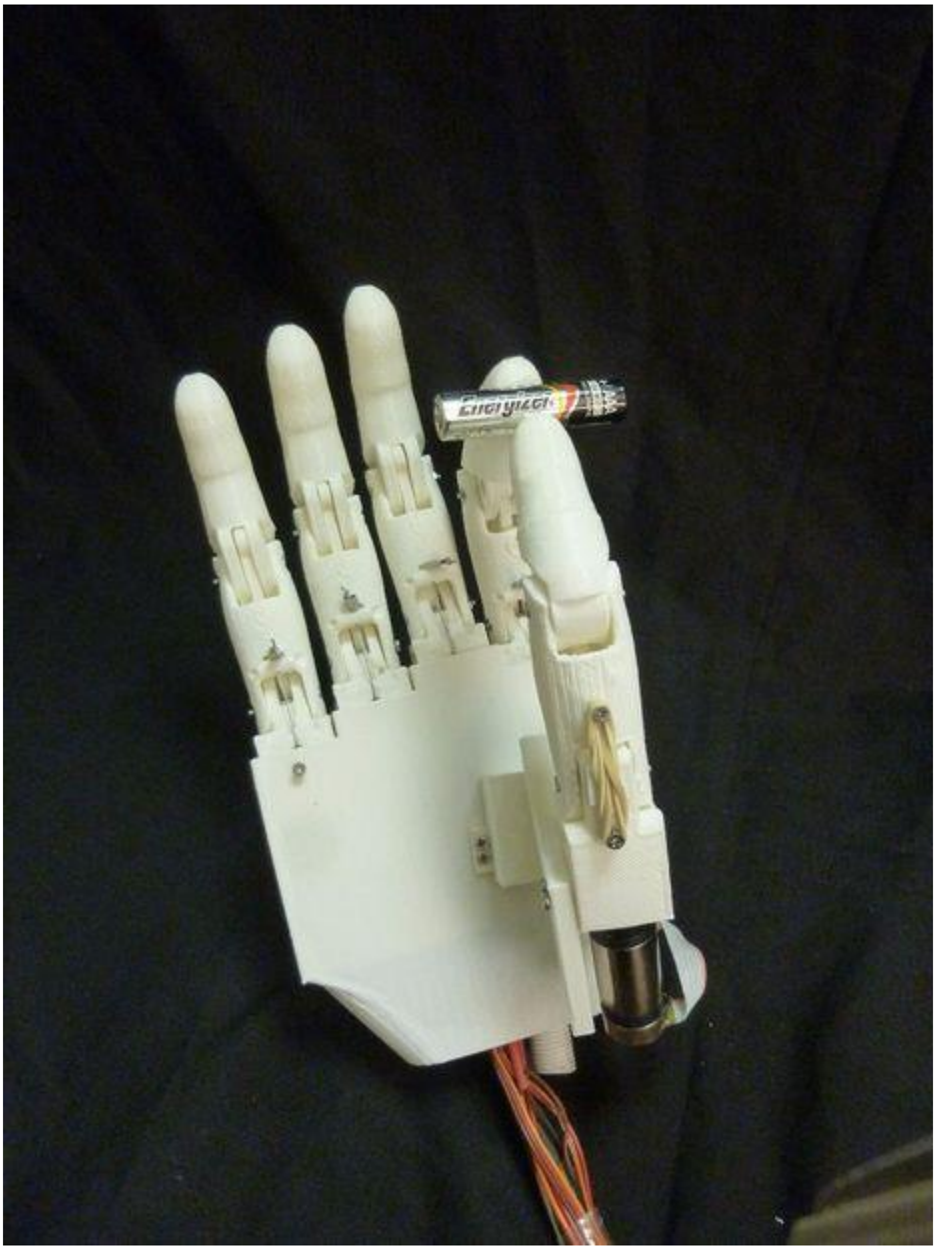

Figure 10. Pinch Grasp of the prosthetic hand[53].

3D Printed Robotic Hand with Bluetooth Control

This prosthetic hand[55] can be fully 3D printed and actuated using 5 servo motors controlling each individual finger. The fingers can be controlled by an Arduino interface such as MyoWare EMG sensors or like in this project using the Bluetooth Low Energy functionality of the Arduino 101.

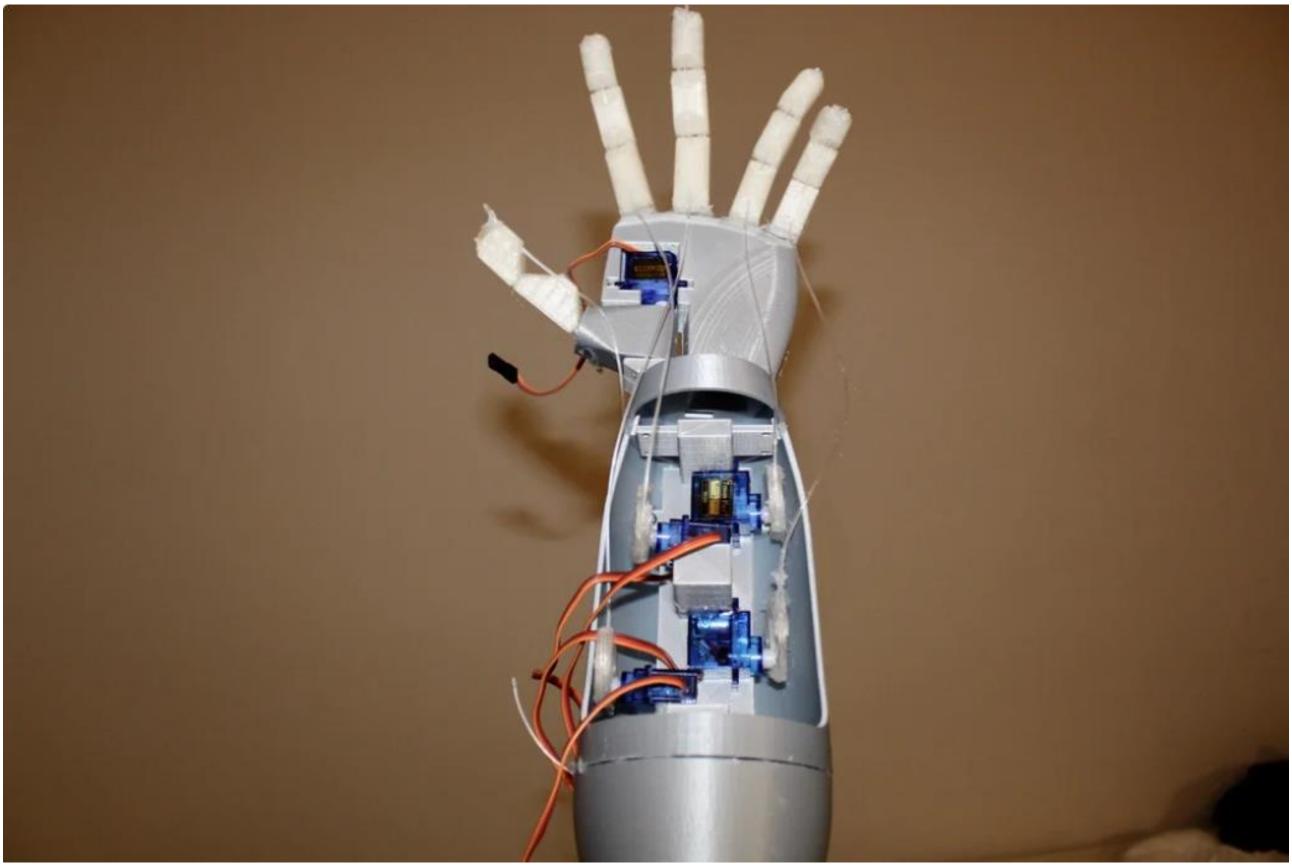

Figure 11. Prosthetic hand with the different wires visible[55].

Once printed the parts must be assembled using glue and the wire replacing the tendons must be added. The crafting is very detailed as well as the programming part.
The Blynk app is available to manage the Bluetooth control over the prosthesis. The app allows a complete customization of the fingers and movements since each finger can be actuated. The part explaining how to create a socket and link it to a patient is however not accurately described.

The Galileo Bionic Hand

This sEMG controlled prosthetic hand[55] can be crafted for the price of about $350 and only weighs 360g. It is a highly functional prosthesis with its electrical design and details about the prosthesis-user interface directly implemented through a hybrid sEMG activated controller. This aspect results in the possibility of complex customized actions in addition to the common types of grasping. This light hand must be attached to a socket for upper limb amputees below the elbow.

Each finger has three phalanges except for the thumb, DC motors drive the tendons and the flexion and extension is performed by a nylon cord and a round elastic cord respectively
The original myoelectric controller has a low cost and high-performance microcontroller unit (MCU), it has signal processing capabilities.

Figure 12. Galileo Hand performing power grasping and peace sign[55].

This prosthetic hand is a light and affordable device that still possesses great grasping abilities, robustness, and durability. It was specifically designed to be repaired easily making it more encouraging for the users to use it more frequently. The minimum flexion and extension time of the fingers are respectively about 800 ms and 600 ms, the abduction and adduction of the thumb is around 150 ms. Each finger can hold loads below 5 kg when the DC motor is not driven and below 3.5 kg when driven. The thumb can achieve up to 6 different movements such as abduction, adduction, extension and flexion[56].

3.5. Overview

To summarize the system, an sEMG-based prosthetic hand requires these elements: *sEMG sensors* capturing the muscle signals, an *sEMG interface* (preferably wearable) that transmits the data to a *processing device* that classifies the data and interprets them into the motion/grasp. It then emits the information toward a *control interface* on the *prosthetic hand* to perform the grasp.
This system has a requirement to work efficiently. First, it must include real-time (response time below 400 ms) and accuracy in the treatment of the input data. Then, the weight and size must be taken into consideration for the comfort of the patient. The communication between the sEMG electrodes, the processing device, and the control interface must be convenient. If a wireless system is used the autonomy of its batterie must be considered[6,27,37,57].

4. Discussion

This paper represents a source for the scientific community, more precisely for the people not familiar with the prosthetic hand domain. There are many articles available on prostheses that are very detailed and therefore hard to digest for a newcomer. The objective here is to simplify the subject, allowing to have a detailed summary about prosthetic hands. Hence, this paper is hopefully interesting for people beginning in this domain who want to get an overview about what exists.
Creating prostheses with affordable materials opens a new world of accessibility for the people who cannot afford the industrial models. This englobes medium and low wage families in less developed countries, NGOs or anyone interested into crafting prosthesis.
I present the mechanisms used in prosthetic hands, the technologies used and how they are put together. I presented different options available on the current market with direct links to websites selling them. Even though many perspectives were given this sole article does not give a total representation and comprehension on how to make one from the start. Some parts such as the data analysis require knowledge in programming.

This paper is about research and not about experiments directly, I could not test each prosthesis with patients. The main goal was to summarize and to show what is available and possible.

5. Conclusions

The various aspects concerning prosthetic hands, the data recording using sEMG, the data analysis using a software and training the algorithm used, and the controlled prosthesis itself were presented. The different electronics parts may vary but I still presented online websites on which sEMG and control interface can be purchased. To create a prosthesis the components must first be 3D printed based on the template chosen. Once assembled the prosthesis must be adapted according to the person's physical parameters and then the parts must be linked. The sEMG records the electrical stimulations of the arm and sends them to a processing device that classifies them and interprets the signals into a specific grasp. The grasp is induced by the control interface on the prosthesis.

Annexes

Review of 58 hand prostheses

The department of BioMechanical Engineering from the Delft University of Technology in the Netherlands made an interesting review[6] of 58 hand prostheses allowing a great overview of the current hand prostheses available and their different features. The review only took prosthetic arms that are affordable with a maximum price of $500.
Several tables with the elements presented before will be shown. The article gives an entire review of the 58 hand prostheses with its different features.

	Type of Prosthesis	Type of Actuation	Type of Control	Weight (g)	Force distribution	Flexor	Extensor
Prostheses found in the scientific literature							
Andrianesis' hand [1], Figure 2(a)	Forearm	EP	EMG	350	Independent	Cables/cords	ML
Bahari's hand [2]	Forearm	EP	EMG	–	Independent	ML	Cables/cords
Gosselin's hand [3], Figure 2(b)	Forearm	BP	SH	–	Distributed	Cables/cords	Cables/cords
Gretsch' HAND [4]	Forearm	EP	EMG	240	Independent	Cables/cords	Elastic cords
Groenewegen's hand [5]	Forearm	BP	–	71	Distributed	ML	CM
O'Neill's HAND [6]	Forearm	EX	EMG	960	Independent	Cables/cords	Cables/cords
Simone's hand [7]	Forearm	EP	EMG	–	Independent	Cables/cords	Cables/cords
Prostheses found by performing an internet search							
3D-printed prosthesis ecuador [16]	Forearm	EP	EMG	–	Independent	Cables/cords	Cables/cords
Adjustable thumb [17]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Biohand [18]	Forearm	EP	EMG	–	Independent	ML	ML
Bionico hand [19]	Forearm	EP	EMG	–	Independent	Cables/cords	Cables/cords
Cyborg arm [20]	Forearm	BP	Elbow	–	Equal	Cables/cords	Elastic cords
Cyborg beast [21], Figure 2(c)	Hand	BP	Wrist	1.315	Equal	Cables/cords	Elastic cords
Cyborg beast with I.W.M. [22]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Dextrus EMG [23]	Forearm	EP	EMG	450	Independent	Cables/cords	Cables/cords
DIY prosthetic hand & forearm [24]	Forearm	EP	Voice	–	Independent	Cables/cords	Cables/cords
Falcon hand V1 [25]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic bands
Falcon hand V2 [26]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic bands
Flexy arm [27]	Forearm	BP	Elbow	–	Equal	Cables/cords	CM
Flexy hand [28]	Forearm	BP	–	–	Equal	Cables/cords	CM
Flexy hand 2 [29]	Hand	BP	Wrist	–	Equal	Cables/cords	CM
Flexy hand – filaflex remix [30]	Forearm	BP	–	–	Equal	Cables/cords	CM
Galileo hand [31]	Forearm	BP	SH	–	Equal	Cables/cords	Elastic cords
HACKberry [32]	Forearm	EP	EMG	–	Independent	ML	ML
Handiii [33]	Forearm	EP	EMG	–	Independent	ML	ML
Handiii COYOTE [34] Figure 2(d)	Forearm	EP	EMG	750	Independent	ML	ML
Hollies hand [35]	Hand	BP	Wrist	–	Equal	Cables/cords	CM
InMoov 2 hand [36]	Forearm	EP	EMG	450	Independent	ML	ML
IVIANA 2.0 [37] Figure 2(e)	Forearm	PS	N/A	–	N/A	N/A	N/A
JD-1 [38]	Forearm	BP	–	–	Distributed	Cables/cords	CM
K-1 [39]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Latest bionic arm [40]	Forearm	EP	EMG	250	Independent	Cables/cords	CM
Limbitless Arm [41]	Upper arm	EP	EMG	–	Equal	Cables/cords	CM
Manu print (Re hand) [42]	Forearm	BP	–	–	Distributed	Cables/cords	Elastic cords
Mind controlled robotic hand [43]	Upper arm	EP	EEG	–	Independent	Cables/cords	Cables/cords
Muscle robot hand [44]	Forearm	EP	EMG	–	Independent	Compressed air	CM
Not impossible [45]	Forearm	BP	Elbow	–	Equal	Cables/cords	Elastic cords
Nu hand [46]	Forearm	EP	EMG	–	Independent	Cables/cords	Elastic cords
Odysseus hand [47]	Hand	BP	Wrist	–	–	Cables/cords	Elastic cords
One-hinged Cyborg beast [48]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Prosthetic/robotic hand [49]	Forearm	BP	–	–	Equal	Cables/cords	Elastic bands
Prótesis Cosmética [50]	Forearm	PS	N/A	–	N/A	N/A	N/A
Raptor hand [51]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Raptor reloaded [52]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
RIT arm [53]	Forearm	BP	Elbow	–	Equal	Cables/cords	Elastic cords
Roboarm [54]	Upper arm	EP	EEG	2000	Independent	Cables/cords	Cables/cords
Robohand [55]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Robot hand [56]	Forearm	EP	EMG	–	Equal	Cables/cords	CM
Scand [57] Figure 2(f)	Forearm	PA	N/A	–	N/A	N/A	N/A
Snap-together Robohand [58]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Tact [59]	Forearm	EP	EMG	350	Independent	Cables/cords	Elastic bands
Talon flextensor 1.0 [60]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Talon hand 2.0 [61]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords
Tenim hand [62]	Forearm	BP	SH	–	Distributed	Cables/cords	Cables/cords
The lucky paw prosthetic hand [63]	Hand	BP	Finger	–	Equal	Cables/cords	Elastic cords
Victory hand [64]	Forearm	BP	SH	–	Distributed	ML	ML
Youbionic [65]	Forearm	EP	EMG	–	Independent	ML	ML
Zero point frontiers [66]	Hand	BP	Wrist	–	Equal	Cables/cords	Elastic cords

BP: body-powered; EP: externally powered; PS: passive static; PA: passive adjustable; SH: shoulder harness; ML: mechanical linkages; CM: compliant mechanisms.

Table 1. Table presenting an overview of the prosthetic hands with the exact type, the type of actuation, the type of control, the weight, the force distribution, the flexor and the extensors[6].

	Fabrication method	Material	Material cost ($)	Design availability
Prostheses found in scientific literature				
Andrianesis' hand [1], Figure 2(a)	SLS	Duraform HST	–	No
Bahari's hand [2]	SLA	Acrylic plastic	–	No
Gosselin's hand [3], Figure 2(b)	FDM	ABS	–	No
Gretsch' hand [4]	FDM	ABS	300	No
Groenewegen's hand [5]	SLS	Nylon	–	No
O'Neill's hand [6]	FDM	ABS	500	No
Simone's hand [7]	Polyjet	Full Cure 720	–	No
Prostheses found with the internet search				
3D-printed prosthesis ecuador [16]	FDM	–	270	No
Adjustable thumb [17]	FDM	ABS	–	No
Biohand [18]	FDM	–	±300	No
Bionico hand [19]	FDM	ABS	250	Yes
Cyborg arm [20]	FDM	ABS	–	No
Cyborg beast [21], Figure 2(c)	FDM	ABS	50	Yes
Cyborg beast with I.W.M. [22]	FDM	ABS	–	No
Dextrus EMG [23]	FDM	PLA or ABS	±1000	Yes
DIY prosthetic hand & forearm [24]	FDM	–	–	Yes
Falcon hand V1 [25]	FDM	ABS	–	Yes
Falcon hand V2 [26]	FDM	ABS	–	Yes
Flexy arm [27]	FDM	FLA & Filaflex	–	Yes
Flexy hand [28]	FDM	FLA & Filaflex	–	Yes
Flexy hand 2 [29]	FDM	FLA & Filaflex	–	Yes
Flexy hand – Filaflex remix [30]	FDM	Filaflex	–	Yes
GalileoHand [31]	FDM	PLA or ABS	–	Yes
HACKberry [32]	FDM	–	200	Yes
Handiii [33]	Unknown	–	300	No
Handiii COYOTE [34], Figure 2(d)	Unknown	–	300	No
Hollies hand [35]	SLS	Nylon	–	Yes
InMoov 2 hand [36]	FDM	–	–	Yes
IVIANA 2.0 [37], Figure 2(e)	Unknown	–	–	No
JD-1 [38]	FDM	Nylon	–	No
K-1 [39]	FDM	–	–	No
Latest bionic arm [40]	FDM	–	±3000	No
Limbitless arm [41]	FDM	ABS & Ninjaflex	350	Yes
Manu print (Re hand) [42]	FDM	–	20	No
Mind controlled robotic hand [43]	FDM	ABS	500	Yes
Muscle robot hand [44]	FDM	PLA & Silicone	–	Yes
Not impossible [45]	FDM	–	100	No
Nu hand [46]	FDM	–	–	No
Odysseus hand [47]	FDM	ABS	–	Yes
One-hinged Cyborg beast [48]	FDM	ABS	–	Yes
Prosthetic/robotic hand [49]	FDM	PLA	1	Yes
Prótesis Cosmética [50]	Unknown	–	–	No
Raptor hand [51]	FDM	PLA	–	Yes
Raptor reloaded [52]	FDM	PLA	–	Yes
RIT arm [53]	FDM	–	–	Yes
Roboarm [54]	FDM	PLA	350	Yes
Robohand [55]	FDM	ABS	500	Yes
Robot hand [56]	FDM	ABS & flexible plastic	–	Yes
Scand [57], Figure 2(f)	SLS	DM_9795 & DM_9770	–	No
Snap-together Robohand [58]	FDM	PLA	–	Yes
Tact [59]	FDM	–	250	Yes
Talon flextensor 1.0 [60]	FDM	ABS	–	Yes
Talon hand 2.0 [61]	FDM	ABS	–	Yes
Tenim hand [62]	SLS	Nylon with ceramic layer	–	No
The lucky paw prosthetic hand [63]	FDM	–	–	Yes
Victory hand [64]	FDM	–	100	No
Youbionic [65]	SLS	Nylon	±1000	No
Zero point frontiers [66]	FDM	PLA	5	No

Table 2. Table showing the fabrication methods, the material, the cost and the design availability[6].

				Range of motion					Grasp type	
	Joints	DOF	Actuators	MCP joints (°)	PIP joints (°)	DIP joints (°)	Thumb flexion (°)	Thumb circumduction (°)	Adaptive grip	Achievable grasps
Prostheses found in scientific literature										
Andrianesis' hand [1], Figure 2(a)	15	15	9	0-105	0–90	0–25	0–90	0–50	Yes, Me.	Power, precision, lateral + H,T,S
Bahari's hand [2]	14	14	5	0–80	0–100	0–65	0–80	N/A	Yes, El.	Power, hook, spherical
Gosselin's hand [3], Figure 2(b)	15	15	1 (BP)	0–90	0–90	0–90	0–90	0–25	Yes, Me.	Power, precision, lateral
Groenewegen's hand [4]	15	15	1 (BP)	0–90	0–45	0–45	0–90	N/A	Yes, Me.	Power, lateral
Gretsch' hand [5]	10	10	5	0–100	0–90	N/A	0–90	N/A	Yes, El.	Power, hook, lateral
O'Neill's hand [6]	15	15	5	0–90	0–90	0–90	0–45	0–90	Yes, El.	Power, precision, lateral
Simone's hand [7]	15	15	5	0–110	0–90	0–90	0–45	N/A	Yes, El.	Power, precision
Prostheses found with the internet search										
3D-printed prosthesis ecuador [16]	15	15	5	0–90	0–90	0–90	0–90	0–90	Yes, El.	Power, precision, lateral + H,T,S
Adjustable thumb [17]	11	11	1 (BP)	0–45	0–60	N/A	0–60	N/A	No	Power, precision, lateral
Biohand [18]	10	10	5	0–90	0–90	N/A	N/A	0–45	Yes, El.	Power, precision, lateral
Bionico hand [19]	16	16	5	0–75	0–90	0–80	0–90	0–45	Yes, El.	Power, precision, lateral + H,T,S
Cyborg arm [20]	10	10	1 (BP)	0–45	0–60	N/A	0–60	N/A	No	Power, lateral
Cyborg beast [21], Figure 2(c)	10	10	1 (BP)	0–45	0–60	N/A	0–60	N/A	No	Power, lateral
Cyborg beast with I.W.M. [22]	10	10	1 (BP)	0–45	0–60	N/A	0–60	N/A	No	Power, lateral
Dextrus EMG [23]	15	15	5	0–90	0–90	0–90	0–90	0–90	Yes, El.	Power, precision, lateral + H,T,S
DIY prosthetic hand & forearm [24]	16	16	5	0–75	0–90	0–80	0–90	0–45	Yes, El.	Power, precision, lateral + H,T,S
Falcon hand V1 [25]	13	13	1 (BP)	0–90	0–90	0–45	0–90	N/A	No	Power, lateral
Falcon hand V2 [26]	11	11	1 (BP)	0–90	0–90	N/A	0–90	0–90	No	Power, Precision, lateral
Flexy arm [27]	14	14	1 (BP)	0–45	0–80	0–45	0–30	N/A	No	Power, lateral
Flexy hand [28]	14	14	1 (BP)	0–45	0–80	0–45	0–30	N/A	No	Power, precision, hook, lateral
Flexy hand 2 [29]	14	14	1 (BP)	0–45	0–80	0–45	0–30	N/A	No	Power, lateral
Flexy hand – Filaflex remix [30]	15	14	1 (BP)	0–90	0–90	0–45	0–30	N/A	No	Power, lateral
GalileoHand [31]	11	11	1 (BP)	0–90	0–90	N/A	0–90	0–90	No	Power, precision, lateral
HACKberry [32]	10	10	6	0–90	0–90	N/A	N/A	0–90	Yes, El.	Power, precision, lateral
Handiii [33]	15	15	6	0–90	0–90	0–90	0–90	0–90	Yes, El.	Power, precision, lateral + H,T,S
Handiii COYOTE [34], Figure 2d	15	15	6	0–90	0–90	0–90	0–90	0–90	Yes, El.	Power, precision, lateral + H,T,S
Hollies hand [35]	10	10	1 (BP)	0–45	0–20	N/A	0–20	N/A	No	Power, lateral
InMoov 2 hand [36]	15	15	4	0–90	0–90	0–90	0–90	0–45	Yes, El.	Power, precision, lateral
IVIANA 2.0 [37], Figure 2(e)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
JD-1 [38]	14	14	1 (BP)	0–45	0–45	0–45	0–45	N/A	No	Power, lateral
K-1 [39]	14	14	1 (BP)	0–90	0–90	0–45	0–90	N/A	No	Power, lateral
Latest bionic arm [40]	15	15	5	0–90	0–45	0–20	0–90	0–60	Yes, El.	Power, precision, lateral + H,T,S
Prostheses found with the internet search										
Limbitless arm [41]	14	14	1 (BP)	0–45	0–80	0–45	0–30	N/A	No	Power, precision, hook, lateral
Manu print (Re hand) [42]	14	14	1 (BP)	0–90	0–90	0–45	0–45	N/A	Yes, Me.	Power, lateral
Mind controlled robotic hand [43]	16	16	5	0–75	0–90	0–80	0–90	0–45	Yes, El.	Power, precision, lateral + H,T,S
Muscle robot hand [44]	5	>5	1(Air)	0–90	0–90	0–90	0–90	N/A	Yes, Pneumatic	Power, lateral
Not impossible [45]	10	10	1 (BP)	0–90	0–90	N/A	0–60	N/A	No	Power, lateral
Nu hand [46]	19	19	1 (BP)	0–90	0–90	0–90	0–90	0–30	No	Power, precision, lateral + H,T,S
Odysseus hand [47]	6	6	1 (BP)	0–90	0–45	N/A	0–45	N/A	No	Power, lateral
One-hinged Cyborg beast [48]	8	8	1 (BP)	0–45	0–60	N/A	No thumb	No thumb	No	Power
Prosthetic/robotic hand [49]	15	15	1 (BP)	0–90	0–90	0–90	0–90	N/A	No	Power, lateral
Prótesis Cosmética [50]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Raptor hand [51]	10	10	1 (BP)	0–80	0–90	N/A	0–70	N/A	No	Power, lateral
Raptor reloaded [52]	10	10	1 (BP)	0–80	0–90	N/A	0–90	N/A	No	Power, lateral
RIT arm [53]	14	14	1 (BP)	0–90	0–45	N/A	0–30	N/A	No	Power, lateral
Roboarm [54]	14	14	5	0–90	0–90	0–90	0–90	N/A	Yes, El.	Power, precision, lateral + H,T,S
Robohand [55]	10	10	1 (BP)	0–90	0–90	N/A	0–90	N/A	No	Power, lateral
Robot hand [56]	15	15	1 (BP)	0–90	0–90	0–90	0–90	N/A	No	Power, spherical
Scand [57], Figure 2(f)	1	1	1(BP)	N/A	N/A	N/A	0–90	N/A	No	Power, lateral
Snap-together Robohand [58]	10	10	1 (BP)	0–90	0–90	N/A	0–90	N/A	No	Power, lateral

Table 3. Table showing the range of motion, the grasp type with the different specific features such as the number of joints, degrees of freedom, actuators etc[6].

These tables give a nice overall comprehension of the affordable prosthetic hands that are currently in development or available.

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