ROBOTIC ARM TECHNICAL OVERVIEW 2019

TECHNICAL DOCUMENTATION

MULTIPLE AWARD WINNING INNOVATIVE PROJECT

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I - GENERAL OVERLOOK

Abstract

In this work, we set out to create a complete mechanical design of a prosthetic hand using additive manufacturing technology, namely 3D printing through the Thermoplastic Extrusion technique. In addition to possessing gross and fine motor capabilities essential for physical survival, the hand is fundamental to social conventions, enabling greetings, artistic expression, and syntactic communication. For millennia, people have used cutting-edge technology to design smart devices to facilitate the reintegration of hand amputees into society.

Note

The hand is an important part of the human body and it has a wide range of functions. Losing a hand can be very difficult and require psychological support and physical rehabilitation. Most hand amputations occur in older men, most commonly as a result of work-related trauma or other causes. For centuries, people have used technology to create prosthetic hands that function the same as the original hand. Recent advances in prosthetic technology have allowed people to regain some sensorimotor control and even transplant a hand.

Objective

In this project, we undertook a comprehensive mechanical design of a hand-controlled prosthetic using additive manufacturing technology, specifically 3D printing. The goal of this project was to create a prototype that could be used as a basis for a future product, but which also provides a mechanistic investigation into what is possible with alternative design approaches.

II - AWARDS

The robotic arm competed in eleven different competitions, and these were its results ordered according to the grandeur of the competition:

- Diploma of EXCELLENCE - EURO INVENT 2019
- Diploma of EXCELLENCE - EURO INVENT 2020
- Diploma of EXCELLENCE - Technical University of Moldova - INVENTICA 2019
- Diploma of Achievement MEDAL INVENTICA - INVENTICA 2019
- Diploma YOUNG INVENTOR PRIZE - INVENTICA 2020
- Diploma Procopiu (first prize) - The creativity competition in physics and technologies "Ștefan Procopiu" (the county stage)
- Diploma Procopiu (first prize) - The creativity competition in physics and technologies "Ștefan Procopiu" (the national stage)
- First prize - National science and technology competition "ROSEF" 2019
- First prize - The national competition of electronic constructions T.E.A.M. 2019
- First prize - Intercounty electronics and robotics competition ELECTRON XXI 2019
- First prize - The national competition "ÎNVĂȚĂM SĂ INVENTĂM" 2019

III - History of prostheses

Brief history

Prosthetics have a long history, starting with ancient Egyptians who made crude wooden prostheses. Over the years, prosthetic technology has improved a great deal, and today they are much more sophisticated. For example, modern prostheses can be made from different materials, including metal, plastic, and wood, and they can be designed to be as functional or as comfortable as possible. Prosthetic technology has been used mainly to help war casualties, but it has also been used to help people who have lost limbs due to accidents or other causes.

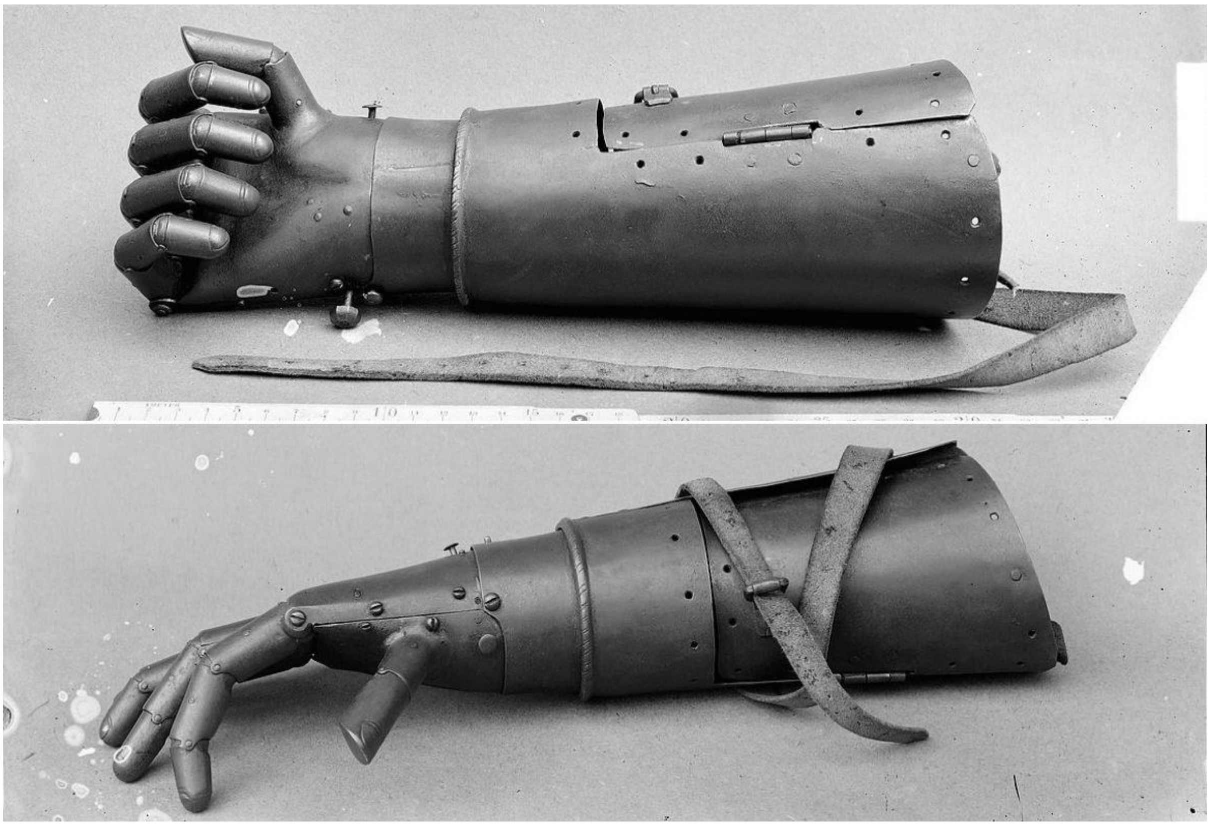
In 1919, a German book entitled "Ersatzglieder und Arbeitshilfen" (Limb Substitutes and Work Aids) proposed concepts for external prostheses using pneumatic and electrical power sources that were too complex to be feasible with contemporary technology. Unfortunately, these revolutionary designs were never realized.

This 1919 German book, Ersatzglieder under Arbeitshilfen (Limb Substitutes and Work Aids), features an early compressed gas prosthetic hand. This type of prosthetic hand was invented in 1919 and used compressed gas to provide power to the fingers. In 1930, an electromagnetic prosthetic hand was developed that used electricity to provide power to the fingers.

After World War II, in order to rebuild the German industry, together with industry giants such as Siemens, prosthetic limbs were developed with a functional purpose. They were called "Workers' arms." The prosthesis helps workers who were missing a limb, to help them at work. It was designed so that certain tools could be attached.

Remarkable models

The iron hand of the German knight Götz von Berlichingen is one of the most famous examples of an early prosthetic hand. Götz lost his hand during the Siege of Landshut in Bavaria in 1505, and an artisan fashioned an iron hand with digits that could be passively flexed and extended at the metaphalangeal, proximal interphalangeal, and distal interphalangeal joints. The device was fashioned as an extension of battle armor rather than a human arm, and due to its weight it had to be attached to Götz's armor with thick leather straps.



Deſcription du Bras de fer.

1 Le bracelet de fer pour la forme du bras. 2 L'arbre mis au dedans du grand reſort pour le tendre. 3 Le grand reſort qui eſt au coulde, lequel doit eſtre d'acier trempé, & de trois pieds de longueur ou plus. 4 Le rocquet. 5 La gaſchette. 6 Le reſort qui poiſe ſur la gaſchette, & arreſte les dents du rocquet. 7 Le clou à vis pour fermer ce reſort. 8 Le tornant de la haulſe de l'auant-bras, qui eſt au deſſus du coulde. 9 La trompe du gantelet faict à tornant auec le canon de l'auant-bras qui eſt à la main: leſquels ſeruent à faire la main prone & ſupine : c'eſt à ſçauoir prone vers la terre, & ſupine vers le Ciel.

Italian historian and doctor Paolo Giovio found that the Turkish pirate Horuk Barbarossa lost his right hand at the Battle of Bugia (circa 1517), and he was given an iron replacement that allowed him to continue fighting. Another example of an iron hand was the one created by a Dutch craftsman for Duke Christian of Brunswick, who lost his left hand at the Battle of Fleury (circa 1622). One of the first descriptions of a noncombinative prosthetic hand was in 1600 by the Italian surgeon Giovanni Tommaso Minadoi, who described an amputee who could remove his hat, untie a bag, and even write with a quill. In the 16th century, French military surgeon Ambroise Paré drew the first detailed design of a spring-loaded prosthetic hand, nicknamed "Le Petit Lorrain" after the craftsman who modeled it. Paré also drew a prosthetic arm for an above-elbow amputation.

IV - Current solutions

Types of prostheses

The history of prosthetic devices is still in its early stages, but has been modernized in recent decades thanks to new technologies. There are two main types of prosthetic devices: mechanical and myoelectrical.

No Prosthesis

Some people choose not to wear a prosthesis. However, before the user makes a decision, it's important to consult with an upper limb prosthetist to be sure the risks are understood. Overusage of the sound side of the user's body to compensate for a lost limb, may lead to experiencing problems with body symmetry, alignment and posture.

Passive Prosthesis

Passive prostheses are devices that look like natural arms and hands. They are lightweight and can help people with disabilities to improve their function by providing a surface for stabilizing or carrying objects. Passive prostheses may be covered with high-definition silicone that closely resembles the person’s sound arm, hand and fingers, or a more basic production glove. Multi-positional joints are sometimes combined with a passive prosthesis to provide the option of being able to position the shoulder, elbow, wrist or finger joints to improve a person’s function. For example, using the sound hand, a multi-positional shoulder, elbow or wrist joint can be positioned at a specific angle, making it easier to hold or carry something. Multi-positional finger joints can be moved into position to allow a high-definition restoration to grasp small objects.

Body-Powered Prosthesis

Body-powered prostheses work with a system of cables and harnesses. This system captures movements from the user's remaining upper body, which is then used to control the prosthesis. As the user becomes more accustomed to the feeling of varying tension on the cable, they may be able to improve their sense of the position of the limb and the degree of opening on the terminal device. Manual labor users may prefer body-powered prostheses because they are durable and work basic functions.

Electrically Powered (Myoelectric) Prosthesis

An electrically powered prosthesis includes motors and batteries that provide movement and power to the prosthesis. Sensors or inputs that detect movement of muscles in the residual limb or upper body send signals to the motors in the prosthesis, telling them what movements to make. Many electrically powered prostheses have the option of being covered with a cosmetic glove. A cosmetic glove is available in a wide range of flesh tones and can even be customized to match the remaining hand as closely as possible. Myoelectric prostheses are controlled by the voltage generated by a biochemical process in the human body. This voltage is measured at the level of the skin surface, and it creates electrical tension with each contraction of the muscle. This tension can be used to control the myoelectric prosthesis. Weak myoelectric impulses are amplified and transmitted electrically to the prosthesis as control signals.

Hybrid Prosthesis

Hybrid prostheses have both body-powered and electric components. This combination can provide a better overall function for people who have lost a lot of their mobility. For example, a hybrid prosthetic might have a larger area of functionality than either type of prosthetic alone. This could make it more useful in activities like work or normal life.

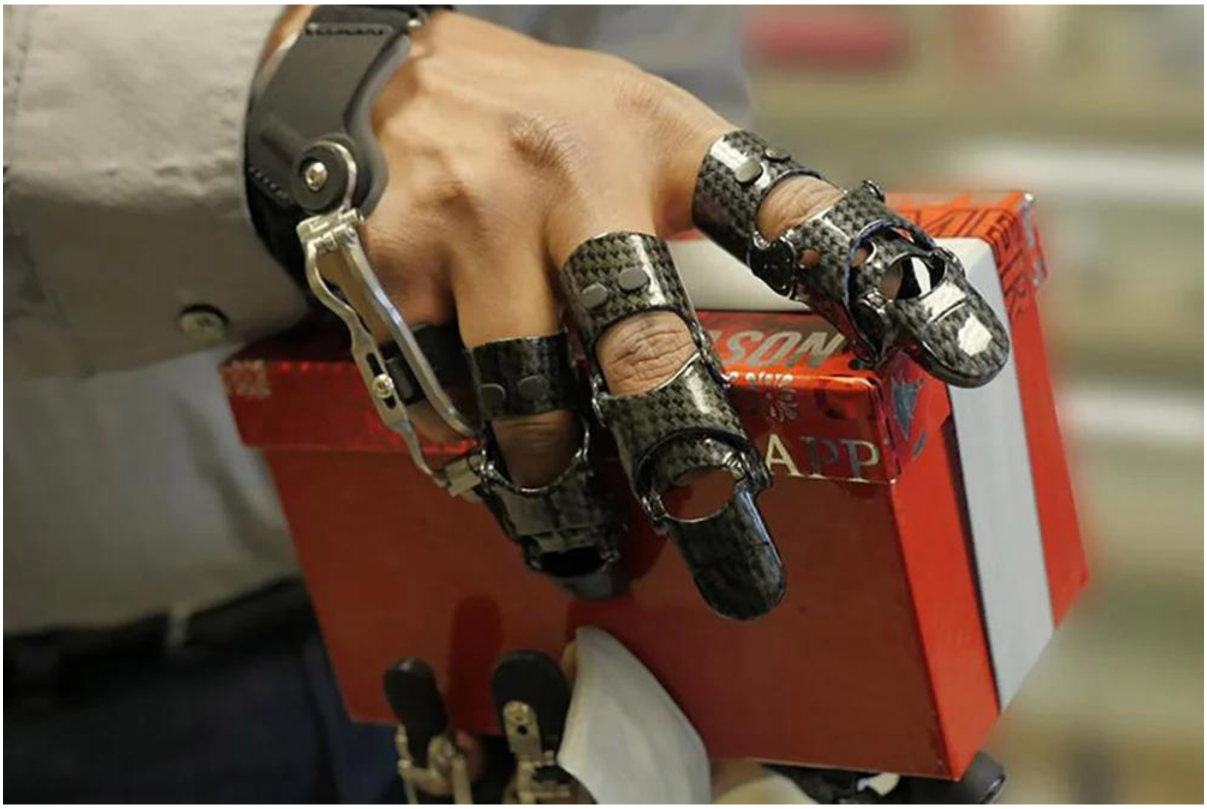
Activity-Specific Prosthesis

Activity-specific prosthetic devices are specifically designed to help people who have lost a limb do the same activities that they were able to do before. We make these devices specifically for people who have different types of upper limb differences, so they can continue to participate in activities they love.

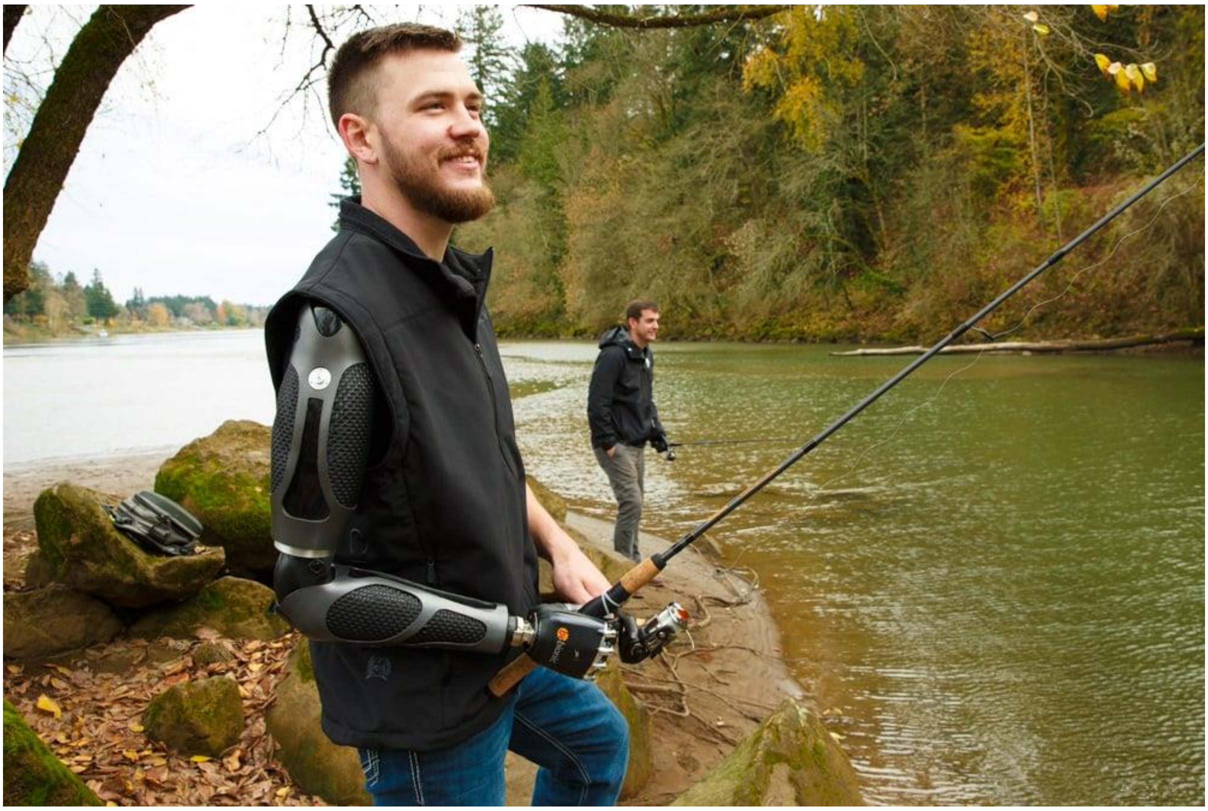
On the following pages there are pictures showing the different types of prostheses mentioned above.

NO PROSTHESIS

PASSIVE PROSTHESIS



BODY-POWERED PROSTHESIS



ELECTRICALLY POWERED (MYOELECTRIC) PROSTHESIS

HYBRID PROSTHESIS

ACTIVITY-SPECIFIC PROSTHESIS

V - Design process

Electronics used

The parts used in this project were chosen based on their compatibility with other parts, ease of programming, and compactness.

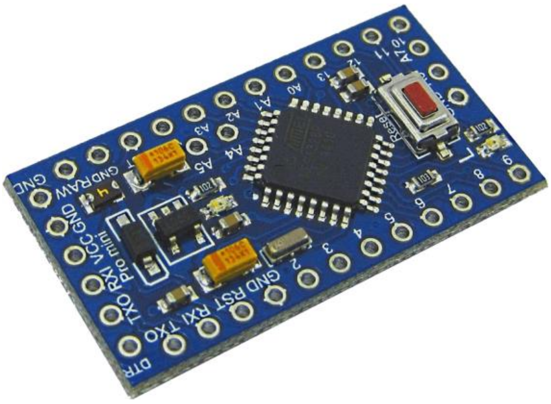
This project was built on the Arduino platform, using the Pro Mini model. This board is small and available in 3.3V and 5V versions, powered by the ATmega328P.

The motors were chosen based on their power development per occupied volume and the MG996R servomotors were an obvious choice. MG996R is an upgraded version of MG995 servo, and its PCB and IC control system makes it far more accurate. Its internal gearing and motor have also been upgraded to improve dead bandwidth and centering. It is generally a great choice for RC airplanes, helicopters, cars, and many more applications.

The prosthetic arm also has a SG90 servomotor used directly for the thumb movement. Being tiny, lightweight, and with a sufficiently high output power, it was an easy choice for the sensor.

EMG MyoWare is the sensor of choice for measuring muscle contraction signals and bringing it to an usable digital reading. Other passive components were used for the power supply part of the circuit.

On the following page are pictures of the components used.



ARDUINO PRO MINI

MG996R

SG90

EMG MyoWare

Programming

The main logic of the program is based on how the sensors react when the user tenses the forearm muscle. When the muscle is in a medium level of tension, the sensors provide a value that's greater than 100mV, but not greater than 200mV. This tells the program to run. When the muscle is relaxed, the sensors read lower than 70mV. This signals the program to make a change.

A servo library helps to program and control the robotic arm. In the source code can be found many functions that are specific to the Arduino board, which help with the limited amount of memory available. A good understanding of the C++ programming language is needed in order to make sure the program runs quickly on the microcontroller.

Main specifications of the microcontroller can be summed up by the clock frequency (16Mhz), storage (32KB ROM and 2KB RAM) and architecture (8-Bit AVR). More detailed information can be found in the datasheet of the chip (ATMega328P).

3D Design

Three-dimensional (3D) printing is an additive manufacturing process that creates a physical object from a digital design. The process works by laying down thin layers of material in the form of liquid or powdered plastic, metal or cement, and then fusing the layers together. 3D printing is a very fast and easy way to get prototypes from a digital format in physical form. The main advantages are as following:

- Cost effectiveness
- Flexibility and speed
- Reliability

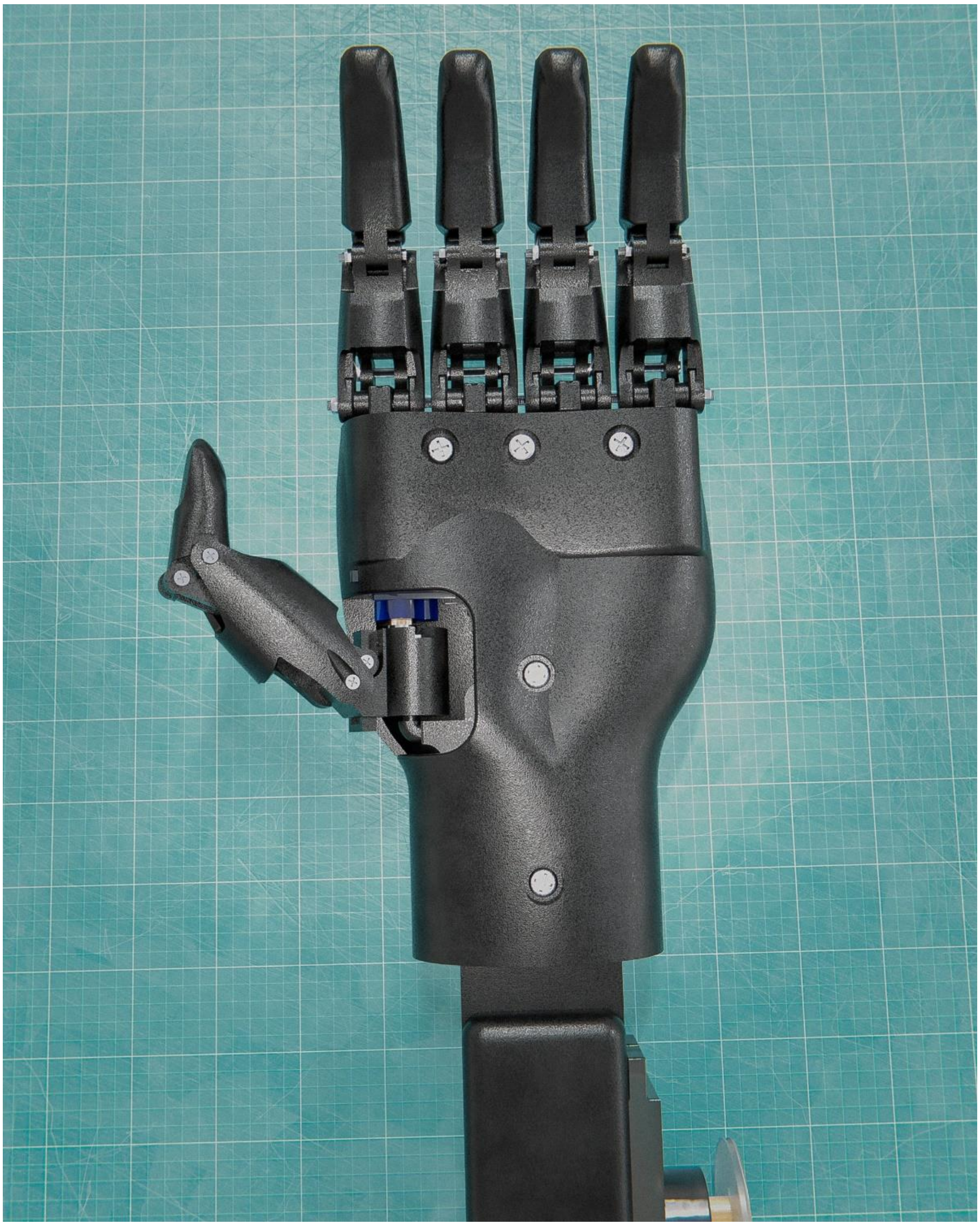
As a single-step manufacturing process, 3D printing saves time and costs associated with using different machines for manufacturing as it uses only the amount of material needed for the part itself with little or no waste. 3D printing allows for more complex designs without the design restrictions of traditional manufacturing processes. It speeds up prototyping by manufacturing parts within hours and is cheaper and quicker than machining. Design modifications can be completed at a more efficient rate and the printer can work without constant supervision.

The main material for 3D printing is plastic, although some metals can also be used for 3D printing. However, plastics have advantages because they are lighter than their metal equivalents. Not only can the fabrication of a part be time-saving with 3D printing, but the design process can also be very fast with the creation of print-ready STL or CAD files. Parts are produced using only the materials needed for the part itself, with little or no wastage compared to alternative methods that are cut from large pieces of non-recyclable materials.

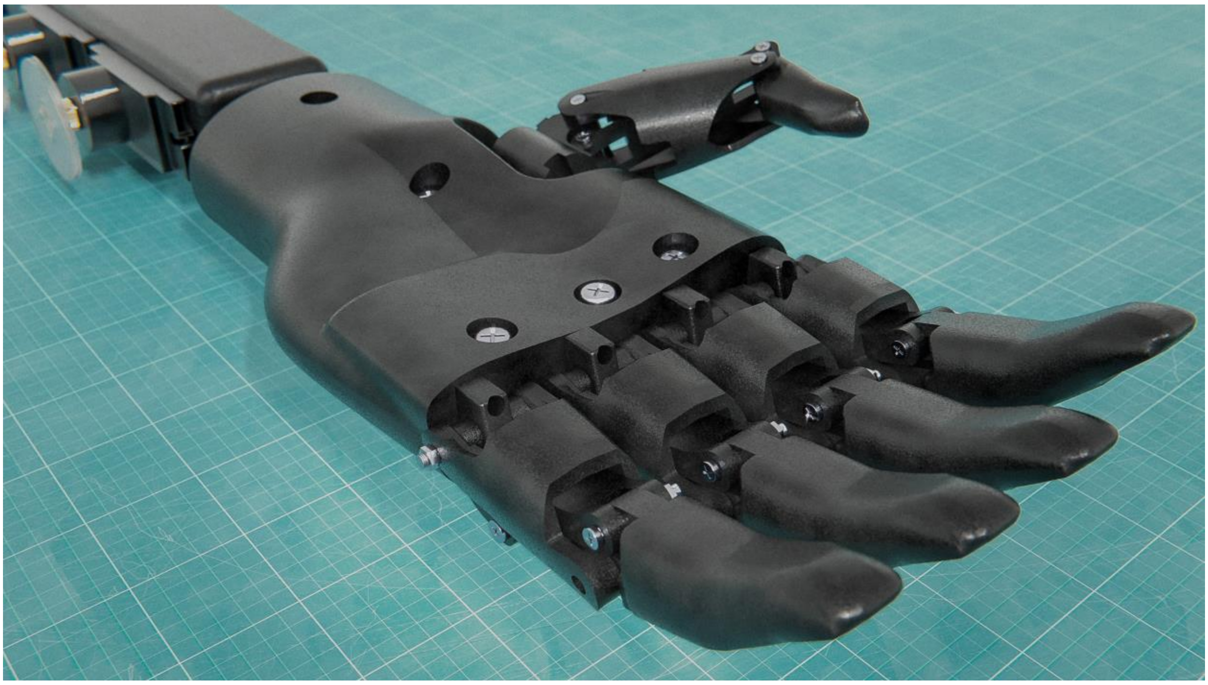
Upgrades

The biggest improvement in bionic prostheses is from the point of view of the materials used in their structures. The next biggest improvement is in methods of controlling the motors. One solution I propose is using flex sensors to copy the movements of the user's organic hand. Structurally, materials such as carbon fiber or steel can be used in place of plastic. A fine balance between cost and resistance is set by the usage purpose of the auxiliary arm.

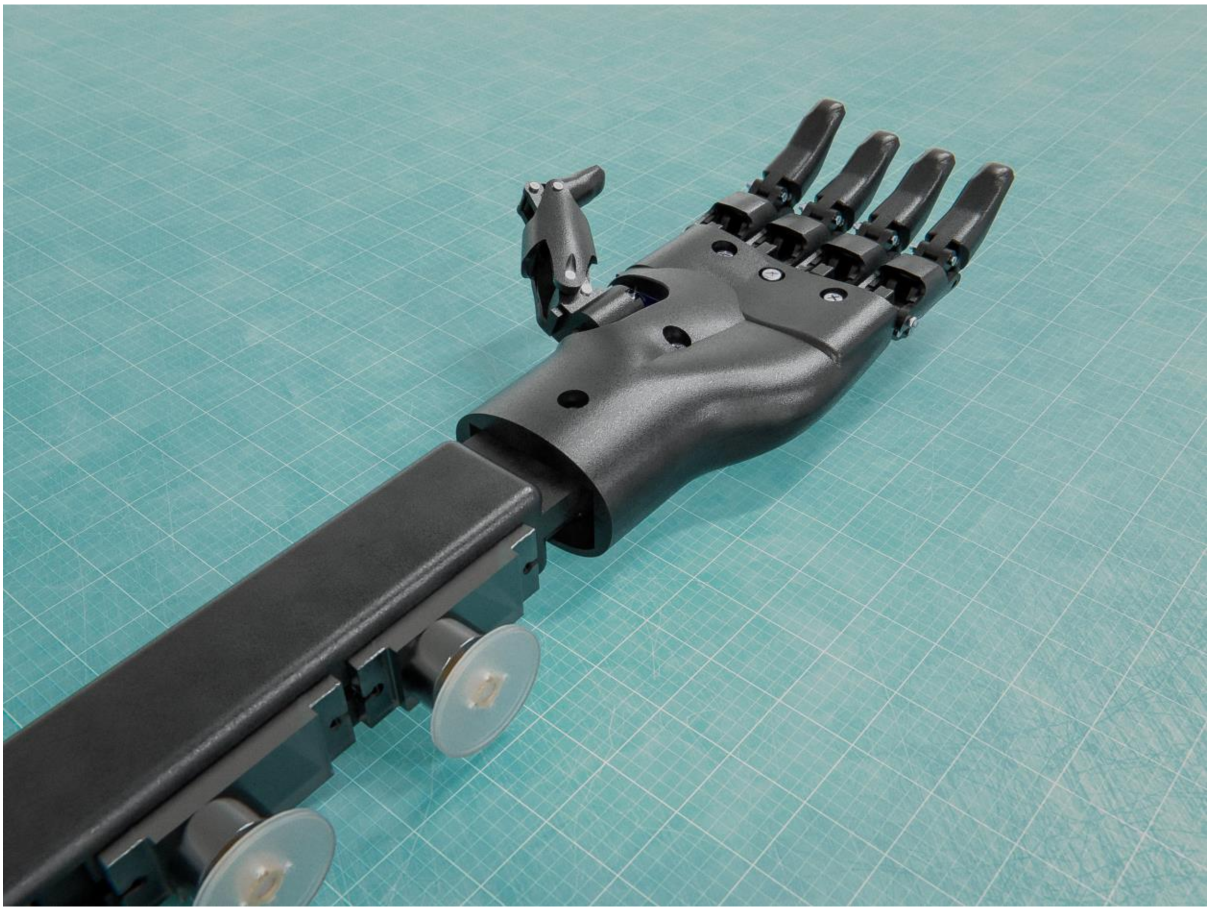
On the following pages there will be pictures of the actual 3D printed robotic arm.



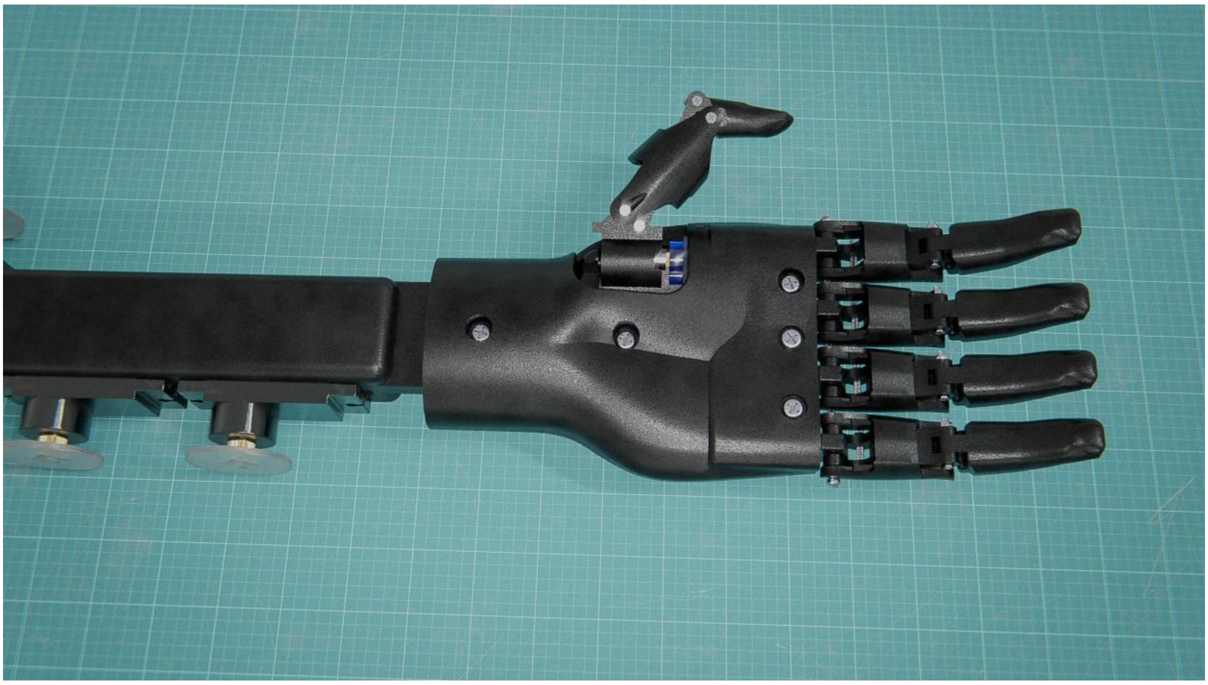
1 - TOP VIEW OF THE PALM



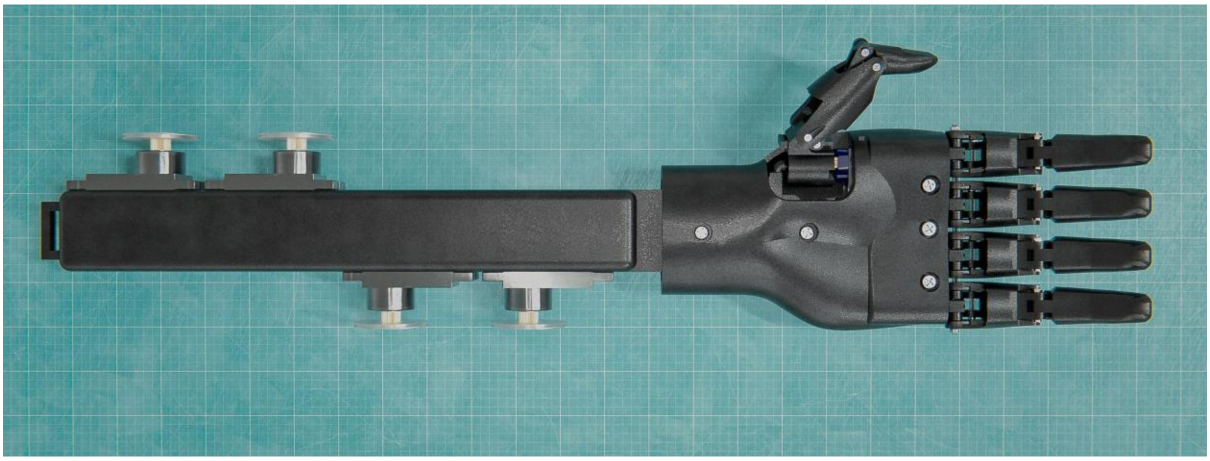
2 - FINGERS CLOSEUP



3 - WRIST AND FOREARM



4 - PALM AND FOREARM



5 - THE ROBOTIC ARM IN ITS ENTIRETY

VI - SOURCES

1. Datasheets on the component's manufacturer's site
2. armdynamics.com/our-care/prosthetic-options
3. twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons
4. wikipedia.org/wiki/3D_printing
5. ncbi.nlm.nih.gov/pmc/articles/PMC4128433/