MyOrthotics: Digital Manufacturing in the Development of a DIY Interactive Rehabilitation Orthosis

Adriana Cabrera

Adriana Cabrera, Hochschule Rhein-Waal
Kamp-Lintfort, Germany
adriana.cabrera@hochschule-rhein-waal.de

Abstract

Digital manufacturing and additive processes have become more prevalent in recent years due to the increased accessibility of tools and the individualization in the processes of prototyping. In comparison to the past, the process was individualized, taking months and requiring detailed research and development made by physical therapists and small manufacturers. Until now, this process is still done in the same long and expensive process. MyOrthotics is an orthosis development using Digital Manufacturing (Reversing Engineering, 3D Printing, electronics) to produce an individual and low cost solution for hand and arm disabilities, allowing patients, therapists, and practitioners to develop this assistive device in collaborative maker spaces.

Keywords

Assistive technologies for persons with disabilities; Orthotics, human factors, DIY; digital manufacturing; embodiment devices.

Figure 1: Development from the sketch to the final prototype using traditional and digital prototyping technique to produce MyOrthotics.

1 Introduction

Digital manufacturing (3D Printing, Laser Cutting, Electronics Design, Embedded Programming, etc) have become increasingly popular in almost any field of interest such as computer science, design, automobile industry, textiles, architecture among many others. In recent years, mostly private non-commercial users took over these techniques and make extensively use of them. FabLab's maker Spaces and other Groups of interest arose. The Fab Labs[1] ("Fab Foundation," ,2016)support the development of

[1] *Fab Lab* is the educational outreach component of MIT's Center for Bits and Atoms (CBA), an extension of its research into digital fabrication and computation. A Fab Lab is a technical prototyping platform for innovation and invention, providing stimulus for local entrepreneurship. A Fab Lab is also a platform for learning and innovation:

digital fabrication, contribute in the creation and production of prototypes and allow the global community to take up a challenge and solve it. As a consequence, there is a shift from experts only usage to almost everyone and this applies to almost any domain

A special domain is the medical field i.e. orthopaedics, Every person's body is unique and in case some loses capabilities such as being able to move her arm, hand, etc., prosthetic and orthotic limbs might help for a solution, furthermore the manufacturing of this process demands the development of a bespoke products with expertise and dedication for creating such detailed devices. (Hofmann et al., 2016)("The Raptor Hand – Enabling The Future," n.d.).

This is why custom manufacturing (Rovelo, n.d.), and producing products with orthopaedic technologies for individual patients is such a challenging process (P. Rovelo 2016).

The cooperation of Fab Labs in the development of individual devices and how this process can contribute to help of disabled people by using Open Source software and hardware to support the assistive technology development (Schull, 2015) are primary factors that can reduce the costs and provide solutions in cases that are not available in the market.

This paper presents an initial work of a 3D printed orthosis for a real case of customizing the design of an interactive orthosis for a patient with a paralysis of the left hand and forearm. The use of digital manufacturing, 3D printing and electronics production offer the possibility to produce an affordable solution.

2 RELATED WORKS

The development of the 3D printed prosthetics through the E-Nable community[2] has increased in the last years ("Enabling The Future," 2016.). This community spreads this concept of collaborative technologies and share knowledge that has been incredibly useful for people that have some background in this area. The construction of DIY orthoses and prostheses have similarities, for example the Raptor hand[3] (Wege and Hommel, 2005) which is one of the first models of a 3D Printed prosthesis helps in the development and understanding of the DIY orthosis construction. Nevertheless, the development of an orthosis has different requirements, such as, the weight of the body and the strength of the fingers that are completely different.

Other studies focus on wearable robotic arms (Kang et al., 2016) in the area of orthotics and get insights in movement and interaction. Conventionally, these robots were designed in three ways: a link-based rigid exoskeleton (Wilton, 2013), a polymer-based soft exoskeleton using pneumatic actuation (Lee et al., 2014) and a fabric- based or soft silicone exoskeleton using a tendon drive (Polygerinos et al., 2015). All these different applications in robotic arms are incredible works and encourage the development of a precise system using sophisticated actuators, nevertheless the systems are not designed as DIY. This is also the case of the Polymer-Based Tendon-Driven Wearable Robotic Hand (Kang et al., 2016), which has advantages and disadvantages regarding to the actuation method. The implementation of a pneumatic actuator makes the devices harder to carry and the stabilization of the movement of the wrist is not

---

a place to play, to create, to learn, to mentor, to invent. To be a Fab Lab means connecting to a global community of learners, educators, technologists, researchers, makers and innovators- -a knowledge sharing network that spans 30 countries and 24 time zones. Because all Fab Labs share common tools and processes, the program is building a global network, a distributed laboratory for research and invention *(FabLab foundation, 2016)*

[2] The *e-NABLE Community* is made up of teachers, students, engineers, scientists, medical professionals, tinkerers, designers, parents, children, scout troops, artists, philanthropists, dreamers, coders, makers and everyday people who just want to make a difference and help to "Give The World A Helping Hand."

It supports an international network of passionate volunteers using 3D printing technology and education to develop and deploy hyper-affordable prosthetic devices to children and other underserved populations around the world in a safe, sustainable manner. (Schull, 2015),(Hofmann et al., 2016).

[3] *The Raptor Hand* is designed with ease of printing and assembly in mind. Features include 3D printed snap pins, a modular tensioning system, and compatibility with both Velcro and leather palm enclosures. ("The Raptor Hand – Enabling The Future," n.d.)

considered. As a DIY system, the appropriation and customization of the system must be considered in terms of complexity of this system.

Other types of orthoses with a rigid exoskeleton structure are considered in the works of ZMorph and Elisa Wobel, in the *3D Printed Rehabilitation Orthosis* ("The Making of a 3D Printed Rehabilitation Orthosis," 2016)This implementation works in linear movements, permitting the structure and synchronization of these movements. In fact, the development of the MyOrthotics design is based on this kind of construction, nevertheless without an interactive system, the construction is not able to offer to the patient the flexion and extension movements.

MyOrthotics system uses Myoelectrical signals ("MyoWare Muscle Sensor," n.d.) and electromechanical actuation, (it will be explained in the interaction part). It includes a splint in the forearm and back of the hand in order to immobilize the wrist. The mechanism to mobilize the fingers make use of three servo motors: one for the thumb, one for the index finger and one for the middle finger. These are attached with the ring and little finger and the connection to this mechanism cause the flexion and extension. These motors respond to the impulse of two Myo sensors located in the tricep and bicep muscles of the patient.

3 CASE

The development of MyOrthotics is based on a patient around 60 years old. He has a semi paralysis in the left part of his body, a condition that he suffered after brain tumour removal. The goal is to develop an individualized orthosis that permits the recovery of the movement of the hand in order to be independent in different daily activities like grasping a coffee mug, opening an envelope, and using the mouse and keyboard. He lives in the most industrial region of Germany, nevertheless there isn't any kind of orthosis that can help with his symptoms. Furthermore, the treatment therapies and infrastructure, in his situation, implicate a huge cost. It is expected that he will recover a little bit of the movement of the hand in the long run.

- ***Nerve disorder***: There are more than 100 kind of peripheral nerve disorders ("Peripheral Nerve Injury," 2015) that can affect one or several nerves causing spasticity[4] . There's still a lot of untapped potential for helping the patients with cases of mild and partial paresis, who need lighter and more comfortable 3D printed rehabilitation orthosis.

4 PROCEDURE

MyOrthotics is the solution to this case. Using digital manufacturing techniques to actuate in an individual case, such as 3D scanning, different 3D Printing techniques, and electronics production a, to create a proper solution in an efficient procedure for the patient.

The objectives in prototyping MyOrthotics are the following:

• To customize and produce an orthosis for a patient using reverse engineering, instead of the traditional processes of moulding and casting, to accelerate the production.

• To simplify the fabrication, assembly and the repair of the orthosis, which the patient can do himself.

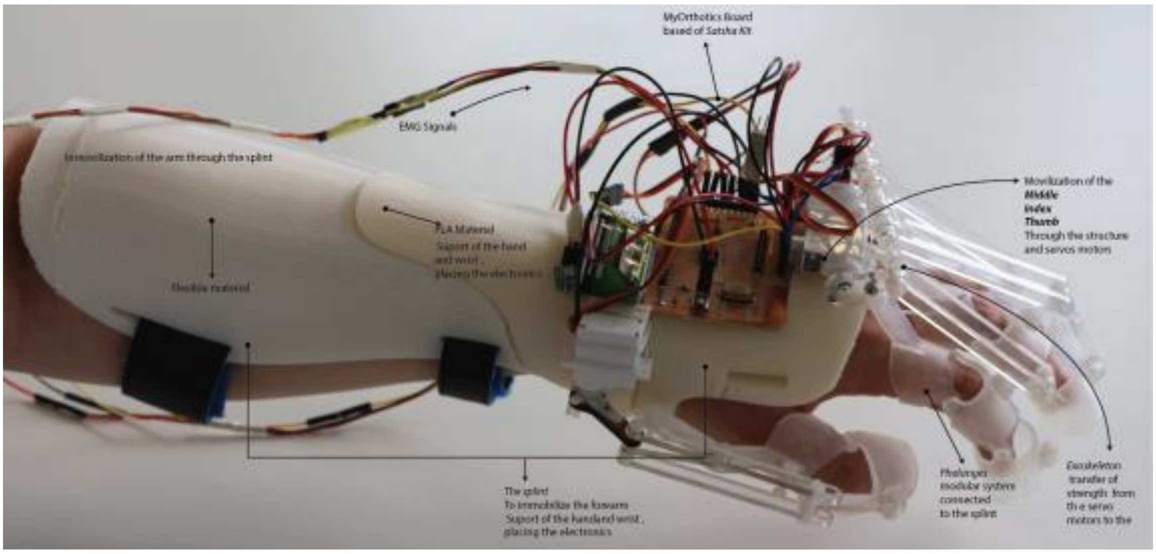
• To provide the parametric design of the models and design reference for future innovations.

• To propose the accessible materials for every patient.

• To simplify the electronic design based on an open source board, affordable and possible to make in each Fab Lab.

[4] Spasticity is a condition in which certain muscles are continuously contracted. This contraction causes stiffness or tightness of the muscles and can interfere with normal movement, speech, and gait. it is usually caused by damage to the portion of the brain that controls voluntary movement. ("AANS | American Association of Neurological Surgeons," 2006.)

• To familiarize the patient and therapist with the process of production of the orthosis, enabling the



understanding of the benefits and constraints of the prototyping and learning through this process.

- Figure 1: Development from the sketch to the final prototype using traditional and digital prototyping technique to produce MyOrthotics.

Design Criteria:

- The model has a semi parametric design. The arm must be scanned in order to modify the 3D scan model and to produce a parametric 3D model.
- The *phalanges* were modelled in a parametric design, in order to make them adequate for each finger and also for in the future to adjust this model for different patients. Each phalange is connected to the splint and each finger to the corresponding servomotor.
- The *splint* is designed to perform the following tasks: to immobilize the forearm, and place the hand and wrist in an adequate position.
- The first part covers the back of the hand and the wrist, stabilizing the position of the hand. In order to attach and stabilize the whole function of movement in the fingers, the external surface at the same time supports the electronics, the micro controller board, and servo motors.
- The assembly of the joints and the structure is responsible for distributing the force in the fingers.
- The *exoskeleton* enables the transfer of strength to the fingers through the phalanges and is connected with the servomotors. The servomotors are connected to the Myo sensors in the tricep and bicep muscles, in order to generate analog values and send the impulses to the microcontroller board. More details will be presented below, in the Interaction section.

5 ANALYSIS AND DESIGN

- ***Reverse engineering and modelling:***

  In the first trial only the forearm and the palm of the hand was scanned, due to the spasticity in the patient’s fingers, in order to generate the first model of the splint. The Sense 3D scanner was used for this model, because the condition of the patient prevented holding and extension of the fingers for a long periods of time. The scanner provided good results in a short period of time.

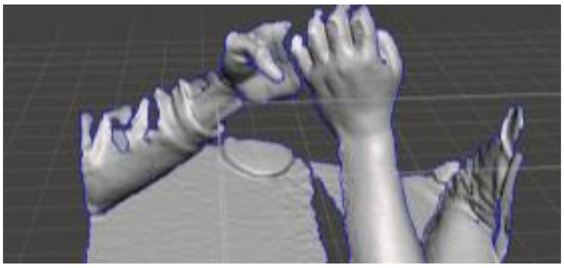


Figure 3. 3DScan of the patient

The model was edited in Fusion 360, a complete computer aided design (CAD) software for a variety of applications. This program especially supports the parametric tools and analytic mesh tools that are well-suited to the challenges faced in designing DIY prosthetics and orthotics.

Figure 4. Free Form in 360 function from Fusion 360 software allowing the creation of mesh nodes in X and Y direction which are attached in the original 3D Scan.

The model of the fingers is based on the index finger with three phalanges, permitting the customization of the other fingers and also the customization of the model for other patients. The joint mechanism permits the printing of the pieces and joining of the phalanges, for having the whole movement of 90 degrees, as you can see in the in the following picture.

The exoskeleton is independent from the 3D printing process, to accelerate the process; it was prototyped with the laser cutter and following the linear function of transferring the strength between the motors and the phalanges.

Figure 5. Parametric model of the phalanges and joints between them

The exoskeleton is independent from the 3D printing process, to accelerate the process; it was prototyped with the laser cutter and following the linear function of transferring the strength between the motors and the phalanges.

The Interaction:

MyOrthotics has a system based in the mechanical movement of the three principal fingers: the index, thumb and middle finger.

This system allows the following functions:

- Measuring the MYO signals of the bicep and tricep muscles, in order to provide sufficient information to the micro-controller.
- Sending the information through the microcontroller to the actuator.
- Development of a microcontroller board for programming and controlling the flow of information.

MYO (electromyography) and MYO ware (“MyoWare Muscle Sensor,” n.d.)

This is a sensor that permits the measurement of muscle activity. Measuring muscle activation via electric potential, referred to as electromyography (EMG), has traditionally been used for medical research and diagnosis of neuromuscular disorders. However, with the advent of shrinking, and yet more powerful microcontrollers and integrated circuits, EMG circuits and sensors have found their way into prosthetics, robotics, and other control systems (Kamiski, 2016). The use of this sensor permits the mapping of the ROW values from a very sensitive lecture until the very strong movements depending of the calibration.

Mechanical actuator and motor

The actuator should follow and support the forces and mechanical resistance due to the spasticity of the muscles. As is showed in the following pictures:

The goal of the actuator and the exoskeleton is to recover the traction and extension of the phalanges, distributing the strength in the proximal and distal phalanges, through the skeleton.

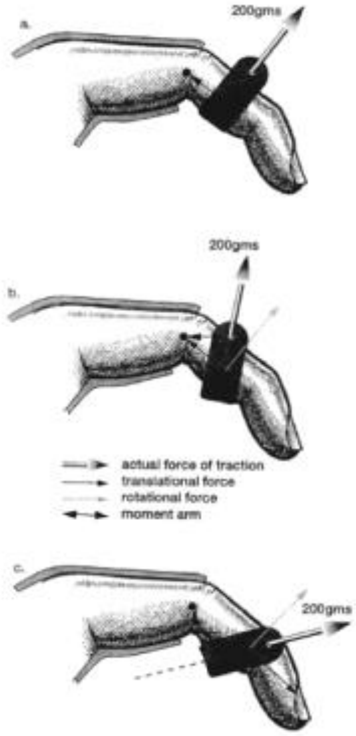


Figure 7. Mechanical Resistance of the spasticity considering forces and angles of the fingers movements. (Illustration. J, Wilton, 2014) [19].

In the first trial, I considered using Smart Nitinol Wire (SMA) in order to embed it in the splint.

Advantages: The use of Nitinol produces a natural movement making it ideal for body devices. Due to its flexibility, the actuators can be integrated in the shape of the orthotic.

Disadvantages: Less force: depending of the diameter of the wire, the force is directly proportional to the needed current (force).

Retraction: for the simulation of the muscles, the capacity of reaction should be within milliseconds, that the commercial SMA cannot achieve (time/speed) (gravity can improve the results of retraction). The current needed for all the functions of the hand, could impose a risk in this area that has a lot of contact with different surfaces and materials.

The consideration of an accessible motor enables the easy and understandable process, combining the rotation of the motors in this case around 60 degrees with the function of the exoskeleton. The servomotor offers more strength in the mobilization of the fingers, and at the same time, a motor which is light and simple to use, wearable and provides enough torque to move at least three fingers (900 grams) plus the weight of the material (15 grams).

For more information about this trial you can see ta video of the torque of the motor and the movement trough the skeleton in the following https://youtu.be/GWtmCX_sRwc

For index and thumb fingers there is a servomotor for each one that is responsible for the flexion and extension as is illustrated in the Figures 8 and 9. The index is the most important finger in which I based the implementation of the phalanges design. The thumb has two phalanges. Instead of creating a circumduction movement (circular movement of the finger), it makes a linear movement that is synchronized with the index finger for grasping objects. The motor of the middle finger is attached to the two others finger to achieve the whole movement of the hand.

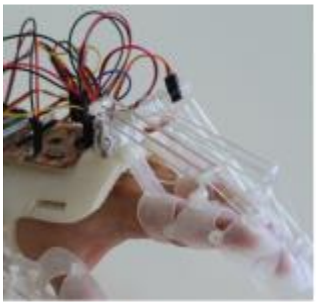



Figure 8 . Extension of the finger through the Exoskeleton and the motors torque (90 degrees). Figure 9. Flexion of the finger through the Exoskeleton and the motors torque (90 degrees)

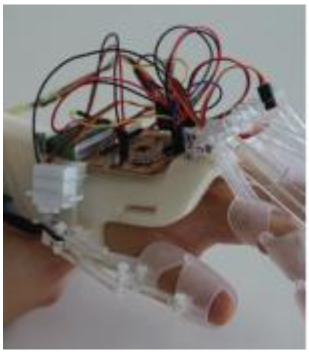



Figure 8, 9. Flexion and extension of the Thumb finger.

Microcontroller board and programming

In the MyOrthotics case, the board is made to generate enough connection for the devices. This board was made in the Fab Lab using the Milling Machine MDX40a Roland model and the open source software Fab Modules, reducing the costs and customizing a special board for MyOrthotics project. For more information, visit the Github

page.

The board is programmed in Arduino IDE software, following the function of:

- Mapping the threshold sensor and defining two statuses: one impulse for closing and one for opening.
- The Myosensor in the bicep controls the movement of the index finger, and the sensor in the tricep controls the movement of the thumb and the middle finger.
- The mapping and calibration of the Myosensors and the motors and servomotors enable the customization of the interaction of this orthosis in case of improvements or degenerative diagnostic of the patient.

6 TESTING AND RESULTS

General patient Feedback: In the first meeting (1.jun 2016) the patient had an abstract idea of the implementation of this process, with the visualization of the 3D Scan provided clear idea of the orthosis procedure. However, the patient had at that time only had an abstract idea of the orthosis Figure 11.

In the second meeting trough the visualization of the first model, the 3D printed finger structure of the fingers enables a small test with the little finger, testing the joints, explaining about the materials and the functions of the structure of the phalanges. The patient could get a better idea increasing the interest for the development of the process.

Figure 11. 3D Scanning Process forearm and back of the hand. https://youtu.be/7QCgrAymrlM

The model and the 3D printed phalanges were tested with three different kind of materials, and also, these tests illustrate the constraints of the materials.

The first trial with PLA generated a very rough surface due to the supports.

The second trial with flexible material (Innoflex 45% elasticity) was successful. Nevertheless, the interior part came out a little bit rough, which means that the interior parts of the pieces should be sanded.

Figure 12. Printed Process whit PLA material, 13. Innoflex Flexible material, 14. Clear resin 3D printed material.

The printed parts were made in the final test with clear resin, printed in a 3D SLA printing process (Formlabs), providing a flat and fine surface that allows a smooth and comfortable hygienic contact with the skin.

Figure 15. 3D Printed Thumb phalanges testing the accuracy and calculating the size of the exoskeleton connections.

In the next meeting was tested the first 3D printing model of the splint, In this trial the whole splint with PLA in the Big Rep 3D Printer, the splint fitted perfectly to the patient, however this model provided evidence that the design of the orthosis required the use of a flexible material for the forearm arm, and rigid material for the wrist and the back of the hand.

Also, the patient was surprised of the colour and was sceptics of the use of this device.

In this meeting, the test of the first prototype of the orthosis was made by the patient, as is showed in the Figure 16.

The sensor was calibrated with the refined signal using the Interface in a manner that The patient could see the interaction of the arm and the values.

Figure 16. Testing the part and the interaction of the Myoware connection of the Myoware to the SatshaKit and assembling the Satshakit + Myoware + Motor + Orthotics Prototype. https://youtu.be/_kyQ4P8TT0I

The second prototype consist in the development of the back part of the hand printed with Polylactic Acid (PLA), as it supports more strength and also for the support of the electronics rigid materials as the PLA are recommended.

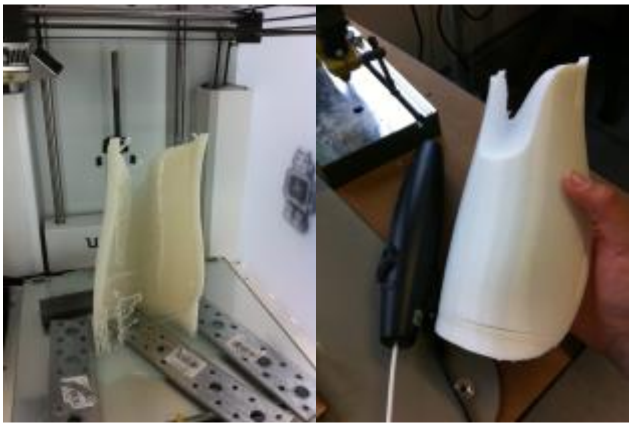


Figure 17. 3D Printing Process of the flexible part of the splint.

The second part of the splint using Innoflex 45% natural white, the assembling of the electronic and in this day I tested the function of the orthosis, looking for the movement function and at the same time the constrains of the material with the following performance:

7 PERFORMANCE AND AFFORDANCE OF THE SYSTEM

With this orthosis the patient was able to produce the flexion and expansion of the index, middle, and thumb in a correct posture, showing improvements in a short time of the prototype. The whole development process lasted around one month, including research and design.

With the initial prototype, the movement of the index finger, enabled, for example, the use of the mouse of a computer could be achieved.

The patient provided positive feedback and was impressed with the new result. In addition, he confirmed that the use of the design would be beneficial in his daily activities by allowing fine adjustments of fingers and providing him the ability to grasp his walker, thereby allowing him more personal independence.

The cost of the MyOrthotics initial prototype for all the material is around 170 euros . This includes the different 3D printed materials (PLA, flexible materials, clear resin), Electronics (Servo Motors, Sensors, DIY microcontroller board), laser cutter materials, accessories, Velcro band, and joints. The construction of the orthosis with the easily accessible materials allows production of this in any part of the world.

Figure 18. Testing of the second prototype of the Orthosis in the Fab Lab Kamp-lintfort, during the presentation project of the FabAcademy 2016 https://youtu.be/rnSr5HDS5wQ

8 EVALUATION AND FUTURE WORKS

MyOrthotics would not have been possible to realize without the interest and case of the patient, Frank Miller. The purpose of development of the orthosis was in order to help Frank with his disability. It explores how digital fabrication can contribute to the improvement of treatment for this disability in combination with traditional techniques, for better results.

With the visualization of the 3D Scanning, model and prototype of his orthotic, the patient could participate in and understand the whole process.

Making the first prototype of the orthotic for my own hand put me in the shoes of the patient, having only one hand for adjusting the things as the other one was occupied with the prototype, simulated the disability.

Bringing the Patient to the Lab and the explaining how the process was done, experimenting from a very abstract to a functional prototype in this case the orthosis, was a huge surprise for the patient, and it also brought hope and expectations for his new orthotic.

Future works:

There are many possibilities for improvements in this work. During this process, different experiments were made in taking measurement of each finger. I tried to do the 3D scan of each finger, nevertheless it didn't work very well. In the end, I still wasn't able to find the right adjustments for the patient fingers. Due to the complex case of deformity and spasticity of the hand, the moulding and casting method is still the more traditional, and for this purpose, it is the next step for development of better accuracy of measurement for the finger phalanges. After the casting of the mould, one can then proceed to do the 3D scan of the fingers.

About the splint: I have to do some adjustments and also consider that if Frank recovers a little bit of the movement of the wrist, I could use this data as a measurement for another sensor. In the splint will be consider the case of the electronics.

My idea is to implement a new board, using the Satsha Micro, in order to reduce the size of the board, making it more wearable. MyOrthotics Sku, based on the Satsha Micro, is the customization of the size and it adapted the I/O entrances of the MyOrthotics

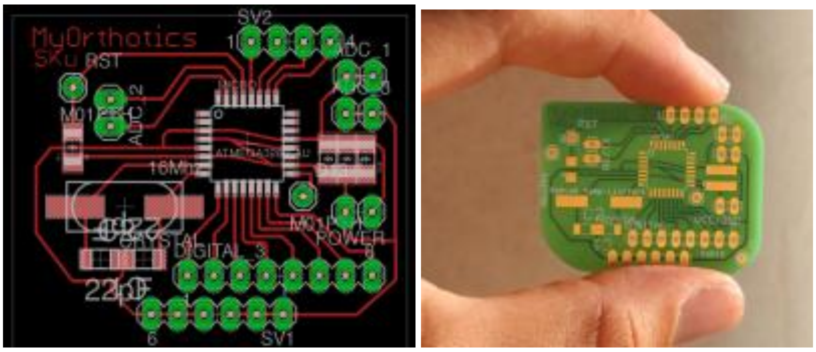


Figure 19. Schematic and proto board of the MyOrthotics Sku board

In the future, it could be evaluated to implement or develop the MyO sensor not only reducing the cost of the processes, and making this accessible for other people but also adapting it better for daily use.

The system is designed to be replicated and individualized for other patients with similar disabilities, and, also I hope that the project grows in the open source community supporting assistive devices.

9 SUMMARY AND OUTLOOK

This work presents the development of a DIY orthosis using Digital Manufacturing, evaluating the case of a patient with spasticity in his left hand. MyOrthotics was made possible with the collaboration of the patient and with the advisement of the physical therapist. This project ("A,Cabrera," 2016)was developed during the Fab Academy 2016 Course, supporting different areas of prototyping. Personally, I assumed the challenge of the individualization of a prototype using digital manufacturing, however I consider that the background of the traditional techniques contributes and support the development of this bespoke work, and the transfer of knowledge between the therapist and my colleges was fundamental to archive the results of MyOrthotics. This model is 100% made in the FabLab Kamp-Lintfort("FabLab Kamp-Lintfort | FabLabs,"2017.). This factor highlights the importance of materials and tools related to prototyping, that encourage user engagement in design, thus demonstrating that the assistive technologies can be developed in collaborative and transdisciplinary environments.

From this workflow derived recommendations for advances that would enhance the prototype assistive devices.

This work also argues the benefits of the open source of the parametric design and the contribution for future works, encouraging patient's families and practitioners in the collaborative spaces to learn and share this knowledge.

Acknowledgments

Through the whole process I had the support of the therapist Mr. Carsten Rubel, from the company VitalCentrum HODEY AG Germany, who contributed greatly with his medical expertise.

Thank you so much for your support. I would also like to thank Mr Frank Miller As patient of the MyOrthotics Project. For his patience and making this project possible, very thanks Frank.

Also Daniele Ingrassia, my classmates from the Fab Lab Kamp-Lintfort, and Support of the Faculty of Communication and Environment of the University of applied Science Rhine-Waal during the realization of the Fab Academy 2016, and the 3D-Kompetenzzentrum Niederrhein for the support, and the countless individuals who shared their knowledge, expertise and generous assistance, making this experience an unforgettable and amazing journey. To all of you, I extend my deepest appreciation

References

AANS | American Association of Neurological Surgeons, n.d. URL http://www.aans.org/ Retrieved July 14, 2017

Enabling The Future (2016). Enabling Future. URL http://enablingthefuture.org/ Retrieved July 14, 2017

Fab Foundation, (2017) http://fabfoundation.org/ Retrieved February 1, 2016

FabLab Kamp-Lintfort | FabLabs (2017). FabLabs io - Fab Lab Netw. URL https://www.fablabs.io/labs/fablabkamplintfort Retrieved July 14, 2017.

Hofmann, M., Harris, J., Hudson, S.E., Mankoff, J., (2016). Helping Hands: Requirements for a Prototyping Methodology for Upper-limb Prosthetics Users, in: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, CHI '16. ACM, New York, NY, USA, pp. 1769–1780. doi:10.1145/2858036.2858340

Kang, B.B., Lee, H., In, H., Jeong, U., Chung, J., Cho, K.J., (2016). Development of a polymer-based tendon-driven wearable robotic hand, in: 2016 IEEE International Conference on Robotics and Automation (ICRA). Presented at the 2016 IEEE International Conference on Robotics and Automation (ICRA), pp. 3750–3755. doi:10.1109/ICRA.2016.7487562

Lee, S.W., Landers, K.A., Park, H.S., (2014). Development of a Biomimetic Hand Exotendon Device (BiomHED) for Restoration of Functional Hand Movement Post-Stroke. IEEE Trans. Neural Syst. Rehabil. Eng. 22, 886–898. doi:10.1109/TNSRE.2014.2298362

MyoWare Muscle Sensor, n.d.

Peripheral Nerve Injury (2015) . Saebo. URL https://www.saebo.com/peripheral-nerve-injury/ Retrieved July 14, 2017.

Polygerinos, P., Galloway, K.C., Savage, E., Herman, M., Donnell, K.O., Walsh, C.J., 2015. Soft robotic glove for hand rehabilitation and task specific training, in: 2015 IEEE International Conference on Robotics and Automation (ICRA). Presented at the 2015 IEEE International Conference on Robotics and Automation (ICRA), pp. 2913–2919. doi:10.1109/ICRA.2015.7139597

Project Development (2016) URL http://archive.fabacademy.org/archives/2016/fablabkamplintfort/students/124/18.10.FinalResults.html Retrieved July 14, 2017.

Rovelo, P., (2017). Additive Manufacturing in the medical and dental technology industries (2016). 3D Print. Ind. URL https://3dprintingindustry.com/news/additive-manufacturing-medical-dental-technology-industries-80348/ Retrieved July 14, 2017.

Schull, J., (2015). Enabling the Future: Crowdsourced 3D-printed Prosthetics as a Model for Open Source Assistive Technology Innovation and Mutual Aid, in: Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility, ASSETS '15. ACM, New York, NY, USA, pp. 1–1. doi:10.1145/2700648.2809870

The Making of a 3D Printed Rehabilitation Orthosis, (2016) . ZMorph Blog - Artic. Case Stud. News 3D Print.

The Raptor Hand – Enabling The Future, n.d. URL http://enablingthefuture.org/upper-limb-prosthetics/the-raptor-hand/ Retrieved July 14, 2017.

Wege, A., Hommel, G., 2005. Development and control of a hand exoskeleton for rehabilitation of hand injuries, in: 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems. Presented at the 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 3046–3051. doi:10.1109/IROS.2005.1545506

Wilton, J., (2013). Hand splinting orthotic intervention: principles of design and fabrication, 2nd edition. ed. Fremantle, Western Australia Vivid Publishing.