RE-DESIGN OF A PROSTHESIS SIMULATOR FOR ABLE-BODY PEOPLE

Internship report

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Contenido

Introduction

The prosthetic field is in development at this time, since technology contributes to the progress and improvement of the already existing devices. There are different kinds of prosthesis: cosmetic, body-powered and myoelectric, or externally powered prosthesis [1].

Cosmetic prosthesis doesn't have other function than to look real, usually they have gloves that mimic perfectly the skin of the user, but they can't be used to perform any actions. The body powered prosthesis are mechanical devices that are controlled with other healthy part of the body, normally, the contralateral shoulder to the absent limb.

The externally powered prostheses are controlled with external motors and switchers and are suitable for certain activities. They can be rigid, with absence of wrist, which makes them more uncomfortable, having to use more compensatory movements, and causing more CANS. Therefore, there is a need to incorporate more degrees of freedom (DOF) in the current devices. The hardware is ready but the reading of the signals is the most challenging part, making the translation between the user and the device. They use myoelectric signals of the remaining muscles in the stump to control the motors. There are several ways to obtain these signals, using the EMG, features or the processed myoelectric signals and pattern recognition.

Pattern recognition [2] is a promising technique that is based on the theory that each muscle movement produce a different pattern in the EMG, and it compares the form of the waves, instead of the parameters, as the amplitude. It has its advantages such as that it uses natural hand and arm movements, it can be used to control more than the 2 degrees of freedom (DOF) used in the current prosthesis and different sites can be used for the control. But, in the other hand, it is not very developed yet, it has some flaws for example, it has to take into account, the changes performed in the muscles sites since the amputation, the reinnervation of the nerves, the changes in the kinematics of the arm. These flaws must be improved with research.

Each one of the different types of prosthesis have its advantages and disadvantages, body powered prosthesis are easier to use, but they are not very natural, and they usually are task oriented, meanwhile myoelectric hands can be helpful in more situations, but on the other hand they weight more and are more difficult to control. This difficulty lies in the fact that there are not enough signals in the remaining limb or that the systems used to read them are not developed enough to make the use of this kind of prosthesis intuitive enough. For these reasons a high percentage of amputees decide to renounce to their prosthesis.

The goal of researchers is to improve prosthesis in order that they are useful, comfortable and easy to learn. But there is a shortage of patients with transradial amputations, therefore the need for a simulator to be used on able-body people appears.

1. State of the art

Analyzing a review of current simulators for hand prostheses performed by the University of Salford (Manchester) and titled "An investigation into the use of able-bodied myoelectric prosthesis simulators in the literature (a design review)", it is possible to see that most of the simulators have similar characteristics. They have to have some common requirements, such as:

- Myoelectric prosthesis simulators (MPS) have to replicate prosthesis as closely as possible in order to be truthful for research.
- As the objective is to have more subjects for research, it has to be adaptable to different people.
- It has to control hand movement, restraining the hand in a relatively fixed position in order to have a reference position.
- To be able to use pattern recognition, electrodes must be placed always in the exactly same position, being and advantage to have housed electrodes.
- It should be comfortable, since it is created to be wear as long as possible, as a real prosthesis.

The fundamental differences between different designs are found in the place where the prosthetic hand is placed, while some of them decided to place it in line with the real hand, more distal, or disto-lateral, as it is the case of Anders et al. Others prefer to place it under the real hand but also a little more distally, since it has to mimic the actual lengthening that the prosthesis users suffer because of the prosthesis.

Another significant difference is how they attach the prosthetic hand to the arm of the able body user. Some of them use rigid molds where the arm is place, others used a glove that can be adjusted depending on the user thanks to Velcro fasteners, or hold them with the real hand grasping a handle. Almost all of the simulators have the wrist fixed, preventing it from doing pronation and supination movements

The MPS developed by the rehabilitation department of the UCMG and described in Bouwsema et al. (2008/2010/2012) [3] was the one that scored better in the comparison performed by the reviewers where they took into account the above-mentioned requirements.

In order to keep investigating and improving patter recognition control and being able to test these improvements the simulator that was created has the following characteristics:

It consists of an adjustable (using Velcro stripes) glove reinforced in the base with carbon fiber and foam, where a steel bar is attached in which the Michelangelo hand (Ottobock) is attached under the real hand a bit more distal. As it is under, and not in one of the laterals it is less heavy. The base has to be as rigid as possible and fit the hand and forearm of the user perfectly in order to withstand the prosthesis and be stable. It ends in the middle of the forearm, leaving space to place the electrodes in the bulk of the muscle. In the future, they were thinking on substituting the glove made of fabric by a 3D printed rigid base.

Fig.1: Current design

2. Problems with the current solution

A session was organized to try the simulator in order to get familiarized with it and test the current assembly.

The main problem with the current simulator is that the wrist is fixed with the glove, and it doesn't allow pronation and supination movements of the wrist. It prevents you for making almost any movement, apart from flexion and extension. Other movements are interesting in order to advance in the investigation of improving pattern recognition control for more degrees of freedom, allowing the user to perform a wider range of tasks.

Another problem, of the current device is that it is very heavy, which makes it uncomfortable to wear. The placement of the prosthetic hand can solve this problem up to certain point, being heavier when placed at the sides of the real hand than above/under. But the prosthetic hand itself is heavy, so the solution to this problem should also be focus towards reducing the load in some way.

Some improvements can be made, for example, the fact that the fingers can't be moved. This is not a priority, since although you can't move the fingers, the signals to move them are send, and the pattern can be extracted anyway.

Of all these problems, the one that is more important is the supination/pronation movement and it is in this one that we are going to focus our efforts during this project.

Analysis phase

1. Problem definition

The fact that the hand prostheses are not very intuitive, which cause rejection in a great number of cases [4], and that there is a lack of upper limb prosthesis users make difficult the improvement and research on this field. With that goal in mind, a simulator is needed, in order to use able-body people for the research. But this simulator has to mimic as best as possible the prosthesis used by an amputee for the results to be useful and truthful. As we have already seen, there are several simulators up to this point, but neither of them is perfect. The focus of this project would be to find ways to improve the design already existing in the UMCG in order to have a more satisfactory result.

2. Stakeholders

The stakeholders' analysis is a representation in form of table of the people interested in this project, their expectations, potentials and deficiencies, implications and conclusions.

Person	Characteristics	Expectations	Potentials and deficiencies	Implications and conclusions for the project
Patient	After suffering and amputation the patient requires a limb that replaces the lost one	The limb is required to help the patient perform daily activities as easy as possible	Has high expectations and they are highly demanding in terms of performance	The prosthesis need to be improved to satisfy the demands
Physician	Wants to offer the best possible solution to the patient	Easy to learn and to wear and high response. Should not harm other body parts	Actual prosthesis doesn't satisfy the clients	It has to be light, functional and
Researcher	Works on improving the prosthesis to make them more functional and useful	Reception of signals must be improved	Doesn't have a lot of patients to test advances	It is needed a simulator that allows to test in able-body people
Company	Wants to sell as much product as possible, offering value	Make money	The percentage of rejection is high	Pattern recognition techniques must be improved

Table 1: Stakeholders Analysis

3. Cause and effect

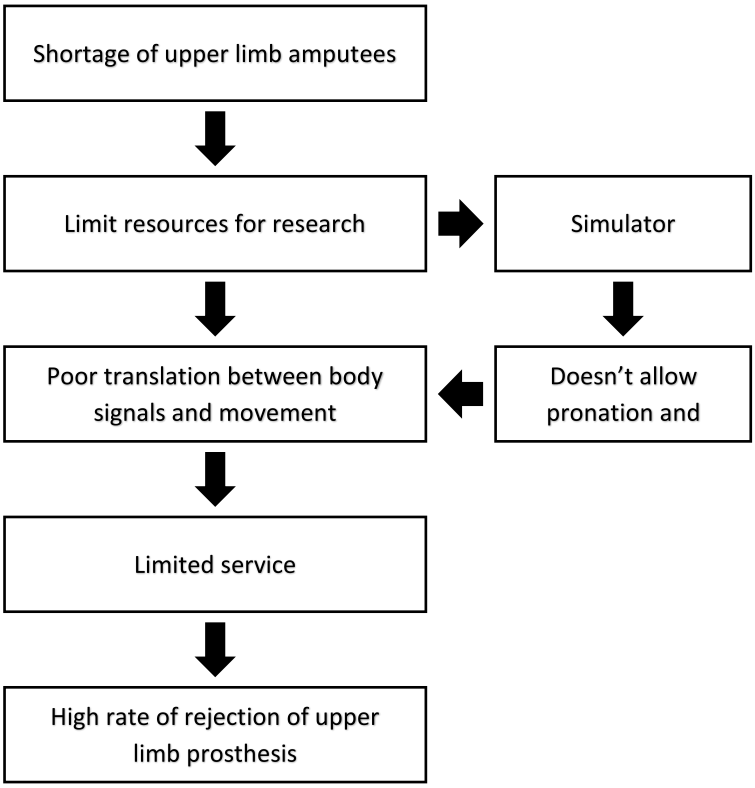

Figure 2: Cause and effect diagram of the problems involved.

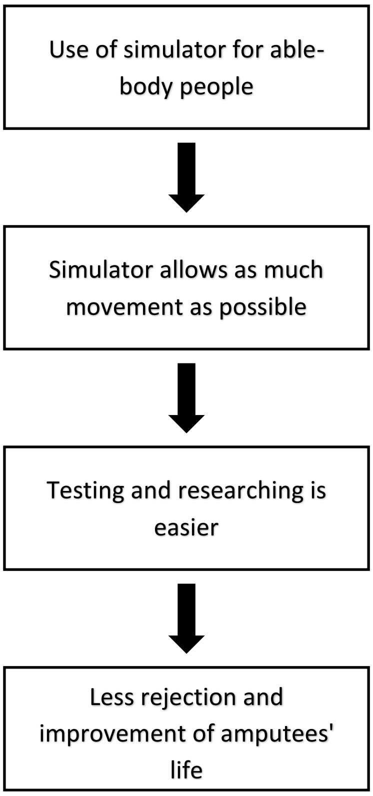

Figure 3: Cause and effect diagram of the prosthesis simulator.

4. Goal

The goal of the simulator is to allow the testing of pattern recognition methods in able- body people. To achieve this purpose the user must be able to move the wrist in all directions, as it would do without the simulator. The prosthetic hand must be linked to the real arm by any means, but it should be stable, leave space for the electrodes that are going to read the signals and it should be as light as possible, taking into account that the prosthetic hand already weights ~400 gr.

The main problem with the actual device is that it prevents the movement of the wrist, which doesn't allow the user to perform the pronation and supination movements. Another inconvenient of the current design is that when moving the hand, the device moves with it too, which makes more difficult the performance of certain activities.

5. Design assignment

The design assignment is to redesign the upper limb prosthesis simulator in order to make it suitable to test pronation and supination hand movements, which means that the wrist has to have free movement range. This is the main objective to be accomplished but there are some other modifications that can be an improvement, as the distribution of weights.

One possible strategy that can be followed to achieve the abovementioned objectives is to modify the linkage of the prosthetic hand to the healthy arm taking into account that it has to be stable. If needed, it can also be change the position of the prosthesis compared to the healthy hand, because in the current position some tasks might be difficult to achieve. Finally, the distribution of weights has to be contemplated to provide that the simulator doesn't harm the user.

6. Functional analysis

The main function that is required by the design is to be able to make pronation and supination movements with the healthy arm, without these movements affecting the prosthesis. So, we have to focus on how we transport the material, how we move the wrist. After that, we have to pay attention to the material connection, how the prosthesis is attached to the healthy arm, and finally, separation of energy, how can we do that the movement of the wrist is not propagated to the prosthesis.

Figure 4: Functional analysis.

7. Requirements and wishes

A list of design requirements has to be developed, in order to create a solution that fulfills the expectations. On the other hand, a list of wishes would be written, in which some aspects that would be desirable, but in a second place, can be found.

<u>Requirements:</u>

- Adaptability:
  - The simulator has to be used and adapted to different sizes of hands and arms.
  - There has to be no compensatory movements that may cause pain.
- Durability:
  - It has to be reused and the materials have to be strong enough to last at least 3 years.
- Functionality:
  - The simulator must leave free space in the forearm for the colocation of the electrodes.
  - Has to leave the wrist free to move.
  - Resemble as close as possible a healthy hand.
- Safety:
  - The material can't hurt people

- Comfortable to wear
- Distribution of weight

Wishes:

- As light as possible.
- As cheap as possible.
- Some sort of cable and battery management.
- It would be nice to have the possibility of moving the fingers independently.

Synthesis 1:

1. Pre-concepts:

One way to help the flow of ideas is to make a morphological scheme, which consists on identifying the sub functions, making a list of possible solutions for these sub functions and trying to combine these solutions into a definitive one.

In the particular case of this project, the table would be like this:

Sub function	Solution 1	Solution 2	Solution 3
Linking	Fixed to a bar	Stripes	Air cuff
Rotation mechanism	Ring inside of another ring	Sensors of motion and motors	Gears
Weight bearing	Distributing weight in a bigger surface	Anchoring to other parts of the body	Light materials

Table 2: Morphological scheme

In order to end up with a solid final concept is needed to brainstorm about the product and came up with ideas to solve the current problem. In the pre-concepts ideas are not discarded, but listed and analyzed. In the next steps they will be narrowed, combined if necessary and developed more in depth.

1. Rings:
   The idea would consist on a set of two rings around the wrist. The outer ring would be fixed, and the prosthetic hand would be attached to it, whereas the inner ring would be able to spin, and it is attached to the wrist allowing the pronation and supination movement. It can be mounted in the current support system (the glove).

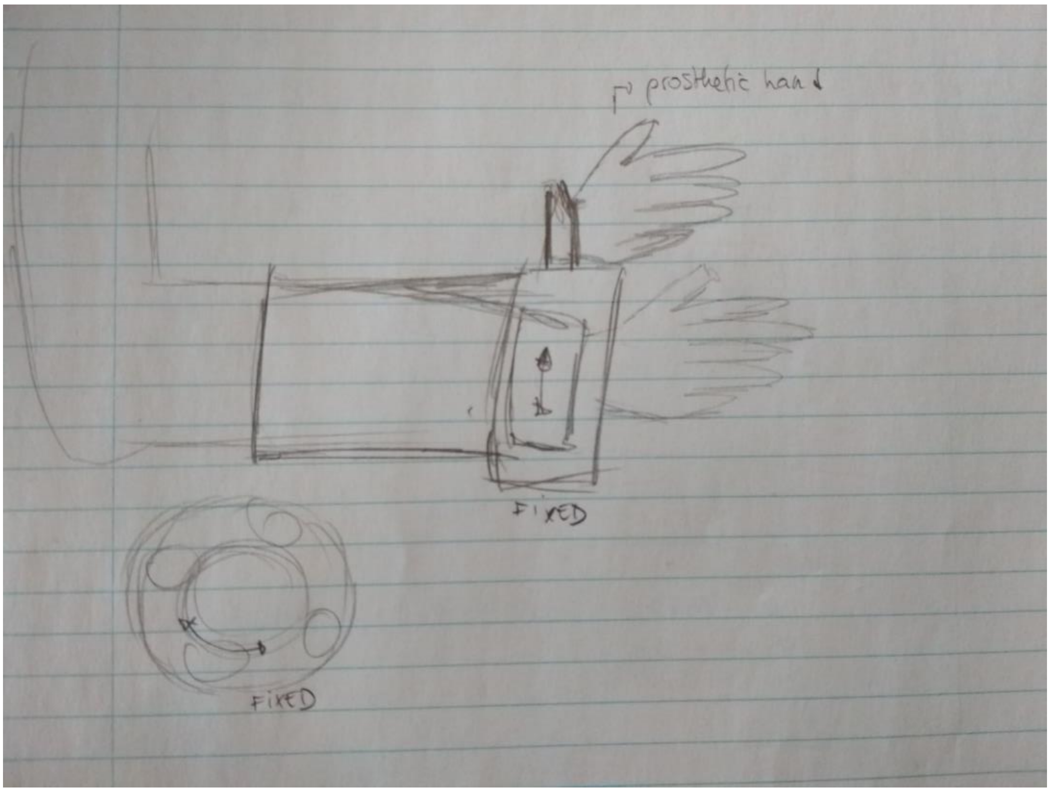

Figure 5: Sketch idea 1.

+ It allows pronation and supination movements.
+ Weight is distributed.
+ Adaptable to different people.
- Flexion and extension movements can be compromised (if needed).
- It can add weight to the already heavy hand.

2. Suspension system:

   The idea would be to use gyro stabilization and accelerometer technology. The apparatus is called gimbal and this kind of technology is used a lot in photography, to stabilize cameras. The gimbal allows the object mounted on it to remain independent of the rotation of its support.

   Mounting the hand in the base, would allow to move the wrist and the hand will remain steady.

Figure 6: Gimbal

+It allows all kind of movements of the wrist.
- Maybe it makes the simulator very heavy.
- It should be tested to see if it compromises the movement of the able hand in any other way.

3. Attach the prosthesis to the forearm leaving the wrist free and reinforcing the linkage:
   The idea is to leave the wrist free, but at the same time support the weight.
   + The wrist is free to move.
   + Simpler idea.

   - The weight will be supported by a smaller area of the arm, which can make it heavier.
   - The fitting to the forearm can be worse.

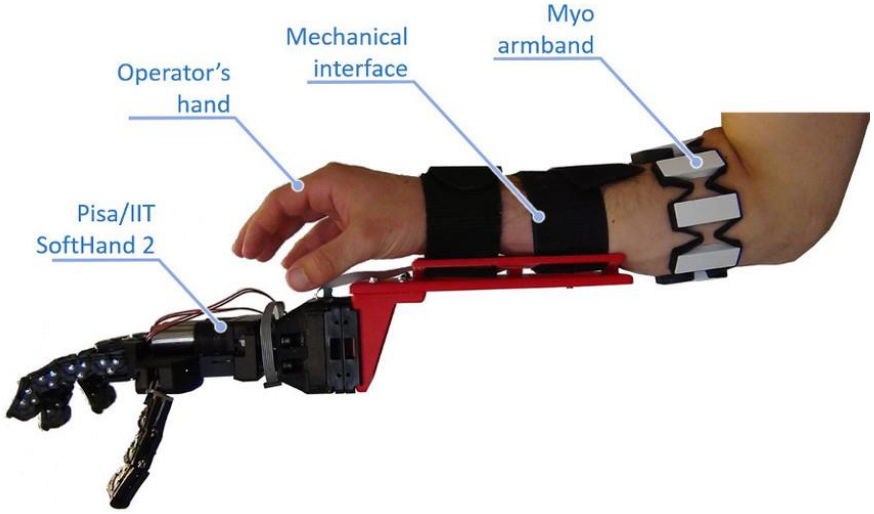

Figure 6: Attachment to the forearm[5]

4. Attach the prosthesis to the fixed part of the arm (above the elbow).
   It would be anchored to a fixed part of the body, where the rotation of the wrist/forearm would not affect it, but at the same time it would be near the actual hand position, which is preferred.
   + Not affected by pronation and supination movements.
   + Weight bear by stronger muscles.
   - It might be more uncomfortable to wear, or difficult to put.

5. Combination of 1 and 4.
   Double ring with the fixed part until the elbow for fixed anchoring. The fixed part would go up to the wrist, allowing flexion/extension movement.

6. Placing the hand distally, with the actual hand free to move.
   The hand would be after the real hand instead of under it[6]. That would be done by attaching two bars at both sides of the forearm that would be shaped in order to leave enough space for the hand to move and they would be linked together after the hand, forming a platform for the prosthesis to be mounted.

Figure 7: Hand placed distally [7].
+ You can move the hand freely.
+ The hand prosthesis would be in a natural position.
- The weight is increased because of the position of the hand.

7. Coupling the prosthesis to the other arm, or to the table.
   + The movements of the arm would not affect them.
   + Could be a solution for testing pattern recognition in its initial stages.
   - You can't perform some activities with it.
   - It wouldn't resemble a hand prosthesis as well as the other simulators, but maybe it can be used to check if something works.

2. Selection:

The last step of this synthesis phase 1 is to select one of the concepts described in this section as the final concept and develop it more in depth. In order to select which idea would be the chosen one, all of them would be scored based on how well they fulfill the requirements. In case there is a tie, it would be solved by punctuating according to the wishes. The way the scoring is distributed is from 0 to 2 (0 = "Not fulfilled", 1= "Fulfilled if changes are made", 2= "Fulfilled"). The requirements would be ranked from less to most important and at the end, the score would be multiplied by the rank to know the weight of each requirement.

Weight	Requirements/ Pre-concepts	1	2	3	4	5	6	7
	➤ Adaptability:							
7	The simulator has to be used and adapted to different sizes of hands and arms.	1	2	1	1	1	1	2
4	There has to be no compensatory movements that may cause pain.	2	1	2	2	2	0	2
	➤ Durability:							
2	It has to be reused and the materials have to be strong enough to last at least 3 years.	2	1	2	2	2	2	2
	➤ Functionality:							
6	The simulator must leave free space in the forearm for the colocation of the electrodes.	2	2	2	1	1	2	2
9	Has to leave the wrist free to move.	1	1	2	2	2	2	2
8	Resemble as close as possible a healthy hand.	2	2	2	2	2	1	0
	➤ Safety:							
1	The material can't hurt people	2	2	2	2	2	2	2
3	Comfortable to wear	1	2	1	1	1	2	2
5	Distribution of weight	0	1	1	2	2	0	2
	Sum	61	70	75	74	74	57	74

Table 3: Decision chart base on the requirements.

Number 3 is the one that scored higher and it was also the option preferred by the supervisor of the project, therefore it will be developed more in detail, taking into account that some changes must be performed in order to improve it, for example, it has to be adjustable to different sizes, it has to be comfortable and not load too much weight in the forearm area. Solutions to these problems would be provided in the synthesis 3 phase.

Synthesis 3

The idea chosen to be developed is to try to attach it to the forearm only, leaving the wrist free. This concept is similar to the current design of the simulator, and it is going to be used as base to develop the new one, for this reason a trial session has being scheduled to determine which changes can be performed to improve it.

In order to bear weight and fit properly, the socket has to be as long as possible taking into account that it has to leave the wrist free to move and space to place the electrodes in the muscle belly. Two different sizes of socket are proposed to satisfy this need in both males and females with the highest precision possible without having to personalize the socket for each user, which would be expensive in a long term. In average, male forearm length is 29.03 cm and female length is 26.25 cm [8]. The muscle belly is located approximately 5 cm distal to the elbow. 7 centimeters from the elbow would be left to make sure the electrodes can be placed at the right place. Therefore, the two lengths would be: 22 cm for male users and 19.25 cm for females.

In order to provide stability, the mount where the prosthetic hand is placed has to be rigid, to prevent it to bend or deform under the weight of the prosthesis. To minimize the weight the material used has to be as light as possible but tough, for example carbon fiber or polycarbonate. Polycarbonate, or PC [9], is a strong, durable and lightweight plastic very popular in the field of 3D printing [10], because it is also very easy to mold and has a very high impact strength. As we want it to be cheap also, polycarbonate is best choice, since you can 3D print the scaffold and it will be cheaper than carbon fiber.

As the base must be adjustable for different people and the rigid part cannot be changed for each user, a solution would be to insert in the base a sleeve that can be inflated by pumping air, like the one used to measure blood pressure, in this way, the base would be pressed tightly to the forearm. Another option are the Vac-Lok cushions [11], used in radiotherapy, which are filled with small polystyrene beads, and take the form of the patient when a vacuum is drawn through a valve, being reusable for different patients. It would be used in the base to adjust the size of the different users' forearms and the secured with straps. The air cuff or the Vac-Lok cushion would be attached to the mount by straps or glue.

In the base of the mount, a T-shaped protuberance would be placed longitudinally, with holes in its axis. The prosthetic hand will be mounted in a platform, that will fit the guiding rail in the mount and that will be secured sliding a bar through the holes, making it possible to change the longitudinal position of the hand.

In future works, and after testing to see if the design is firm and can be used for testing pattern recognition improvements, it can be studied the possibility of being able to change the position of the hand to distal position.

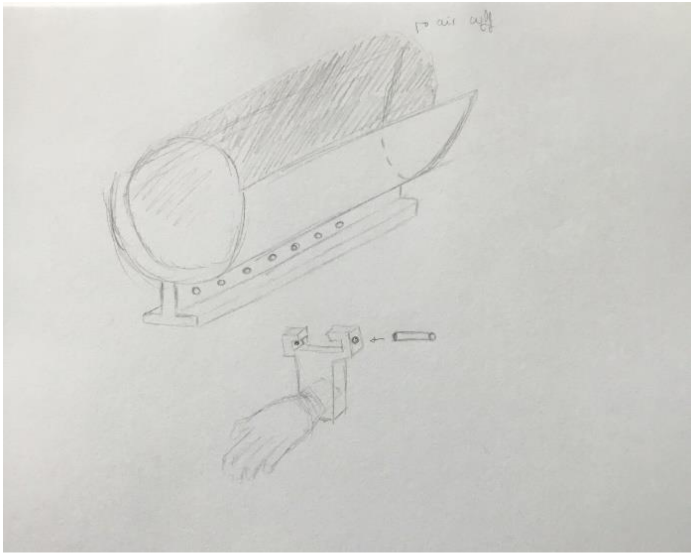

Figure 8: Sketch final concept.

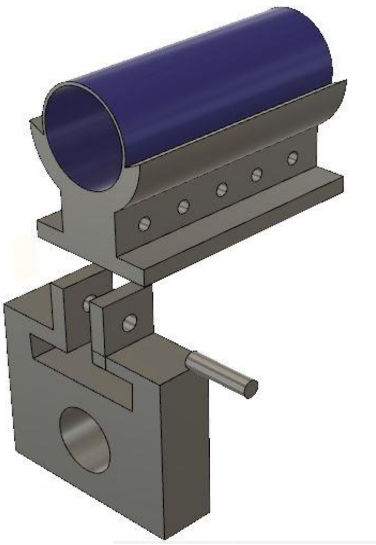

Figure 9: 3D model final concept.

Cost Analysis

An estimation of the prices it would cost to develop this idea is made in this section, taking into account all the materials involved besides the Michelangelo prosthetic hand, which is already in possession of the team. These materials include the plastic used to 3D print the base of the simulator, the air cuff used to adjust the simulator to the forearm and stripes to attach the air cuff to the mount base. A table with the market prices found on the internet is shown below:

Parts	Material	Price
Mount base	Polycarbonate filaments	36$/kilo
Inflatable camera bracelets (air cuff)		16$
Stripes	Nylon stripes	3$/meter

Table 4: Cost analysis

Of course, the air cuff would have to be ordered specifically for the forearm, meaning that one part of the cuff has to have a greater diameter than the other, corresponding to the middle part of the forearm and the wrist, which may make the air cuff more expensive.

Risk Analysis

The method used to perform the risk analysis is the FMEA (Failure Mode and Effect Analysis) where a table of possible risks is made, in every part of the process. Below, table x shows these risks with an identification for future references:

Category	Description	ID
Fabrication	3D model is wrongly design	1.1
	Materials are not delivered properly	1.2
	There are errors in the 3D printing process	1.3
Assemblage	The simulator is assembled incorrectly	2.1
Storage	The device is damaged	3.1
	It is stolen	3.2
	Some parts are broken	3.3
Functioning	The hand is not stable enough	4.1
	The simulator doesn't fit properly	4.2
	It damages the user	4.3

Table 5: Possible risks

Once we have the risks, the probability of those risks to happen is estimated as well as the impact that it would have in the performance of the product. Probability and Impact are important to calculate the priority of the risks, which ones are more urgent and need revision and plans to resolve them in case the risk takes place. Priority is calculated with the following formula:

$$Priority = \frac{(Probability\ +\ Impact)}{2}$$

Depending of the value of the priority it is classified as low, average or high.

$$Priority < 50\ \rightarrow\ Low$$
$$50 \leq Priority \leq 60 \rightarrow Average$$
$$Priority > 60 \rightarrow High$$

In the following table the scoring of the priority is shown:

ID	Probability	Impact	Priority	Classification
1.1	30	60	45	Low
1.2	10	60	35	Low
1.3	20	50	35	Low
2.1	15	50	33	Low
3.1	10	60	35	Low
3.2	15	70	43	Low
3.3	20	50	35	Low
4.1	35	60	48	Low
4.2	30	75	53	Average
4.3	25	100	63	High

Table 6: Risk classification

After the priority classification a plan can be made to solve the potential problems that the average and high labelled risks may have, because they are the more urgent ones. In this particular case there are two risks in that category, which are that the simulator doesn't fit properly and that it can damage the user. If it doesn't fit we have the second option, use the Vac-lok cushions and stripes to tie the base and if it damages, the stripes can be covered by foam to prevent them for digging into the flesh.

Conclusion

To conclude, an idea has been developed trying to give an alternative solution for the anchoring of the hand prosthesis simulator to the healthy arm of an able-body person, making it adjustable for different users and leaving the wrist and the hand free to move. Future works would be the building of the idea, 3D printing the base and buying the rest of the components and testing the new device. One of the main requirements was to have the hand stable, and taking into account the calculations made before, and that the air cuffing is made of a soft material, it may be the case that the prosthesis moves a little. In that case, the second option (using the Vac-Lok cushion) would be contemplated, because, although it may be more expensive, the use of this cushion would make the base fit any forearm in a unique way, and then, the base will be tied with stripes. Apart from the fit adjustment to the forearm, the other important requirement is that the prosthetic hand doesn't turn and change places when pronation and supination movements are performed. It would have to be tested, but the farthest from the wrist you make the tight attachment, the less the hand would move, although it may be possible that the movement couldn't be completely eliminated, due to the anchoring to a rotating part of the body. Anyway, it would allow you to perform tasks, because the hand is free to make any movement, and this movements would be transmitted to the prosthesis via pattern recognition control.

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