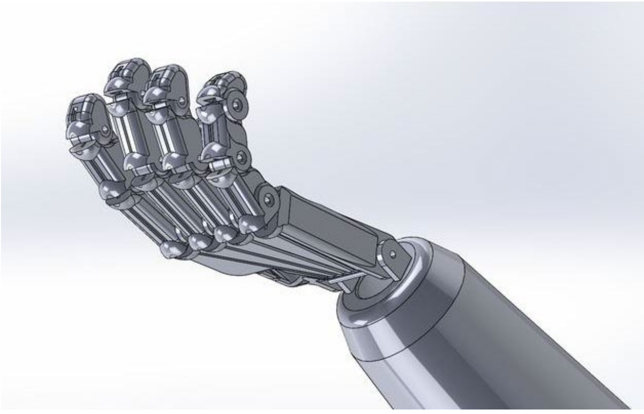

TESI REPORT

Course 2022/2023

LIMB PROSTHESIS WITH ARTIFICIAL SKIN

Limb amputations are a more common problem than we think. That is why we have developed a very realistic prosthesis that comes with an ultrasound-powered muscle detector and an artificial skin, all thanks to Megamorph.

Team Superhumans

Aaron Vaquero, Estela Álvarez, Gabriel Marí, Miguel Tarancón

esade RAMON LLULL UNIVERSITY · UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH · IED · ATTRACT

Outline

1. Project text

Limb amputations are a more common problem than we think. In fact, there are more than three million amputations each year due to several reasons. Prostheses try to make life easier for the people who suffer from it, but a lot of developments are still needed to obtain good replacements for real limbs.

Our solution consists of a prosthesis that uses Megamorph, acting both as an ultrasound transceiver and a pressure sensor. It detects the muscle activity around the amputation point with ultrasounds, and then converts this to movements of the prosthesis. Moreover, covering all the prosthesis with Megamorph, we can detect the pressure and create kind of an artificial skin.

With these two features, we are closer to creating a more realistic prosthesis than ever before.

2. Key insights on the process

The graphene membrane turned out to be reasonably suitable for detection tasks together with ultrasound, as the pixels can operate as mechanical transceivers. Applying certain voltage to the membrane it bends at a frequency, emitting ultrasound waves. As the graphene is sensible to mechanical perturbations, it can also act as a receiver, and the combination of pixels receptions results into a precise mapping.

Regarding the ultrasound applications, it is a current suitable technology for body scanning and commonly used in echography procedures. Now imagine a kid gets hurt and parents want to check if any bone is fissured or broken, and can do so with a simple phone. Moreover, a doctor can instantly check whether there's a need to go the hospital or some rest is enough for the moment. Thus, could be helpful to solve hospital congestion and as well during the follow-up after an injury. As the pixels are in a micro scale it can fit in any device, despite size and hardware due to Megamorph's easy integration. Probably some years will have to pass until phones' hardware will be embedded enough to incorporate ultrasound detectors. Nevertheless, Megamorph stands as a great solution for a couple of reasons. In the first place it provides a great resolution in the imaging due to its precision and granularity when sampling. In addition, its low energy consumption and compatibility makes it feasible in any embedded system or device.

When talking about ultrasounds, other possible applications show up. For instance, a microscale, taking advantage of the 10 microns size pixel and sensibility of the graphene layer. At some point the team found out that ultrasounds are useful to remove microplastics in water. Basically, the device would emit ultrasound waves creating stationary waves at certain points where microplastics would be trapped and filtered. The recent research regarding this filtration system has some limitations, as the actual probes are done in a millimetric pipe, with a low flow capacity. Thus, at the moment would not be a feasible idea to clean oceans from microplastics as it would not be able to make any effect, but it could be integrated in washing machines and other home appliances for chemicals filtering. Though for the case, other cheaper filtration methods would be preferably in the sustainability/cost trade-off.

Then, stepping back to body detection, another solution took place, use Megamorph to scan muscle activity in real time. As well, we took other similar directions such as a haptic feedback device, to control a robotic arm simply by moving your arm on the Megamorph device and detecting the movement throughout ultrasound waves mapping. Useful in some dangerous manufacturing processes, involving toxic substances.

This direction started to open an interesting window in the body care area. That's when the team looked on prosthesis and started to think how could Megamorph help people who suffered an amputation. Now the challenge was to build a prosthesis that could be freely controlled and be sensible to contacts.

To provide the desired movement to the hole prothesis, Megamorph was a suitable solution as recently discussed, as it allows the real-time muscle activity scanning and thus placed in the amputation point reveal the intended movement. Combined with neural networks and machine learning to interpret those samples and recreate any movement. Talking about the sense of touch, placing Megamorph all around the prosthesis as an “artificial skin” would do the work, and this time the Megamorph pixels would act as force detectors, being able to map the contacted area and the pressure applied as the graphene layer is sensible to mechanical perturbations, just like commented previously. Now Megamorph would indeed complete those tasks, although there is one constraint about bringing the information detected by the Megamorph skin up to the brain to be properly processed. Since ultrasound don't work with neural impulses and current methods based on electrodes are not precise enough, it's not a worthy option yet. For this reason, the team decided to bring an alternative until electrode technology is sufficiently developed and trigger certain areas around the amputation point, involving a new learning process of sensations.

3. Design process

The process started with a display formed by and array of micropixels called Megamorph. This graphene pixels can operate in a wide range of frequencies, from visible spectrum up to ultrasound waves. At this point the brainstorming process was focused on applications based on mechanical waves, taking profit of the Megamorph features.

After deciding on what would be the final application for which we would use Megamorph, we began to study how we could efficiently apply it to our proposal.

We started with the analysis of existing prostheses and the study of the anatomy of the hands and other upper limbs. We also take into account the communication made between the brain and the muscle that makes the movement thought by the patient to be executed.

In the challenges faced throughout the design process, we encountered several challenges that required careful consideration and problem-solving. Some of the difficulties included:

a. Miniaturization: Integrating Megamorph technology into a prosthetic device required overcoming size and weight constraints without compromising functionality or user comfort.
b. Sensory Feedback: Ensuring the prosthetic device provides users with appropriate sensory feedback was a complex task. The ability to gauge grip strength and object manipulation is crucial for a natural and intuitive user experience.
c. Customization: Designing prosthetic devices to cater to individual needs and preferences posed a challenge, as each user may have unique requirements and anatomical considerations.

The development of the design was based on our previous studies, aiming to find the materials and ways of execution that would result in the lowest possible cost and production time, and seeking for a financially accessible final product that could be applied even in the most remote places. It involved understanding the technology, researching potential applications, discarding unfeasible options, and selecting prosthetics as the focal point.

The main proposal aims to develop a prosthetic device utilizing Megamorph to enhance individuals' ability to perform simple tasks, thereby improving their quality of life. The process encountered challenges related to miniaturization, sensory feedback, and customization, which required innovative solutions. By addressing these challenges, we aim to create a meaningful social impact and contribute to the advancement of assistive technologies using Megamorph.

4. Introduction of the final prototype

The final prototype is an arm prosthesis with two key features.

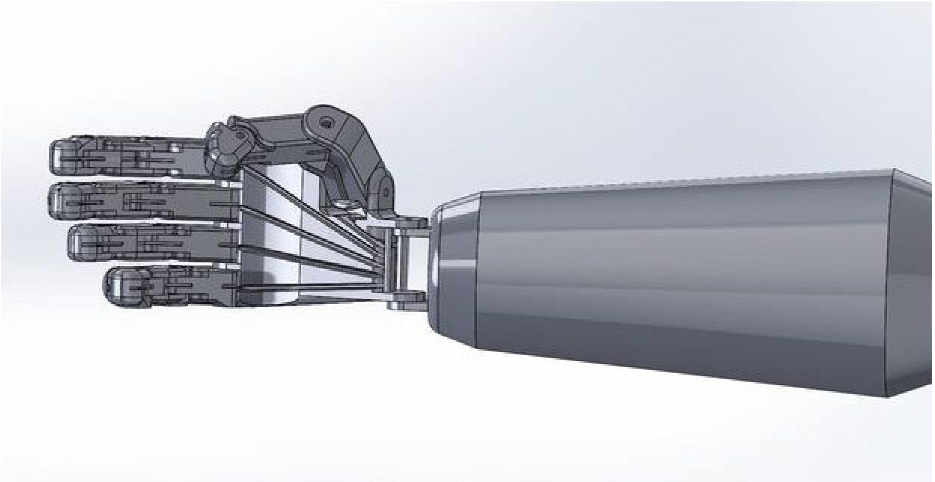

Figure 1: Final prototype

The first one, which is the one that differentiates it from the rest of prosthesis, is the wat it detects the muscle activity at the amputation point. Around the insertion cavity of the prosthesis, there is a like a bracelet that surrounds the arm which is made with Megamorph. This acts as an ultrasound transceiver, and can measure the different variations of the muscles when the person tries to move the arm. These measurements are taken to the processor of the prosthesis, which is inside it, and, through AI and other algorithms, is converted to the proper movements of the prosthesis. These movements are carried out by different mechanical parts and engines, like the ones we have at actual prosthesis.

The other feature is what we call an "artificial skin". This is a coating of Megamorph around the prosthesis which can detect, at different points, the pressure we are doing. Here, Megamorph has a completely different use, because it is acting as an haptic sensor. The measurements are processed by the on-board computer of the prosthesis and are converted to signals that are recognized as touch for the brain. Here, AI could be used to create more real signals, which are as close as possible to those that carry nerves to the brain.

At this point, we have a technological difficulty that we have to overcome. It is the method by which we transmit the touch signals to the body of the person. We have though two possible solutions. The first one is doing it by electromyography techniques. They consist of many micro needles that are attached to the arm's patient around the amputation point, and the signals are transmitted to the nerves and all the way to the brain. With this solution, we could obtain a nearly realistic sense of touch.

However, we have thought a second stage solution that could lead to an even more realistic sense of touch. When nerves connections are further investigated, we could transmit the signals directly to all of them, so we could create signals like the real ones and send them to the brain. The patient would be able to feel the same exact sensations as the ones of the real limb. Moreover, we could send the signals to the nerves wirelessly if a receiver is put inside the patient. This way, we would obtain a completely non-invasive prosthesis, that would permit the patient to remove and put it whenever he wants.

5. Insights from Dr. Lluís Guirao interview

Dr. Lluís Guirao, an expert in the field of prosthetics, recently provided a wealth of information regarding the latest developments in the industry. The primary focus of the discussion was the potential benefits and challenges associated with modern prosthetic technologies, including non-intrusive myoelectric prostheses, haptic feedback, and osseointegration.

According to Dr. Guirao, a major advantage of myoelectric prostheses is their non-intrusive nature, which allows the device to be placed within the socket without the need for surgical alteration of the conventional part. The most advanced versions of these prostheses have the capacity for a significant range of movements - up to 18 to 22 different patterns - although it should be noted that many patients may not currently be able to fully utilize this potential.

One standout feature of these devices is the proportional controls, which enable the user to regulate the speed of the prosthetic movement. However, the level of muscle atrophy in the patient can present a challenge to this system, since it limits the capacity to access the 22 movements. In other words, the current does not have a resolution good enough to read atrophied muscles, therefore patients can only access 3-4 movements of the potential 22.

Manufacturers such as Ottobock and Össur are leading the way in this technology, offering multi-articulated hands with up to 8 channels. The latter company, based in Iceland, has developed a prosthetic system that uses intuitive controls: the user simply thinks about the movement, and it's executed by the prosthetic via muscle control.

The myoelectric prosthetic system, named Mioplus, is praised for its high precision and intuitive interface. Patients using this system could potentially perform up to 18 to 22 movements. However, again, the atrophy of the muscles still limits the access to the 22 movements. The key to this system is its intuitiveness, as users can initiate movements as naturally as if they were using their own limbs.

In terms of sensory feedback, Dr. Guirao discussed the advances in haptic technology. This includes variations in color and sound as ways to convey information to the user. In Sweden, prosthetics with thermal feedback are being developed, although pressure feedback is not yet a feature. Ideally, such haptic feedback mechanisms should be integrated within the prosthetic socket, reducing the reliance on external devices.

Dr. Guirao also mentioned a surgical procedure known as Targeted Muscle Reinnervation (TMR), pioneered in Chicago, which is invasive but can reposition muscles for improved prosthetic control. This process is ideal for amputations that are proximal to the shoulder.

Osseointegration, a procedure where the prosthesis is directly attached to the bone, was also discussed. This method offers increased potential for sensation and movement but comes with a higher risk of infection due to the intimate bone connection.

While these technological advances are impressive, Dr. Guirao emphasized that the real challenge lies in patient training and adaptation. This is not a criticism of the technology, but a reminder that patients need time and support to fully utilize these advanced systems.

Lastly, he touched on some practical considerations in prosthetic use, such as seasonal changes leading to contraction or enlargement of the prosthetic socket, and the associated sweating that can impact fit. Mobility within the socket is key, and we believe that Megamorph could be vital in ensuring the prosthesis remains securely in place.

Although promising technologies like Mioplus have emerged in recent years, Dr. Guirao highlighted that the prosthetic revolution is still very much in progress, and there is still much to be achieved.

From this interview we had the confirmation from Dr. Guirao that Megamorph potentially can help in certain key points. For example, the precision of Megamorph can be essential to have a higher resolution of the atrophied muscle, and therefore easy the process of the patient to access to the potential 22 movements.

Moreover, the Megamorph's precision can really help during the sessional changes of the muscles in terms of enlargement and contractions. These changes can really affect the movement of the prosthetics, since the change of form of the muscle difficult the process of reading them and therefore the AI can interpret nor translate what is the action that the prosthetic must do according to the movements of the limbs in the amputation zone. With higher precision it is easier to read the changes that the muscles have gone through and train ai to adapt to these sessional changes.

6. Reflection of the student learning

Throughout this project, we have not only learned how to collaborate effectively with individuals from diverse backgrounds, but also how to effectively communicate our professional terminology using different vocabularies to enhance our interactions.

Given that we all hail from different universities, we faced the challenge of coordinating our schedules, which necessitated learning how to work independently without the need for daily meetings. This experience taught us the importance of setting clear rules and effectively distributing workload based on each team member's competencies.

One aspect that we particularly appreciated was the opportunity to engage in coaching sessions, where we could discuss and seek guidance for any uncertainties we encountered. Consulting with our instructors clarified our doubts and provided us with valuable insights to guide our project direction. Moreover, this project has sparked an interest in scientific research as a potential professional path for many of us. We have realized that we would like to delve deeper into this field and explore its possibilities. It is worth noting that other team members brought their expertise in the business world and its methodologies, which further enriched our collective experience.

In conclusion, regardless of our respective fields of expertise, this project has been a highly rewarding journey for all of us. We have grown both personally and professionally, and we look forward to continuing our exploration and pursuit of knowledge in various domains.

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