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1 Preface:

The motivation we found about artificial bodyparts is just about the interest in robotics. The variety of the parts you can replace, with what you can replace it, is just really inspiring. It is very interesting to see how creative people got in order to replace certain body parts. Also the aspect that prostheses are helping people a lot is important. A look into the future just leaves open what can happen. Nobody can really know what boundaries we're gonna push within the next decades. And that it's so open to what might happen we think is really interesting. The ethical and functional questions raised about the topic are all really interesting and are bound with us wanting to know more and more about the topic. It's a subject we knew little about before that paper. But after we dealt with that matter, we feel like we really learned a lot about the prostheses.

2 Introduction:

2.1 What is the recent scientific history? Are there any recent events?

May 20, 2015 the New York Times published an article of prosthetic limbs being controlled by thought. It's the story of Les Baugh, who lost his arms as a teenager. He contributes to a study (Johns Hopkins University) for the control of these limbs to be controlled through the mind. This special prosthesis can pick up signals from his brain with an implanted chip and with that can control his arms. This artificial limb is called M.P.L. which stands for Modular Prosthetic Limb. The problem with this special limb is that there are only about 10 fully funtional ones existing and that their cost is around 500'000 dollars each.

October 15. 2015 researches from Standford University in California were able to reproduce mechanoreceptors. Mechanoreceptors are the part of our skin where we can feel when something or somebody touches it. What that means is they made a flexible material which is able to "sense" different pressure applied on it and give signals out.

September 21. 2015 based on the research and results of the John Hopkins University and from Standford University it was possible to create an arm that restores the sense of touch of a person. While the prosthetic arm of the JHU only sent signals, the newer prosthesis also receives them with the artificial skin. This will make handling objects easier and will give the people who have lost a hand, or are paralized the ability to feel again. The chip giving and receiving those signals is wired directly into the brain in two main areas -> the brain's motor cortex region and the sensory cortex. This was made possible by the so-called DARPA (USA's Defense Advanced Research Projects Agency) with their direct comment: "We've completed the circle" and what they mean with that is that they made a prosthetic arm that can feel and move just like a normal arm, but is robotic.

2.2 Where and why is the technique used?

We're focusing on the replacement of limbs in general but the really interesting parts of research in the area of robotics or artificial limbs is with arms and especially hands. But the application of robotic prosthesis really doesn't have ends with replacing limbs. You can somewhat easily, if there's enough money around, replace every bodypart of the human body, besides some internal organs, such as the brain. But you can even get a nonrobotic prosthesis of your eye. The technique of replacing a limb or something else of your body is either because you've lost that part, be it through an accident or anything else, or you want your arm to be robotic, which would lead us in the direction of cyborgs. Either way you can replace your missing bodypart for the sakes of: Beauty/ fashion, discreetness, and maybe soon even enhancement So the boundaries of the prostheses are yet to be discovered.

2.3 Are there alternative treatments?

Instead of robotic prostheses you could also replace them by nonrobotic prosthesis. There are a lot of different kind of nonrobotic prostheses. There are websites for alternative prosthetic services. There you can really costumize your artificial limb. This has somewhat turned into art, where you really are completely free to do with it what you want. E.G. you can have a plastic snake going through your arm if you like that or you could have a so-called gadget arm (see picture), where you can pull out one of your fingers to get some matches!

There is always the oppertunity of just not replacing the missing part of your body, to not cover it.

3 Function

In this part will be explained how different prostheses function and what the advantages and problems of those different types of prostheses are.

3.1 Leg prostheses

Leg prostheses, which are used in everyday life, have sensors built in, which are observing the environment all the time and automatically adjust the deflection of the knee to the situation. Like this, the porter of the prosthesis doesn't actively move his prosthetic leg but the prosthesis itself makes the right moves in order to walk. With such prostheses, even complex movements like walking backwards or climbing stairs can be done.
Despite this advanced method, prosthetic legs are still far away from working as good as a biological leg. The cycle, of nerves sending information to the central nervous system, which proceeds this information and sends signals back in fractions of seconds, is just too hard to copy.

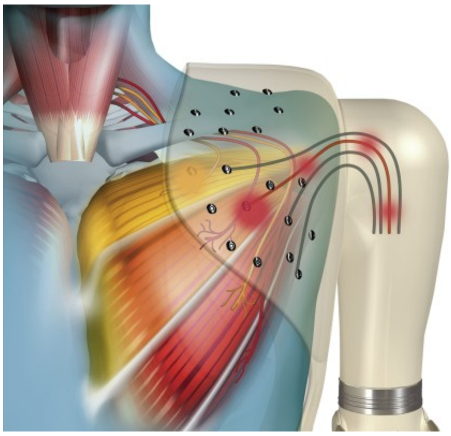
3.2 Arm and Hand prostheses

A human hand can do 22 movements simultaneously she has 22 so called degrees of freedom. On top of that, she has many thousands of sensors that can measure many information like force, pressure, heat, pain and so forth. Hand prostheses can therefore not be automatized like leg prostheses. The user has to be able to actively control the movement of the prosthesis. There are many different approaches on how to build a prosthesis that works like a human Hand. However, most prosthesis can do far less than a human hand can.

3.2.1 Myoelectric Prostheses

Myoelectric prostheses use signals from muscles and proceed them into movements of the prosthesis. The muscles work as an intensifier of the nerve signals.
One possibility is to use the muscles in the remaining part of the arm. Electrodes on the skin, measure the activity of those muscles and if the user contracts those muscles, the electrodes capture this myoelectric signal, which is then proceeded into a certain movement, by example closing the hand. If the user now wants to make another movement with his arm, by example bending his elbow, he first has to switch over to this other command, normally by the short contraction of two muscles. If he now contracts the muscles in his arm stub, the electrodes once more capture the myoelectric signal and the signal is proceeded into a bending of the elbow.
This method works very reliable since 30 years, because it isn't very complex, and is therefore often used. However, to be able to use this kind of prosthesis properly you need a lot of training, because it is obviously not very usual to move your hand with the muscles in your upper arm. Also even the best prostheses of this kind, only have a maximum of 6 degrees of freedom rather than 22 and you can't feel anything that you touch with the prosthesis.
Some advanced models of myoelectric prostheses can recognize up to 10 different muscle-contraction-patterns and can therefore steer several degrees of freedom simultaneously. But these prostheses only work well in laboratories under perfect conditions. In everyday life, there are too many disturbing factors. If by example the place of the electrodes changes, the prosthesis doesn't work anymore.

3.2.2 Targeted Muscle Reinnervation (TMR)



TMR is a special method of using a myoelectric prosthesis. The nerves, which originally supplied the amputated arm and hand are redirected into other muscles. Usually this muscle is the big pectoral muscle (Pectoralis major). The big pectoral muscle first gets segmented into four parts. Then the nerves get redirected in such a way, that they grow into the muscle. The big pectoral muscle now sends the necessary myoelectric signals which are used to steer the prosthesis.
This surgical intervention works out of two reasons. First the CNS (central nervous system) sends the signals for moving the not anymore existing body part even years after the loss of it. Secondly peripheral nerves are very good in regenerating and can even grow into other muscles.
It takes about half a year after the operation until the nerves have grown into the new muscles and the patient can start to use the prosthesis. During this time, he trains his pectoral muscles and helps the nerves to grow into the muscles by imagining to move his nonexistent arm and hand.
When the nerves are grown into the muscle, the imagination of a certain movement of the hand, generates a certain myoelectric signal which is then again caught by electrodes and proceeded into the right movement. The imagination of different movements should generate myoelectric signals at different places. The further apart these places lay, the easier it is to

read them. In the ideal case, the patient should be able to move his artificial arm simply by imagining the movements. Just like moving a biological arm.
TMR doesn't only work with the big pectoral muscle. If there is still a part of the arm remaining, the nerves can also be redirected into the muscles of this arm stub. Sometimes there are even some muscles transplanted in order to create a good working stub.
Another advantage of the TMR is, that people with an amputated arm often feel pain because the remaining nerves just don't stop to grow and form so called neuroma which after sometime have to be removed operatively. When the nerves are redirected into muscles, they don't form neuroma but grow into the muscles and create new synapses there.
An interesting aspect about the TMR method is that not only motoric nerves, but also sensory nerves grow into the muscle. This means, that if something touches the chest of the patient and these nerves get stimulated, the patient has the feeling, that something is touching his nonexistent hand. Actual research is investigating on how to use these nerves best for giving a feedback to the CNS when something is touched by the artificial hand.

3.2.3 Shared Control

The so called shared control approach has similarities with the leg prostheses described earlier. Optical and inertia sensors can recognize an object when the prosthesis comes close to it. The prosthesis then automatically makes the correct movements in order to grab the object. The user only gives the order to grab the object through myoelectric signals. The user can also interrupt the process of grabbing or direct the process completely by himself if he needs to.
The biggest challenge with this method is the exact recognizing of the object with the sensors.

3.2.4 Functional electric stimulation

This method does only apply for patients that have been paralyzed and can't move their arm anymore. Through low electrical impulses in order to stimulate certain nerves, which then leads to the right muscles contracting. The prosthesis is normally a gauntlet, which you can take on and off. The gauntlet is connected to a sensor which is attached to a body part that can still be moved by the patient. If the sensor is by example attached to the shoulder, the patient can close his hand if he moves his shoulder upwards, and open the hand again if he moves his shoulder downwards.

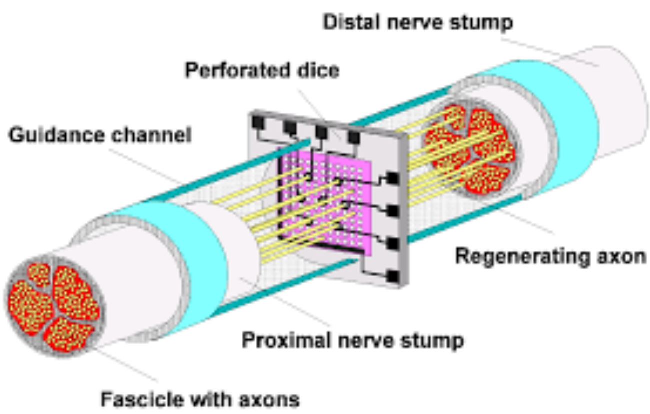
3.3 Invasive signal capturing

In most prostheses electrodes measuring myoelectric signals are attached on the skin of the patient. However, signals can be measured with a higher precision if the electrodes are attached directly on the muscle or even inside the muscle. In addition, electrodes on the skin sometimes slip off or change their place slightly. This inaccuracy doesn't exist if you implant the electrodes. These implanted electrodes send the signals to the prosthesis wireless because if cables come out of the skin, the risk of infections is pretty high.

3.4 Connection to Nerves

Most prostheses are myoelectric, that means they get their signals from the movement of muscles and not from the nerves directly. The method of implanting electrodes directly into the nerves is being investigated. There already have been some successful experiments but

at the moment this technique is not very far developed. The big problem is that you can’t attach an electrode to every single nerve fibre. Therefor one electrode often gets different signals from different nerves, which are also overlapping themselves.
On top off that it is difficult to distinguish between motoric and sensory nerve signals Also the risk of destroying some nerves while implanting the electrodes is relatively high. However, if you could manage to find the right nerves and implanting electrodes there, you could probably build a prosthesis that works much more like a human arm or also leg. you could even get the sensory nerves to send back information to the CNS when the artificial limb touches something.

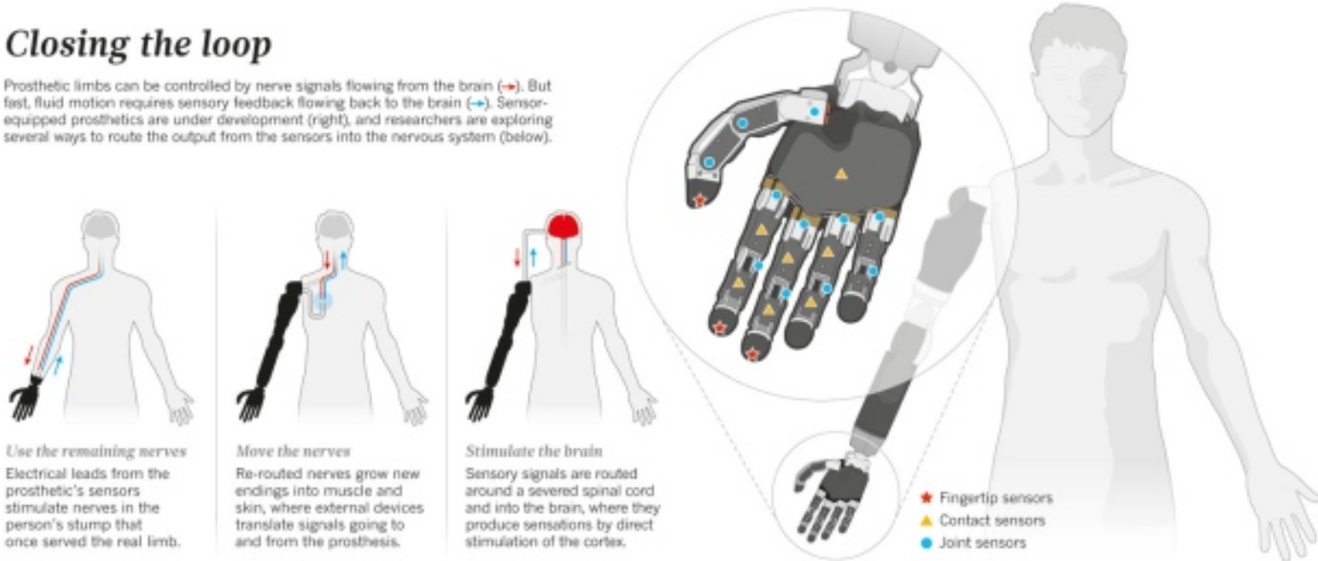


This picture shows a neuro sensor chip implanted directly into a nerve

3.5 Connection to the brain

Similar to the nerves the implantation of electrodes into the brain in order to steer prostheses is being investigated. There have already been successful tests on humans, where by example a paralyzed person was able to drink from a glass with a robot arm just by imagining the required movements. The difficulty in this method lies in the complexity of our brain. We just know to less about which part is responsible for which exact movement. Also the operation with which the electrodes get implanted is quiet complex and risky. You can however already get good signals with the so called EEG-method where the patient wears a “thinkcap” with many electrodes on it. With this method, the patient could also receive some sensory feedback directly in the brain if the prosthesis comes in contact with something.

These are the three different approaches on giving a sensory feedback to the CNS



4 Discussion:

4.1 What progess was made with the application of the chosen technique?

The history of prostheses is actually very old. One of the oldest pieces is from ancient egypt. The wooden and leather toe is from 950 – 710 B.C. But the egyptians weren't going for the functionality or medical use but rather for the aesthetics coming with it. Prosthetics are even mentionned in the history of the greek where Hegesistratus cut off his foot to escape the spartans and then later replaced it with a wooden foot. But not only the greek and the egyptians had the idea of replacing a missing bodypart, the romans as well. There's a story of a roman general whoms hand was cut off and to run into battle he was given a metal hand. But as with every other invention there have been ideas worth expanding and some which are left aside. One thing that has prevailed for example is the having the foot in a locked position, wheras the iron prosthesis was an idea left aside. The pegleg is one of the first "regularly" done prosthesis for the leg but only for the wealthy in 471-1000 A.C. It's basically just a stick from below the knee. An artificial leg from 300 B.C. has been found in 1858 which was made from wood, iron and bronze. In the renaissance other than the materiels nothing really changed from wooden only it went to iron, steel, copper and wood. Around 1530 Götz von Berlichingen has made an iron hand which was incredible for the time back then. It was able to move the fingers, the thumb in with two joints and was able to bend the hand. Ambroise Paré was like a father to prostheses and amputation. He also invented a prosthetic leg from above the knee, that was in the second half of the 16th century. The evolution of prosthetics has led to using differnet materials, such like plastic and aluminium. Robotics and their research have also led to a huge improvement in that field. Today the best of the prostheses look very similar to a natural limb and also are easily movable. The first step towards the movement of the prosthetic limb was to connect the muscle to it, so you would have to tense a muscle 2-3 or more times to let the prosthesis perform the movement you wanted from it. That has to be very tiering over time. Then there was the possiblity of the artificial limb to be connected to the nerves themselves and receiving the electrical signal from the nerve, which of the muscles should be tensed. There were also prosthetic limbs especially legs which could process the environment and like this tell what you were going to do next and do the step basically for you.

The newest method is that there's a chip implanted attached to your brain and it sends the signals, which the brain would send to the limb, it sends it to the robotic limb. With this very advanced technique paralized people can wear prosthesis and move again. The next step was to let the robotic bodypart "feel". Electrical signals from the chip were sent to the brain and let it "feel" again.

4.2 What future research steps?

Future research steps would be to make the robotic limbs more powerful and less energy consuming. Maybe have them have easily replacable parts. Speed and reaction time of the prostheses can be improved. Also making the movements more natural and making it look better is still apart of investigation. One of the biggest future steps will be to create a more realistic sensory feedback, when the prosthesis touches something, that means to make the prosthesis able to feel things.

4.3 Discussion of ethical apsects?

Who has the right to get the newest and really expensive prostheses? In the U.S.A. people who served the army and lost limbs get the newest possible technology and don't have to pay a lot for it, because the state takes a lot of thse costs. People who have lost their limbs in accidents get low cost artificial replacements with low functionality and low aesthetics. With not everybody just getting the newest available technology it is becoming a market, with advertisement and all that, and with that money gets an even bigger influence over the human race than it had before. Have or have-not a limb. There is a story of a boy that wanted an artificial hand from the NHS (National Health Service) who turned him down, he then asked Mercedes, if they would help pay it if he placed their logo on it. They gave the boy 30'000 dollars. This is advertisement on a new level.

And what if those bionic limbs would let you type faster, or let you run faster? Be more accurate and stronger? Would you have the right to amputate your natural arm/ leg/ whatever it be? Would only the rich get access to it? Would a natural limb be a disadvantage and the business would be actively looking for people with artificial limbs?
Richer and poor even bigger gap inbetween?

With these bionic limbs, there is also a danger of them getting hacked. How do you handle that?

5 Summary

All in all, the research and progress in functional artificial limbs is a very actual topic. Every year improvements are made in the technologies of prostheses and they might raise some big ethical questions in the future. However, in our western world, only a small amount of the population is in need of a prosthesis, which makes the topic less important for our every day life. This is also why many prostheses struggle to sell themselves and you may have to ask yourself if its worth to put much research in something only very few people can use.
We both found the topic very interesting and were sometimes really fascinated of what robotic arms are able to do and how they help people.

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Plus some videos on youtube on humanoid robots, androids and prosthesis.

6.2 List of literature

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7 Attachment:

7.1 Interview

Our interview partner was the PhD Levi Hargrove, who is working at the Rehabilitation Institute of Chicago, which is one of the leading institutes in prosthesis research all over the world and from which we often read during our research. We were in contact with him through Mail and these are his answers to our questions:

Our paper, and with that our questions too, relate specifically to prostheses which can be moved and which are replacing either a leg or an arm.

1) What exactly is your job?

I am director of a research and development lab that creates prosthetic arms and legs. I supervise engineers, scientists and students. I write grants and journal papers. I also write software algorithms and analyze data.

1.1) Is it in the research area or engineering?

I perform both research and engineering activities. We do research to identify problems, and then engineering to solve them.

1.2) With what type of prothesis are you working?

I am working on two different bionic leg prostheses, a bionic wrist, and bionic hand/fingers.

1.3) Why have you chosen that area as your profession?

I chose this profession because it is rewarding to help amputees and is very challenging. I always liked math and science, so this was a natural area for me to work in.

1.4) Why do you think your area of work is especially interesting?

Most engineers work with equipment like electronic circuits. I get to work with people and equipment. It is very fun and challenging how to get people to work well with prosthesis. I like trying things and then asking them how they like it.

1.5) What does your regular working day look like?

I get into work around 7:45 and answer my emails until around 8:30. Then I typically have a few meetings in the morning, and do some data analysis or build something like a prototype. After lunch, I usually have a few more meetings and then work on a journal paper or grant. I leave work around 6 at night usually.

1.6) Where?

I work at the Rehabilitation Institute of Chicago which is a specialized hospital in downtown Chicago. My lab is on the 14th floor.

1.7) With whom?

I have around a team of 15 people that work for me.

1.8) When?

Monday – Friday, 8:00-5:00 pm are normal working hours.

2) Is it painful to implant an artificial limb?

Most artificial limbs are not implanted. They are held on with a socket. This is like a shoe that goes over your foot. They are not painful, but they are hot and heavy.

3) Can your body get exhausted by using the prosthesis? (e.g. doing hard physical work)
Sure, if people walk a lot or work a lot they get tired. It takes around 60% more energy to walk with a prosthesis.

4) How affordable is a prosthesis? Is it only for the richer people?

There are a wide variety of options for people. Some are cheap, and some are expensive. In the US they are mostly covered by insurance.

5) Is it possible for the prosthesis to show defects?

Yes, this is possible. When they show defects they send it back to the manufacturer for repair.

5.1) Should you be worried that if, for example, you're carrying a pot with hot water your artificial arm sits out and you get burned?

Yes, you need to be careful when wearing the prosthesis. Most people have someone like a therapist teach them how to use it and what they should and shouldn't do with it.

6) Could you produce artificial body parts in moderation to lower their price or is every prosthesis a unique or specifically produced?

Yes this is possible and people are working on it. The prosthses is produced in bulk and the socket is customized for each person.

7) Is it possible to hack an artificial limb?

It is possible to hack anything.

8) Could it be controlled through an external computer? (Especially those implants controlled through and implanted chip onto your brain.)

It could be, but people don't want to carry an external computer with them when they go shopping or do other activities they like to do.

9) Do you have to charge the battery of a prosthesis?

Yes, once a day.

9.1) And if yes, how?

You just plug it into a charger like when you charge a mobile phone.

9.2) Or does it produce its power somehow else?

No it is battery powered.

10) Is it possible that in the future artificial body parts will function equally to our natural body parts, or that they even surpass them?

I think this is very doubtful in the next 20 years. Someday perhaps.

11) How comfortable/suitable are artificial body parts for sex? -Is it imaginable to replace sex organs?

Yes, these exist.