Bionic Hand

Sahla Yoosuf Husain Ahmed
Department of Computer Science
Ansar Women's College, Perumpilavu, P.O Karikkad,
Thrissur -680 519

1 Abstract

Background: Bionic prosthetic hands are rapidly evolving. An in-depth knowledge of this field of medicine is currently only required by a small number of individuals working in highly specialist units. However, with improving technology it is likely that the demand for and application of bionic hands will continue to increase and a wider understanding will be necessary.

Methods: We review the literature and summaries the important advances in medicine, computing and engineering that have led to the development of currently available bionic hand prostheses.

Findings: The bionic limb of today has progressed greatly since the hook prostheses that were introduced centuries ago. We discuss the ways that major functions of the human hand are being replicated artificially in modern bionic hands. Despite the impressive advances bionic prostheses remain an inferior replacement to their biological counterparts. Finally we discuss some of the key areas of research that could lead to vast improvements in bionic limb functionality that may one day be able to fully replicate the biological hand or perhaps even surpass its innate capabilities.

Conclusion: It is important for the healthcare community to have an understanding of the development of bionic hands and the technology underpinning them as this area of medicine will expand.

Keywords: Bionic hand, Prosthesis, Amputees, Bionic limb, Robotic hand.

2 Introduction

The human hand is able to perform a complex repertoire of sophisticated movements that enables us to interact with our environment and communicate with one another. The opposable thumb, a rarity in nature, has helped us achieve high levels of dexterity allowing our evolution to proceed rapidly over other creatures. To perform complex hand movements we need to synthesize an enormous amount of somesthetic information about our environment including fine touch, vibration, pain, temperature and proprioception.

The sensory and motor cortices span large, complex areas of the brain and are devoted to interpreting the vast sensory input and using it to fine-tune the motor control of over forty separate muscles of the forearm and hand. This delicate, sophisticated arrangement allows us to perform precision activities such as writing and opening doors whilst simultaneously avoiding noxious stimuli.

Loss of a hand can be devastating and unlike losing a leg the functional limitations following hand loss are catastrophic. The primary causes of hand loss are trauma, dysvascularity and neoplasia. Men are significantly more likely than women to lose their hands with 67% of upper limb amputees being male. Upper limb amputations most commonly occur during the productive working years with 60% between the ages of 16 and 54. The functional demands in this patient group are high and their expectations of a prosthetic limb mirror this.

A few hundred years ago a hand amputee would have been condemned to a hook prosthesis that had limited function and carried significant social stigma. However in today's society a hand amputee can expect a replacement hand that replicates a whole host of normal hand functions and looks remarkably life like. Significant advancements in bionic hand technology have occurred and this field is now considered to be a triumph of medical engineering excellence.

The alternative option to a bionic hand is a hand transplant, which was first performed in 1999. There have been successes in this field but there are major drawbacks to the widespread use of transplantation. The requirement for a donor limb that matches the recipient in terms of size and shape mean suitable donor limbs are rare. The recipient's reliance on long-term immunosuppression and the complexity of transplant surgery are likely to limit transplantation as the major reconstructive option for amputees. Therefore the more widespread option for an upper limb amputee is to opt for an artificial replacement.

The modern prosthetic hand has been designed to closely approximate the natural limb in both form and function. Despite the fact that the bionic hand was recently hailed as a triumph of engineering excellence it remains an inferior replacement to the real thing and consequently there are a number of barriers to its uptake amongst the upper limb amputee population. These prevent the prosthetic hand from achieving the ultimate goal of any prosthesis: 100% acceptance by its users.

So, how close are we to creating an artificial hand that is a perfect replica of the real thing? Can we expect that medical and engineering advancements will continue to improve upon nature and eventually deliver a bionic hand that enhances our strength, speed and abilities far above human norms? Will we all be like the Six Million Dollar Man or the Bionic Woman one day?

3 Classification of Prosthetic Hand/Arm

Similar to the other consumer products the prosthesis has followed the stages of evolution, development and innovation. Replicating any human part is not an easy task. Researchers have to repeatedly reanalyze the need of the prosthesis on the basis of the expectations of the patient keeping in mind age, sex and the profession. This literature survey revealed many researchers in race to design most efficient and perfect 'machine' which exactly looks like a real hand and works like a real hand.

Table 1: Presents Classification of Prosthetic as per amputation

SN	Type of amputation	Type of prosthetic
1	Shoulder disarticulation	From shoulder
2	Elbow disarticulation	Below elbow Above elbow
3	Wrist disarticulation	Below elbow
4	Trans carpel disarticulation	Below elbow
5	Finger amputation	Below elbow

Automated Prosthetic arms are considered as biomedical devices and developing the same is interdisciplinary activity i.e. combination of mechanisms and electronics. The selection of prosthetic arm depends upon type of the disarticulation the patient has undergone and the patients need. Please refer figure 1.

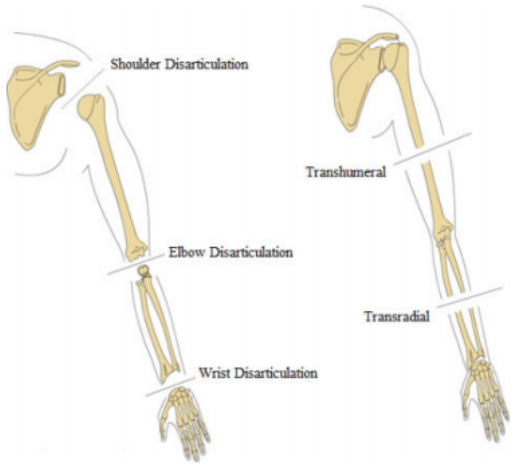

Figure 1: Amputation level

3.1 Amputation above elbow (AE) or Transhumeral Prosthesis

It is an artificial limb which replaces an arm missing above the elbow. It has complexities related to movements to the fingers, wrist and elbow. Refer figure 2.

Figure 2: Transhumeral Prosthesis

3.2 Amputation Below elbow (BE) or Transradial Prosthesis

It is an artificial limb which replaces missing arm below the elbow.

Figure 3: Transradial Prosthesis

3.3 Electronic Transradial or Wrist Disarticulation Prosthesis

Figure 4: Wrist Disarticulation Prosthesis

3.4 Finger Disarticulation Prosthesis

Figure 5: Finger Disarticulation Prosthesis

4 Motor control

THE human hand is by nature so complex that replicating its functions using a bionic device is a significant challenge. Controlling a bionic limb must be quick, easy and reliable for it to have any advantage over a non-functioning alternative.

The most basic, controllable, artificial limbs rely on a system of cables attached to a harness that the user wears. Motion of the residual limb relative to the patient's body controls the movement of the prosthesis. These limbs require the user to have enough strength to operate them and they are limited to a small repertoire of movements. However they are cheap to produce and are relatively easy to use, so they can be a suitable option for people with low demands.

4.1 Traditional Prosthetic Hooks/ Body Powered Hooks

Prosthetic hooks were originally developed in the early 1900's. They have proven to be an effective and reliable tool for amputees to use in their daily lives. Although there are several variations of prosthetic hooks, they all behave in the same general way. There are two hook shaped metal prongs which pivot at the rear section. The prongs are normally held together through spring force. The spring force is supplied by what are known as "tension bands" in the industry, essentially strong rubber bands. The users can decide how much spring force is required for a given task, and may manually add or remove tension bands as needed with their other hand. The prong hooks are opened by a cable placed under tension. The cable is pulled by a harness being worn by the user consisting of a strap going across the torso and both shoulders. This means that a user must flex their back or shoulders to accomplish the opening action of the terminal hook.

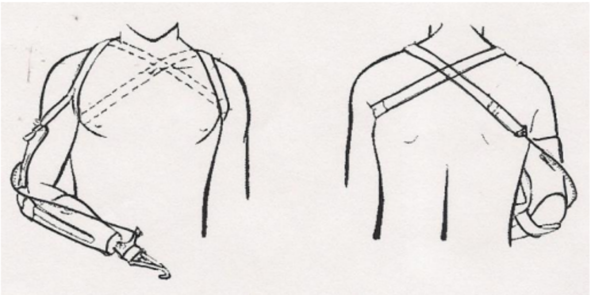

Figure 6: Prosthetic Hook and Harness

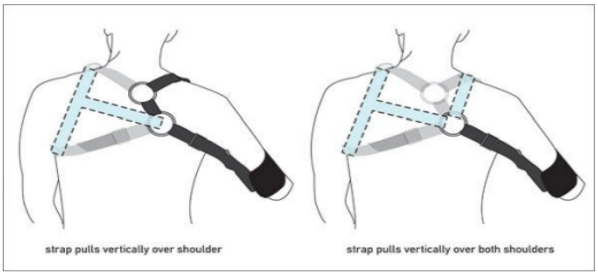

Figure 7: Body Powered Harness Motion

There are several advantages to using prosthetic hooks. Hooks are incredibly reliable; there is only one or two moving parts the entire system. There are no batteries to be charged and there are no electronic components which could possibly fail. In general if something needs to be adjusted with the system common hand tools can be used. The hooks can handle high mechanical loading which are useful for physical labor and strenuous tasks. Users have no fear of damaging components of the hook through rough usage. The inside of the hooks are generally lined with a high grip rubber material. Overall the prosthetic hook systems are very cost effective considering their long lifespan. An entire strap and harness with hook would usually cost less than $9,000 and last many years very easily. Simply put, a user would have no worry about component failure on a day-to-day basis. The bulk of that cost comes from the custom molded socket. The socket is usually made of carbon fiber and molded individually for each user depending on their unique amputation.

Limitations

- Prosthetic hooks come with their own limitations. The single greatest limitation stems from the fact that the holding force of the hooks is supplied ready manually adjusted spring tension bands. In order to have a high gripping force, the user would have to strain their muscles to open the hooks which can lead to muscle fatigue or pain. High gripping force is generally desired when handling a large or heavy object. For example, holding onto a broom handle or rake proves to be quite challenging due to the large amount of force required. Related to the limitation of muscle force required to open prosthetic hooks, users often report pain from a strap and harness during activities which require frequent opening and closing of the end effector. One frustration with prosthetic hooks comes from having to change the tension bands manually in order to adjust the gripping force. Multiple tension bands have to be carried at all times and require use of a secondary hand and earth to make changes. The same force desired to securely hold a heavy object is enough to crush a lightweight object such as a thin plastic bottle or some foods.
- One overarching issue found the prosthetic hooks stems from the social stigma of people who are seen as different in society. Everyone in the world strives to be seen as normal and lead a normal functioning life. Far too often, amputees report discomfort in social situations from being stared at or treated differently. Prosthetic hooks standout easily with their unusual shape and function. Many people still associate prosthetic hooks with pirate hooks sadly. In addition to social issues, wearers of prosthetic hooks report dissatisfaction in their personal lives in and relationships with friends and family. Users find it more challenging to show affection through their prosthetic hook because of its unusual shape and feel. It can be challenging to care the harness with certain styles of clothing.

ACHIEVING a more complex set of movements relies on integration with a digital control method. These can be very basic, such as placing a controlling unit into the user's shoe, or very complex such as myoelectric control that interprets electrical activity in the neuromusculature of the limb stump to allow motion.

Myoelectric control is the most widely used control in commercially available bionic limbs. It relies on complex algorithms to make sense of the massive amount of electrical activity in the stump, which is affected by everything from movement in the shoulder or elbow to the heartbeat. Techniques such as electrical pattern recognition can be used to activate whole muscle groups that form components of certain movements. For instance electrical activity in the flexor compartment of the forearm will lead to flexing of the bionic hand. Nevertheless learning how to use a myoelectrically controlled prosthesis can be time consuming and difficult and there must be enough electrical activity in the limb stump for them to work. Improving the accuracy of computer algorithms that decode the signals is a substantial area of research at present.

4.2 Myoelectric Technology

Myoelectric upper limb technologies use electrical signals generated by muscles in the residual limb to control the movements of prosthesis. When the user contracts certain muscles, surface electrodes in the socket detect the muscle signals and send them to a controller, which triggers tiny, battery-powered motors to move the fingers, hand, wrist or elbow. The advantages of myoelectric prostheses include more intuitive control of the prosthesis, increased grip strength, access to multiple grip patterns and more natural hand movements.

Myoelectric technologies are available for all levels of upper limb loss.

Myoelectric Fingers

Electric finger solutions for those with finger amputations consist of individually-powered prosthetic fingers that can bend, touch, pick up and point. Electric finger solutions are custom built to replace any missing fingers and work in harmony with any remaining fingers.

Figure 8: Myoelectric finger

Myoelectric Hands

Fully articulating myoelectric hands are available from a variety of manufacturers in multiple sizes and configurations. Some of the most popular devices are:

- The Taska Hand
- The bebionic
- The i-limb
- The Michelangelo Hand

4.2.1 BeBionic and iLimb Hands

Figure 9: BeBionic Hand

Figure 10: iLimb Hand

Several years ago, robotic prosthetic hands with individually articulated fingers were released onto the market. These hands were completely revolutionary in their look and function compared with other prosthetic options that existed. Touch Bionics was the first company to release one of these hands known as the "iLimb". The iLimb is based around the design of an individual finger, known as "digits" by 14 Touch Bionics. Each finger contains its own motor and gearbox which is very helpful when designing a prosthetic hand which must fit inside human proportions. In fact, amputees who are only missing partial fingers may simply use as many Digits as they need in a custom solution from Touch Bionics. Each finger has a joint at the base and one pivot point at the first knuckle. The fingertip is passively actuated by being pulled on by a cable. One interesting mechanical aspect of the fingers is a spring linkage which allows the fingers to be manually bent inwards to prevent damage if the hand hits into a hard object. Altogether, the iLimb has 5 degrees of freedom. User input is controlled through myoelectric sensors reading the muscle signals remaining on a portion of an amputees arm. The control is designed to be intuitive in this sense that a person should optimally be able to open and close their hand with the same muscle signals they would normally send them to an actual human hand. Touch bionics boasts 14 different grip patterns which are all subtle variations of the most commonly used patterns.

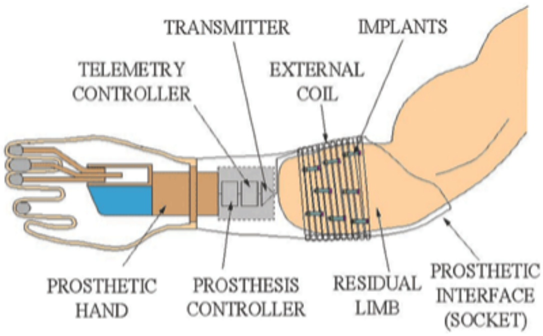

Figure 11: Myoelectric Control Example

How it works

The iLimb is an externally powered prosthesis often controlled by myoelectric signals, meaning it uses muscle signals in the patient's residual limb to move the device. Electrodes are placed on the user's bare skin above two preselected muscle sites. When a user contracts these muscles, the electrodes pick up subtle changes in the electrical patterns and send these signals to a microprocessor which instructs the iLimb to open and close.

Triggers

The iLimb can open and close into several different grip such as a lateral grip or precision pinch. Users can assign their most commonly used grip to up to four different muscle triggers.

1. 'hold open' (using the open signal for a set period of time)
2. 'double impulse' (two quick open signals after the hand is fully open)
3. 'triple impulse' (three quick open signals after the hand is fully open)
4. 'co-contraction' (contracting both the open and close muscles simultaneously)

When the user activates any one of these triggers, the iLimb will move into the grip that has been assigned to it.

The number of triggers programmed depends on each individual's ability to control and activate the signals. As the user's control and strength improves over time with practice, the user can assign more triggers to grips for improved dexterity and function.

Overall, the iLimb is a fantastic product which has given a tremendous amount of increased functionality to the lives of many amputees. The cost of the hand would be a staggering $60,000.

Figure 12: Darin Sargent with his "i-limb"

The iLimb however does not have an actively powered positionable thumb. The user must use their other hand to manually rotate the angle of the thumb. For example, if a user is eating a meal and has their hand in a key grip mode for holding onto a spoon or fork, and then decides to drink from a glass or cup, the user would have to manually rotate the thumb down until it is in position for a cylindrical grip. The iLimb does at least contain a sensor to recognize the current position of the thumb to help ensure the hand is not going to damage itself in certain grip modes. There is also no force feedback provided to the user, so it can be difficult to perform precision tasks. As a result of the lack of force feedback, users may inadvertently drop objects because they are not being gripped firmly enough, but there is no indication before it is too late and the object has fallen.

The **BeBionic** hand is incredibly similar in construction to the iLimb. The BeBionic hand was produced by RSL Steeper with the intention of offering similar functionality to the iLimb at a slightly reduced cost. Some people speculate that the hand is a direct spinoff based on identical mechanical components. There are little to no functional differences between the two hands, so they are considered the same for the sake of discussion.

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Central and peripheral motor and somatosensory pathways retain significant residual connectivity and function for many years after limb amputation and this property has been exploited by researchers using a technique called targeted motor reinnervation to increase the accuracy of myoelectrically controlled prostheses.

In this technique the nerves that once supplied the amputated limb muscles are surgically anastomosed into the remaining muscles of the amputation stump to create independently controlled nerve-muscle units. The reinnervated muscles act as biological amplifiers of motor commands in the amputated nerves and the surface electromyogram (EMG) can be used to enhance control of a robotic arm. This technique has shown promising results with the ability to achieve intuitive control of multiple functions in a bionic hand.

An alternative system being developed to increase accuracy of myoelectric prostheses involves the implantation of bipolar differential electromyographic (EMG) electrodes within the muscle to create a system capable of reading intra muscular EMG signals that increases the number of control sources available for prosthesis control.

4.3 Targeted Muscle Reinnervation(TMR)

Targeted muscle reinnveration, usually referred to as "TMR" is a complicated surgical procedure for high level arm amputees that takes nerves previously dedicated to hand, wrist or elbow motion, and rewires them into adjacent muscles, dramatically amplifying the nerve signals with the goal of providing users with "thought control" of their myoelectric prosthesis.

Current myoelectric prostheses for above-elbow and shoulder disarticulation levels provide up to three degrees of freedom:

1. Flexing and extending the elbow 'hold open' (using the open signal for a set period of time)
2. Turning the wrist in or out
3. Opening and closing the hand or electronic terminal device

These motions are typically controlled one at a time by electrical signals from one or two muscle sites (known as "EMG sites") in the residual limb or upper shoulder area.

TMR surgery creates additional EMG sites that are controlled with distinct and intuitive muscle contractions, some of which can occur simultaneously and with less mental effort. When combined with occupational therapy, the result is a high level of intuitive control, which can significantly enhance the functional use of the prosthesis.

4.3.1 Mind Controlled Bionic Arm

The Rehabilitation Institute of Chicago introduced the first woman to be fitted with its "bionic arm" technology. Claudia Mitchell, who had her left arm amputated at the shoulder after a motorcycle accident, can now grab a drawer pull with her prosthetic hand by thinking, "grab drawer pull." That a person can successfully control multiple, complex movements of a prosthetic limb with his or her thoughts opens up a world of possibility for amputees.

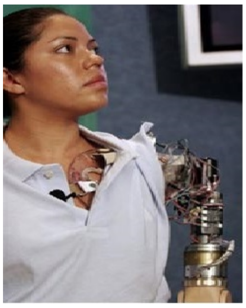

Figure 13: Claudia Mitchell with her "bionic arm"

How it works

The "bionic arm" technology is possible primarily because of two facts of amputation. First, the motor cortex in the brain (the area that controls voluntary muscle movements) is still sending out control signals even if certain voluntary muscles are no longer available for control; and second, when doctors amputate a limb, they don't remove all of the nerves that once carried signals to that limb. So if a person's arm is gone, there are working nerve stubs that end in the shoulder and simply have nowhere to send their information. If those nerve endings can be redirected to a working muscle group, then when a person thinks "grab handle with hand," and the brain sends out the corresponding signals to the nerves that should communicate with the hand, those signals end up at the working muscle group instead of at the dead end of the shoulder.

Dr. Todd Kuiken of the RIC developed the procedure, which he calls "targeted muscle re-innervation." Surgeons basically dissect the shoulder to access the nerve endings that control the movements of arm joints like the elbow, wrist and hand. Then, without damaging the nerves, they redirect the endings to a working muscle group. In the case of the RIC's "bionic arm," surgeons attach the nerve endings to a set of chest muscles. It takes several months for the nerves to grow into those muscles and become fully integrated. The end result is a redirection of control signals: The motor cortex sends out signals for the arm and hand through nerve passageways as it always did; but instead of those signals ending up at the shoulder, they end up at the chest.

To use those signals to control the bionic arm, the RIC setup places electrodes on the surface of the chest muscles. Each electrode controls one of the six motors that move the prosthetic arm's joints. When a person thinks "open hand," the brain sends the "open hand" signal to the appropriate nerve, now located in the chest. When the nerve ending receives the signal, the chest muscle it's connected to contracts. When the "open hand" chest muscle contracts, the electrode on that muscle detects the activation and tells the motor controlling the bionic hand to open. And since each nerve ending is integrated into a different piece of chest muscle, a person wearing the bionic arm can move all six motors simultaneously, resulting in a pretty natural range of motions for the prosthesis.

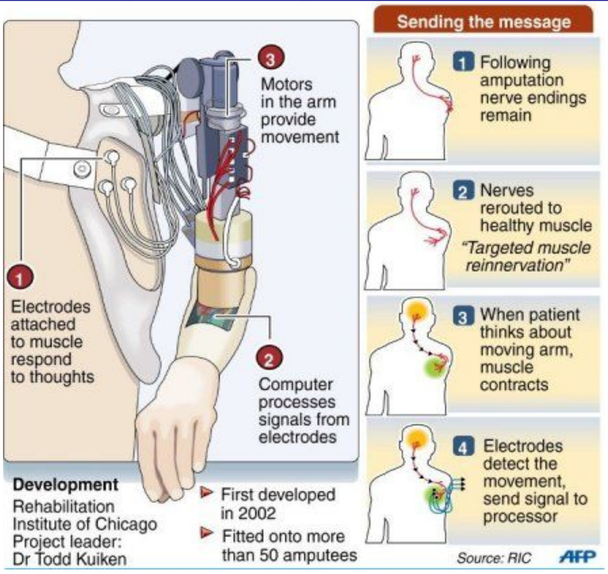

Figure 14: Bionic arm working example

4.3.2 Control bionic hand without help of vision

There's no arguing that prosthetics have come a long way. Controlling a robotic limb with your brainwaves was impossible a mere decade ago; now it seems routine. More than ever, scientists are squeezing increasingly dense sets of motors and sensors into replacement limbs. The result is sophisticated bionic appendages capable of fine, dexterous movement. **But there's a problem:** without a direct visual, the wearer has absolutely no idea what their bionic arm is up to. They don't know where the arm is in space, how fast it's moving, or where it's going. This intuitive sense of body positioning, dubbed kinesthesia, has been hard to build into prosthetics. It's not touch—kinesthesia uses feedback from the joints and muscles to compute where your limbs are even without direct touch feedback. Yet, like touch, kinesthesia is essential for fine motor control: this is the sense that lets you shove a handful of popcorn into your mouth while keeping your eyes on the big screen. It's behind seemingly mundane actions such as scratching your back or catching a ball. "Somebody with a prosthetic hand, since they can't feel the movement of their device, they essentially have to compensate [for] that with vision," said lead author Dr. Paul Marasco at the Cleveland Clinic, who collaborated with the University of Alberta and University of New Brunswick. This kills any sense of ownership of the arm.

Good Vibrations

The new device restores kinesthesia using a seriously clever body hack. When you vibrate a tendon at 70 to 115 Hz, it makes it feel like the associated joint is moving. The illusion is strong enough that the person thinks their limbs are contorted into impossible positions or that their nose is growing like Pinocchio's. By vibrating multiple tendons, scientists can induce the sensation of complex arm movements in space without anything physically moving.

Scientists have known about this phenomenon—dubbed the vibration-induced kinesthetic illusion—since the 1970s, but no one's ever tested it in amputees before.

The volunteers in this study had previously undergone surgery to rewire the remaining nerves in their upper bodies to other muscles. For example, the nerve that normally controls the elbow is hooked up to chest muscles. When the patient thinks about moving his elbow, the nerve sends the command to the chest muscle. This activity is then picked up by a sensor that, in turn, instructs the prosthetic arm's elbow to move accordingly. The team first vibrated the volunteers' chest, bicep, and triceps tendons—where the remaining nerves were rerouted to—and asked them to mimic the perceived movements in their missing hands with their remaining one.

Incredibly, different vibration paradigms mapped onto a library of complex hand motions. For example, stimulating the biceps in most patients generated the "cylinder grip," in which the hand is loosely clenched as if wrapping around a tube. Other motions included the thumb and index finger "fine pinch," or the thumb, middle, and index finger "tripod pinch." In all, the team identified 22 different hand motions, or precepts.

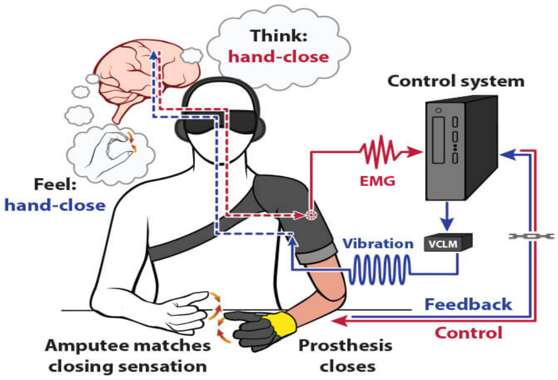

Figure 15: Operating bionic hand without help of vision example

A Kinesthetic Interface

The next step was to put this library to use. The team developed a neural-machine interface with two lines of communication. When the patient thinks about moving the bionic arm, the signal is picked up from the re-innervated muscle to control the prosthesis. At the same time, it also triggers a small but powerful motor to vibrate the muscle, generating the kinesthetic illusion.

The improvement was evident within minutes. Using computer simulation software, the volunteers could easily close their virtual prosthetic hands a quarter, half, or three quarters of the way without watching the hand. In contrast, with the vibrations turned off they performed significantly worse—one patient had nearly no sense of hand position without adding the hack.

Kinesthetic feedback was even more powerful than vision for fine motor control. When asked to catch a virtual ball using their virtual hands, kinesthetic reflexes kicked in far faster than visual feedback, allowing the volunteers to reach out precisely and intuitively. Even with blindfolds and noise-canceling headphones on to block off the world, the volunteers easily followed instructions to close the bionic hand into a cylinder grip. What's more, they had no trouble reporting the status of the prosthetics—whether they were open or closed.

When you reach your hand out to grab your coffee cup or another object, your brain is signaling certain muscles to move. As your hand moves in response, nerves for those muscles send a message back to the brain about the movement. You don't have to see your hand to know that you've grabbed your cup. You can feel it. Without these messages from the muscles and nerves, a person with a prosthetic hand or arm must rely on the eyes to relay messages about movement to the brain. But feedback from vision alone can be a clumsy substitute for complex sensory feedback.

4.3.3 Osseointegration

Osseointegration(OI) is a surgical procedure that enables amputees to attach a prosthesis directly to the bone of their residual limb with a titanium implant, eliminating the need for a socket. By making it possible to safely attach a prosthetic limb directly to the body without the need for a socket, OI is improving the lives of amputees around the world through the comfort and natural movement of an OI prosthesis.

Figure 16: Luke arm prosthetic recipient Junius Moore: and Matt Albuquerque, president and founder of Next Step Bionics & Prosthetics

Junius Moore, 35, is the world's first recipient of an osseointegrated **LUKE arm** combined with post targeted muscle reinnervation (TMR) surgery. This first-of-its-kind prosthetic advancement will pave the way for similar procedures in the United States, benefiting trans-radial (lower arm), trans-humeral (mid-arm), and shoulder disarticulation amputees.

Next Step conducted the first public demonstration of the LUKE arm prosthesis and the fitting that makes it possible to have it integrated into the patient's living bone and controlled by muscle movements in the remaining limb at a news conference on 12 DEC 2018 at Next Step's headquarters in the Med-Tech Mill Yard in Manchester.

Moore, a trans-humeral (mid-arm) amputee due to a motor vehicle accident, underwent targeted muscle reinnervation (TMR) surgery by the renowned Dr. Albert Chi, M.D., FACS, Oregon Health Science University (OHSU). By taking advantage of existing neurological pathways, Dr. Chi rewired the nerves that once controlled Moore's hand and arm to control the prosthetic device.

Moore was initially fit with a LUKE arm prosthesis but quickly realized he wanted more than what the socket technology could provide. He opted to undergo osseointegration surgery by Dr. Munjed Al Muderis, orthopedic surgeon and clinical lecturer at Macquarie University and The Australian School of Advanced Medicine, Sydney, Australia. Osseointegration allows the prosthesis to be anchored directly to the bone, giving patients freedom of movement, eliminating the need for a socket.

5 Sensation

OUR hands allow us to interact with our environment. We use the sensory input for touch, to fine-tune movements and to avoid harm. A continuing challenge for prostheses developers is to replicate the sensory function of the hand. Sensation in a bionic limb can be divided into two distinct categories e sensory information interpreted by the device itself and sensation that is perceived by the user.

Modern units have developed simple techniques for interpreting tactile sensory information that the devices use intrinsically to modify their activity. For example information on grasp strength ensures a user will not break objects by holding them too tightly whilst information provided by detection of sound from microphones embedded in the hand ensures that the object will not slip out of the grip and be dropped. This information, required for direct control of the device, can be interpreted via a low-level control loop thus decreasing the cognitive load of the user and increasing patient acceptability. These features improve the functionality of the device but do not provide the user with any sensory information about their surroundings.

Providing a sensory input from a bionic limb that is capable of being perceived by the user is far more complex. One approach is to utilize the concept of multimodal plasticity where loss of one sensory modality can be compensated by another. For example hearing can partly compensate for the loss of touch if auditory feedback is given when a bionic limb comes into contact with an object.

Another approach is to try to replicate sensation by transferring stimuli from electronic sensors in the bionic limb to natural sensors on the skin of the limb stump which the patient perceives as coming from the amputated limb. This has been difficult to achieve but recent work has successfully replicated more complex sensory modalities such as cutaneous proprioception alongside fine touch and pain sensation. It is hoped that this technique can be further developed to provide a complete range of sensations.

Direct interfaces with the peripheral or central nervous systems may provide the solution to enhanced sensation from bionic hands and ultimately come closest to restoring the original sensory perceptions of the hand. The use of intraneural electrodes that are capable of delivering information directly to the peripheral afferent nerves within the residual limb has shown promising results in delivering meaningful sensations to amputees. Delivering sensations through this approach has been shown to improve control as it allowed amputees to control the grip force and joint position of their artificial limb more accurately without relying on visual input. One of the main advantages of a sensitized bionic limb is the accelerated rehabilitation program as the patient finds it more intuitive to learn how to control when they are receiving tactile feedback from the device.

With advancements in these technologies we may soon be able to re-wire the sensory input to the peripheral nervous system so that the central nervous system can perceive sensations coming from a bionic limb as if it were the natural limb.

5.1 Bionic hand allows patient to 'feel'

Figure 17: Igor Spetic with his bionic arm with realistic finger sensation.

Igor Spetic, 49, lost his right hand in a work related accident five years ago. But on Oct. 9, he got to bring home an innovative prosthetic hand for the first time, one that not only has more precise gripping, but gives him back his sense of touch.

The hand was created by researchers at Case Western Reserve University, which was granted$4.4 million from the Defense Advanced Research Projects Agency (DARPA) for their work creating a prosthetic hand that can feel. The goal is to make a hand that allows someone to function in a way that allows him to forget he doesn't have the real version.

What's exciting about Case Western's technology is that it creates a connection between the prosthetic and the brain, allowing users to actually feel the sensation of picking up on object.

How it works:

- Sensors in the prosthetic hand measure the pressure applied to various objects as the hand closes around them.
- The measurements are then recorded, converted into a neural code, and sent through wires to electrodes that were surgically implanted around nerve bundles in Spetic's forearm and upper arm.
- When the neural code reaches Spetic's nerves, the signal is transmitted through

his healthy neural pathways that weren't affected by his amputation, to his brain.

- The brain interprets the signals as feel- ing, as if from a normal hand.

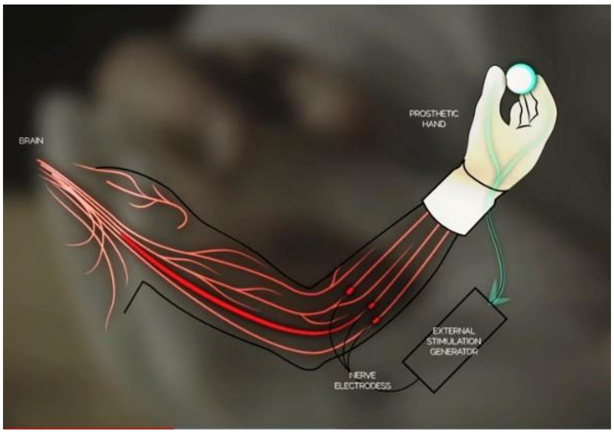

Figure 18: How finger sensation is achieved: Even though the sensor is gone, the wires that communicate the information to the brain still exits. Devices was developed which can go on to those wires and apply electrical information that communicates with the wires and send it back to the brain.

Electrical impulses in the nervous system con- vey information between brain cells or along the neurons in the peripheral nerves that stretch throughout the body. These signals drive the actuators of the body, such as the muscles, and they provide feedback in the form of sensation, limb position, muscle force, and so on.

By inserting electrodes directly into mus- cles or wrapping them around the nerves that control the contraction of the muscles, we can send commands to those electrodes that roughly replicate the signals associated with moving a hand, standing up, or lifting a foot

Figure 19: An x-ray reveals the sugically im- planted electrode cuffs: in Spetic's forearm and the wires in his upper arm that connects to an external computer.

Engineering such an interface is difficult be- cause it has to allow precise patterns of stimu- lation to the person's peripheral nerves, with- out damaging or otherwise altering the nerves. It also must function reliably for years within the harsh environment of the body.

There are several approaches to designing an implanted interface. The least invasive is to embed electrodes in a muscle, near the point where the target nerve enters that muscle. Such systems have been used to restore func- tion following spinal-cord injury, stroke, and other forms of neurological damage. The body tolerates the electrodes well, and surgically re- placing them is relatively easy. When the elec- trodes need to activate a muscle, however, it of- ten requires a current of up to 20 milliamperes, about the same amount you get when you shuf- fle across a carpet and get "shocked"; even then, the muscle isn't always completely ac- tivated.

The most invasive approach involves insert- ing electrodes deep into the nerve. Placing the stimulating contacts so close to the target ax- ons—the parts of nerve cells that conduct elec- trical impulses—means that less current is re- quired and that very small groups of axons can be selectively activated. But the body tends to reject foreign materials placed within the pro- tective layers of its nerves. In animal experi- ments, the normal inflammatory process often pushes these electrodes out of the nerve.

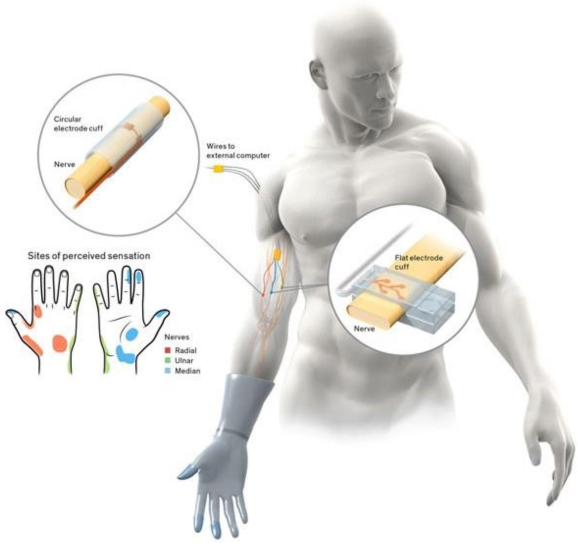

Figure 20: Restoring The Sense of Touch:

To allow a person with a prosthetic hand to perceive sensations, researchers at Case West- ern Reserve University surgically implanted electrode cuffs around the median, radial, and ulnar nerves in the affected arm. The flat- tened cuff [above right] is more effective than the traditional circular cuff [above left] because electrical signals can access the nerve fibers more easily. When precise patterns of electri- cal pulses are sent to each electrode, the sub- ject feels sensations at specific sites on the front and back of his hand, as well as different tex- tures. Although this experimental system uses an external computer, the eventual goal is to implant a controller, which will wirelessly com- municate with the prosthetic hand.

Spetic, the cherry-plucking volunteer, has the flat electrode cuffs placed around the me- dian and ulnar nerves, two of the three main nerves in his arm. He has a traditional circular electrode placed around the radial nerve. This provides a total of 20 stimulation channels in his forearm: eight each on the median and ul- nar nerves and four on the radial nerve. Test- ing revealed that the 20 stimulation points cre- ated sensations at 19 places on Spetic's missing hand, including spots on the left and right sides of his palm, the back of his hand, his wrist, his thumb, and his fingertips.

The next generation of cuff will have four times as many contacts. The more channels, the more selectively it will be able to access small groups of axons and provide a more use- ful range of sensations. In addition to the tac- tile, research is done to produce sensations like temperature, joint position (known as propri- oception), and even pain. Despite its negative connotation, pain is an important protective mechanism. During the tests, one stimulation channel did cause a painful sensation. Eventu- ally, we will be able to include such protective mechanisms.

Result

"The user feels like an actual hand is touching the object. It feels real," says Dustin Tyler, leader of the project and an associate profes- sor of biomedical engineering at Case Western. Until recently, Spetic had been testing Case Western's technology in the lab, but in Octo- ber he took the prosthetic home, and became one of the first people to test such advanced prosthetics in real world situations, outside of the artificial conditions in a lab. Already, he's been able to accomplish small tasks that were once extremely difficult, like cutting fruits and vegetables with a knife, securely holding his coffee cup, and opening bags with both hands instead of using a combination of his teeth and left hand.

"What I'm excited about is knowing that I can go back from being one-handed to being a two-handed person," says Spetic. "Of course it's going to be a relearning of using a right hand that I haven't had for 5 years, but I can hopefully be a two-handed person again."

6 Research to Consider

The ultimate goal is to achieve a "Bio mecha- tronic design" where the mechatronic system of the artificial hand is inspired by and works like the living limb. To achieve this goal there would need to be integration of the prostheses with the central nervous system so that the re- placement moves and is perceived as if it were the natural hand without the requirement for any training or adaptation.

Though the design of prosthetics is con- tinuing to develop and benefits many patients living with an amputated limb, there are still challenges ahead in the design of a prosthetic limb that satisfies intricate requirements, such as easy control of the prosthetic limb and to make this mechanical device cosmetically ap- pealing. There is also the challenge of under- standing the issue of tissue reactions to mate- rial used for the prosthetic limb and how an inflammatory response to such a reaction may interfere with signal transmission of biosensors. In case of integrating feeling of touch, to make a self-contained device that doesn't rely on an external computer, there is a need of miniature processors that can be inserted into the prosthesis to communicate with the im- plant and send stimulation to the electrode cuffs. The implanted electronics must be ro- bust enough to last year's inside the human body and must be powered internally, with no wires sticking out of the skin. There is also a need to work out the communication proto- col between the prosthesis and the implanted processor.

7 Future Scope

The use of intraneural electrodes is perhaps the most promising technology that may hold the key to successful integration of bionic limbs into the biological system. Intraneural elec- trodes interface directly into the nerves in the limb stump and have the ability to carry a bidirectional flow of information between the bionic limb and patient. It is a daunting en- gineering challenge, but when succeeded, this haptic technology could benefit more than just prosthetic users. Such an interface would al- low people to touch things in a way that were never before possible.

Imagine an obstetrician feeling a fetus's heartbeat, rather than just relying on Doppler imaging. Imagine a bomb disposal specialist feeling the wires inside a bomb that is actually being handled by a remotely operated robot. Imagine a geologist feeling the weight and tex- ture of a rock that's thousands of kilometers away or a salesperson tweeting a handshake to a new customer.

Such scenarios could become reality within the next decade. Sensation tells us what is and isn't part of us. By extending sensation to our machines, we will expand humanity's reach—even if that reach is as simple as hold- ing a loved one's hand.

8 Conclusion

The prosthetic hand of the middle ages was present merely as a prop. Today we have bionic hand prostheses that give much better func- tionality, are acceptable to more patients and are durable and comfortable. However these prostheses still have to overcome considerable hurdles in order to mimic or even improve upon the intrinsic hand and they carry significant economic implications. The advancements in this field of medicine are exponential and it is likely that within 10 years there will be com- mercially available limbs that provide both sen- sation and accurate motor control from day 1. Being Bionic raises a new question, can a bionic arm outlast the human one?!!! Well, even the most advanced prosthetic is not a replacement for a flesh and blood limb. As the technology progresses, we are likely to progress with it. Most prosthetics are still in their infancy and are limited to medical use. But what happens when these technologies be- comes more advanced, smarter and stronger. Will normal people want them? Policy makers have already started to bring up the issue that as soon as it becomes more mechanical, our laws will have to evolve to reflect how we look at privacy access in domain of our own bodies, making them do what we don't want them to do. I really believe that in the end, we will be able to do those kinds of things but humanity have so much to gain here.

So... **YES**. I think all these technologies will change us but I don't think that's a bad thing.

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