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Interface technologies applied for bionic prosthetic limbs

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Abstract. For a very long time, people have wished for a way to repair a broken limb and make it work again. The limbs are responsible for the vast majority of human movement, grasping, and other actions. If you lose them, your mental and physical health will suffer drastically. The quality of life for amputees continues to improve as new and better prosthetics are developed thanks to advancements in technology. Effective use of prostheses requires that they be attached to the user's natural body in some way. The development of prosthetic limbs, therefore, relies heavily on the findings of studies examining prosthetic limb interfaces. This paper provides a summary of the research conducted on prosthetic interface technologies since 1985 through a method of literature review. The purpose of this paper is to provide a concise overview of the current technologies employed in the field of prosthetic interfaces and to speculate on the direction of future research and development in this area.

Keywords: Prosthesis, Electrode interface, EMG, Vibrotactile, Osseointegration

1. Introduction

Making sure amputees have more control over prosthetic activities has long been a focus of bionic prosthetics research. Amputees' primary method of controlling prosthetic limbs currently is through neural interfaces implanted in the nervous system. By allowing paralyzed people to control an external assistive device with brain signals, brain-machine interfaces are one clinical research application that hopes to restore motor and somatosensory function [1]. New approaches are also being explored to connect the residual peripheral nerves of an amputee to electrode arrays for direct control of prosthetic lower and upper limbs. Neural prostheses have proven to be invaluable research tools outside of the clinical setting, shedding light on the function of individual neurons and their activation patterns in both normal and abnormal states. As a general rule, it is preferable for there to be consistent, long-lasting connections established between the device and the neuronal population of interest.

This paper provides a summary of the research conducted on prosthetic interface technologies since 1985 through a method of literature review. Technologies like electromyography (EMG), which analyses the electrical activity in muscles, vibration-tactile interfaces (which may one day help amputees regain touch), osseointegration (which helps prosthetics blend in with bone), and renewable electrode interfaces (which can be recharged) are all examples. Some possible answers to the technical problems that the interface technology has run into are also explored in this paper.

This paper provides a concise overview of the current technologies employed in the field of prosthetic interfaces and speculates on the direction of future research and development in this area, hoping to make some contributions to the research field..

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2. Prosthetic limbs

2.1. The current status of prosthetic limbs

Patients can choose between RPHs, hook-equipped mechanical prostheses, and cosmetically-focused passive prostheses[2]. 53% of below-elbow amputees in Sweden, the UK, and Canada wore a cosmetic prosthesis, 13% used a hook, 4% used a cable hand, and 30% used a myoelectric robotic limb. Despite early success in the late 1990s, hand transplanting is not yet considered a feasible treatment (rejection and immunosuppression).

Most amputees still utilize gadgets that haven't altered much in nearly half a century. This is the result of decades of bionic prosthetic limb research. This discrepancy makes obvious when you consider the difficulty of developing a prosthetic upper limb, especially hands. Prosthetic hands are vital for amputees to regain mobility with prosthetic limbs since grasping is one of the most challenging coordination skills. It's also highly sensory. We can only accomplish seamless natural-artificial integration by combining revolutionary mechatronic technologies for highly sensorized robotic hands with novel approaches for efficient nervous system interfacing.

The Body harness is the most common interface in use today. Methods like surface EMG, intracranial EMG, vibrotactile interface, transcutaneous electrical nerve stimulation (TENS), functional electrical nerve stimulation (FINE), and osseointegration are all tried and true at home. HD-sEMG, Regenerative electrodes, TiMEs, LIFEs, Sieve Electrodes, and the Utah Array are just some of the integration technologies available for use in the lab[4]. The history of prosthetic interface technology from its inception to the present day will be outlined below.

2.2. Possibility for a human to control prosthetic limbs

Early in 2005, testing on rats and monkeys confirmed that the neocortex could be used to control a prosthetic instrument[5]. Gregory et al. looked into whether or not the prosthetic could be controlled by untrained subjects, and they tested whether or not the device could use a suitable decoding method autonomously without input to the neural encoding of motor parameters in the cortex. The experimental findings demonstrate that even subjects with no prior experience controlling a prosthetic limb can learn to generate neural signals that regulate the limb with repeated training. These signals can be used with other devices immediately, without any special instruction. This is crucial data for future work on electrode interfaces for prosthetics.

2.3. Early prosthetic interface technology

Prosthetic limbs were first linked with body harnesses. Physically, they fuse the prosthesis with the body. Conventional figure-of-eight and figure-nine harnesses are unpleasant and unattractive[6]. Even though users have focused harness comfort and aesthetic undergarments, the original harness design remains substantially similar from 1860. To do so, the axilla bypass ring, T-shirt system, and ipsilateral scapular cutaneous anchor system were developed. The Anchor System is the only public alternative to its 2006 patent. A flat plastic patch over the scapula connects the body to the prosthesis' Bowden cable. Anchor System eliminates restraints and restores full mobility to the unaffected side.

Prostheses driven by the user's body should offer proprioceptive feedback and fine-tuned force control. Body-powered prostheses have better proprioception than myoelectric prostheses. The Anchor System improves direct force transfer and high-resolution tactile input. By restricting contralateral shoulder motions and proprioceptive input, the Anchor System may impair perception and control. Prosthesis limits user's movements. The classic figure-of-nine harness should provide superior force perception and control than the Anchor System.

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3. Technologies used on interface of bionic prosthetic limbs and tectological obstacles

3.1. Technologies used on interface of bionic prosthetic limbs

3.1.1. sEMG and iEMG. In 1985, scientists began measuring arm flexion with EMG signals. Both technologies are commonly utilized for biomedical data collecting.

sEMGs used to control myoelectric prostheses. Surface signals are convenient and unobtrusive in modern myoelectric control literature. Intramuscular recordings can avoid some of the constraints of sEMG-based control, such as the need for continual electrode contact with the skin[7]. ImEMG can record from deep muscles with low EMG crosstalk. In vivo electromyography (ImEMG) is not clinically practicable since it requires percutaneous wire/needle electrodes. ImEMG could become a viable signal source for myoelectric prostheses using wireless implanted recording technologies. ImEMG for myoelectric prosthesis control is crucial.

Lauren.H.Smith et.al. trained sEMG and imEMG signals to predict 1-DOF and 2-DOF wrist rotation, wrist flexion/extension, and hand open/close movements. Classifier configuration and signal source combinations affected 1-DOF and 2-DOF classification errors (p 0.01). Figure 2 illustrates. Motion categorization was unaffected by classifier settings or signal sources.

A parallel classifier using imEMG has lower overall, 1-DOF, and 2-DOF error than one using sEMG (p 0.01). ImEMG improved accuracy slightly over sEMG.

3.1.2. Vibrotactile interface. Upper limb amputees have been able to achieve higher levels of function since about 2009 thanks to advancements in prosthetic arm design. However, upper limb prosthesis control is restricted by the absence of sensory feedback to the user. Aimee's findings bear this out. Targeted reinnervation, a novel surgical procedure developed by E.Schluz et al. for amputees, may be able to restore this feeling[8]. During targeted reinnervation, surgeons direct regrown nerves to supply previously unsupplied areas of skin and muscle. Reinnervated muscles contract electrically, and this is translated into movement at the prosthetic arm. Re-nerved skin can also be felt on the amputated limb.

Using vibration testing at four distinct frequencies, the skin on the chests of three shoulder-level amputees who underwent targeted reinnervation surgery were compared to healthy individuals. Sensitivity to electric shock was measured using the chest and arm skin of the control group and the contralateral chest and arm skin of amputees. An artificial nerve was implanted in the amputated arm and hand, and vibrations were then administered to the regrown skin. Re-innervated chest skin thresholds were found to be within the normal range of values when compared to those of the control group. These thresholds mirrored those recorded from the contralateral chests of the two unilateral amputees but were greater than those recorded from the contralateral hands. The ability to perceive vibrations appeared to be virtually normal in the location where the nerves were rerouted, suggesting that the reinnervating afferents successfully rejoined the mechanoreceptors. Users of prostheses may rely on residual limb sensation after undergoing targeted reinnervation.

3.1.3 Osseointegration. Per-Ingvar Brnemark of Sweden discovered in the early 1960s that his titanium chambers remained firmly implanted in the tibias of rabbits without experiencing any major soft tissue reaction or loosening[9]. There was no way to remove the titanium chambers from the skeleton after the experiments were done. As a result of these unexpected findings, P.-I. Brnemark conceived of titanium implants as a possible restorative option for tooth loss. P.-I. Brnemark performed the first human trial of intraosseous dental prosthesis anchorage in 1965 on an edentulous patient. Numerous long-term clinical trials proved the benefits of "osseointegration," the structural and functional connection between living bone and titanium implant.

The biomechanical investigations of P.-I. R. Brnemark and colleagues led to the introduction of osseointegration for amputee rehabilitation in the 1990s. These experiments led to future implant designs and osseointegration rehabilitation regimens.

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Surgery improved throughout the 1990s. During the initial osteointegration process, the dermal flap's direct bone attachment was unclear. The redesigned osseointegrated bone and choreographed hearing aids (BAHA) treatment focused on hair follicles within a 15 mm radius of the abutment hole and soft tissue reduction at the stump's end. By minimizing tissue movement, this method reduced soft tissue issues.

R. Brnemark standardized the implant technology, surgical process, and postoperative rehabilitation protocol based on early clinical trials [8]. This led to the invention of OPRA (Osseointe- grated Prostheses for the Rehabilitation of Amputees). The software is OPRA (Osseointe- grated Prostheses for the Rehabilitation of Amputees). In 1998, femoral implants were standardized; by 2003, forearm, humeral, and thumb systems were as well. OPRA provides standard operating procedures and rehabilitation protocols for femur, humerus, forearm, and thumb amputees.

Fixture, abutment, and abutment screw are the main parts of contemporary osseointegration. The interior of the bone cortex is engaged by threads on the fixture's exterior. The skin-penetrating abutment is connected to the rest of the fixture via a press-fitting internal connection at the distal end, which is then secured with an abutment screw.

3.2. *Technological obstacles to collecting biological signals through interfaces.* With the advent of brain prostheses, there has been a rise in the importance of collecting and analysing bioelectrical signals. This is due to the lack of sufficient data connecting specific brain signals to their functional implications in human kinematics. In response to this need, electrodes such as the Utah Array and the Michigan Array were developed. These devices can be implanted in the brain and read off electrical signals from the nervous system. Intuitive actions may be more easily linked to specific signals with the help of these electrical impulses[10]. However, these electrodes in the brain's cortex eventually stop working and are unable to reliably provide adequate electrical signals over the long term[11]. Modes of failure were classified as either biological, material, mechanical, or unknown. Biological failures include, but are not limited to, an immune response from the tissue, either extra- or intra-parenchymal, to the sensor as a foreign body, or clinical complications resulting from the implant (e.g. peri-operative bleed). The failure of a material is often related to flaws in the design or natural wear and tear (e.g. leakage of insulating materials). Mechanical failures are associated with external factors that move the sensor from its intended location or severely damage the hardware and prevent recording (e.g. connector removal by a monkey). Unknown failures result from signal loss that cannot be pinned down to one of these sources

4. Solutions and prospects

4.1. Solving problems through regenerative electrode interfaces

To solve the problem of implanted electrodes' inability to provide stable, reliable data over the long term, Cort H. Thompson et al. proposed several methods to improve the connection of neurons with implanted electrodes.[12] Redesigning the prosthetic architecture to include finer geometries and/or providing topographical cues to guide regenerative nerve growth, as well as adding material coatings and bioactive molecules to the prosthesis, are examples of these strategies.

4.2. Future prospects

The rapid expansion of neural prostheses' use in both clinical and academic settings for the treatment of neurological disorders attests to their incredible potential to change how neurological injuries and diseases are treated and researched in the future. However, the existing designs have a major mismatch between the features of biological and synthetic substrates at the device interface, leading to poor electrode-neurite integration. To ensure the long-term efficacy of neural prosthesis, regenerative therapies that promote or sustain neuronal growth and survival at the device interface hold promise.

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5. Conclusion

Researchers in 2005 found evidence for the feasibility of human manipulation of prosthetic limbs, meaning amputees are no longer limited to custom hands that are immobile. Now that we have the technology to read the electromyographic impulses our muscles emit, we can create prosthetic limbs that mimic their natural function.

Established implantable technologies, such as cuff electrodes, may soon allow for more widespread integration of simple somatosensory feedback. Motor decoding using shared-control techniques and machine learning may allow for continuous control of a single finger and larger sets of grasps. Future prostheses may include soft implanted electrodes that may encode sophisticated sensory information (such as proprioception, temperature, touch, and nociception) and decode it for motor control using deep learning. Before this can be done, system integration, electronic miniaturization, processing capacity, surgical technique, electrode durability, the robotic hand, and somatosensory data encoding must be addressed.

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