International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 04 April 2025
Page No: 1810-1817
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0262

Advanced Electro-Muscular Bionic ARM

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Abstract

The human hand is an intricate system, with numerous degrees of freedom (DoFs), embedded sensors, actuators, tendons, and a complex hierarchical control mechanism. Despite this complexity, the effort required for a person to perform various movements is minimal. In contrast, prosthetic hands are mere imitations of the natural hand, offering significantly reduced grasping capabilities and lacking sensory feedback to the user. Several attempts have been made to develop multifunctional prosthetic devices controlled by electromyography (EMG) signals, harness (kinematic hands), dimensional changes in residual muscles, and more. However, none of these methods allow for the "natural" control of more than two DoFs. This paper reviews traditional methods for controlling artificial hands using EMG signals in both clinical and research contexts. It also discusses potential future advancements in the control strategies for these devices. This paper introduces an innovative approach to controlling multifunctional prostheses based on the classification of myoelectric patterns. It is shown that the myoelectric signal exhibits a deterministic structure during the initial phase of muscle contraction. Features are extracted from several time segments of the myoelectric signal to preserve the pattern structure. These features are then classified using an artificial neural network. The proposed control signals are derived from natural muscle contraction patterns, which can be reliably produced with minimal subject training. The new control scheme enhances the number of functions that can be controlled by a single myoelectric signal channel without increasing the effort required by the amputee. Results supporting this approach are presented.

Keywords: *Electromyography (EMG) signals, kinematic hands, Servers.*

1. Introduction

The motto of the new era in medical sciences is, "Repair it if you can, replace it if you can't." Replacing a hand is a challenging task, highlighting the complexity of the human body. For years, people have sought substitutes for lost body parts by replacing them with various artificial devices. The bionic arm is a revolutionary concept for amputees worldwide, offering one of the closest alternatives to a natural limb. The core idea behind this technology is to enable the arm to move using brain signals, a significant improvement over previous prosthetic upper limbs. In the case of the bionic arm, nerve conduction signals from the brain or muscles are captured, amplified, and converted into mechanical energy to drive the prosthetic device, i.e., the arm. Prosthetics have been in use for some time, and they are constantly being refined to meet human needs. While various prosthetic devices have been developed to perform specific functions, they do not always meet the full range of actions required. The bionic arm, however, promises to replicate the full range of human upper limb movements, even performing complex tasks like unscrewing a bottle cap or picking up a coin from the ground. Such

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advancements in technology are moving us closer to making the bionic arm function much like a natural human arm. Though bionic arms are not yet widespread due to their high cost and limited availability, they hold immense potential to transform the lives of amputees. Medical and engineering professionals must continue to collaborate and research to improve these devices, making them more efficient and capable of mimicking natural arm movements. Patients often prefer a more natural-looking artificial hand over a traditional hook, but such hands have limitations: they are heavy, not waterproof, and the skin-like gloves placed over them lack the durability for long-term use. Recent advancements in actuators and sensors have been progressing rapidly, bringing us closer to mimicking the human arm more closely. To make bionic arms more accessible, all these factors must be taken into account. This paper critically analyzes these aspects and connects them to ongoing research in the development of bionic arms, shown in Figure 1 [1-2].

Figure 1 Image

2. Literature Survey

2.1 Actuation Systems

Robotics has often looked to biological muscle tissue as a benchmark for developing new artificial muscle actuators. Specifically, skeletal muscles exhibit remarkable capabilities, making them a unique and desirable actuator for prosthetic applications. Some key properties of biological muscles include:

- A high power-to-weight ratio.
- Inherent compliance and damping.
- The ability to perform fast, controllable actions.
- A wide dynamic range. [3]

Erkan Kaplanoglu [4] (2012) proposed an interesting method for actuating prosthetic hands using shape memory alloys (SMAs). SMAs return to a predefined shape or size when subjected to the appropriate thermal treatment (heating or cooling). For example, a design from Vanderbilt University utilizes SMA springs, which contract when heated by an electric current, causing the fingers to close due to tension in the tendons.

However, there are two primary disadvantages associated with using SMA actuators:

- **Complex Control System:** The rate of SMA contraction, the response of the spring, and the varying weights of objects all make it difficult to develop a precise control system for SMA actuators.
- **Slow Response Time:** The process of heating the SMA and waiting for it to cool can be time-consuming, which makes the opening and closing of the fingers relatively slow.

Despite these challenges, as SMA technology continues to advance, it may become a viable actuation option for artificial hands. One significant advantage of SMAs is that they are noise-free and lightweight, which could be beneficial for prosthetic applications, shown in Figure 2.

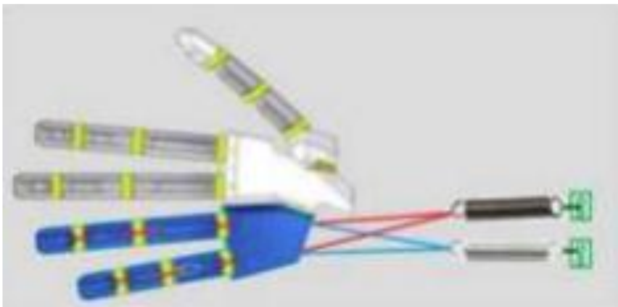

Figure 2 Image

Liangjian Zhong et al. [5] (2019) demonstrated a method of actuation that has gained significant attention in recent years, particularly in the fields of biomimetic technology and collaborative robotics. This method is highly regarded for its lightweight design, strong output power, and inherent safety. Pneumatic artificial muscles (PAMs) are tensile actuators that mimic the natural movement of human muscles. PAMs consist of a tube and connectors, with

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the tube made from a rubber diaphragm reinforced with non-crimped aramid fiber yarns on the inside. When the pressure inside the tube increases, the tube expands outward. As a result, the diameter of the tube increases, while its length decreases, causing the PAM to contract and generate pulling actuation. When the pressure drops back to ambient levels, the external woven mesh helps the PAM return to its initial state. Experimental results show that the swing angles of the two arms using PAMs can closely follow the desired trajectory, with tracking errors of the upper and lower arms within 0.25° and 0.3°, respectively. However, the motion accuracy of PAMs is significantly affected by the hysteresis effect. Michael C. Yip et al. [3] (2017) studied another promising actuator: the super-coiled polymer (SCP). This actuator is created by twisting polymer threads to an extreme until they form coils, resulting in an actuator with a power-to-weight ratio, strain, and deformation that rival or even exceed human skeletal muscle, while maintaining a rope-like form factor. SCP actuators were initially produced using carbon nanotube polymer yarns that were twisted into coils and are capable of being activated electrically, chemically, and photonically. These actuators can achieve tensile strains of up to 8%. Interestingly, the same effect can be achieved using commercially available fishing lines and sewing threads by heating and cooling the coiled actuators. SCP threads can generate significant mechanical power in a desirable form factor, and they are easy to manufacture and cost-effective. The key benefits of SCP actuators are their accurate control, inherent compliance and damping, and fast activation. These characteristics make SCP actuators particularly well-suited to the needs of artificial muscles [6-10].

3. Characteristics of The Human Hand

The human hand is an incredibly complex and versatile structure, offering a unique combination of anatomical features that make it capable of performing a wide range of tasks with precision and dexterity. Some of the key characteristics that define the human hand include:

- **High Dexterity and Precision:** The human hand's ability to perform intricate movements, such as picking up small objects, writing, or performing delicate surgeries, is unparalleled in the animal kingdom. This dexterity is due to the fine control offered by the fingers, thumb, and wrist.
- **Degrees of Freedom (DoFs):** The hand has multiple degrees of freedom, with each finger having its own independent movement control. This allows for complex motions like gripping, twisting, or bending, which are crucial for many everyday activities.
- **Sensory Feedback:** The human hand is equipped with a dense network of sensory receptors that provide real-time feedback to the brain. This feedback includes touch, pressure, temperature, and pain sensations, which are vital for tasks that require precision and force regulation.
- **Force and Strength:** Despite its relatively small size, the human hand is capable of generating significant force, especially with the fingers and thumb working together in various grasps. This allows for tasks ranging from light touch to heavy lifting.
- **Flexibility and Adaptability:** The hand can adapt to a vast range of tasks, from delicate movements like typing on a keyboard to more strenuous actions like lifting or carrying. Its flexibility in form and function is key to its versatility.
- **Inherent Compliance and Damping:** The hand’s soft tissues provide compliance and damping, which help in absorbing shocks and providing a more natural feel when interacting with objects. This helps reduce the risk of injury during forceful movements or when gripping fragile objects.
- **Grip Types:** The human hand can perform various types of grips—such as precision grips, power grips, and hook grips—allowing it to manipulate objects of various sizes, shapes, and textures with ease.
- **Independent and Coordinated Movements:** The hand's ability to coordinate movements between its five fingers, particularly the thumb, allows for fine manipulation and complex gestures. The

thumb's opposition to the other fingers is a key feature that sets the human hand apart from those of other animals.

These characteristics collectively contribute to the exceptional versatility of the human hand, making it one of the most sophisticated and functional parts of the body, shown in Figure 3 [11-14].

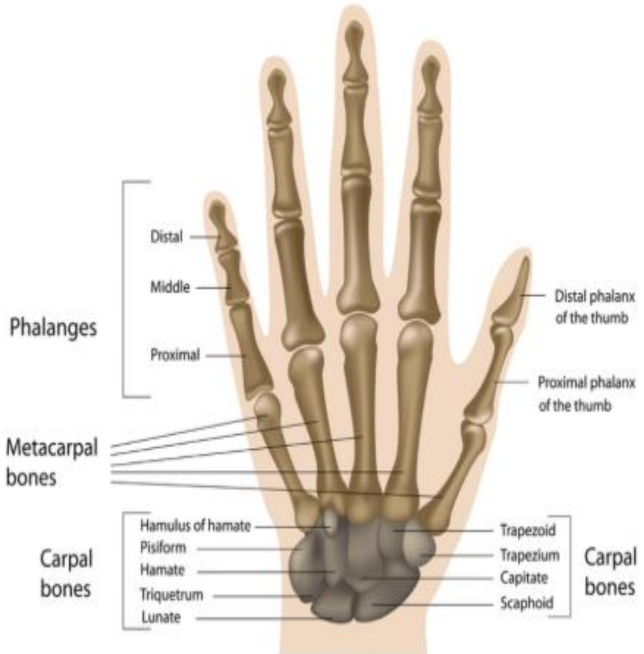

Figure 3 Image

4. Characteristics of Prosthetic Hands

Prosthetic hands are artificial devices designed to replace the lost or amputated human hand. While advancements in prosthetic technology have made significant strides, prosthetic hands still face many challenges in fully replicating the functionality and dexterity of a natural hand. Below are some key characteristics that define prosthetic hands:

- **Limited Dexterity and Precision:** Unlike the human hand, most prosthetic hands still struggle to match the dexterity and fine motor control required for delicate tasks. While prosthetic hands can perform basic gripping and pinching motions, the level of precision and fluidity seen in the human hand is not yet fully achievable.
- **Degrees of Freedom (DoFs):** Prosthetic hands typically have fewer degrees of freedom compared to natural hands.
- **Lack of Sensory Feedback:** One of the most significant differences between natural hands and prosthetic hands is the lack of sensory feedback. Prosthetic hands do not provide tactile sensations, such as pressure, temperature, or texture, which are essential for tasks requiring fine motor control. Without sensory input, users must rely on visual cues or trial and error to gauge the force and positioning of their grip.
- **Durability and Weight:** Many prosthetic hands are designed with durability in mind but can often be heavy, especially if they are constructed with robust materials to withstand regular use. Lighter materials, such as carbon fiber, are often used to reduce weight but may come at the expense of durability. Achieving a balance between weight, durability, and function remains a key challenge in prosthetic hand development.
- **Grip Types and Strength:** Prosthetic hands typically offer limited grip types, such as power or pinch grips, but may struggle to replicate the full range of human grasps, such as the precision grip or lateral pinch. The strength of the grip can also be a limitation, especially when handling fragile or heavy objects, as many prosthetic hands cannot apply the same level of force as a natural hand.
- **Power Source and Maintenance:** Prosthetic hands are typically powered by batteries or external power sources, which need regular recharging or replacement. The power supply can limit the usage time and convenience for the user. Additionally, maintenance and calibration of the prosthetic hand are crucial for optimal performance, but can sometimes be complex and require professional intervention.
- **Cost and Accessibility:** The cost of advanced prosthetic hands, particularly those with myoelectric control and high functionality, remains a barrier for many amputees. Access to these prostheses is limited by both cost and geographic availability, and insurance

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coverage can often be inadequate, shown in Figure 4 & Figure 5.

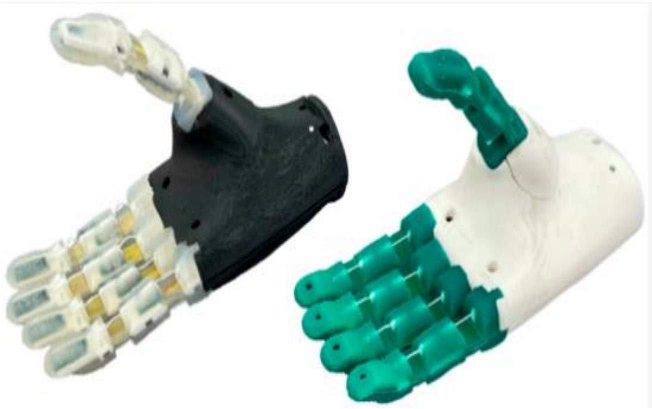

Figure 4 KIT Prosthetic Hands

Figure 5 Image

Although prosthetic hands have come a long way in terms of functionality, there are still many challenges to overcome to make them as intuitive, adaptable, and capable as the natural human hand. Ongoing research into better control methods, materials, and actuation technologies aims to close the gap between artificial and biological hands.

5. Discussion

Prosthetic hands have evolved significantly over the years, moving from simple mechanical devices to more sophisticated systems that incorporate advanced technologies such as myoelectric control, sensors, and robotics. Despite these advancements, prosthetic hands still face considerable challenges when compared to their biological counterparts. This discussion will explore the current state of prosthetic hands, the challenges they face, and the future directions in which technology may take them.

1. Advancements in Prosthetic Hand Technology

In recent years, there have been notable improvements in the design and functionality of prosthetic hands. Myoelectric prosthetics, which are controlled by the electrical signals from the user's residual muscles, have become the standard for modern upper-limb prostheses. These prostheses can perform various functions, such as opening and closing the fingers, and even more complex gestures, like rotating the wrist or controlling individual finger movements.

Furthermore, advancements in the development of actuators, sensors, and materials have enhanced the prosthetic's ability to mimic the natural movements of the human hand. Pneumatic artificial muscles (PAMs) and shape memory alloys (SMAs) are examples of such technologies that have shown potential for providing better actuation with higher compliance and flexibility.

2. Challenges of Prosthetic Hands

While prosthetic hands have made considerable strides, there are still significant challenges to overcome:

- **Limited Dexterity and Range of Motion:** Prosthetic hands, even with advanced technologies, still have limited dexterity compared to biological hands. Although many prosthetics offer a range of basic movements, achieving fine motor control like the ability to type, grasp small objects, or perform intricate tasks remains a challenge. Many prosthetic hands have limited degrees of freedom (DoFs), which makes performing complex hand movements difficult.
- **Lack of Sensory Feedback:** One of the major limitations of current prosthetic hands is the absence of sensory feedback. Natural hands rely heavily on sensory input—such as touch,

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pressure, and temperature—to adapt and respond to the environment. Without this feedback, prosthetic users must rely on visual cues or trial and error, which limits the accuracy and safety of their movements. While some prostheses are starting to integrate sensory systems, these are still in the early stages of development and are often not as effective or natural as the sensory feedback from a biological hand.

- **Control Complexity:** The control of prosthetic hands remains an area where significant progress is still needed. Although myoelectric control provides a more natural way to control the prosthesis, it often requires extensive training and can be prone to errors. Moreover, controlling more than one or two degrees of freedom with a single myoelectric signal is difficult. As a result, prosthetic hands with more complex movements and higher functionality typically require multiple control channels or additional sensors, which increases both complexity and cost, shown in Figure 6.

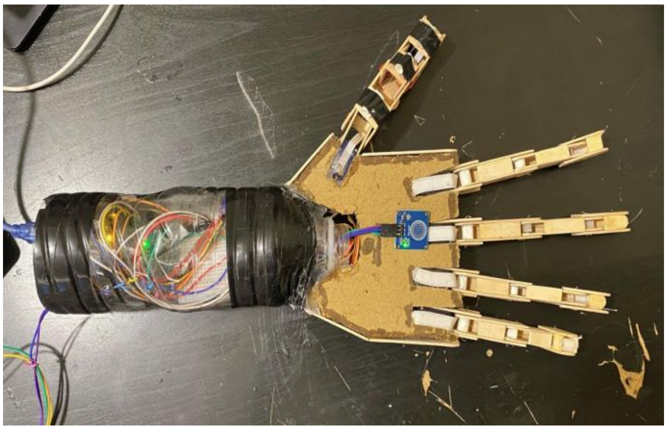

Figure 6 Image

- **Comfort and Aesthetics:** Many prosthetic hands still struggle with providing both comfort and aesthetics. While functional prostheses may prioritize performance, they often lack the ergonomic design or realistic appearance that many users desire. Additionally, the materials used in prosthetic hands can sometimes be uncomfortable or difficult to wear for long periods. The external cosmetic coverings of prostheses are often prone to wear and tear, reducing their lifespan and appearance.
- **Cost and Accessibility:** Despite technological advancements, high-functioning prosthetic hands remain expensive. The costs of materials, research, and production can make advanced prosthetic hands inaccessible to many people, particularly in low-income areas or developing countries. Furthermore, insurance coverage for prosthetic devices is often insufficient, which can prevent many amputees from obtaining the prostheses they need, shown in Figure 7.

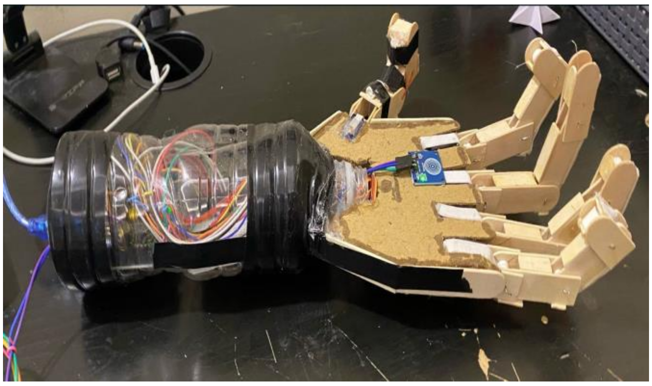

Figure 7 Image

Conclusion

While prosthetic hands have made significant progress in replicating the functionality of the human hand, there is still a long way to go before they can truly match the dexterity, comfort, and natural feedback of biological hands. As technology continues to evolve, however, the future of prosthetic hands looks promising. With further advancements in actuation systems, sensory feedback, and customization, prosthetic hands could one day provide amputees with an experience that is much closer to that of a natural, functional hand. further underscores its effectiveness. Participants reported a more positive aiming experience and perceived less lag when bullet magnetism was enabled, indicating that aim assistance not only improves objective performance but also enhances the subjective feel of the game.

- **Future Directions:** As research in biomimetic robotics and prosthetics continues, several exciting advancements are on the horizon:

- **Advanced Actuators and Control Systems:** The development of more efficient and precise actuators, such as soft actuators (e.g., pneumatic artificial muscles) and super-coiled polymers, could help achieve a greater range of motion and dexterity. Additionally, advancements in machine learning and artificial intelligence may allow for more intuitive control systems, enabling prosthetic hands to better adapt to the user's natural movements.
- **Sensory Feedback and Neural Integration:** One of the most promising areas of research is the integration of sensory feedback into prosthetic hands. Technologies such as sensory electrodes, haptic feedback, and neural interfaces could allow amputees to regain some of the tactile sensation of a natural hand. This would be a major breakthrough in improving the overall experience and usability of prosthetic devices.
- **Personalization and Customization:** Future prosthetic hands may incorporate more personalized features, allowing users to select the level of functionality, aesthetic design, and comfort that suits their needs. Advances in 3D printing could play a significant role in creating customized prosthetics at a lower cost, which would increase accessibility and provide better options for a wider range of users.
- **Improved Materials:** Research into new materials that are lighter, stronger, and more durable will likely result in prosthetic hands that are not only more functional but also more comfortable and longer-lasting. The use of advanced composites, bio-compatible materials, and self-healing materials could improve both performance and lifespan.

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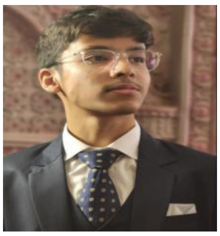

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