Evaluating Low-Cost EMG Prosthetics: Accessibility, Control, and Performance

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Abstract

Prosthetic technology has improved significantly over the past few decades, especially with the development of electromyography (EMG)-based systems. These systems allow users to control artificial limbs using signals from their muscles, making movements more natural and easier to learn. However, many advanced prosthetic devices are very expensive, often costing tens of thousands of dollars, which makes them inaccessible to a large number of users. This creates a clear gap between technological advancement and real-world accessibility.

This paper examines whether low-cost EMG-based prosthetic systems can serve as a practical alternative to high-end devices. It focuses on comparing these systems in terms of control, performance, and accessibility. The study uses a qualitative approach based on existing research and real-world case studies. Four systems are analyzed: the Open Bionics Hero Arm, the DEKA (LUKE) Arm, the Ottobock bebionic hand, and open-source EMG prosthetics such as e-NABLE and Arduino-based designs.

The findings show that low-cost prosthetics are far more accessible, with some open-source models costing only a few hundred dollars and are capable of performing basic everyday tasks such as gripping and holding objects. However, they generally lack the precision, strength, and durability seen in high-performance devices. In contrast, advanced prosthetics offer better control and a wider range of movement, but remain unaffordable for many users.

Overall, this study suggests that low-cost EMG prosthetics are a practical solution for improving accessibility, although further improvements are needed to enhance their performance and reliability

Introduction

For the United e-NABLE Coalition's (UEC) Quality Assurance team, nearly 90% of Kwawu arms require restringing due to manufacturing flaws, design inaccuracies or damage during shipping. This additional step slows down production, wastes resources and reduces the number of prosthetic devices that could be produced and shipped to patients. While this may seem like a small, localized issue, it reflects a much larger global problem. The gap between production and need is significant. Globally, more than 2.5 billion people require assistive technology and a large number of them do not have access largely due to high costs and limited healthcare services

(World Health Organization, 2022). This lack of access has real repercussions as prosthetic devices help individuals who have suffered limb loss regain independence and carry out normal everyday activities.

UEC's problem can be solved through the use of Electromyographic prosthetics (EMG). Unlike traditional body powered prosthetics which rely on cables and body movements to operate, EMG prosthetics use electrical signals generated by muscles control movement. These prosthetics are often more capable and reliable than string-based prosthetics. Recent developments in EMG-based prosthetics include better sensors, more advanced control systems, and improved designs that allow users to perform more natural and flexible hand movements, especially when compared to traditional mechanical devices (Chen et al., 2023, Abdikenov et al., 2025). The benefits are not only functional but improve the overall experience for users. These improvements make prosthetics easier and more intuitive to use as movements can be controlled through muscle signals (Chen et al., 2023).

However, prosthetics are personal tools, and their effectiveness ultimately depends on the individual using them. Body-powered and myoelectric prosthetics each have their own strengths in terms of durability, control, and comfort, and no single type works best for every user (Engdahl et al., 2024). Because of this, it is often difficult to compare performance across different kinds of prosthetics. EMG users were marginally more accurate at identifying object stiffness when using only visual feedback compared to BP users. There were also considerable variations in performance across participants which suggests that interpreting feedback is reliant on more factors than simply prosthesis design (Engdahl et al., 2024). Factors such as user experience, training, and environmental conditions also play a role.
Still, myoelectric prosthesis have proven to be more efficient for patients. Real-world reports show that modern bionic hands are already helping users perform everyday tasks such as holding objects and eating, which improves independence and confidence (BBC News, 2022).

Current prosthesis models, EMG-based and body-powered alike, suffer from some important limitations like restricted functionality and limited utility. The high abandonment rate of prosthetic hands, largely due to amputees not receiving intuitive and natural myoelectric control, needs to be looked into and improved (Chen et al., 2023).

EMG-based prosthesis have many advantages apart from pure functionality. As prosthetic technology continues to improve, issues such as fairness, accessibility, and ethical use are becoming more important in both research and real-world applications (Gavette et al., 2024). High-functioning prosthetics are built using expensive parts and are then sold at prices which are unaffordable for users. In fact, around 48% of individuals without an upper limb who do use prosthesis cited cost as a major limiting factor (Engdahl et al., 2024). Direct comparison between high-performance systems and low-cost alternatives are very few, especially in real-world conditions. With prosthesis moving towards newer solutions, it is important for these advantages to be balanced with user needs and affordability. While more cost-effective options may not provide the same level of benefits as their higher-end counterparts, they are necessary for making prosthetics accessible to a larger number of people (Gavette et al., 2024).

The Central Research Question for this study is "How do low-cost EMG prosthetics compare to high-end systems in terms of accessibility, control, and performance?
The study looks at factors such as accessibility cost, control, performance, durability and issues of equity and the global access gap. These areas help explain what factors make prosthetic devices powerful and useful for users. Figure 1 focuses on cost, one of the most important considerations for consumers, and compares the prices of different prosthetic models.

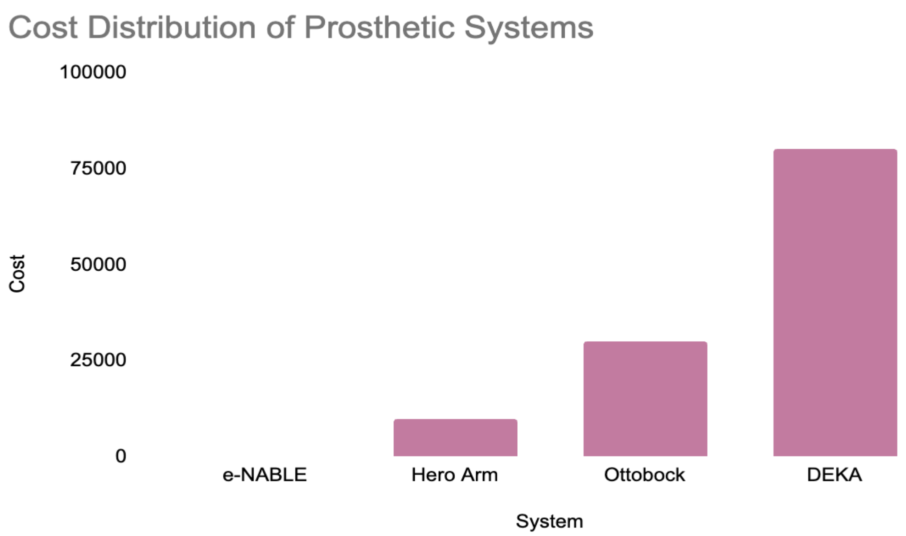

Figure 1: Cost Comparison of Different Prosthetic Systems
Source: Created by the author using illustrative data

Literature review

3.1 Fundamentals of EMG Prosthetics (100% human)
EMG signals are electrical signals generated by muscle contractions and detected through the use of surface electrodes. These electrodes detect weak signals from the muscles and send amplified signals to a microprocessor which then converts them into movement. Typically, low-cost prosthetic models use two electrodes. These signals, unlike body-powered triggers, do not require large physical movements from the user.

Additionally, several studies suggest that high-performing EMG based prosthesis have more adaptive and advanced features that enable more intuitive and natural movement compared to traditional prosthetics (Chen et al., 2023; Quadrelli et al., 2025; Parajuli et al., 2019). Many high-performing EMG-based prosthesis have multiple degrees of freedom and can support advanced control methods such as pattern recognition and simultaneous control, which allow for more natural, real-time movement. These models also typically use more than 16 closely spaced electrodes to generate two-dimensional maps of muscle activation, allowing to capture signals that lower density systems cannot (Quadrelli et al., 2025).

EMG signals increase when muscles contract and decrease when muscles relax. This pattern can be clearly seen in Figure 2.

Figure 2 shows how the EMG signal changes during muscle activity over time. At the beginning, the signal is very low because the muscle is relaxed. The signal then increases between Time 3 and Time 4 as the muscle contracts and becomes more active. After reaching the highest value, the signal slowly starts decreasing, showing that the muscle is relaxing again. By Time 7, the signal falls to 0 because the muscle is no longer active.

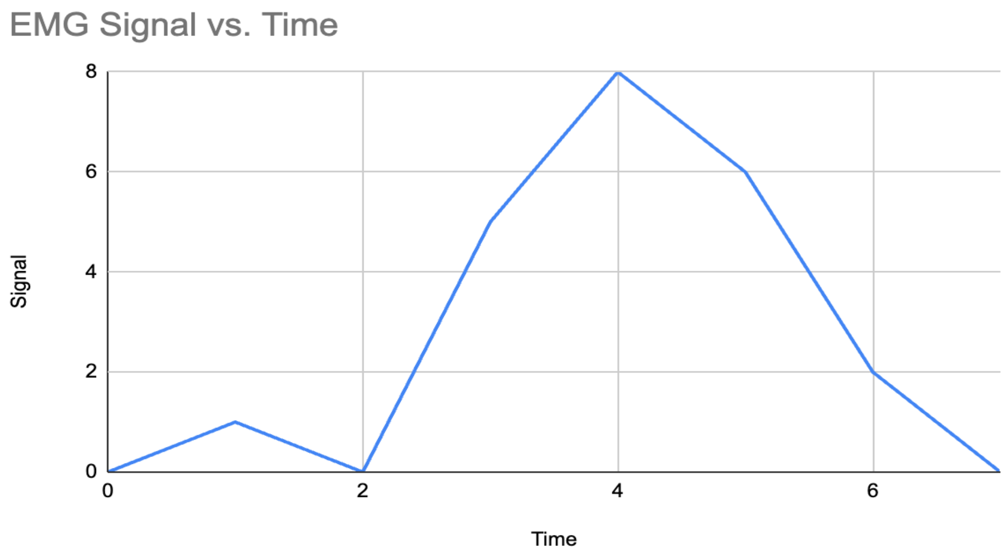

Figure 2: EMG Signal vs Time
Source: Created by the author using illustrative data

The X axis represents time during the EMG recording while the Y axis represents the strength of the EMG signal produced by the activity of the muscle.
Source: Created by the author using sample data

However, high-performing EMG prosthesis still face difficulties related to integration, accessibility, and design trade-offs. Because most commercial prosthesis rely on only two surface EMG electrodes, they are limited to controlling one joint at a time, making complex everyday tasks more difficult to perform (Quadrelli et al., 2025). Development on these prostheses is also limited. Current research mainly focuses on developing prostheses which have a higher number of total gestures rather than improving the ease of use. Even with low-cost models, users often require high amounts of training for effective real-world use (Chen et al., 2023).

3.2 Types of Prosthetic Systems

There are several types of prosthetic systems, including body-powered systems, myoelectric systems (EMG-based), and hybrid systems that combine elements of both. Body-powered (BP) systems rely on body movement, and offer certain advantages when compared to myoelectric systems, like extended physiological proprioception, a phenomenon exclusive to body-powered models. This phenomenon provides a sense of position and effort at the terminal device transmitted through a cable, which EMG users lack and therefore rely extensively on their vision during grasping and manipulation (Engdahl et al., 2024). However, this sensory difference does not always lead to functional disadvantages, as performance gaps decrease when visual feedback is given (Engdahl et al., 2024).

In movement quality and control precision tests, myoelectric prostheses and body-powered prostheses were found to be only slightly different in performance. While movements with EMG prostheses were typically slower and less smooth in object manipulation tasks when compared with body powered prostheses, the differences were not present for all tasks and overall differences between models were often minimal (Engdahl et al., 2024). Even when overall performance appears similar, the prosthesis models still differ in how they operate. Body-powered prostheses rely on physical effort through a cable and harness system that is generally reliable but offers limited degrees of freedom (Walters et al., 2025).

In contrast, EMG prostheses, while being more capable, are less durable. Through EMG signals and electric motors, these systems are versatile and offer improved grip strength, but they are more complex and sensitive to environmental factors like sweat and dirt (Walters et al., 2025). To compensate for the weaknesses of both myoelectric and body-powered prostheses, hybrid prostheses were developed. Hybrid models combine mechanical and electronic elements to provide both electronic control and mechanical reliability.

Commercial myoelectric systems are typically limited by the number of electrodes available; and hybrid designs partially address this by supplementing EMG inputs with body-powered control, thereby increasing the number of active control sites without requiring complex multi-channel signal processing (Walters et al., 2025).

Each system differs in cost, complexity, and usability. BP prostheses are regarded as the "standard of care" while EMG devices are typically used when BP devices prove to be insufficient (Engdahl et al., 2024). Body-powered prostheses are typically lower in cost when compared to EMG models, making them more accessible (Walters et al., 2025). However, hybrid models provide alternate solutions for users who cannot effectively operate either a purely body-powered or a purely myoelectric prosthesis by itself. One paediatric study (Spaeth et al.)

involved a child unable to generate enough EMG signal amplitude to reliably control an EMG-based hand; instead, a low-cost cable-operated switch was used (Walters et al., 2025). In cases like these, hybrid systems can improve usability as they balance the strengths of both EMG and BP models.

3.3 Performance Factors

Myoelectric prostheses' performance is determined by several design factors including control accuracy, responsiveness, and range of motion. Control accuracy directly affects how precisely users can execute movements. Methods such as neural networks and convolutional neural networks can recognize hand patterns with high accuracy, but managing complex movements in real-time remains a challenge (Won et al., 2024). Accuracy can also be improved through complex predictive techniques, like ridge regression. In one myoelectric model, the root mean square error (RMSE) improved to 7.80 degrees, an improvement of about 25.92 degrees compared to before its application. The low-cost analogue model produced an RMSE of 32.70 degrees (Won et al., 2024). These metrics display how predictive techniques significantly improve control accuracy.

The quality of performance is also influenced by responsiveness, which determines how quickly prosthesis reacts to user input. This is a key limitation of many myoelectric models. Delays exceeding 300 ms have been shown to negatively impact user performance in remote operations. Many control systems account for this Electromechanical Delay (EMD), which is the time lag between generation of EMG signals and resulting movement, through predicting user intent (Won et al., 2024). High-level amputation introduces a different challenge: the muscles normally used for hand movements may not be available due to the amputation. In such cases, EMG sensors may need to rely on muscles in the chest, shoulder, or back which may produce weaker signals and make the prosthesis harder to control reliably (Tchimino et al., 2024).

Many control systems also perform better with EMG feedback, which provides users with real-time information like grip strength, touch, or joint position back to the user. In one study, when EMG feedback was provided for the participant, the overall success rate in force matching tasks improved by approximately 30% compared to the no-feedback condition. Without feedback, the participant consistently overshot the target force in the majority of trials (Tchimino et al., 2024). Feedback systems are closely linked responsiveness, making both important factors in overall prosthesis performance.

While it is not a design aspect, user training and training burden also dictates how effectively control systems can be used. Training burden refers to the data collection routine that users must perform to calibrate the controller's machine learning model. Deep learning control methods require lengthy training routines to collect all muscle and limb position data, which can become burdensome for many users. In one study, transfer learning reduced this burden. This is significant because for a deep learning controller (RCNN-TL) training took approximately 50 seconds using a single-position routine, while for a linear discriminant analysis-based controller (LDA), training was required across multiple positions and sessions (Williams et al., 2024). In another study, user experience directly correlated with the effectiveness of EMG-based control: after only brief familiarization with a model through EMG feedback, the participant achieved an overall success rate of 87% (Tchimino et al., 2024).

As shown in Figure 3, prosthetic hands support multiple grip patterns.

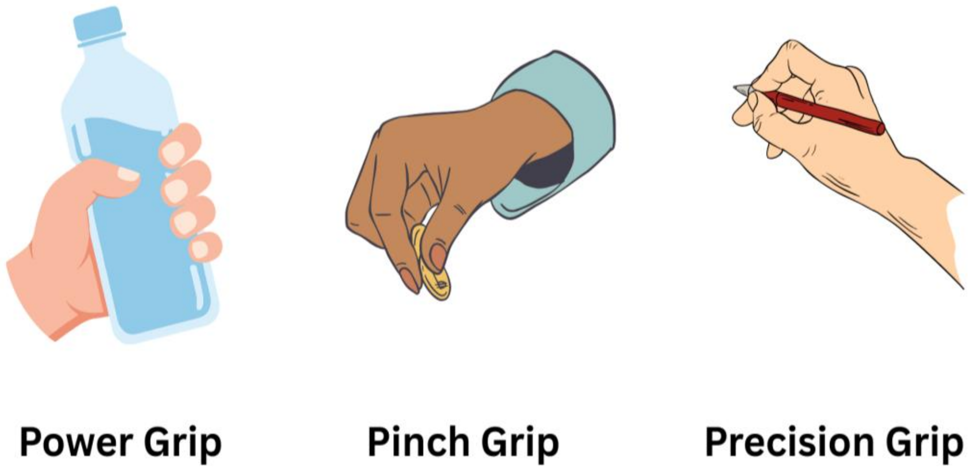

Figure 3: Grip Types
Source: Created by the author using illustrative data

3.4 Limitations and Challenges
Advanced prosthetics come with high costs, limiting access for many users. As a result many users are pushed towards low-cost models that struggle with functionality, durability and comfort. Low-cost models are limited by a low electrode count. Most commercial prosthetic devices rely on surface EMG (sEMG) electrode signals to function properly. Low-cost models often use only 2-6 electrodes, while the higher-end HD-EMG systems typically use 16 or more electrodes to detect muscle activity (Quadrelli et al., 2025).
This difference leads to many limitations with low-cost systems.

One key capability, pattern recognition, is not used in many low cost systems as it requires greater computational power and a larger number of sEMG electrodes (Donnelly et al., 2025). Advanced High Electrode density interfaces (HD-EMG) often use 16 or more closely spaced electrodes to make signals more accurate, but these systems come with strict technical requirements, such as specific electrode sizes, and analog to digital conversion to minimize noise (Quadrelli et al., 2025). These advanced features increase the cost and complexity of these advanced systems, making them unaffordable for low resource communities.

Electrodes used in low-cost models also lead to durability and performance issues. A conducive electrolyte gel is used in gel electrodes to maintain stable skin contact and reduce noise from movement. However, the electrolyte gel can dry out over time, leading to signal failure (Kamavuako et al., 2021). Another commonly used variety, solid metal dry electrodes, are reusable and do not require adhesives. However, they are more expensive and may lose signal quality during movement (Kamavuako et al., 2021

One viable alternative is the embroidered textile electrode, which is flexible, reusable, and is able to conform to the shape of the arm while maintaining stable skin contact for extended periods. It is also around 40% cheaper than traditional models (Kamavuako et al., 2021).

While gel electrodes provide high-quality signals, they require constant maintenance to keep them wet, creating another cost barrier.

Low-cost systems that substitute wet electrodes with dry ones to cut costs often come with low signal quality and reduced control (Quadrelli et al., 2025). Signal drift and the requirement for repeated recalibrations are ongoing challenges with prosthetic systems.
Because of these performance and maintenance issues, many prosthetic devices are eventually abandoned by their users. The overall abandonment rate of upper limb prosthesis is nearly 44%, with myoelectric devices accounting for 92% of these cases, largely due limited comfort and difficulty of use (Quadrelli et al., 2025).

3.5 Research Gap
While many studies cover the performance capabilities of systems in theory, there is limited research of how they work in real world situations. Although many machine learning models display high accuracy in lab settings; however, they require repeated recalibrations in real-world situations to remain effective (Abdikenov et al., 2025).

Furthermore, most amputees rely on models that haven't evolved in decades showing that breakthroughs in research struggle to translate into real-world adoption (Batista et al., 2025). Another gap is the lack of focus on affordability and user needs. New models are also often not user oriented as they are developed without sufficient user or clinician inputs (Gavette et al., 2024).

Additionally, low-cost systems and high-end prosthetic systems are rarely compared against each other especially in real world settings (Abdikenov et al., 2025). When some amputees receive prosthesis from insurance companies, they are often reassured on the efficacy of lower cost alternatives. However, there is limited evidence to evaluate whether low cost prosthetics can be sufficiently functional for everyday users (Gavette et al., 2024).

Methodology

This study uses a qualitative and comparative research approach based entirely on secondary data. The aim is to evaluate the feasibility of low-cost EMG-based prosthetic systems by comparing them with high-performance commercial devices. Since there is no access to laboratory facilities or equipment, the study relies on existing peer-reviewed research, technical reports, and published case studies.

A structured literature search was carried out using databases such as Google Scholar, PubMed, IEEE Xplore, and ScienceDirect. Key phrases used in the search included "EMG prosthetics," "myoelectric control systems," "low-cost prosthetic design," and "prosthetic accessibility." Only sources published in English after 2015 were included to ensure that the data reflects recent developments in the field. Sources that lacked clear methodology, reliable results, or relevance to EMG-based prosthetics were excluded.

The study focuses on four case studies: Open Bionics Hero Arm, DEKA (LUKE) Arm, Ottobock bebionic hand, and open-source EMG prosthetic systems such as e-NABLE and Arduino-based designs. Each system was analyzed using common criteria including cost, control accuracy, range of motion, usability, and accessibility.

A comparative approach was used to identify patterns across these systems. This method allows the study to combine technical understanding with real-world applications, providing a balanced evaluation of both performance and accessibility in prosthetic technology.

Results

Case Study 1: Open Bionics – Hero Arm (2017)

Purpose

This case study is about the Hero Arm, a bionic arm reliant on both 3D printed parts and myoelectric systems. The arm was developed by Open Bionics and released in 2017. The purpose of its development was to design a prosthetic that is both accessible and feasible for everyday use. It is a customizable arm per individual, offering different hand sizes, battery layouts, and either a 3-motor or 4-motor configuration. The 3-motor configuration offers 4 grip patterns, while the 4-motor version supports 6 grip patterns. Because of its modular design, it is especially popular among younger users who can see it evolve with their age. The device is compliant with CE, UKCA, and FDA regulations, confirming it meets all safety standards.

Technology Used

The Hero Arm is controlled by two EMG sensors embedded in the arm that detect muscle movements and translate them into hand responses (Open Bionics, n.d.). The arm is also functional for users with only one viable muscle site due to an alternating toggle system and one electrode. The arm socket is a custom 3D print designed from a scan of each user's residual limb (Open Bionics, 2023). Its 3D-printed components are integral for maintaining both weight and manufacturing costs low, which is a design choice to support global supply shortfalls. The arm is also very customizable due to its modular design and can come with a 3-motor design or a 4-motor design (World Health Organization, 2022).

Key Findings

The Hero Arm's ability to operate with either 3 motors or 4 motors allows it to offer between four and six different grip patterns: Fist, Hook, Tripod A, Tripod B, Pinch A, and Pinch B. Each of these grip patterns is suited to different everyday tasks (Open Bionics, 2023). Each pattern also can handle a varying amount of weight, from 500 grams to 13 kilograms (Open Bionics, 2023). The Hero Arm comes at a significantly lower cost than high-end modular alternatives. Through its simple customization, the arm appeals to young children especially who adapt often (World Health Organization, 2022). Movement speed in the arm is controlled at a proportional rate by how firmly the user tenses their muscles; smaller tensing produces slow movement and higher tensing produces quicker movement (Open Bionics, n.d.).

Impact

The Hero Arm's customizable and modular nature allows for broader accessibility. Among young users, swappable cosmetic covers allow for more personalization. The adjustable BOA Fit system enables the user to fine-tune the fit throughout the day without sacrificing comfort (Open Bionics, n.d.). The arm is also a low-cost EMG-based control system, providing assistive technology with reduced financial hardship (World Health Organization, 2022). Each model is custom-built by the user and still maintains advanced bionic systems (Open Bionics, 2023). The device also supports bilateral amputees while being suitable for users across all age ranges. It comes along with a Sidekick app that provides training tutorials and configuration options to extend accessibility (Open Bionics, 2023).

Limitations

The Hero Arm's rating of IP20 indicates it is not waterproof; water-damage also nullifies its 12-month warranty, reducing the arms sustainability. The arm has a maximum load of 13 kg and cannot be used in contact sports or while driving (Open Bionics, 2023). The five-year service for the arm requires annual professional maintenance (Open Bionics, 2023). While the arm is accessible at first to low-resource users, the support infrastructure needed after is less accessible (World Health Organization, 2022). Users are also instructed to never modify or repair the arm themselves and instead contact a prosthetist, creating dependency and more spending (Open Bionics, n.d.). Over time, the fixed socket length leads to EMG sensors gradually shifting out of their original position, lower control responsiveness. Finally, if a user uses the single-site option, the design is far more complex and reduces control precision significantly (Open Bionics, 2023).

Case Study 2: DEKA Arm (LUKE Arm) (2014)

Purpose

The DEKA (also known as LUKE) Arm is a high-performance prosthetic system that provides advanced control for partial or full upper limb amputations. The arm is designed for transradial, transhumeral, and shoulder disarticulation amputations. It was developed by DEKA Research & Development Corp. It was funded and supported by DARPA and developed from the mid-2000s until 2014. The arm is now manufactured by Mobius Bionics in Manchester, New Hampshire. It is meant for users 18 years and older. It is one of the most advanced prosthetic systems currently available and is both customizable and expensive.

Technology Used

The arm includes a sensor that provides grip force feedback and can sustain functionality with both light rain and the collection of dust (Health.mil, 2017). The DEKA Arm relies on a flexible, multi-input control system. Along with surface EMG electrodes and pressure switches, wireless IMUs (inertial measurement units), rocker switches, and linear transducers are all used to offer several control inputs (Mobius Bionics, 2019). In the arm's maximum configuration, it offers 10 degrees of freedom with a wrist flexor, wrist rotator, elbow flexor, humeral rotator, shoulder flexor, shoulder abductor, and multi-articulating hand with four degrees of freedom. The joints are controllable simultaneously and preprogrammed grip patterns are provided (Mobius Bionics, 2019). The Generation 3 model of the DEKA Arm is available in 3 configurations, including the Radial Configuration (RC), the Humeral Configuration (HC), and the Shoulder Configuration (SC), for transradial amputees, transhumeral amputees, and shoulder disarticulation or forequarter amputees, respectively. (Resnik et al., 2018).

Key Findings

The DEKA arm's multi-input system and simultaneous multi-joint actuation allows for high precision and quick responsiveness (Mobius Bionics, 2019). The high amount of degrees of freedom also enables almost natural arm function in controlled environments. The grip force feedback also allows the user to understand real-time situations and adjust (Mobius Bionics, 2019). Additionally, the large variety of control inputs allows for user adaptability (Health.mil, 2017). The Radial model weighs 1.4 kg, the Humeral model 3.4 kg, and the Shoulder model 4.7 kg. One study ran after in-laboratory training found that the DEKA arm was slower in task completion with an effect size of 0.76; however, after in-home training, the arm passed conventional standards in performance metrics and performed at the standard for task completion with an effect size of 0.71 (Resnik et al., 2018). Self-reported usability also improved with lab training and home use with effect sizes of 0.55 and 0.49. Participants found it substantially easier to do self-dictated tasks using the DEKA arm as depicted by the PSFS, with large effect sizes of 1.67 in laboratory training and 2.13 in home use (Resnik et al., 2018).

Impact

The DEKA Arm significantly enhances user independence and quality of life, demonstrating the full potential of advanced EMG systems with multi-control input and setting a benchmark for other models (Mobius Bionics, 2019). The arm's weather resistance and 10 degrees of freedom define it as the ceiling of myoelectric models (Mobius Bionics, 2019). The study done with in-laboratory training and at home use provided information on functional performance and quality of life that was unavailable on the DEKA Arm previously. The finding that training and home use improves performance suggests that the true potential of advanced prosthesis systems can be elevated even higher after real-world use (Resnik et al., 2018). The study also reinforces that the Gen 3 model has significant improvements in hand shape and foot controls compared to the Gen 2 model (Health.mil, 2017).

Limitations

The DEKA Arm comes at a very high cost, limiting accessibility for most users (Health.mil, 2017). The study sample conducted with in-laboratory training and at home use used a study sample of 23 participants and 15 participants respectively, reflecting a small sample size. Several sub-group comparisons were underpowered and may have led to limited statistical output (Resnik et al., 2018). The study period was also capped at 12 weeks, suggesting more training time may improve functionality even further. However, the time frame did convey how the arm requires extensive training and support; even after such preparation, some participants had not fully learned how to use the device, meaning it is a steep learning curve for users (Resnik et al., 2018). Along with cost challenges, the need for a certified prosthetist and specialized healthcare and because the prosthesis is made for users 18 and older, which leaves younger users out, the prosthesis has a very narrow accessibility gap (Mobius Bionics, 2019).

Case Study 3: Ottobock Bebionic Hand (2010s)

Purpose and Background

The Ottobock Bebionic Hand was first introduced in 2010 by Otto Bock Healthcare Products GmbH, with newer versions being released throughout the 2010s. The Bebionic Hand comes in three different variants and is controlled using myoelectric energy. The arm is intended for users with amputation levels ranging from below-elbow to shoulder amputations. It was designed as a commercial, mid-range prosthetic that balances comfort, functionality and everyday use. The aim was to provide advanced hand movement while still remaining practical for daily activities. The arm is primarily used in clinical and rehabilitation settings where training and customization support can be provided for users.

Technology Used

The bebionic hand relies on EMG-based control that uses muscle signals from the user's residual limb to drive the hand's movements. The hand offers 14 different grips through two thumb positions: opposite and lateral (Ottobock, 2022). These grip patterns help users perform everyday activities in a natural way. Bebionic hand's sensor system enables the user to switch between multiple hand positions without relying on highly complex inputs (Ottobock, n.d.). This makes the system easier to learn and use as compared to some other advanced prosthetic systems. The device also uses bluetooth connectivity and can be configured through a PC connection. Its configuration can be altered using a program switch at the back of the hand that controls all power and mode features (Ottobock, 2022). The hand can also connect with other Ottobock prosthetic parts such as elbow joints and wrist rotators making it very adaptable for different users with different amputation types.

Key Findings

The bebionic hand is a turning point in the lives of many users as it helps restore independence in their everyday lives. Its ability to mimic real hand movements across multiple grip configurations and its reliable physical construction is a big reason the arm is considered a high-end prosthetic system (RP Technologies, n.d.). The arm's ability to change between thumb positions allows users to perform different tasks effectively. For example, the tripod grip can be used for holding pens and coins, the active index grip for spray bottles, the precision open and closed grips for tabletop tasks, the key grip for spoons and paper, the finger point for keyboards and buttons, the column grip for light switches and the mouse grip for using a computer mouse (Ottobock, 2022). The fingers are designed to fold away when brushing against objects, serving as a key safety feature that prevents damage to the device (Ottobock, n.d.). The device also offers audio beeps and vibration signals as feedback, so the users do not have to rely only on visual confirmation while moving the arm. This additional feedback increases the confidence and control of users in their daily life. As compared to other more complex prosthetic systems, the bebionic hand is often considered easier to use as it has a simplified grip-switching system and intuitive controls (Ottobock, 2022).

Impact

The bebionic hand acts as a middle ground in the prosthetics market, being more functional than low-cost systems and more accessible than the highly complex systems like the LUKE arm. Because of this, the arm is very beneficial to users in all parts of the world (RP Technologies, n.d.). The bebionic hand is compatible with both standard Bluetooth software and advanced Myo Plus pattern recognition systems making it a versatile device for a wide range of users (Ottobock, n.d.). The three wrist variants serve users with all lengths of forearms and provide fine adjustments for users who struggle with precise actions. The device can be enhanced through a range of Ottobock elbow components and wrist rotators, allowing for more integration. This feature makes the arm extremely useful in clinical settings (Ottobock, 2022).

Limitations

Despite being more accessible to users than other high-end systems, the bebionic hand is still more expensive than most other EMG alternatives. Compared to other models like the LUKE arm, its performance falls short in highly advanced tasks (RP Technologies, n.d.). Although the arm does offer a technical finger replacement feature, it still relies on Ottobock specific components that limit customization and repair (Ottobock, n.d.). The device is vulnerable to moisture, dirt, and solid particles. It is also extremely susceptible to high temperatures and water (Ottobock, 2022). Other high-frequency communication devices like metal detectors or scanning systems also pose a threat to the bebionic hand, and it is recommended that users stay at least 30 cm away from even mobile devices to ensure no bluetooth interference. Performance also depreciates greatly as battery life drops, with very limited grips being available at lower battery levels (Ottobock, 2022).

Users may also require professional fitting, training, and maintenance support, which can increase long-term costs and therefore reduce accessibility.

Case Study 4: Open-Source EMG Prosthetics (2013+)

Background and Purpose

Many other open-source EMG prosthetics have been developed to improve accessibility for users, often at the cost of advanced performance. The WHO estimated that nearly 40 million amputees live in developing countries while only around 5% of them have access to any prosthetic device. In the United States, prosthetic arms range from $5,000 USD for basic models to over $100,000 for advanced neuro-prosthetic versions (Cutipa-Puma et al., 2023). The Zero Arm, an ultra low-cost robotic hand prosthesis, was developed to solve this accessibility gap by maintaining precision and durability despite lower cost materials.

During the 2010s, Arduino based systems popularised the idea of low cost prosthetics that brought together simple electronics with 3D-printed components. The e-NABLE community, founded in 2013, is a global volunteer network where volunteers develop and distribute accessible prosthetic models using mostly 3D printed parts. Many of these systems are open source, allowing developers and users to modify, improve and customize them to suit individual users. Most of these designs rely on elements from Arduino-based arms and are focused on being affordable, accessible and customizable.

Technology Used

Basic EMG sensors are a common feature of all open-source EMG models, where they work in combination with Arduino-based microcontrollers to control one-degree-of-freedom (Rodrigues et al., 2025). These sensors detect electrical signals from muscles and convert them into movement commands for the prosthetic hand.

The Zero Arm relies on an Emotiv Insight EEG headset for signal acquisition. For control, the device uses an Arduino Nano for feedback, as well as a Raspberry Pi Pico as the primary microcontroller. The arm also relies on 29 different 3D printed parts (Cutipa-Puma et al., 2023).

The usage of 3D printed parts enables users to personalize the prosthetic without major increases in manufacturing costs (Rodrigues et al., 2025). Most open-source prostheses rely on ABS, PLA, and Nylon to balance durability, flexibility and ease of fabrication (e-NABLE, n.d.).

Key Findings

Some open-source models provide reliable detection of muscle contractions at a threshold of 7 ADC units and an actuation response time of 150 ms (Rodrigues et al., 2025). Arduino-based models also can reach accuracies of as high as 97.25% while maintaining extraction times of only 26ms per window, making them practical, low-cost models ideal for basic prosthetic control.

These systems show that even low-cost systems using simpler hardware can provide good functionality.

One Arduino-based model was developed at an ultra-low cost of only $259.86, making it an extremely affordable option with reasonable performance (Boubker et al., 2024). The total expense of the Zero Arm is about $600, which is still much more affordable compared to many commercial EMG-based prosthesis. The arm also is fairly reliable, with an 86.67% success rate with everyday tasks (Cutipa-Puma et al., 2023). Although these low cost systems do not match advanced commercial prosthetics in terms of performance, they still meaningfully help many users who may not otherwise have any access to a prosthetic device.

In the e-NABLE community, a variety of designs have emerged as a result of the large global volunteer network contributing to development and testing. This community driven approach encourages rapid prototyping and continuous improvement of open source models (e-NABLE, n.d.).

Impact

Open-source EMG-based prostheses provide affordable options with good functionality. Many of these arms also include sensory feedback, elevating the system beyond basic entry-level models (Boubker et al., 2024). The e-NABLE platform has brought together volunteers throughout the world to design and produce these prosthetics, with over 600 schools participating in donating models worldwide (e-NABLE, n.d.). Like other open-source models, Zero Arm's use of 3D printed parts demonstrates how weight can be reduced and customization can be achieved at a lower cost. Its model also relies on a machine learning system that achieved an object-detection success rate of 70% despite its low cost (Cutipa-Puma et al., 2023). The open-source hardware stack relying on Arduino-based and other microcontrollers as well as cheaper parts is driving the expansion of prosthetic availability for users across different economic backgrounds (Rodrigues et al., 2025). These systems become especially useful in low resource regions where commercial prosthetic options may either be too expensive or difficult to access.

Limitations
Due to their lower cost, open-sourced models lack many advanced features compared to superior commercial models. Arduino-based systems often rely on threshold-based activation rather than pattern recognition. Combined with a limited number of electrodes, this reduces the level of freedom and may lead to delayed, less natural movements (Rodrigues et al., 2025). As a result, performing non basic, complex tasks, may pose a challenge.

EMG signals from these models are also often unreliable, and limited testing may reduce durability. Additionally, the 3.7 V LiPo battery lasts only around 4 hours before needing a recharge (Rodrigues et al., 2025). 3D printed pieces may also wear out faster and require frequent replacements (Cutipa-Puma et al., 2023). Fine and precise movements are also a challenge, and open-source models are often vulnerable to water, fine dust, and dirt (Cutipa-Puma et al., 2023). Because the devices are body-powered and developed without any warranties, they are both less precise and less suited for high-performance tasks; in the e-NABLE community, the lack of professional supervision leads to very few clinical-grade models (e-NABLE, n.d.). The machine learning that some Arduino-based models rely on is also limited, being only trained on small datasets such as 128 samples and may lack the computational power needed for advanced learning. Most open-sourced models struggle with wear on their microcontrollers over time as well, leading to additional costs in the future (Boubker et al., 2024).

Figure 4 compares functional capabilities of prosthetic systems included in this study. The DEKA Arm shows the best overall performance, while the e-NABLE systems show limited functionality due to their focus on low cost and accessibility

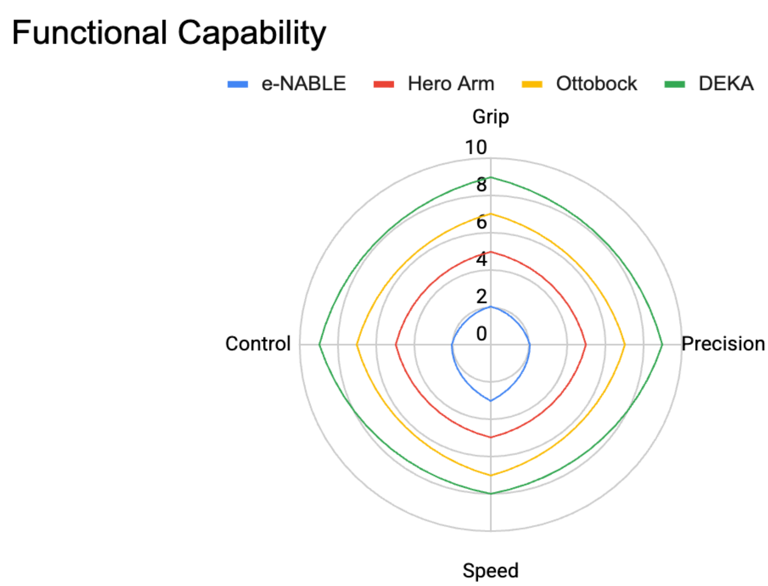

Figure 4: Comparison of Functional Capabilities across different prosthetic systems
Source: Created by the author using information from the case studies.

Discussion

5.1 Cross-Case Analysis

Different prosthetic models are designed to meet different user needs and no one system is ideal for all users. In general, higher cost systems tend to have more features with higher performance. Myoelectric prosthesis, which are often more expensive, also often provide more functionality and better performance compared to passive models (Wilson et al., 2025). It is important to note that higher cost does not always correspond to higher performance. In one study, body-powered systems were able to utilize force feedback to a greater extent than myoelectric systems in a series of tasks, supporting the idea that lower-cost systems can also offer good functionality (Engdahl et al., 2024). Similarly, the Hero Arm showed that a more affordable prosthetic can still provide multiple grip patterns and offer great functionality for everyday use. High-end systems can offer more precision and control. Specifically, advanced technology models offered improved mobility, independence and safety for many users particularly in clinical settings (Gavette et al., 2024). However, low-cost systems remain very important as they are more accessible and affordable, even if less powerful. For example, the e-NABLE and Zero Arm case studies showed that open-source prosthetics can provide very affordable options for cost conscious users who cannot buy or access commercial devices. Recent developments in machine learning and AI could further improve the responsiveness, accuracy and ease of use of prosthetic models (Gavette et al., 2024).

5.2 Accessibility vs Performance

Cost has been one of the biggest challenges for amputees in need of prosthetic devices. One study showed that 48% considered cost a major reason for not adopting a prosthesis (Wilson et al., 2025). The case studies were indicative of a clear trade-off between affordability and performance. Lower-cost systems such as the e-NABLE and Zero Arm may not provide all the benefits that their higher-end counterparts do, but they do provide basic functionality at a lower cost, making them more available for users who are challenged for resources (Gavette et al., 2024). On the other hand, high-end systems such as the DEKA Arm provide better precision, control and functionality, but require stable internet connection, compatible hardware and software, and specialized training making them expensive and less accessible (Gavette et al., 2024). Middle ground systems such as the Hero Arm and Bebionic Hand balance cost, functionality, and customization. Their adaptable designs can be customized for individual use and they often provide the most feasible solution for many prosthetic users (Engdahl et al., 2024).

Table 1 compares all systems across variables. It demonstrates how models with higher cost have better accuracy and grip, but lower accessibility.

Table 1: Cross Case Comparison

System	Cost	Accuracy	Grips	Access
Hero Arm	Medium	Medium	Moderate	Medium
DEKA	High	High	High	Low
Ottobock	High	High	High	Medium
e-NABLE	Low	Low	Low	High

Source: Created by the author using information from the case studies.

5.3 Technical Limitations

Advanced models require various levels of training before users can take full advantage of all their features. For example, in the DEKA Arm case study, a significant improvement in performance was seen after users received targeted training in using the prosthetic in everyday situations (Resnik et al., 2018). In the absence of such training, these models are often abandoned by users (Gavette et al., 2024). In low-cost devices, hardware limitations can reduce performance. Factors such as the prosthetic being too heavy, heat buildup, limited control and lack of sensory feedback can lead to discomfort and difficulty of use (Gavette et al., 2024). For instance, the e-NABLE and Zero Arm are relatively inexpensive as compared to advanced systems, but they also offer fewer control options and less sensory feedback when compared to the more expensive commercial devices (Gavette et al., 2024). Research has also shown that Myoelectric systems are generally more accurate at identifying object stiffness when only visual feedback is available. However, although Myoelectric systems are generally more advanced and offer greater control, body powered systems tend to perform better in tasks which depend on force feedback (Engdahl et al., 2024).

5.4 Future Outlook

Machine learning and artificial intelligence could play an important role in the next generation of prosthetic devices, helping them with accurate signal processing and better control (Gavette et al., 2024). However, future models need to focus on designs that are more user friendly. Prescription based designs that include advanced prosthetic features and yet are tailored to the specific needs of the individual user can improve both performance and usability. Additionally, advanced signal-processing and AI based systems are likely to succeed only when they are designed around the needs and comfort of the user (Wilson et al., 2025). The case studies in this research show that factors like user comfort, training and customization are as important as advanced technology. Open-source innovation may grow from incorporating ideas and opinions from a wider base of users and developers to encourage wider adoption in the future (Gavette et al., 2024). Use of better materials in the future can further reduce weight, improve durability and functionality under different temperature conditions, reduce noise, and provide more comfortable harnesses (Engdahl et al., 2024).

5.5 Ethical Considerations

At times, prosthetic technologies are not equally available to all users. Users who are financially constrained or have less access to healthcare may find it difficult to obtain advanced models. This raises an important ethical issue as even the most advanced prosthesis will have very limited impact if they are not available to a wider population and the people who need them the most (Engdahl et al., 2024). Promoting health equity and ensuring all who need prostheses have access to models using advanced technologies can increase independence, thereby improving the quality of life of many amputees. While it is important to meet safety standards and develop high quality devices, it is equally important that affordability and accessibility be considered during the design process (Gavette et al., 2024). It is ethically important that the healthcare system ensures that all amputees get the treatment and solutions they need irrespective of whether they are covered by medical insurance or not (Gavette et al., 2024). Another ethical challenge is prosthetic abandonment. Users may stop using prosthetic devices due to dissatisfaction with models, cost of repairs, and inconvenience of use. With both cost and functional dissatisfaction being reasons for abandonment, more affordable prosthetics that are reliable, comfortable and easy to use are needed to reduce the inequality gap (Wilson et al., 2025).

Conclusion

In conclusion, it can be said that EMG prosthetics can significantly improve the daily life of people with upper limb amputations. These devices help users perform a wide range of movements and complete everyday tasks with a high degree of independence. Modern prosthetics have become more accurate, responsive and easier to use over time. However, many users still face challenges like high costs, limited access and difficulty or discomfort in using these devices especially the advanced models.

A close look at open-sourced models from the e-NABLE community demonstrates how 3D-printed sockets, open-sourced hardware and software, and simple calibration toolkits are low-cost, functional solutions (Abdikenov et al., 2025). Still, high-end systems, such as HD-EMG models with machine learning, can achieve more accurate control and better gesture recognition compared to standard commercial systems (Quadrelli et al., 2025). However, these systems often require advanced hardware and processing power, increasing their cost and making them less available to many users, especially those with financial constraints (Walters et al., 2025).

As shown in Figure 8, there is generally a trade-off between cost, performance, and accessibility with a few exceptions. The most expensive commercial models of prosthetics come with the highest levels of control and accuracy, while lower-cost devices generally offer fewer features.

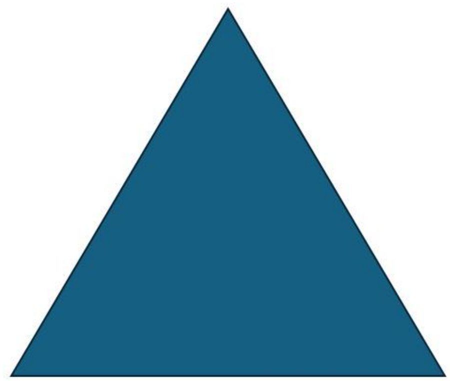

Figure 8: Cost-Performance-Accessibility Triangle indicating balance between crucial factors. Source: Created by the author using information from the case studies.

Going forward, researchers should aim to develop models which are both affordable and effective. Research also needs to be standardized with better-defined categories (such as hybrid-powered, active wrist control). This would help in customizing devices for individual users which would of great benefit to them (Walters et al., 2025).

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