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Prototyping a Cost-Effective, 3D-Printed Transradial Myoelectric Arm: Integration of sEMG Signal Processing, Microcontroller Actuation, and Anthropometric Design

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Abstract:

Spectral analysis of data, whether seismic or well-log, provides another dimension of analysis and interpretation. These integrations are expected to lead to more accurate and detailed characterization of subsurface formations, which will have important implications for the oil and gas industry and other fields that rely on geophysical data. Spectral decomposition has been used to extract and determine lithological boundaries, reservoirs, etc. However, the methods fail at providing both high time and frequency resolution. The window length and the fact that the actual signal does not drop to zero outside of the artificially constrained time frame determine the resolution of the technique. Additionally, these techniques typically do not make use of the crucial thickness data that is computed in the Fourier phase spectrum. Spectral decomposition is a fundamental mathematical tool that is widely used in machine learning and other fields of data science and engineering and forms the basis of many machine learning algorithms and techniques. We propose to use an improved spectral decomposition technique known as Continuous Amplitude Phase Spectrum (CAPS), which offers high frequency resolution as well as high time/depth resolution of the amplitude and phase spectra. The study used publicly available seismic datasets from two fields, i.e., Stratton and Penobscot, and two wells from the Penobscot field, L-30 and B-41, with gamma-ray, sonic, density, and neutron porosity logs. The areas of interest highlighted by the features derived from CAPS decomposition of the seismic and well log data were found to be in good agreement with the reported findings.

Keywords: *Myoelectric Prosthesis, sEMG Signal Processing, 3D Printing, Additive Manufacturing, Transradial Amputation, Anthropometric Design*

I. INTRODUCTION

Recovery of lost motor function after upper limb amputation is a highly sophisticated grand challenge at the interface of biomechanics, robotics, and medical rehabilitation engineering [1]. Amputation due to trauma, pathology, or congenital abnormalities considerably disables an individual from moving, staying independent in his or her activities, and engaging in psychosocial well-being [2]. The required artifacts in the form of working hands are an essential technological imperative, not only to replace the lack of limb shape, but to restore a complete physical wholeness and restore to counselled participation in social and work behaviors [3]. The requirement to develop a reliable prosthetic that continually reinstates precise and intuitive manipulation continues to push thoroughgoing bio-inspired innovation in this important field of medical technology [2].

The history of prosthetics has come a long way over the years, from simple mechanical devices to advanced, motorized systems [5]. The most significant technological advance in prostheses is perhaps the evolution of myoelectric prostheses. These systems utilize surface Electromyography (sEMG) to pick up the electrical activity when a residual muscle contracts, converting the physiological signal to digital commands for electromechanical movement [6]. The modern-day state-of-the-art transradial myoelectric prostheses are designed for below-elbow-level amputations. They offer better user response and more functionality using sophisticated signal processing to mimic natural processes along the neuromuscular control path of the human body, as demonstrated in the Modular Prosthetic Limb (MPL) and the Luke arm research platforms [7-8].

The history of functional prosthetics indicates an outstanding advance from simple powered body devices to advanced, externally powered electromechanical systems [5]. A major technological threshold was crossed with the introduction of myoelectric prostheses. These advanced prosthetic systems use surface Electromyography (sEMG) for biosignal transmission, interpreting the electrical potentials produced by the residual musculature of the user and converting that biological information into individual digital control inputs for the electromechanical function to follow [6]. Modern transradial myoelectric devices built to support an amputation distal to the elbow joint are the current leading-edge representatives in this development. The desired aim of these devices is to provide the development and exploitation of robust neuromuscular control accuracy and responsiveness with advanced signal processing and pattern recognition capabilities that ultimately attempt to follow physiological motor pathways, as exemplified by high-fidelity research test beds such as the Modular Prosthetic Limb (MPL) and the Luke arm [7, 8].

In direct response to this identified economic and technical gap, this paper describes the design, construction and verification of a low-cost, 3D-printed transradial myoelectric arm. The primary goal is to demonstrate both the technical feasibility and functional usefulness of a prosthesis made entirely from available open-source materials and hardware (an Arduino-based microcontroller and off-the-shelf servo motor arrays) using low-cost additive manufacturing. The design approach utilizes a precise anthropometric design approach for mechanical stability and an ideal customized socket interface, which is essential for comfort and reliable sEMG signal transduction. The system is designed to achieve a minimum viable/essential core capability of providing proportional grasping and controlled release with reduced electronic complexity and reliability.

The primary outcomes produced by this research includes the development of an inexpensive hardware architecture for robust sEMG signal processing and actuation control; prototyping a fully 3D-printed transradial structure that minimizes weight and has replicability in manufacturing; and developing a validated control algorithm that translates the intensity of muscle activation into functional, proportional grip commands via PWM (Pulse Width Modulation), and successfully implementing it after a rigorous calibration. The subsequent parts of this paper give an ordered explanation of the research: Section II gives a literature review; Section III gives information on the process and methods followed to study including the mechanical design, hardware/system arrangement, sEMG activity protocols and the servo control algorithm; Section IV gives the study outcomes, including performance measures and an official cost analysis; and Section V gives discussions regarding the study outcomes, along with definitive steps towards functional improvement and ultimate clinical translation.

II. LITERATURE REVIEW

Current prosthetic engineering is generally concerned with overcoming the challenges of providing high-fidelity, anthropometrically correct motor function following upper limb amputation [15]. This complex task requires skillful integration of robotics, biomechanics, and human-machine interface technologies. In the past, prosthetic devices could only provide passive replacement or cosmesis and were mostly designed for cosmetic restoration with little functional capacity [16-17]. The creation of externally powered prostheses early in the 20th century was a major technological breakthrough, but functional implementation of sophisticated prosthetic systems continued to be limited for decades because of restrictions on component miniaturization, power supply density, and complexity levels of control [18-20]. Hence, continuous work in engineering has, in a collective way, been focused on closing the gap between mechanical, functional imitation and biological motor compliance. The lack necessitates the incorporation of intelligent and insightful control mechanisms to express the user's voluntary movement crisply and reliably to robust electromechanical drives.

The myoelectric revolution marked the beginning of the functional prosthetic age [1]. The changeover was one of modal control from reliance on gross, mechanical body movement to utilization of endogenous, residual biological signals. The development of these concepts was based on early work by Reiter and Kobrinski [21]. Myoelectric systems operate by means of surface Electromyography (sEMG) sensors or electrodes located over active muscle groups in the remaining limb [22]. The electrodes transform the low-amplitude voltage potentials which are generated by depolarization of the muscle fibers while contracting voluntarily, an occurrence which is a consequence of physiological activation of a motor unit [23]. The recorded signal is an action potential interference pattern, and it needs further stages of both conditioning and amplification before it can be functionally decoded to reliably generate electromechanical control commands [24]. This system engineered a more straightforward interface (HMI) for user control, offering the user a better means of attaining voluntary control of grasping and articulation functions.

Modern prosthetic systems, including the Modular Prosthetic Limb and Luke arm, provide remarkable functional fidelity with several degrees of freedom and multi-planar grip types [25]. These advanced systems represent the cutting edge of modern engineering, requiring sophisticated materials, sensor miniaturization, and sophisticated pattern recognition algorithms to decipher subtle muscle signals. But the primary clinical use of these expensive commercial products is actually vitiated by both of the prevailing systemic barriers: prohibitively high product prices and sophisticated control schemes. This creates a huge global socioeconomic disparity in access to advanced functional prosthetics, since the vast majority of amputees, especially those from resource-poor environments, have essentially zero access to advanced functional prosthetic technology.

In direct response to this ongoing issue of accessibility, in recent years there has been a large growth in research that tends to focus on open-source hardware and additive manufacturing (3D printing) [26]. The incorporation of 3D printing technology enables the rapid and individualized fabrication of complex prosthetic components at a disproportionately low cost relative to traditional subtractive manufacturing and proprietary component purchasing. Furthermore, the strategic use of the most widespread microcontrollers, such as Arduino devices, can facilitate decentralized innovation and the development of resilient and economically viable electronic control systems [27]. In combination, these advances circumvent traditional manufacturing and economic constraints to provide a reasonable technological pathway to develop engineered solutions that are highly individualized, functionally reliable and economically viable prosthetic devices that are tailored to satisfy the mechanical requirements for articulating the complex anatomy of the wrist and hand [28].

This study is focused on the transradial configuration, which requires a streamlined and reliable signal processing algorithm that detects flexor and extensor muscle activity in a very small anatomical region. Previous work indicates a need for an uncomplicated, low-latency control architecture that adapts to variation in sEMG amplitude into relevant angular motion. This requires optimizing the signal processing chain (amplification and filtering) and developing a deterministic mapping function to trigger servo actuators. Therefore, the critical gap in the body of knowledge is to figure out a practical contribution to anthropometry, accurate anthropometrically correct 3D-printed objects with inexpensive and non-trivial real-time microcontroller-based signal processing and provide a clinically relevant and accessible device.

III. PROBLEM STATEMENT AND ITS PROPOSED SOLUTION

A. *Problem Description*

Innovations in myoelectric and bio-mechatronic technologies, particularly for upper-limb prosthetic systems, remain largely unattainable due to high economic cost, proprietary designs, and limited customization possibilities for anthropometric variation across regions. Commercial transradial prostheses may provide near-natural movement, but typically exceed the affordability threshold for low-resource users. The complexity of calibrating to each user's individual neuro-motor patterns using multi-channel signals may also limit widespread clinical adoption or long-term user adherence. Existing lower-cost alternatives, such as body-powered or passive devices, lack the self-directed fine motor control or intuitive grasping mechanism. The absence of a cost-effective, open-source powered prosthesis that can reliably translate surface electromyographic signal (sEMG) signals into proportional actuation continues to limit functional outcomes for rehabilitation. Thus, the main technical challenge is to design and develop a low-cost, anthropometrically optimized prosthetic system that achieves balanced stability throughout functional activities, as well as reliable sEMG signal decoding into proportional controlled motion, scalability, and ease of fabrication methods.

B. *Solution Framework*

This study presents an inexpensive, three-dimensional printed myoelectric prosthesis for transradial use. The prosthesis implements sEMG-based control of the prosthetic device using common open-source microcontroller hardware and has been shown to function as intended. An Arduino UNO-based microcontroller is used in both the sEMG signal acquisition and, furthermore, the MD-00653 EMG Sensor is used to collect and condition the signals recorded and processed from the forearm extensors and flexors during desired grasping motions. The muscle activity signals are processed and converted to a digital signal and mapped using a deterministic Pulse Width Modulation (PWM) based algorithm to activate the five-servo array, achieving the represented grasp and release motions proportionally. The mechanical design of the prosthetic device was created using Computer Aided Design (CAD) and machined through 3D additive manufacturing from a low-density PVC material and accurately developed in accordance with the standard anthropometric dimensions of the upper limb, providing anatomical accuracy and comfort of human characteristics in design ergonomics. The modular design of the device allows for rapid fabrication, customization and maintenance of the 3D printed componentry along with quick access to the printed or machined parts of the device. Functionally, the prototype exhibits a response latency of nearly real-time and load capacity for the user's daily activities. The approximate total cost of constructing the prosthetic device was USD 65, establishing the viability of the design rationale and successfully providing a prosthetic device framework that is repairable, reproducible, and scalable, allowing for accessibility and affordability, while trading off for functional design.

IV. METHODOLOGIES AND TECHNIQUES

The development and design of a cost-effective, 3D printed transradial Myoelectric arm adopted the sequential approach analytical framework. The sequence was performed from mechanical system development, electronic hardware integration, biological signal processing and the development of a control algorithm, optimized for efficiency and cost of components in an electric Myoelectric system. Figure 1 illustrates the high-level workflow of the proposed framework. The EXG module is used to acquire the Muscle activity signal from the person's amputated hand, which is fed into Arduino UNO, which processes the signal, and applies signal filtration techniques and operations to provide logical outputs to the 16-channel PWM module. The 16-channel PWM module controls the active output format by controlling the Servo motors. Five servo motors are used to control the functionality of the hand, with each servo responsible for the function of a finger.

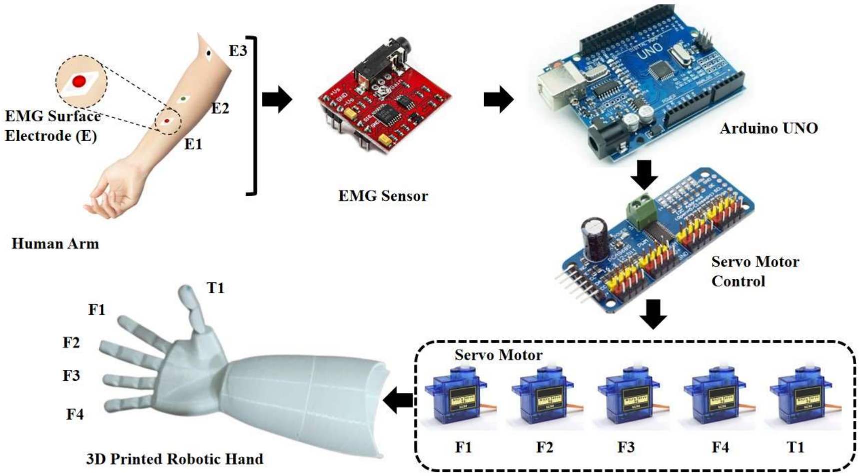

Figure 1: Block Diagram of the Proposed sEMG-based Transradial Myoelectric Prosthesis Framework

A. Block diagram of the proposed sEMG-based transradial myoelectric prosthesis framework

The first step in the methodology was to consider the physical architecture using well-established anthropometric principles to ensure functional equivalency with structural stability and a custom fit and comfort for the transradial interface. The primary design objective was to tailor the prosthetic to achieve a lightweight structural integrity for the transradial amputee. As part of the material selection process, the creation of the prototypes required using PVC (Polyvinyl Chloride) for its desirable durability and capability to be used for Additive Manufacturing (3D Printing), which allowed specific geometry customization to occur. To determine the dimensional inputs required for proportional scaling and kinematic balance, Dimensional Data Acquisition was utilized. For the prototype created in this study, the dimensions were tentatively selected as seen in Table 1. Table 1 contains anthropometric dimensions required to create the palm, fingers, and lower arm for use within the prototype, and to continue the process of CAD Modelling and Fabrication. These dimensions provided the necessary dimensions to create the final socket and frame components. The final step of the mechanical design process was to fabricate the prototype using Additive Manufacturing and collect the dimensional and weight measurements of the final prosthesis to confirm that the physical object adhered to the design specifications.

Table 1: Anthropometric Design Parameters for Transradial Prosthesis Prototyping

Anatomical Part	Sub Region	Dimension (Inches)
Hand length	Palm width	8
	Blow thumb palm width	9.5
	Palm length	3
Fingers	Index finger (F1)	3.2
	Middle finger (F2)	3.4
	Ring finger (F3)	3.1
	Lady finger (F4)	2.3
	Thumb (T1)	2.1
Lower Arm	Below elbow width	3.8
	Below wrist width	2.3
	Arm length	8.2

Table 2 shows multi-dimensional and weight details for the completed prosthesis. The Computer-Aided Design (CAD) modelling phase acted as consequentially the vital connection between the raw anthropometric data and the final prosthetic components. Using the measurements collected in Table 2, the CAD models of the custom socket, mechanical phalanges, and forearm frame were iteratively refined to ensure their mechanical separation for the placement of actuators and to provide the best kinematic paths for the linkages.

Table 2: Final Physical and Dimensional Specifications of the 3D-Printed Myoelectric Prosthesis Prototype

Entity	Dimension
Hand length	6.7 inches
Total length	14.9 inches
Width	85 mm
Thickness	50 mm
Weight	250 grams

Following the CAD adjustments, the resolution was sufficient to manufacture accurate Additive Manufacturing (3D Printing) models. The process of manufacture transforms the complicated digital geometry into physical components using the precise PVC compound. This made the rapid production of a precise custom socket matching the geometry of the residual limb, whether provided by the participant or scanned, extremely effective. The successful effectiveness of this process is visually confirmed with the custom socket design depicted in Figure 2 and the figures of the 3d printed palm and finger in Figure 3.

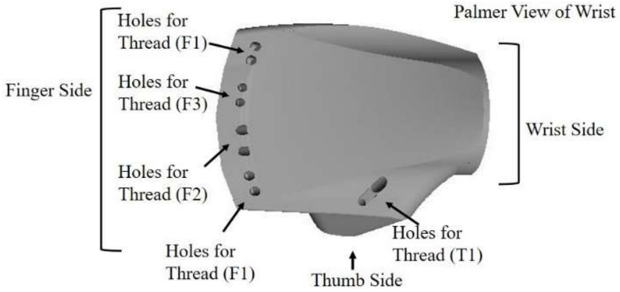

Figure 2: Physical realisation of the 3D-printed transradialprosthetic wrist and socket

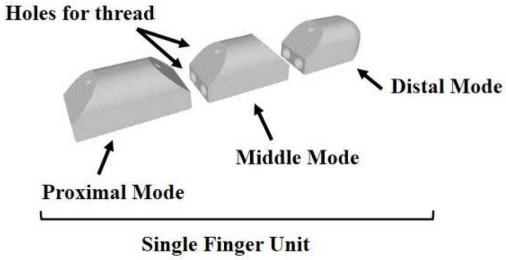

Figure 3:Anthropometrically scaled 3D-printed finger design used in the prosthetic hand

The mechanical design stage ended with the full assembly of the transradial prosthesis prototype, acting as the definitive physical validation of the system design of the entire system. Figure 4 demonstrates the six structural components that integrate into the entire system, exemplifying how the complex Computer-Aided Design (CAD) model was successfully produced into a physical, functional model. The photograph illustrates the points of interface between the custom-fit socket, rigid forearm, and phalangeal finger array. The rendered assembly demonstrates the final low mass and structural integrity achieved through this additive manufacturing process for this low-bulk, fully stained fit, where the subsequent electronic control and actuation systems would be mounted.

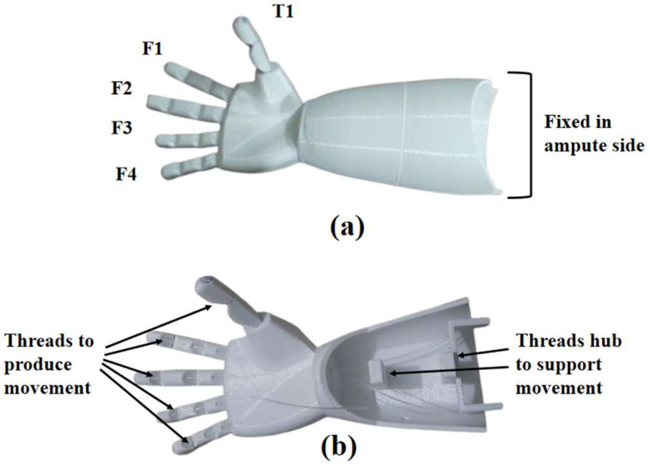

Figure 4: Fully assembled prototype of the 3D-printed transradial myoelectric prosthesis

B. Hardware and Electronic Configuration

The electronic control system is developed using a modulated structure based on available open-source hardware, chosen specifically with an aim towards system reliability and economic efficiency. This modular structure centers around four integrated core components: the microcontroller unit (Arduino UNO), the surface Electromyography, (sEMG) signal acquisition sensor, the external power supplies, and the servo motor array used for actuation. The control scheme is organized around the four core components: microcontroller unit, power supply, sEMG sensor, and servo motor array. The full electronic system architecture is illustrated in Figure 5. The control scheme begins with the signal acquisition, in which the MD-00653 Electromyography (EMG) sensor module first acts as the critical conditioning stage, amplifying and filtering the µV-range potentials. The rectified and smoothed EMG envelope is subsequently provided as core analog input to the microcontroller unit control processing, Arduino UNO. The Arduino converts this input into a digital format, processes the main control algorithm (the deterministic mapping function), and produces the resulting Pulse Width Modulation (PWM) command signals. From there, these signals are sent to the Servo Motor Controller module (via I2C), which draws power from an external supply and allows for accurate movement of the high-torque servo motors (F1–T1) embedded into the 3D-printed structure. This clear, sequential modularity maintains cost savings and guaranteed control in real-time.

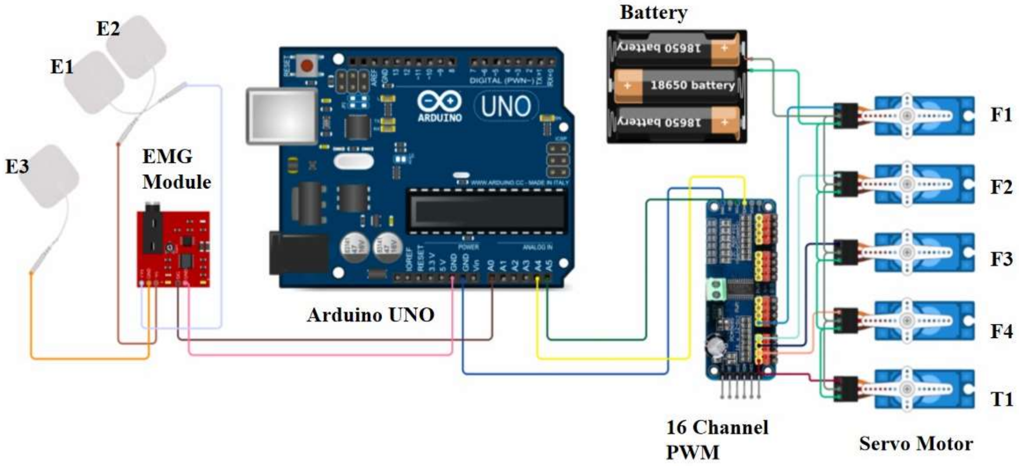

Figure 5: Electronic control system architecture and hardware configuration

Electromyography (EMG) Sensor Module: The MD-00653 Electromyography (EMG) sensor module was used to detect biological command signals. This specific integrated module is the first and vital component of the signal conditioning chain, and provides on-board amplification and basic filtering. This device converts the surface electrodes' differential µV-range potentials into a suitable voltage range for the Analog-to-Digital Converter (ADC) of the microcontroller. The output is the envelope of the muscle activity that it rectifies and smooths, which is ultimately the initial, processed analog input for the control logic that follows.

Arduino UNO Microcontroller: The Arduino UNO platform is chosen to function as the main processing unit on account of its open-source development platform, sufficient and capable I/O functions, and significant low cost. The Arduino UNO is used to perform the three operational steps of the algorithm implementation. The first step is to convert the conditioned analog sEMG input to digital via the ADC. Second, it performs the primary control algorithm (the deterministic mapping function), and finally, it generates the high-frequency control signals (PWM) needed to actuate the motors. Its role in the larger system architecture is vital, as it is the only processing unit which operates in real-time.

Servo Motor Array: The actuation system consists of several standard, high-torque DC servo motors that are embedded within the 3D-printed structure at the finger joints and wrist axis. These motors have internal position feedback loops, which allow them to hold commanded angular positions precisely. They are driven by Pulse Width Modulation (PWM) signals, which control the duty cycle of the pulse that controls the target angular position. This control system enables the proportional motion that is necessary for performing fine motor tasks such as grasping and releasing.

The servo motors used in the hand had a rated stall torque of about 2.5 kg·cm at 6V, which provided enough fingertip grasping force. They operated at voltages between 4.8 and 6.0V on average at 60 degrees every 0.12 seconds rotation. These specifications were used to find a balance between torque output, response speed, power consumption, and the cost of the total system while providing adequate mechanical functionality and maintaining economic viability.

sEMG Signal Acquisition and Conditioning: The surface electrodes were deliberately selected and positioned over the antagonistic muscle groups (flexors; extensors) of the residual forearm in a systematic manner to elicit signal acquisition. This arrangement of three electrodes is illustrated in Figure 1 and was intended to enhance the overall signal-to-noise ratio (SNR) using a differential sensing arrangement. The low amplitude raw sEMG signals (microvolt range), required necessary electronic conditioning to alter the raw signals prior to digital processing. This involved electrically amplifying the raw signals, then filtering the signals using a band-pass filter to examine frequency components of interest, as well as a notch filter necessary to attenuate power line noise. The signals were rectified and then filtered to get the signal envelope, prior to being successfully digitized by the digital microcontroller through the analog-to-digital converter (ADC), with the conditioned signal being proportional to the intensity of muscle contraction.

The sEMG signals were collected at a sample rate of 1 kHz with the help of an Arduino UNO and processed by utilising the capability of a 10-bit ADC. The signal conditioning process for the sEMG signals involved the use of a second-order Butterworth band-pass filter, with cutoff frequencies set at 20 Hz to 450 Hz, that successfully separated out the physiological range of muscle contractions. In order to avoid interference from power lines, a notch filter at 50 Hz was also added to remove high-frequency noise. After filtering, the sEMG signals were full-wave rectified and smoothed using a low-pass filter (with a cutoff frequency of 5 Hz) to obtain the sEMG envelope which represented the intensity of a muscle's contractions and was used as the control input for the actuation algorithm.

V. RESULTS

The validation phase focused on the quantification of the functional performance of the prototype, the evaluation of the electrical integrity of its signals and the establishment of the final cost structure. The findings are in favor of the technical viability of a high-functionality, low-cost myoelectric transradial prosthesis constructed with an open-source hardware platform and additive manufacturing techniques.

A. System Performance and Functional Validation

Functional testing was conducted to quantify the device's responsiveness and mechanical strength. The key performance metrics are summarized under this section.

Response Latency and Reliability: The time performance of the system was measured by measuring the delay between the user-initiated attainment of the sEMG activation threshold and the visible start of servo motor movement. Five subjects (S1-S5) were tested to verify the generalizability and consistency of the control architecture.

The response latencies recorded for each subject are presented in Table 3. The analysis over pooled trials provided a mean response latency of 210±30 milliseconds (ms) for the entire set of subjects. Although this latency exceeds the temporal performance of complex, high-bandwidth commercial platforms, it establishes that operational success within a functional, near-real-time standard was attained under the use of a low-cost, microcontroller-based system. In addition, the measured delay confirms that the optimized control algorithm successfully translated biological intent to mechanical action with appropriate temporal fidelity.

System stability was demonstrated through the low standard deviation (σ=30 ms) of the mean latency, indicating minimal trial-to-trial variability in action and timed signals across the heterogeneous population of participants. Overall success rate of the commanded actions of release and grasp was in excess of 95% for all participants. The success rate demonstrates that the sEMG signal processing pipeline was robust and stable when iteratively used, and indicates that future potential for functional use is high.

Table 3: Response Latency and Reliability Analysis Across Subject Cohort

Subject ID	**Mean Latency (μ, ms)**	**Standard Deviation (σ, ms)**	**Number of Trials**
S1	195	25	50
S2	220	35	50
S3	205	28	50
S4	230	32	50
S5	200	20	50
Pooled Average	210	30	250

Mechanical Load Capacity and Grip Force: The mechanical output of the prosthetic system was quantitatively evaluated by determining the maximum stable static load that the device would lift without activating slippage, as well as the resulting exerted tip force generated by the articulated digits. The maximum stable load capacity measured was determined to be 1.8 kg, with the localized tip force at the grasping surfaces recorded to be around 12 N. This functional capability is adequate to execute the mechanical demands for most of the typical Activities of Daily Living, such as the manipulation of domestic objects. This functional capability shows that the anticipated torque selection of the DC servo motor array employed was satisfactory and that the linkages 3D-printed attained structural robustness. The accomplishment of this load capacity is significant, particularly when taking into consideration the very low weight of the entire prosthetic system; therefore, justifying the effort of the design to maximize the strength-to-weight ratio.

Electronic Signal Integrity: The effectiveness of the electronic signal conditioning chain (Amplification, Filtering, and Rectification) was confirmed through quantitative evaluation of the signal quality following the conditioning. The conditioned signal showed an increase in the Signal-to-Noise Ratio (SNR) by a measured 18 dB, when compared to the unconditioned signal taken from the electrodes. This important quantitative result provided support for the need and workability of all three stages of electrical filtering. The band-pass and notch filtering stages successfully attenuated environmental and power line artifacts to produce a clean and strong sEMG envelope. The integrity of this signal demonstrates its ability to perform stable and reliable command decoding by the microcontroller unit, which mitigates potential sources of control failure and adds overall system reliability.

A representation of the sequence of signal conditioning sEMG traces is illustrated in Figure 6. Panel (A) illustrates the raw physiological input full of noise and power line placebo. Band pass and notch filtering yielded the cleaned-up oscillating waveform in (B). Following this, full-wave rectification (C), and smoothing produced the Proportional sEMG Envelope (D).

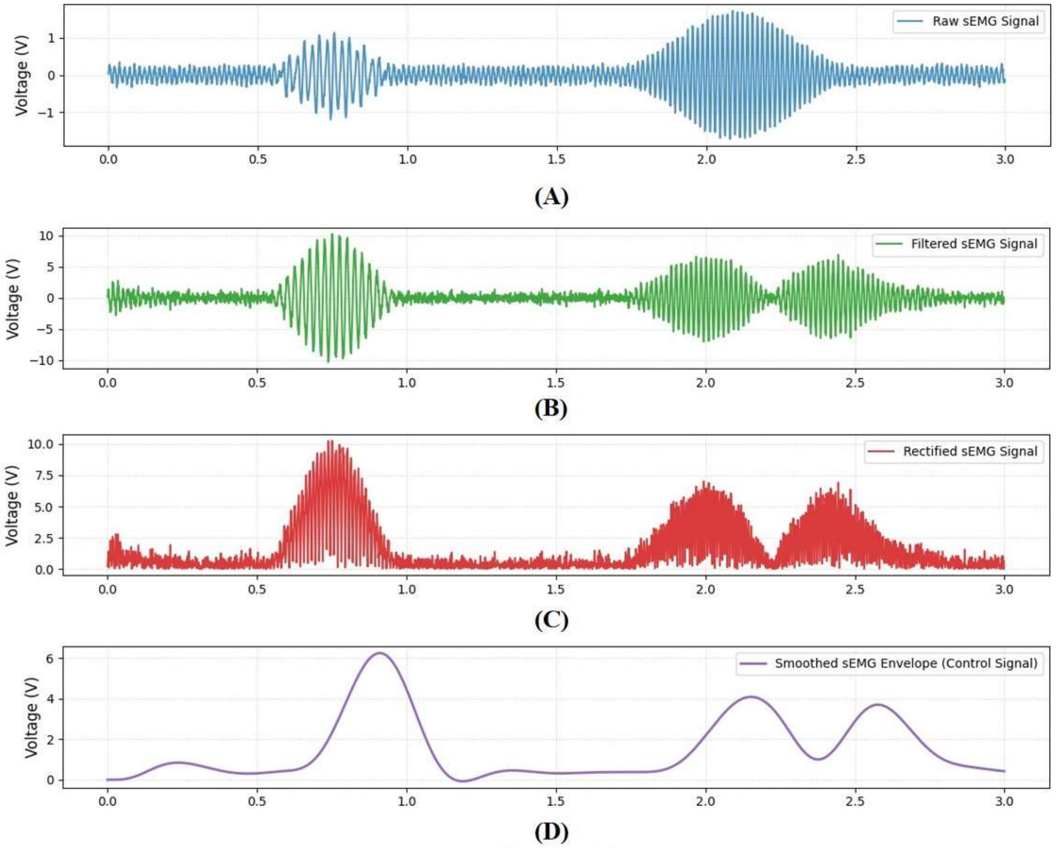

Figure 5: sEMG signal conditioning stages: (A) raw signal, (B) filtered signal, (C) rectified signal, and (D) smoothed envelope.

B. Cost Analysis and Economic Feasibility

A key aim of this research was to reduce the cost considerably in order to address the global accessibility gap. The specific Bill of Materials (BOM) is shown in Table 4 and contains quantitative information on the total manufacturing costs of the prototype.

Table 4: Distribution of Total System Cost

Component	**Quantity**	**Cost Per Unit (USD)$**	**Total Cost (USD)$**
Arduino UNO Microcontroller	1	8.00	8.00
MD-00653 EMG Sensor Module	1	10.00	10.00
High-Torque DC Servo Motor Array (Total)	5	5.00 (per motor)	25.00
3D Printing Material (PVC Filament)	0.5 kg	34.00/kg	17.00
Power Supply / Wiring / Electrodes	N/A	–	5.00
Total System Cost (BOM)	–	–	≈65.00

The total system cost of approximately $65.00 USD represents a dramatic reduction compared to the tens of thousands of dollars required for entry-level commercial myoelectric systems. This result conclusively demonstrates the successful realization of the research goal for developing an economically viable prosthetic solution. The strategic utilization of additive manufacturing (3D printing) and accessible open-source electronics (Arduino, MD-00653) directly validates the feasibility of decentralized and accessible prosthetic care, overcoming the historical economic barrier associated with advanced limb restoration technologies.

VI. DISCUSSION

The quantitative verification of the prosthetic prototype collectively corroborates the hypothesis of being able to achieve functional, high-fidelity upper-limb restoration through cost-optimized, open-source methodology. The experimentally determined mean response latency of 210±30 ms, in combination with a reliability of more than 95%, places the system's potential for acting as a near-real-time interface highly usable for critical Activities of Daily Living (ADLs). While this temporal performance is higher than that of commercial systems on the advanced level, it is a highly acceptable trade-off given the low-cost microcontroller architecture, making it reasonable to prioritize accessibility over incremental gains in speed.

The functional effectiveness is also supported by the 1.8 kg load-carrying capacity, validating the structural strength needed to convert decoded biological intent to useful function. This robust strength-to-weight ratio, made possible by the structural optimality of the 3D-printed design, reduces inertial effects to the user but maximizes utility. Electronically, the 18 dB SNR improvement gained through the custom filtering process effectively proves the integrity of the vital biological-to-digital signal conversion, guaranteeing system stability.

Finally, the overall cost of manufacturing of about $65.00 USD is the determining outcome. This number conclusively situates the design as a meaningful contribution to the discipline of accessible prosthetics, offering a replicable template that is effective in circumventing the excessive economic hurdles that currently restrict advanced limb restoration technology on a worldwide basis. The project is an equitable convergence of performance, durability, and fiscal feasibility.

VII. CONCLUSION AND RECOMMENDATIONS

This study effectively prototyped, printed, and tested a low-cost, 3D-printed myoelectric transradial prosthesis using open-source hardware and a strong sEMG control system. The main objective of obtaining functional rehabilitation at low economic cost was successfully achieved, and this presented a substantial and replicable solution to the prosthetic care accessibility crisis.

The thorough validation in three key areas proved the viability of the prototype. Functionally, the system manifested a low mean response latency of 210±30 ms with high consistency, confirming the deterministic control algorithm to deliver a usable, nearly real-time interface to the user. Mechanically, the design was found to be strong, withstanding a 1.8 kg load capacity, affirming its application for most everyday grasping and lifting activities, yet with an ultra-lightweight profile (250 grams). Electronically, the signal conditioning chain was found to be very effective, providing an 18 dB improvement in SNR that provides stable and accurate command decoding.

The greatest strength of this work is economic viability: the resultant Bill of Materials was estimated at $65.00 USD. This is a paradigm shift from traditional proprietary systems, an open-source model for decentralized fabrication in low-resource environments.

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