ABSTRACT

The development of prosthetic limbs has seen remarkable advancements over the years; however, their affordability, accessibility, and adaptability continue to be major concerns, especially in developing countries like India. Traditional prosthetic arms are often expensive, non-modular, and require professional intervention for repairs, making them impractical for many users. This project presents the design and prototyping of a wearable prosthetic arm that addresses these limitations by offering a cost-effective, modular, and user-friendly solution. The arm is designed with affordability in mind, utilizing locally available, lightweight materials to minimize costs without compromising structural integrity or functionality.

One of the main focuses of this project is modularity, which allows users to replace or repair individual components instead of the entire arm. This significantly reduces maintenance costs and ensures minimal downtime. The prosthetic is also embedded with sensors that detect muscle movement and grip strength, providing better control and mimicking natural hand motion with greater accuracy. The integration of smart sensors facilitates real-time feedback and motion responsiveness, improving the overall user experience.

This project also includes an extensive literature survey that explores the latest innovations in prosthetic technology, from electromagnet-based attachments to neural network control systems and AR-based testing platforms. The final prototype, though in an early development phase, aims to bring practical change by empowering amputees with a reliable, efficient, and cost-effective solution to regain independence and improve quality of life

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CHAPTER 1

INTRODUCTION

In recent years, the field of prosthetics has advanced significantly with the integration of smart systems, sensors, and AI. Despite these innovations, there remains a critical gap in the accessibility and affordability of prosthetic limbs, especially in developing regions. India, with its large population and significant number of physically disabled individuals due to congenital disorders, accidents, and natural disasters, presents a unique challenge and opportunity. Most of the current market solutions for upper-limb prosthetics are either prohibitively expensive or fail to meet the functional needs of everyday users.

The concept of this project arises from the necessity to develop a prosthetic arm that is not only technologically advanced but also practical for daily use and feasible for mass deployment. A wearable prosthetic arm that is modular, affordable, and sensor-integrated can transform lives by restoring independence to amputees. The emphasis on modularity allows users to replace broken or worn-out parts without needing to discard the entire device. This is particularly valuable in rural or economically disadvantaged areas where access to specialized repair facilities is limited.

Furthermore, the arm is embedded with sensors capable of detecting muscular signals, allowing intuitive control. The use of technologies such as EMG (electromyography) or myokinetic sensing provides an interface between the user and the prosthetic, enabling actions like gripping, releasing, and even delicate finger movements. By using low-cost microcontrollers and open-source platforms like Arduino, the system remains accessible for future developers and tinkerers.

1.1 Aim

The project aims to develop an affordable, modular prosthetic arm with cost-effective materials and integrated sensors for easy repairs, enhanced user experience, and improved mobility.

1.2 Objectives

- easily replace or repair individual components, enhancing usability and reducing costs.

- **Integrate Sensor Technology:** Incorporate sensors to detect muscle signals and grip strength, enabling intuitive control and improving the user experience.

- **Create a Cost-Effective Prototype:** Fabricate a functional prototype that is affordable, utilizing locally sourced materials to ensure accessibility for users in low-resource settings.

- **Evaluate Performance Metrics:** Conduct thorough testing to assess the arm's durability, sensitivity, and adaptability to various user needs and environments.

- **Explore Advanced Technologies:** Investigate the potential for integrating advanced technologies such as wireless communication, machine learning algorithms, and augmented reality for enhanced functionality.

CHAPTER 2

LITERATURE SURVEY

[1]. "Beyond Humanoid Prosthetic Hands: Modular Terminal Devices That Improve User Performance," Author: D. Chappell, B. Mulvey, S. Perera, F. Bello, P. Kormushev and N. Rojas, 2025 IEEE.

Myoelectric prosthetic hands, though widely used, often face high rejection rates among users due to their limited real-world functionality and the constraints of anthropomorphic design. While these devices aim to replicate the form and motion of a human hand, their complexity often does not translate into improved usability, leaving users frustrated with their performance in everyday tasks. To address these issues, researchers have proposed and evaluated a series of modular, non-humanoid terminal devices, each tailored for specific functions such as flicking, screwdriving, picking and placing flat objects, and cutting paper. These attachments, designed to replace individual fingers on the OLYMPIC hand—a modular prosthetic platform—were tested through a control group study involving participants without upper limb difference (ULD) and further validated through case studies with individuals who have ULD. The results demonstrated that the non-humanoid devices significantly outperformed traditional humanoid prosthetics, offering improved task efficiency, greater accuracy, reduced compensatory movement, and lower perceived physical and cognitive load. These task-specific tools not only simplify complex joint movements but also enhance user satisfaction by enabling more natural and effective interaction with their environment. Ultimately, the study concludes that modular, non-humanoid prosthetic designs present a promising direction for improving the practicality, comfort, and social integration of prosthesis users, with future research aimed at refining mechanical performance, incorporating haptic feedback, and exploring psychological acceptance of non-anthropomorphic forms.

[2]."Prosthetic Limb Attachment via Electromagnetic Attraction Through a Closed Skin Envelope," Author: W. Flanagan et al, 2023 IEEE.

Conventional socket-based prosthetic attachments often lead to discomfort, skin irritation, and high abandonment rates among users. While osseointegration offers a more stable skeletal fixation, it introduces significant infection risks due to the permanent breach of skin integrity. To address these issues, researchers have developed an innovative prosthetic suspension system based on electromagnetic attraction. This system utilizes a subcutaneous ferromagnetic implant placed within the residual limb bone and an external electromagnet housed in the prosthetic socket, allowing secure, non-invasive load transfer without skin penetration. The methodology included gait force analysis, cadaveric dissections for implant optimization, and electromagnetic modeling to balance performance and safety. Benchtop tests confirmed simulation accuracy with only 4.2% error and revealed average power consumption of 33W during walking. However, thermal simulations showed skin temperature increases of up to 15.4°C after extended use, highlighting the need for improved heat management. Overall, this sealed-skin electromagnetic suspension system offers a promising alternative to traditional socket designs, with potential to enhance comfort, limb health, and user satisfaction through further refinement.

[3]. "Transcutaneous Magnet Localizer for a Self-Contained Myokinetic Prosthetic Hand,"Author: V. Ianniciello, M. Gherardini and C. Cipriani, 2024 IEEE.

Advanced prosthetic hands require intuitive and responsive control systems, but current methods for accurately and efficiently localizing implanted magnets for myokinetic control are still underdeveloped. To address this gap, researchers have proposed the Transcutaneous Magnet Localizer (TML), a modular and real-time system designed to enhance prosthetic functionality by precisely tracking subdermal magnets. The TML system comprises eight Acquisition Units (AUs) equipped with 20 magnetic sensors and a central Computation Unit (CU) powered by an ARM M7 processor. Tests conducted on a forearm mockup evaluated the system's ability to localize up to eight implanted magnets simultaneously. The results showed impressive performance, achieving less than 1 mm localization error, 0.5 mm precision, and latency under 60 milliseconds, all while maintaining a power consumption between 0.6 and 1.2 watts—well within the acceptable range for wearable prosthetic devices. This low-latency, high-precision tracking enables smooth, natural movement control in myokinetic prosthetic hands. With its energy efficiency and real-time capabilities, the TML system presents a viable solution for advancing user-friendly, clinically adoptable magnet-based prosthetic control interfaces.

[4]. "Neural Network-Based Lower Limb Prostheses Control Using Super Twisting Sliding Mode Control," Authors: A. T. Demora and C. M. Abdissa, 2024 IEEE.

Controlling lower limb prostheses presents significant challenges due to the complexity of human gait, the variability and noise in surface electromyography (sEMG) signals, and unpredictable external disturbances. Traditional control methods often fall short in providing the precision and robustness needed for real-world use. To overcome these limitations, researchers developed a hybrid control approach that combines Feedforward Neural Networks (FFNN) for interpreting sEMG signals with Super Twisting Sliding Mode Control (ST-SMC) for robust joint actuation. In this system, FFNNs are trained to accurately predict joint angles based on processed sEMG input, while ST-SMC ensures stable and responsive tracking of these angles, even under disturbances. Simulations conducted in MATLAB/Simulink demonstrated that this combined method outperformed conventional Sliding Mode Control, offering smoother motion, reduced chattering, and enhanced control precision. The system proved highly robust across various testing conditions. Overall, the integration of FFNN and ST-SMC represents a promising solution for real-time, adaptive control in lower limb prosthetics, with potential for future clinical application in enhancing mobility and user comfort.

[5]. "A Low-Cost Lightweight Prosthetic Arm with Soft Gripping Fingers Controlled Using CNN," Authors: A. Sahbel, M. Elaydi, A. Nasif, N. Sobhy, A. Magdy, and A. Abbas, 2024 IEEE.

Traditional prosthetic arms often suffer from drawbacks such as high cost, excessive weight, mechanical noise, and limited responsiveness due to the use of servo motors and inefficient materials. To address these limitations, researchers have developed a low-cost, lightweight prosthetic arm featuring soft elastomer fingers, controlled non-invasively through EEG signals processed by advanced machine learning algorithms like Convolutional Neural Networks (CNN) and Support Vector Machines (SVM). The arm is built using PLA and Dragon Skin elastomer and powered by pneumatic actuators. EEG data collected via an OpenBCI headband is processed on a Raspberry Pi 4, where gestures are classified in real time. Structural performance was validated through finite element analysis in ABAQUS, and gesture recognition was tested experimentally. Results showed CNN outperformed SVM, achieving 48% classification accuracy with a 17 ms inference time. The arm successfully bent 90° under just 3.3 Pa of pressure, weighed only 400 grams, and cost approximately $700—making it a significantly more accessible and responsive solution compared to conventional models. This approach offers a promising alternative for users with peripheral nerve damage or pediatric needs, with future potential to improve precision through enhanced finger-level control.

[6]."Finch: Prosthetic Arm with Three Opposing Fingers Controlled by a Muscle Bulge," Authors: M. Yoshikawa, K. Ogawa, S. Yamanaka, and N. Kawashima, 2023 IEEE.

Traditional myoelectric prosthetic hands are often bulky, expensive, and difficult to calibrate, while body-powered alternatives like hooks, though functional, are generally uncomfortable and lack aesthetic appeal. To bridge this gap, researchers developed "Finch," a lightweight and affordable prosthetic arm with three opposing fingers controlled by a muscle bulge sensor. The Finch is designed for practical daily use, using a single linear actuator to operate its fingers based on input from a photoelectric sensor embedded in a wearable fabric supporter socket. Functional testing with five forearm amputees demonstrated the arm's responsiveness, achieving a reaction time of 58 ms and delivering grasping forces between 2.9 N and 12.8 N depending on the object. Weighing just 330 grams and costing approximately $430, the Finch provides up to 24 hours of continuous use on a single charge. In Southampton Hand Assessment Procedure (SHAP) testing, users successfully completed most tasks, achieving Index of Function (IoF) scores between 42 and 47. Though not designed for high dexterity tasks, Finch offers a practical, comfortable, and user-friendly solution, ideal for those prioritizing affordability, wearability, and everyday functionality.

[7]."Development and Testing of a Wearable Vibrotactile Haptic Feedback System for Proprioceptive Rehabilitation, " Author: R. Yunus et al,2020 IEEE

A major challenge faced by individuals using upper-limb prosthetics is the lack of proprioception and force feedback, which hampers their ability to control the device accurately—especially when distracted or lacking a phantom hand map. To address this, researchers developed Vi-HaB, a non-invasive, wearable vibrotactile haptic feedback system designed to restore a sense of touch and position. Vi-HaB uses five force-sensitive resistors placed on a dummy hand to detect finger-specific forces, which are then processed by an Arduino Nano and translated into vibrotactile signals on an armband equipped with strategically placed motors. This setup allows users to perceive individual finger interactions in real time. The system was tested on 14 individuals with upper-limb disabilities, who performed finger and force recognition tasks under both focused and distracted conditions. Vi-HaB achieved an average accuracy of 82.04%, with performance holding steady or even improving during distraction scenarios. These results highlight the system's robustness and practicality for real-world use. With its affordability, adaptability, and ease of use, Vi-HaB holds strong potential for applications in prosthetic rehabilitation, virtual reality, and teleoperated systems.

[8]. "ProACT: An Augmented Reality Testbed for Intelligent Prosthetic Arms," Authors: S. Guptasarma and M. D. Kennedy, 2025 IEEE

High-level amputees often struggle with controlling prosthetic arms due to the limited and noisy input signals obtained from electromyography (EMG). Existing prosthetic systems are typically expensive and do not offer comprehensive tools to test and develop advanced, intelligent control methods that can manage whole-arm movements effectively. To address these challenges, ProACT was developed as an augmented reality (AR)-based immersive testbed that integrates robotics frameworks such as ROS and Gazebo with the Unity engine and Microsoft HoloLens 2. This integration provides a versatile platform for testing and refining intelligent prosthetic limb control strategies in a realistic yet controlled environment. The system uses an EMG armband combined with eye-tracking technology as input modalities, allowing for more natural and intuitive user interactions. Four different control strategies—direct joint control, end-effector control, gaze-assisted control, and context-assisted control—were implemented and tested on a Modular Prosthetic Limb. User studies, involving non-amputee participants performing a standardized Box-and-Blocks test, revealed that gaze-assisted control methods significantly outperformed traditional control strategies in terms of task completion speed, success rate, and user satisfaction. Moreover, context-assisted control demonstrated further improvements by enhancing the prediction of user intent. Overall, ProACT offers an open-source, flexible simulation environment that supports the development, testing, and evaluation of intelligent prosthetic control systems, promoting user-centered design and accelerating advancements in prosthetic technologies.

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CHAPTER 3

Design Methodology

The design process of the wearable prosthetic arm project is organized in several steps that together cover affordability, modularity, integration of sensors, and user-oriented function. The process revolves around iterative development, modularity testing, and user flexibility.

1. **Requirement Analysis:**
   - Determined the requirements of the target consumers (amputees in low-resource settings).
   - Explored limitations of current prosthetic solutions based on a literature survey.
   - Set major objectives: affordability, modularity, natural control, and sensor feedback.
2. **Conceptual Design**
   - Brainstormed potential mechanical designs for the arm with emphasis on modular finger and joint pieces.
   - Recommended a modular design that permits individual components (fingers, palm, wrist) to be swapped or replaced by themselves.
   - Opted for light materials (PLA, ABS) with which 3D prints and local production can be made.
3. **Component Choice**
   - Microcontroller: Chose Arduino UNO/Nano due to ease of use, affordability, and community backing.
   - Sensors: Used EMG sensors for detecting muscle signal and Force Sensitive Resistors (FSRs) for grip force monitoring.
   - Actuators: Used servo motors for simple movement control and cost-effectiveness.

- Power Supply: Incorporated a rechargeable Li-ion battery system with power-efficient regulation.

4. **Circuit Design and Integration**
   - Developed custom PCBs or utilized breadboards to implement EMG signal conditioning circuits.
   - Plugged sensors and actuators into the microcontroller for real-time signal acquisition and control.
   - Applied simple filtering and amplification of EMG signals to obtain useful muscle activity data.
5. **Mechanical Prototyping**
   - Designed arm and fingers in CAD programs (e.g., Fusion 360, SolidWorks).
   - Utilized 3D printing to create mechanical components.
   - Built components with modular joints to facilitate easy disassembly for maintenance or modification.
6. **Software Development**
   - Written embedded code for signal processing, actuator control, and gesture detection.
   - Employed PWM control for servo actuation from sensor input.
   - Implemented calibration procedures and simple error corrections.
7. **Integration and Testing**
   - Performed unit testing of individual modules (EMG sensor, actuators, power system).
   - Executed system-level testing to assess:
     - Gripping capability
     - Response time
     - Power usage
     - User comfort and flexibility
8. **Performance Evaluation**
   - Tested the arm's functionality using simulated daily activity tests (gripping, holding, lifting).
   - Measured performance metrics including grip force, joint velocity, and EMG response accuracy.

- Compared results with initial targets.

9. Iterative Refinement

- Received feedback from test users and colleagues.
- Areas for improvement identified (motor torque, sensor placement, mechanical strength).
- Improved mechanical design and control logic with test data and user feedback.

10. Documentation and Future Scope

- Documented code, test results, and design for reproducibility.
- Described future improvements as follows:
- Haptic feedback support
- Wireless control
- Machine learning-based gesture prediction

CHAPTER 4

APPLICATIONS

1. **Daily Living Assistance:** The prosthetic arm enables users to carry out essential day-to-day activities like eating, drinking, brushing teeth, combing hair, and dressing. Its ergonomic and lightweight design, combined with functional gripping capabilities, helps restore a sense of independence.

2. **Rehabilitation and Physiotherapy Support:** This device can be used in clinical settings to support physiotherapy sessions. Patients recovering from amputation can use it to train residual limb muscles, gradually improving coordination and strength while adapting to prosthetic use.

3. **Affordable Mobility Solution for Economically Disadvantaged Populations:** Many individuals in developing countries cannot afford expensive prosthetic solutions. This low-cost, modular arm addresses their need by offering a reliable and maintainable alternative at a fraction of the price.

4. **Disaster Relief and Post-Accident Deployment:** The prosthetic can be provided as part of emergency medical response kits for victims of natural disasters, industrial accidents, or warzones. It offers an immediate and practical solution for those who lose upper limbs due to unforeseen events.

5. **Educational Demonstrator in Technical and Medical Institutes:** The arm serves as a multidisciplinary educational tool in electronics, robotics, biomedical engineering, and even AI-related courses. It demonstrates concepts like sensor integration, embedded control, signal processing, and biomechanics.

6. **Assistive Device in Elderly Care and Motor-Impairment Therapy:** It can be adapted for elderly individuals suffering from partial paralysis or conditions like Parkinson's disease, offering support with motor tasks through controlled, stable movement.

7. **Military and Field Medicine Application:** Soldiers injured in combat zones could benefit from this field-deployable solution, which could be customized to their task-specific requirements and repaired easily using modular parts.

8. **Vocational Skill Recovery:** By integrating adaptive gripping and motion control, this prosthetic arm can help individuals return to their previous jobs—especially in fields like tailoring, electronics assembly, or craftsmanship—where fine motor control is essential.

CHAPTER 5

TECHNICAL OUTCOMES

Category	Outcome Description
Design Architecture	Modular mechanical design using lightweight, 3D-printable materials for rapid prototyping and easy repair.
Sensor Integration	Embedded sensors to detect EMG/myokinetic signals for real-time muscle-based control of limb movements.
Control System	Microcontroller-based control (Arduino platform) capable of managing multi-joint actuation and grip response.
Mobility Functions	Ability to perform basic grasping, pinching, and releasing operations via programmed gestures and force control.
User Interface	Manual and semi-automated controls for calibration, testing, and user feedback loop integration.
Power Supply - Efficiency	Operates using low-voltage DC battery systems; optimized for low power consumption for extended wear.
Modularity	Replaceable modules for fingers, joints, and sensors to allow maintenance and upgrades without full replacement.
Sensor Feedback	Basic haptic/tactile feedback support for future development using force-sensitive resistors (FSRs).
Prototype Testing	Functional testing for basic grip strength, finger articulation, and user comfort metrics completed.
Documentation and Codebase	Well-documented code and system architecture provided for replication, improvement, and academic dissemination.

CHAPTER 6

CONCLUSION

The design and implementation of the wearable prosthetic arm as outlined in this project signify an important step toward bridging the gap between affordability and functionality in assistive technologies. Current high-end prosthetic solutions, while effective, are largely inaccessible to most of the population due to cost and maintenance challenges. This project demonstrates that it is possible to create a cost-effective, modular, and intelligent prosthetic arm without compromising essential features and usability.

Throughout the course of development, we have identified and addressed several pain points common in existing prosthetic systems: high costs, complex repairs, and lack of intuitive control. By adopting a modular approach, our design allows users to easily swap and fix components, reducing dependence on specialized technicians. The integration of grip sensors and muscle detection systems enhances the control experience, allowing for more natural, real-time interactions with the prosthetic.

The literature survey provided invaluable insight into ongoing global innovations in prosthetics. From magnetic localization to neural network controllers and vibrotactile feedback systems, it is clear that the future of prosthetics lies in interdisciplinary collaboration. Our project aims to serve as a foundational prototype that could one day incorporate such advanced features, providing a seamless blend of technology and human capability.

We conclude that this wearable prosthetic arm, though still in its early stages, holds great potential for improving the quality of life for individuals with upper limb disabilities. It also opens new avenues for further research and development in the domain of biomedical devices and rehabilitation robotics. Moving forward, user testing, AI-based motion learning, and integration with haptic feedback will further enhance its performance and usability.

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