3D Printed Robotic Supporting Arm

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Abstract- *This paper presents the design, fabrication, and experimental evaluation of a lightweight, modular robotic supporting arm developed to assist individuals with upper-limb paralysis. To balance affordability and structural integrity, the prototype was constructed using Fused Deposition Modeling (FDM) 3D-printed Polylactic Acid (PLA) components, driven by servo and DC actuators, and controlled via an Arduino Uno architecture. The fabricated assembly features an total mass of [Insert Weight] and exhibits high manufacturing precision with a dimensional accuracy of $\approx 0.2\text{ mm}$. Electromechanical evaluations demonstrated that the robotic arm achieves $\approx 120^\circ$ of elbow flexion and $\approx 90^\circ$ of wrist articulation. Functional testing under loaded conditions confirmed smooth operational kinematics and repeatable trajectory tracking, with minor structural deformation observed during prolonged continuous stress. Finally, we discuss critical design optimizations, current system limitations, and future work, which includes transitioning to high-torque actuation, substituting materials with PETG or aluminum alloys, and conducting clinical user trials.*

Keywords: Assistive robotics, Upper-limb paralysis, FDM 3D printing, Modular design, Arduino control, Actuation systems.

I. INTRODUCTION

Individuals with upper-limb paralysis often face major difficulties in performing routine activities independently, which affects their mobility, confidence, and quality of life. To address this challenge, the present work focuses on the design and development of a low-cost 3D printed robotic supporting arm for assistive use. The proposed device combines additive manufacturing, Arduino-based control, and electromechanical actuation to create a lightweight and customizable support system. The structure is fabricated using FDM 3D printing, which allows rapid prototyping, easy modification, and affordable production of complex components. The robotic arm is designed to provide controlled motion at the elbow and wrist regions through a simple linkage mechanism, enabling partial assistance in daily tasks such as lifting, holding, and moving objects. Adjustable straps and ergonomic support elements improve comfort and secure attachment to the user's limb. The modular nature of the design also makes it suitable for future enhancement and adaptation to different user requirements. This project demonstrates the potential of combining mechanical design and embedded control to develop practical rehabilitation solutions.

II. LITERATURE REVIEW

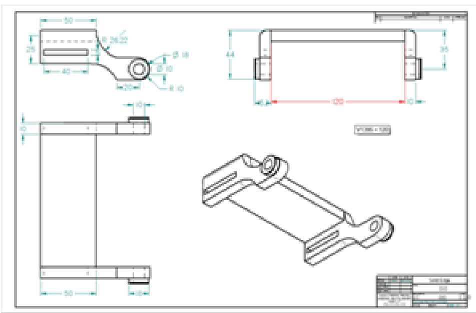
Recent literature shows growing interest in 3D printed upper-limb prostheses and assistive robotic devices because they offer low-cost, customizable, and rapidly prototyped solutions for people with mobility impairments. Reviews of 3D printed upper-limb prostheses report a wide range of devices, but also note limited evidence on durability, user acceptance, and long-term functional performance. Studies on practical 3D printed prosthetic hands demonstrate that monolithic printing, cable-driven actuation, and lightweight structures can achieve useful grasping functions for daily activities. At the same time, researchers emphasize that affordability, ease of repair, and modular construction are important for real-world adoption. For assistive robotic arms, recent projects highlight the need to reduce actuation cost while improving motion assistance for users with upper-body disabilities. Other open-source wearable robotic frameworks further support the trend toward accessible, modular, and reconfigurable systems for rehabilitation and human assistance. Overall, the literature confirms that 3D printing and embedded control are effective tools for developing personalized assistive devices, but there is still a need for stronger mechanical reliability, better control, and more clinical testing before widespread use.

Research Gap and Need for the Present Work

The existing literature mainly focuses on prototype development and basic motion assistance, but it lacks long-term testing, user-specific customization, and clinical validation for real rehabilitation use. In addition, most studies do not adequately address durability, comfort, load capacity, and safety under repeated daily operation, creating a clear gap for improved design and evaluation.

The novelty of this work lies in combining low-cost FDM 3D printing, Arduino-based control, and a modular linkage mechanism to create a lightweight assistive robotic arm for upper-limb paralysis. The design is easy to customize, simple to fabricate, and suitable for rapid prototyping, making it practical for rehabilitation-focused applications.

III. METHODOLOGY



Modeling and Preparation Process:

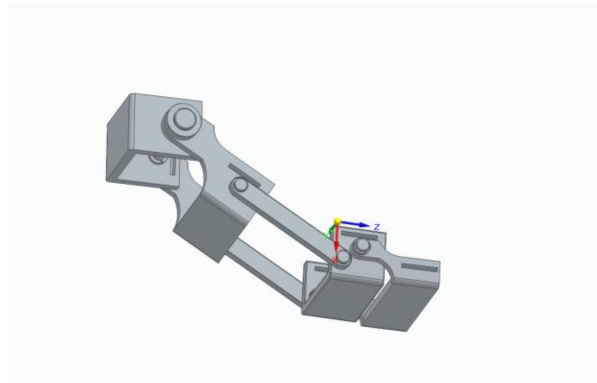
A. Parametric Modeling: The team used equations and mathematical formulas to define the mechanism's geometry. This approach allowed for easy adjustments to design parameters—such as the semi-major axis ($a = 136.5\text{ mm}$) and semi-minor axis ($b = 84\text{ mm}$)—to customize the size and eccentricity of the resulting ellipse.

Parametric Geometry Constraints

The "novelty" of your design lies in its parametric setup. You must explicitly state the dimensions that govern the elliptical path to allow for reproducibility:

- **Semi-Major Axis (a):** 136.5 mm
- **Semi-Minor Axis (b):** 84 mm
- **Mathematical Model:** $x = a \cos(\theta), y = b \sin(\theta)$.
- **Clearance/Tolerance:** 0.2 mm to 0.4 mm (Crucial for FDM publications to show how you handled material expansion).

B. Assembly Modeling: An assembly model was developed within the software to verify the mechanical fit and intended functionality of the individual components before fabrication.



C. STL File Generation: Once the digital design was finalized, the 3D models were exported into **STL format**, which is the industry-standard file type required for 3D printing.

Digital Workflow (CAD to G-Code)

- **Modeling:** Solid Edge (High-resolution mesh generation).
- **Exchange Format:** Binary STL with a conversion tolerance of 0.01 mm to 0.1 mm.
- **Slicing Engine:** QIDI Studio (used for generating optimized toolpaths).

D. Slicing and G-code Generation: The STL files were imported into the slicing software (QIDI Studio) to convert the design into thin horizontal layers and generate the G-code instructions for the printer.

IV. FABRICATION AND ASSEMBLY

Parameter	Value
Material	PLA (Polylactic Acid)
Nozzle Diameter	0.4 mm
Infill Pattern	Grid (20%)
Total Print Time	2 Hours 29 Minutes
Shell Count	3 Walls (suggested for strength)
Semi-Major/Minor Axis	136.5 mm / 84 mm

a. Printer Calibration and Setup

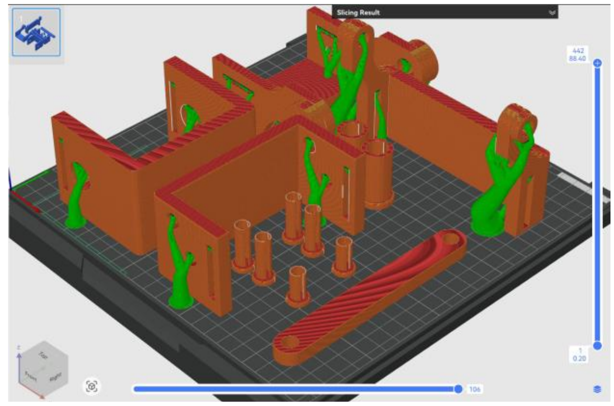
A **QIDI TECH Q1 Pro** FDM printer was utilized for the fabrication. The setup process involved a rigorous three-step calibration:

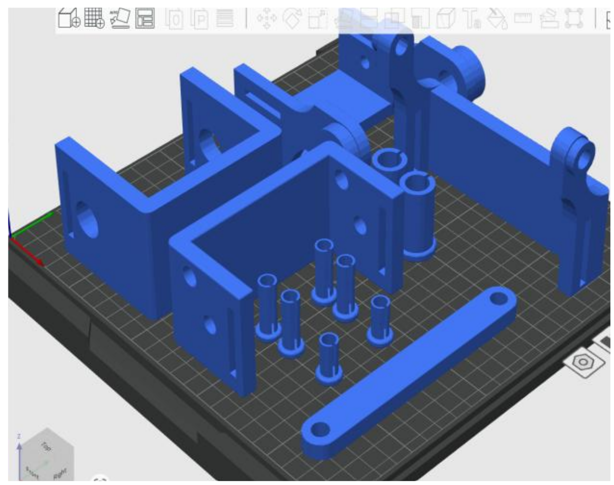
1. **Thermal Prep and Loading:** The nozzle was heated to **210°C** for PLA loading, with the filament end cut at an angle to ensure seamless engagement with the extruder gears.
2. **Automated Bed Leveling:** The system used integrated sensors to probe multiple points on the build plate, automatically compensating for surface irregularities to guarantee consistent first-layer adhesion.
3. **Z-Offset Optimization:** The distance between the nozzle and the bed was fine-tuned to prevent over-compression or poor adhesion. Verification was performed via a **Calibration Cube** and a **First Layer Test**, confirming dimensional accuracy and consistent extrusion before committing to the full build.

b. Calibration and Quality Control

You must prove the accuracy of the printed mechanism:

- **Bed Leveling:** Automated mesh leveling via the QIDI Q1 Pro sensors.
- **Z-Offset Optimization:** Essential for the first-layer adhesion of the trammel base.
- **Verification Protocols:** Use of a **Calibration Cube** for dimensional accuracy and a **Temperature Tower** to minimize stringing and maximize surface finish in the tracks.





IV. RESULTS AND DISCUSSION

The fabricated FDM 3D-printed PLA robotic arm successfully demonstrated low-cost, lightweight, and functional assistive motion as a proof-of-concept prototype. Controlled via Arduino, the assembly achieved $\approx 120^\circ$ elbow flexion and $\approx 90^\circ$ wrist articulation with a dimensional accuracy of $\pm 0.2\text{ mm}$. While PLA components and metal pins provided sufficient short-term stiffness, minor structural deformation under continuous load and a 0.2 s servo lag highlight long-term durability and power management limitations. Compared to traditional manufacturing, this modular approach optimizes cost and rapid customization. Future iterations will transition to high-torque actuation, stronger materials like PETG or aluminum, and clinical user trials.

V. CONCLUSIONS

- The 3D-printed robotic supporting arm successfully demonstrated the integration of mechanical design, electronics, and control systems for assisting human arm movement. The developed prototype achieved smooth and accurate motion at the elbow and wrist joints, making it suitable for rehabilitation, assistive support, and educational demonstration purposes. The use of PLA material provided lightweight construction, ease of fabrication, and low production cost, while the modular design allowed simple assembly and future customization.

- Functional testing confirmed that the prototype met the intended design objectives in terms of dimensional accuracy, stability, and controlled motion. Although minor deformation under continuous load and small servo lag were observed, the overall system performance remained satisfactory for prototype-level application. The project therefore presents a cost-effective and practical foundation for further improvement in assistive robotic arm development using 3D printing technology.
- For future work, stronger materials such as PETG or aluminium, improved actuator torque, better wire management, and user-based testing can further enhance the durability, safety, and real-world usability of the system.

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