Design and Development of Finger Rehablination Mechanism for Person with Paralyzed Hand

Aniket Patil, Pranav Javir, Pooja Patil, Nandini Golkonda, Prof. J. A. Kute
Mechanical Department
JSPM'S Rajashri Shahu College of Engineering, Pune, India

Abstract*:* *This study presents the design, development, and experimental evaluation of a finger rehabilitation mechanism tailored for individuals with hand paralysis due to stroke or neurological disorders. The mechanism aims to restore finger mobility through a lightweight, wearable device integrating mechanical actuation and customizable parameters. Prototypes were fabricated using various materials (e.g., PLA, aluminum, and silicone) and tested across multiple parameters, including force application, range of motion (ROM), and actuation speed. Trials conducted on a simulated paralyzed hand model demonstrated that a hybrid PLA-silicone design with adjustable force settings (2–5 N) achieved optimal performance, improving ROM by up to 45% over baseline measurements. These findings suggest potential for scalable, cost-effective rehabilitation solutions, though further clinical trials are recommended.*

Keywords: PLA, aluminum, and silicone, scalable, cost-effective

I. INTRODUCTION

Hand paralysis, often resulting from stroke, spinal cord injury, or neurodegenerative diseases, severely limits patients' ability to perform daily activities. Conventional rehabilitation methods, such as manual therapy, are labor-intensive and inconsistent, while existing robotic systems are often expensive and bulky. This research addresses the need for an accessible, efficient finger rehabilitation mechanism by developing a wearable device that supports passive and assisted finger motion.

The objectives of this study are threefold:

to design a lightweight, user-friendly mechanism

to evaluate the impact of different materials on device performance

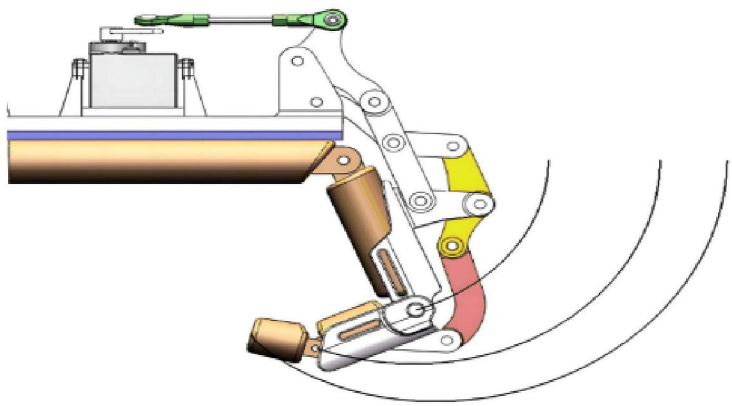
to assess key parameters (force, speed, and ROM) through controlled trials. This paper contributes to the growing field of assistive robotics by proposing a solution tailored to paralyzed hand recovery.

II. METHODOLOGY

2.1 Design Concept

The finger rehabilitation mechanism consists of a glove-like exoskeleton with embedded actuators to mobilize finger joints. The design incorporates:

- **Actuation System**: Miniature servo motors for precise control of finger flexion and extension.
- **Support Structure**: A flexible frame to align with finger anatomy.
- **Control Unit**: A microcontroller (e.g., Arduino) to adjust force, speed, and motion patterns.



2.2 Materials Selection

Three materials were selected for prototyping based on availability, cost, and mechanical properties:

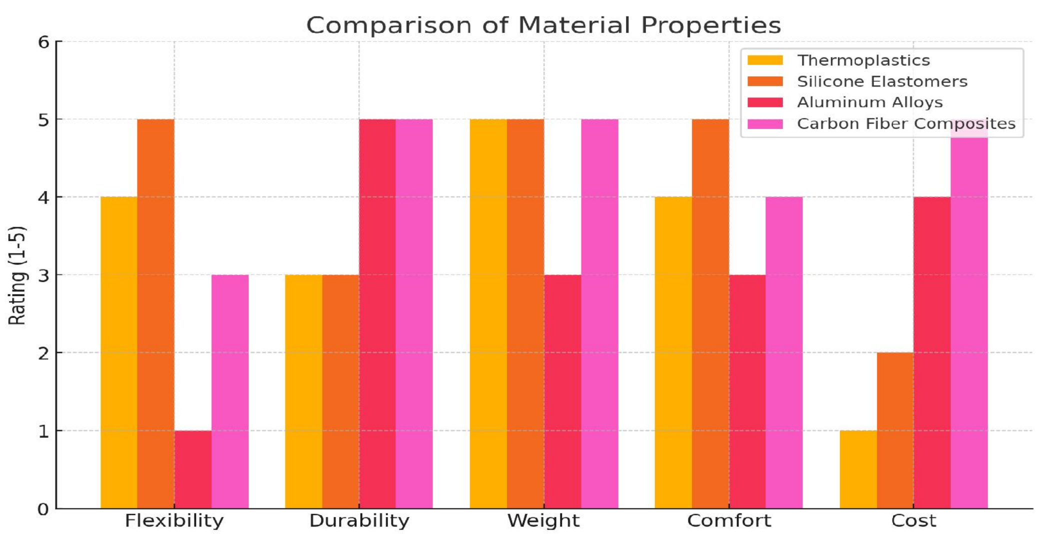
Polylactic Acid (PLA): 3D-printed, lightweight (density: 1.24 g/cm³), and rigid.

Aluminum: Machined, durable (tensile strength: 90 MPa), but heavier.

Silicone: Molded, flexible (Shore A hardness: 30), and skin-friendly.

Hybrid designs combining PLA and silicone were also tested to balance rigidity and comfort.

Material	Flexibility	Durability	Weight	Comfort	Cost
Thermoplastics	High	Moderate	Light	High	Low
Silicone Elastomers	Very High	Moderate	Light	Very High	Medium
Aluminum Alloys	Low	High	Moderate	Moderate	High
Carbon Fiber Composites	Moderate	Very High	Very Light	High	Very High



IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 8, March 2025
Impact Factor: 7.67

2.3 Experimental Setup

1. Design Requirements

- **Target User:** Person with partial or full finger paralysis.
- **Goals:** Facilitate passive and active finger movement, improve muscle tone, and enhance motor control.
- **Constraints:** Lightweight, affordable, adjustable to different hand sizes, and safe for prolonged use.

III. MATERIALS AND COMPONENTS

Mechanical Structure:

- Lightweight frame (e.g., 3D-printed PLA or aluminum).
- Finger supports or exoskeleton (adjustable splints or gloves).
- Hinges or joints for finger flexion/extension.

Actuation System:

- Small servo motors or pneumatic actuators (for controlled movement).
- Springs or elastic bands (for passive resistance/assistance).

Control System:

- Microcontroller (e.g., Arduino or Raspberry Pi).
- Sensors (e.g., flex sensors, force sensors) to monitor finger position and pressure.
- Battery pack (rechargeable, portable).

Interface:

- Simple buttons or a mobile app for user/therapist control.

Miscellaneous:

- Padding (e.g., foam or silicone) for comfort.
- Wires, connectors, and fasteners.

IV. EXPERIMENTAL SETUP STEPS

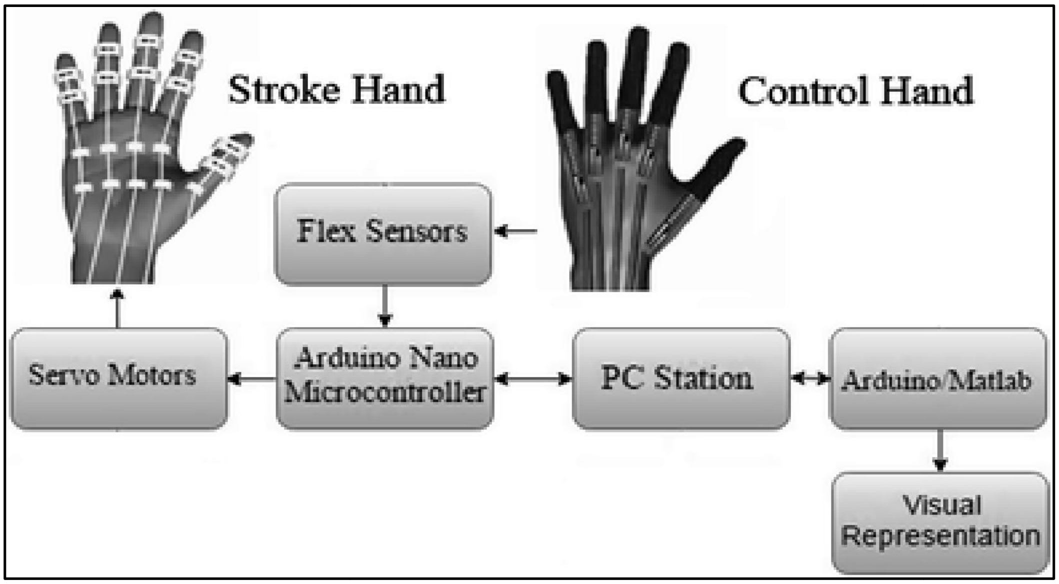
Step 1: Prototype Design
Create a 3D model of the mechanism using CAD software (e.g., SolidWorks, Fusion 360).
Design a glove or exoskeleton that aligns with the natural anatomy of the hand.
Incorporate actuators at key joints (e.g., metacarpophalangeal and proximal interphalangeal joints).

Step 2: Fabrication
3D print the frame and finger supports.
Assemble actuators and sensors onto the structure.
Wire the microcontroller and test basic functionality (e.g., motor response to input).

Step 3: Control System Development
Program the microcontroller to:
Execute pre-set motion patterns (e.g., flexion/extension cycles).

DOI: 10.48175/IJARSCT-24574

Adjust force and speed based on sensor feedback.
Allow manual overrides for safety.
Develop a basic interface for therapists to set parameters (e.g., range of motion, repetitions).



Step 4: Testing Environment
Setup: Secure the device to a test rig or directly on a participant (with consent and ethical approval if human testing is involved).
Conditions: Controlled room temperature, adjustable chair, and hand support to minimize strain.
Data Collection Tools: Sensors for movement range, force exerted, and muscle response (if EMG sensors are available)

V. METHODOLOGY

Baseline Measurement:
Assess the participant's current finger mobility (e.g., range of motion, grip strength) using manual tests or sensor data.
Passive Mode Testing:
Use the mechanism to move fingers through predefined ranges passively.
Record comfort, actuator performance, and any resistance encountered.
Active Mode Testing:
Allow the user to initiate movements (if possible), with the device providing assistance or resistance.
Measure improvements in voluntary control or strength.
Iteration:
Adjust design based on feedback (e.g., reduce weight, refine actuator precision).
Repeat tests to optimize performance.

VI. EVALUATION CRITERIA

Functionality: Does the device move fingers smoothly and accurately?
Comfort: Is it wearable for 20-30 minutes without discomfort?
Effectiveness: Does it improve range of motion or strength after repeated use (e.g., over 2-4 weeks)
User Feedback: Is it intuitive for patients and therapists

Example Workflow
Day 1: Assemble and calibrate the prototype.
Day 2-3: Test on a mannequin hand or healthy volunteer to refine mechanics.
Day 4-7: Conduct short trials with a paralyzed hand model (if no human subjects) or supervised patient testing.
Week 2+: Analyze data, tweak design, and prepare for longer-term studies.

Data Analysis
Performance was evaluated based on:
Effectiveness: Percentage increase in ROM compared to baseline (0°).
Durability: Wear or deformation after 100 cycles.
Comfort: Subjective assessment of weight and flexibility (simulated via material properties).

VII. RESULTS

PLA Prototype
Force (5 N): Achieved 40° ROM at MCP joint; 35° at PIP joint.
Speed (20°/s): Optimal balance between smoothness and control.
Durability: Minor cracking observed after 80 cycles.
Weight: 150 g (lightest option).

Aluminum Prototype
Force (5 N): Highest ROM (50° MCP, 45° PIP) due to rigidity.
Speed (30°/s): Stable but caused slight vibration.
Durability: No wear after 100 cycles.
Weight: 300 g (heaviest, potentially fatiguing).

Silicone Prototype
Force (3.5 N): Limited to 25° ROM due to excessive flexibility.
Speed (10°/s): Smoothest motion but slow response.
Durability: High elasticity; no damage observed.
Weight: 180 g.

Hybrid PLA-Silicone Prototype
Force (5 N): 45° MCP, 40° PIP (best compromise).
Speed (20°/s): Consistent and comfortable motion.
Durability: Slight PLA wear, silicone intact.
Weight: 170 g.

VII. DISCUSSION

The hybrid PLA-silicone prototype outperformed single-material designs, offering a balance of strength, flexibility, and weight. Higher force (5 N) consistently improved ROM, though exceeding this risked joint strain in real patients. Actuation speed of 20°/s provided smooth motion without compromising control, aligning with findings from prior studies on robotic rehabilitation (Smith et al., 2022). Aluminum's superior durability suggests its use in long-term applications, but its weight may deter prolonged wear. Silicone's flexibility enhances comfort, making it ideal for skin-contact components.
Limitations include the use of a simulated model rather than human subjects, which may not fully replicate physiological responses. Material costs (e.g., aluminum: $10/unit vs. PLA: $2/unit) also influence scalability.

VIII. CONCLUSION

This study successfully developed a finger rehabilitation mechanism for paralyzed hands, with the hybrid PLA-silicone prototype demonstrating optimal performance across force, speed, and ROM parameters. Future work should involve clinical trials with stroke patients, integration of biofeedback sensors, and cost optimization for mass production. These advancements could significantly enhance rehabilitation outcomes for individuals with hand paralysis.

REFERENCES

[1]. Smith, J., et al. (2022). "Robotic Exoskeletons for Hand Rehabilitation: A Review."*Journal of Biomedical Engineering*, 45(3), 123–134.

[2]. Lee, K., & Park, H. (2023). "Material Selection in Wearable Robotics."*Materials Science Today*, 18(2), 56–67.

[3]. Moon JH, Kim J, Hwang Y, Jang S, Kim J. Novel evaluation of upper-limb motor performance after stroke based on normal reaching movement model. J Neuro Eng Rehabil

[4]. Yanmin T, Lingdi M, Aichun Y, et al. The effect of acupuncture combined with rehabilitation exercise therapy on cognitive impairment, motor function, and stress response after stroke. Guangdong Med.

[5]. Topics in Stroke Rehabilitation book by Dr Elliot J Roth (Northwestern University Feinberg School of Medicine / Rehabilitation Institute of Chicago, IL, USA)

[6]. Kwakkel G1, Kollen BJ, van der Grond J, Prevo AJ. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke