

## Motivation

- Prosthetics are expensive, limited by access, and often rely on EMG, making them complex and hard to use
- This project develops a voice-controlled, ESP32-based 3D-printed hand for basic gestures, using a finger pulley system

## Design Requirements

### Design Requirements:

- Cost  $\leq$  \$300
- $\geq$  2-hour battery life
- $\geq$  3 motor-driven gestures
- 3D-printed, durable, modular
- Safe (no pinch points, non-invasive)
- Voice control + wireless connection

### Design Standards:

- Wireless:** Bluetooth communication (IEEE 802.15)
- Electrical Safety:** Medical device & battery safety (IEC standards)
- Usability:** Human-centered design and ease of use (ANSI/IEC)
- Manufacturing:** 3D printing materials and processes (ISO/ASTM)
- Mechanical:** Structural design and tolerances (ASME)
- Regulatory:** General FDA guidance for low-risk devices

## System Architecture

### Input (Mobile Application)

Speech  $\rightarrow$  Text  $\rightarrow$  Command

via Bluetooth

### Processing (Voice ESP32)

Command translates into signal

Transfer (UART)

### Execution (Hand ESP32)

Triggers I2C expanders, motor rotation

### Action (Motors and Tendons)

Stepper motors pull on fishing wire, moving fingers

## Design Alternatives

### Alternative 1: External Weight

- Added weights to assist in finger closure
- Simple concept, passive return mechanism

*Limitations:* Increased bulk, reduced portability

### Alternative 2: Gravity-Assisted Motor System

- Vertical motor panel, motors slide up and down
- Weight of motors pull fingers during motion

*Limitations:* High friction, inconsistent movement

## Iterative Process

- Used two microcontrollers to split up voice and movement tasks
- Added extra ports to move each finger independently
- Programmed gestures like "Peace" and "Thumbs Up"
- Built a new prototype with a more natural, lifelike shape
- Made a phone app to trigger actions with simple voice commands



Fig 1: Initial CAD model design

## Final Design and Implementation

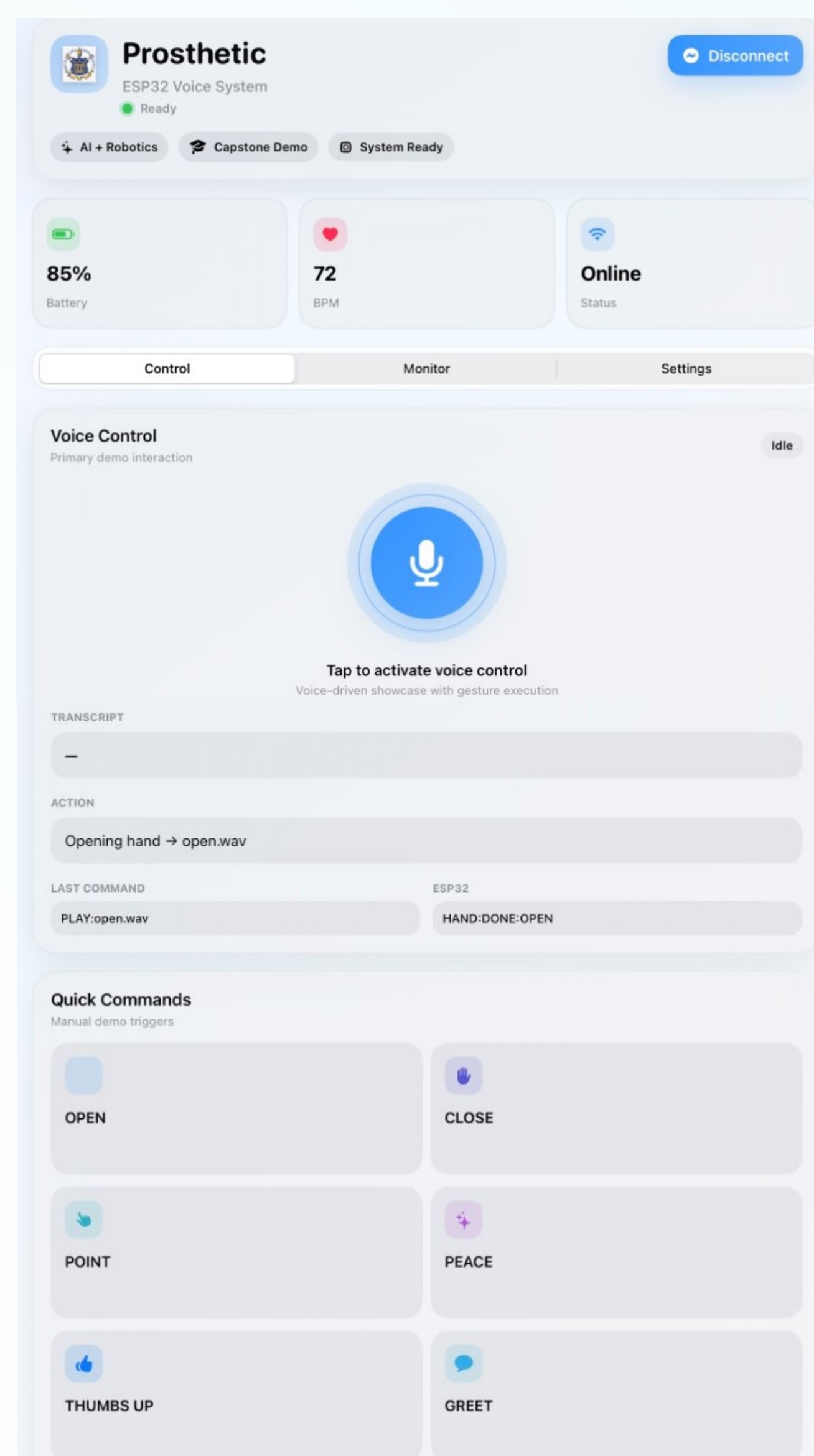


Fig 2: Prosthetic App Design

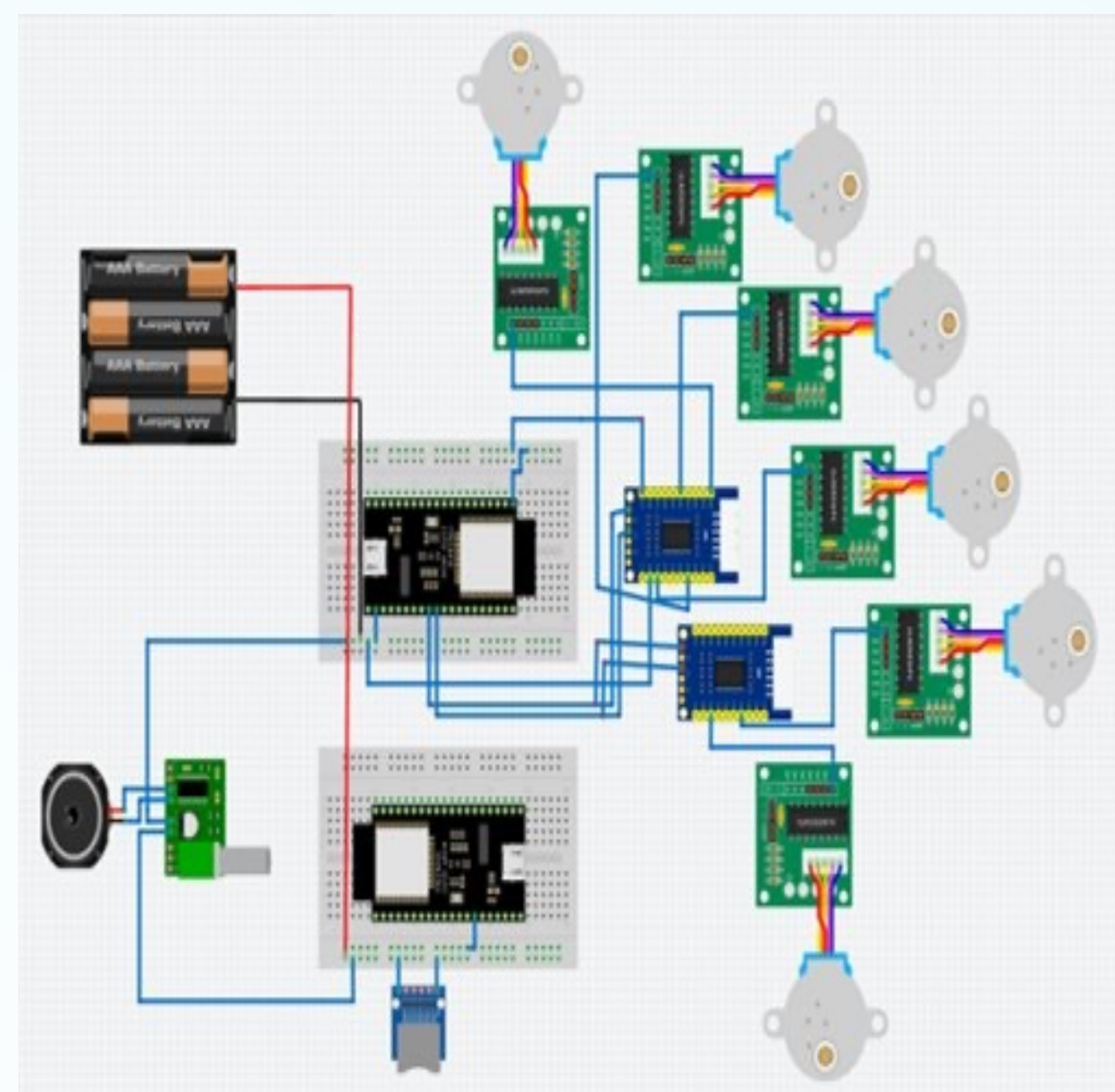


Fig 3: Schematic of electrical components



Fig 4: Final Hand Design after implementation

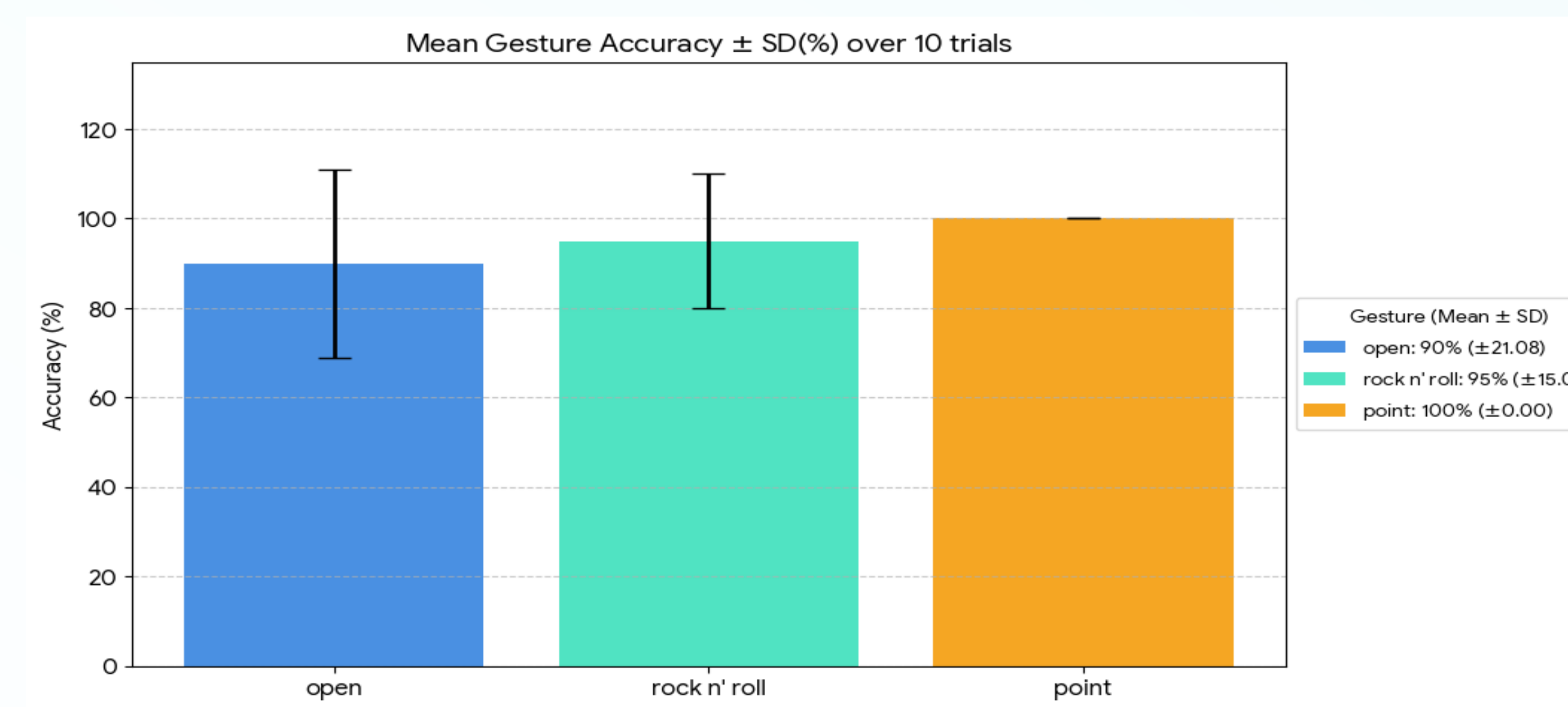


Fig 5: Gesture Average Accuracy  $\pm$  SD (%) of 3 gestures over 10 trials, rated on a 0-2 scale

## Design Evaluation

### Gesture Testing:

- Ran 10 trials on each gesture and evaluated on a 0-2 scale, 0 (failure), 1 (partial execution), 2 (perfect execution)
- Achieved  $\geq$  85% Accuracy
- Required calibration for consistency

### Voice Control:

- Swift app enable fast voice command processing
- BLE communication performed reliably

### Mechanical Performance:

- Improved tendon routing reduced failures
- 6<sup>th</sup> motor improved finger closing

## Conclusion and Discussion

- Voice control offered a simple, non-invasive alternative to EMG systems
- 6-motor design improved finger synchronization and reduced locking
- Consistent and reliable gesture performance ( $\geq$ 85% accuracy)
- Battery life exceeded 2 hours
- Low-cost design maintained strong functionality and performance
- Met key goals: affordability, usability, and accessibility
- Demonstrated feasibility of voice-controlled prosthetic system

**Strengths:** Low cost, easy to use, non-invasive control, reliable performance

**Limitations:** Limited gesture range, latency in finger articulation, ESP32 capabilities and noise sensitivity

This project demonstrates a practical step toward making functional, user-friendly prosthetic technology more accessible to a wider population.

## Acknowledgements

Trinity College Engineering Department  
Professor Gao  
Professor Cheng  
Andrew Musulin  
TRAVELERS

## References

- Arm Dynamics, *Persistence and Prostheses: Pursuing Insurance Provider Approval for Upper Limb Prosthetic Devices*, 2021.
- InMoov Robotics Initiative, *InMoov-Based Robotic Hand: Open-Source Design Documentation for 3D-Printed Modular Robotic Hands*.
- Open-Source Additive Manufacturing Community, *3D Printed Prosthetic Hand: Low-Cost Prosthetic Models Using PLA/TPU for Functional Grasping*.
- Voice Controlled Prosthetic Hand With Predefined Grasps and Movements*, Conference Proceedings.