Humanoid Hand

Operation & Assembly Manual

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

The goal of this project is to design a highly dexterous robotic hand which will serve as a testbed for two of NAU's research labs to dip their toes into the field of prosthetics. The sponsors of this project are Dr. Zach Lerner and Dr. Reza Razavian. The sponsors have set forth two major goals for the hand: 1) to be able to play a tune on the piano and 2) to be able to catch a ball. These requirements set forth a high bar for speed, strength, and dexterity.

The major project deliverables is the Efest Presentation that is on December 5th. The success metrics for the final design that we will be aiming for are as follows. The fingers will need to be capable of exerting 1 N of force at the tip of the finger and will need to have the full or near-full range of motion of the biological hand in order to be able to play the piano. Moreover, the motors will need to be capable of between 100-300 RPM in order to meet the catching requirement.

Fingers are primarily tendon driven with servos at the base of the fingers to facilitate splaying the fingers. The thumb is similar, using tendons to flex and extend the thumb and one servo enabling the thumb's more complex motion. The fingers will have two tendon attachment points. The two bottom segments of the finger have a tendon for extension and bending. The third segment of the finger will be mechanically linked to the motion of the second joint to cut down on how many motors are needed. There are ten motors. All of them will reside in the forearm, driving the tendons. The motors in the forearm will be BLDC motors, chosen for their speed and torque. There are five servos in the hand, chosen for their smaller size. Lastly, each finger will house 2 angle sensors. One at the base joint and one at the second joint of the finger. The angle sensors will be there to ensure accuracy and repeatability of motion. Because the last segment of the finger will be mechanically linked to the second segment of the finger, its angular position can be inferred, avoiding the need for a third angle sensor in the finger.

The results from our literature review and mathematical modelling indicate that joints will need to be well-made and the control scheme will need to be well-programmed. The hand is a complex machine and it is no simple task to adequately mimic its capabilities. The mathematical modelling section of this document goes into more detail regarding these requirements.

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1 Introduction

1.1 Purpose of the Manual

This Operation and Assembly manual was constructed to help guide a new user or team on how to operate the Robotic hand and how to trouble shoot some of the issues that can arise. Throughout building the robotic hand our team ran into multiple different issues such as motor failure, slack in tendons, circuit shortages and quality issues with prints. This manual aims to help solve some of these common problems. To add to that, the manual should assist with how to assemble the hand and better understand the way it works.

1.2 System Overview

The final hand design uses a **fully tendon-driven system**, allowing each finger to accurately replicate biomimetic flexion and extension. The **wrist is fixed** to maximize structural rigidity, simplify control, and ensure consistent fingertip positioning. Each finger includes a **linked mechanism for the fingertip**, meaning distal and middle phalanges move in coordination for natural curling. All actuators are housed in a centralized **motor bank which acts as the forearm of the hand and** improves responsiveness by shortening tendon travel paths. The system's **power draw and thermal behavior** were characterized during testing, showing stable temperatures under continuous load and predictable current consumption during different grasp types. This architecture of the hand supports a wide range of **use cases**, including pinching, grasping, and repeatable gesture tasks for research or demonstration purposes.

2 Assembly

2.1 Required Tools and Components

To fully assemble the humanoid hand system, the user must gather all relevant tools and components prior to beginning construction. The required tools include metric Allen keys, a small Phillips screwdriver, needle-nose pliers, wire strippers, and wire cutters. A soldering iron is necessary for electrical terminations, and a hot-glue gun is needed for breadboard security. The core components required for assembly are: a full set of 3D printed hand and forearm parts, BLDC motors for tendon actuation, servo motors for splay and thumb positioning, motor driver boards, 3 Teensy 4.1s, potentiometers, bearings, joint pins, all associated fasteners, inserts, tendon cord, and the power supply. A more detailed list of materials can be found in the team's BOM in the Final Report.

2.2 Pre-Assembly Checks

Each part must be inspected to ensure quality and functionality, before beginning assembly. All 3D-printed components should be checked for cracks, delamination, or dimensional errors that could affect joint alignments. Bearings should rotate smoothly without binding or resistance. Motors should be bench-tested to confirm they spin freely and exhibit no electrical or mechanical noise. Driver boards should power on correctly without excessive heat, and all potentiometers should exhibit smooth, continuous angle changes when manually rotated. Tendon material should be examined for fraying. Completing these checks reduces the risk of failure and ensures the final assembly operates reliably.

2.3 Finger Subassembly

The assembly of the fingers is fairly straightforward. It is recommended to start with the base segment of the finger (the longest segment). First, notice the cutouts for the bearing and the potentiometer in the pulley. The first step of assembly is to press the bearing into its cutout and the potentiometer into its cutout. When placing the potentiometer, notice the cutout in the finger for wire routing. Guide the wires through this cutout. This process may be repeated for the other segments of the finger, noting that the fingertip does not accept a potentiometer, and the cutout for the bearing is slightly different than that of the other two segments.

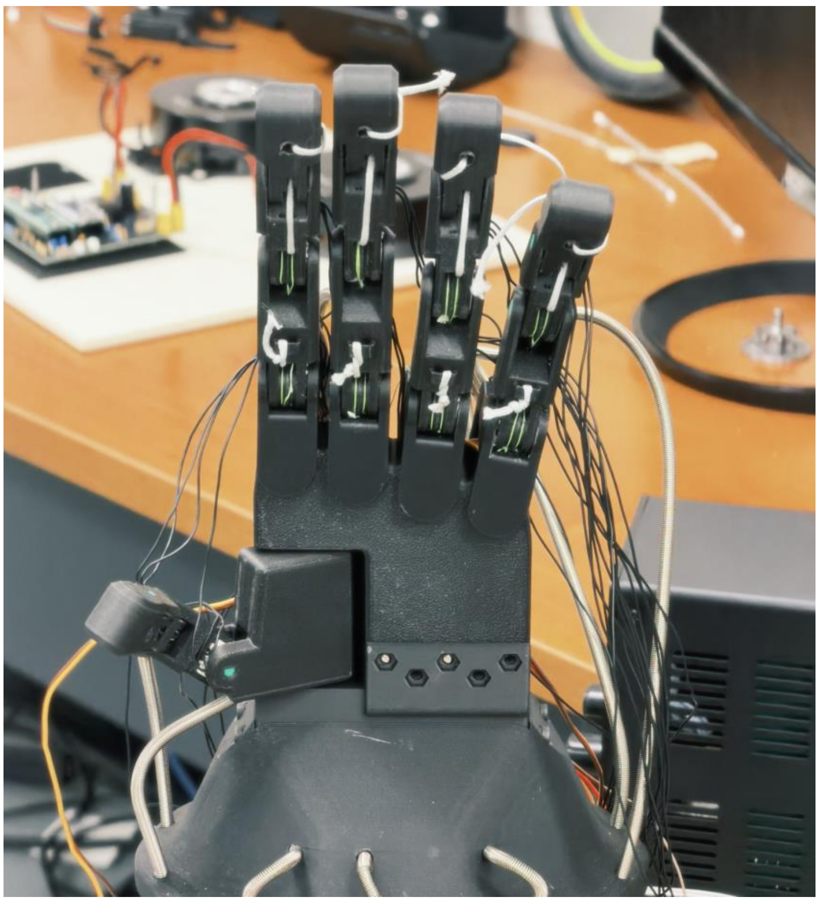
With the bearings and potentiometers in place, the finger segments may be linked together. To do so, begin with the base and middle segments of the finger. Align the segments, noting that the potentiometer of the middle segment should be on the same side as the D-shaped hole of the base segment. With the segments aligned, align a pin with the holes of the segments, noting that the D-shaped side of the pin should be inserted first through the side of the finger with the circular hole. Before pressing the pin into place, ensure that the D-shaped hole of the potentiometer is aligned with the D-shaped hole of the finger. Align the D-shaped side of the pin with the D-shaped hole of the finger and press it into place. Note that a significant amount of force is required.

Attaching the fingertip is a slightly different process. First, take one of the springs and press it into the small hole inside of the middle segment of the finger. Then, move the fingertip into place, aligning the leg of the spring with the small hole in the fingertip. With the legs of the spring in place, press the pin into place. This process can be tricky.

Now we can attach the auxiliary tendon that links the motion of the fingertip. First, tie the tendon to the fingertip using the hole in the fingertip. Now route the tendon as shown in the image, tying it off on the notch on the bottom of the finger's base segment.

Lastly, the finger can be attached to the "knuckle" mounts which attach to the palm using the same method as was used for attaching the base and middle segments.

2.4 Palm and Motor Housing Assembly



To attach the palm to the forearm, fasten the palm base mount to the forearm. Then, with the thumb attached to the palm, press the palm into place, ensuring that the servo arm of the thumb is aligned with its cutout on the palm base mount. The palm may then be screwed into place.

To attach the motors to the forearm, screw the motor onto the forearm, using the topmost hole in the cutout. This will allow us to tension the tendons once they are attached.

To install the tendons, first cut about 1.5ft worth of the included PTFE coated, braided fishing line. Then, tie the fishing line onto the desired finger segment using the small bridge-like extrusions on the pulley. Tie the tendons such that the longer length of line goes toward the forearm for one tendon, and toward the fingertip for the other. Then, wrap the tendons around the pulley one full time, making sure to pass *over* the bridge-like extrusion: this allows the finger to have its full range of motion. Pass the tendons into the hole inside of the finger segment that leads to the bowden tube. Pass the tendons all the way through the bowden tube. Tie the first tendon onto the motor spindle and wrap it around the spindle until tight. Next, tie the second tendon onto the spindle and wrap it in the opposite direction of the first tendon until it is as tight as possible.

If the tendons still have some slack, unscrew the motor, pull it until it's tight, and attach it to the nearest slot.

2.5 Electronics and Wiring Assembly

The pinouts for the driver boards may be gleaned from the motors1_5.ino and motors6_10.ino. Looking at motor 2 as an example, the pin for the motor's angle sensor is defined within MagneticSensorPWM(14, 3, 941). 14 is the pin that the angle sensor's signal wire goes on. 3 and 941 are calibration values for the angle sensor (the angle sensors do not always reach their max and min PWM values, so the "true" max and min needs to be specified in order to ensure proper behavior).

```
// ===== Motor 2 =====
MagneticSensorPWM sensor2 = MagneticSensorPWM(14, 3, 941);
void doPWM2() { sensor2.handlePWM(); }
BLDCMotor motor2 = BLDCMotor(11);
BLDCDriver3PWM driver2 = BLDCDriver3PWM(2, 4, 5, 6); // (A,B,C,EN)
```

Next, BLDCMotor(11) tells the SimpleFOC library that the motor has 11 pole pairs. After that, BLDCDriver3PWM(2, 4, 5, 6) corresponds to the connections of IN 1, IN 2, IN 3, and EN, which are found on the driver boards. These pins are responsible for communicating motor commands from the Teensy 4.1 to the driver board.

The potentiometers were not able to be integrated in into the codebase before the end of the semester. They are connected to their own breadboard (the other two Teensys did not have enough pins). The intention was to have the Teensy hosting the potentiometers to send the angle data to the other two Teensys via the serial pins.

2.6 Disassembly Procedure

Disassembly is largely the inverse of the assembly process. Worth noting is that the pins in the fingers can require a large amount of force to dislodge. It is recommended to use a small screwdriver to press the pins out. These pins shear if the fit in the finger is too tight. It is recommended to have several extra pins on hand.

3 Operation

3.1 Safety Guidelines

The largest safety concerns regarding the humanoid hand surround the electrical systems, followed by moving parts and the proper use of equipment during assembly. Only the approved power supply should be used to prevent electrical overstress of motors or drivers. Exposed sections of electrical components should be kept apart to prevent electrical shorts. If components show signs of overheating, operation must be stopped to allow adequate cooling and prevent damage. Users should ensure that hair is away from joint interfaces while the system is powered. Motors should not be manipulated while power is on to prevent overstressing the motors or tendons.

3.2 Power-On Procedure

Connecting power and initialize controller and verify no abnormal movement

Before powering on, ensure that no bare-metal connections of the electronics are touching. Moreover, ensure that the driver boards are not touching each other. Perform a visual inspection to ensure that all connections are secure. Once this is done, the power supply may be turned on. After doing so, inspect the driver boards to ensure that all of them are receiving power (the red light is on). If any of them are not, power off and check the connections.

With the driver boards powered, the two Teensy 4.1s connected to the driver boards may be plugged into the computer with two instances of the Arduino IDE open. Use one of the instances to connect to one Teensy and the other instance to connect with the other Teensy. With the Teensys connected, the motors will undergo their calibration routine. Once all of the motors have calibrated, commands may be sent to the motors connected to their respective Teensy. The format for motor commands are 0,0,0,0,0 with each zero being replaced with a desired motor angle measured relative to the joint's position at startup.

3.3 Shutdown Procedure

To shut the device down, the best practice is to first turn off the power supply feeding the motors and then disconnect the Teensys.

4 Maintenance

4.1 Routine Inspection

To inspect the device, the following actions are recommended:

- Check the motors for any play
- Check the tendons for any wear, moving each joint back and forth so the whole tendon can be viewed
- Check for any slack in the tendons and address if needed.
- Check the fingers for any play and inspect for any cracks or signs of wear
- Inspect the wires to ensure that all connections are secure

4.2 Cleaning Instructions

Periodical cleaning with compressed air of the finger joints is recommended. If the fingers begin to seize, it will be necessary to take them apart and clean the joints, clearing any debris.

4.3 Tendon Replacement & Re-Tensioning

When tendon wear or slack is observed, the affected tendon should be replaced immediately. Remove the motor from the mount by loosening the screws. Unwind the line from the motor spindle and carefully pull the tendon from the Bowden tube and finger channels. Thread the replacement tendon along the same path and secure it to the finger at the pulley's anchor points. Feed the tendon through the Bowden tube and secure it to the spindle with sufficient wraps. Re-tension the tendon by pulling on the motor, then reattaching it to the forearm with the mounts. Test the finger manually to ensure smooth curling and extension before powering the system.

5 Troubleshooting

5.1 Motor Issues

The motors have three sources of possible issues: their angle sensors, the driver boards, and the Teensys. Because of the complexity of this project, troubleshooting issues can be complicated. It is recommended that if issues arise, a systematic approach to ruling possible causes one-by-one is strongly recommended. Try to isolate the issue as much as possible and incrementally isolate variables to test.

5.2 Sensor or Positioning Problems

The potentiometers in the fingers have fragile solder joints prone to breakage. If any issues arise with them, it is recommended to analogRead() all of them, move each joint, and look for incorrect values.

The angle sensors in the motors have been known to short, causing the motor to behave erratically. If this happens, the angle sensor must be replaced. Replacements may be found here.

5.3 Power Problems

If issues arise with power distribution, check the breadboard which distributes power from the power supply to the driver's boards. Inspect all connections both on the breadboard and on the driver boards.

6 APPENDICES