22 DoF – Full Motion Joint Actuated Robotic Hand

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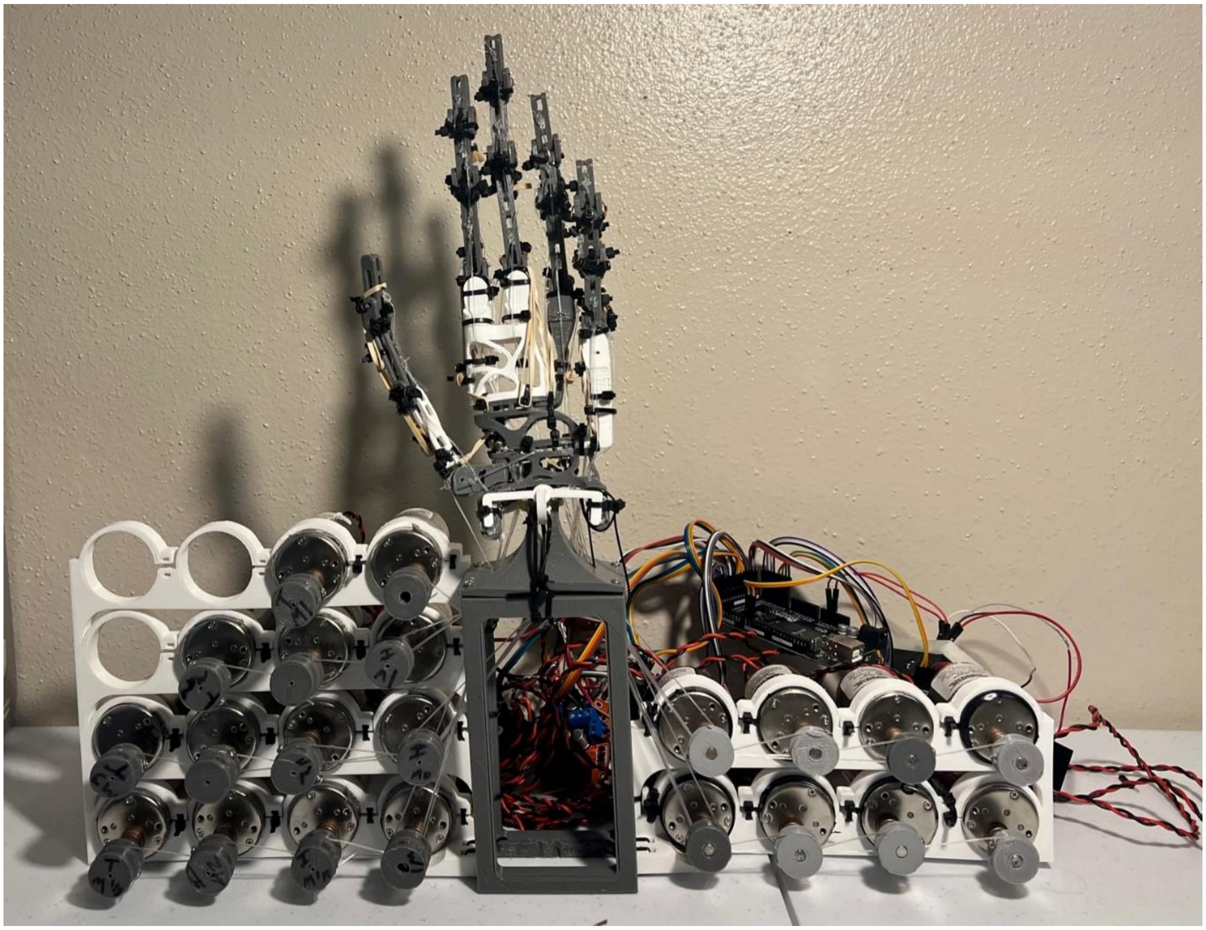


Purpose:

The purpose of the 22 DoF Robotic Hand was to design a mechanical system that was capable of the full dynamic movement of the human hand that was also the same size. One of the most capable research equivalences to this project was the DLR Hand Arm system, from the Institute of Robotics and Mechatronics, German Aerospace Center, with 17-19 DoF in hand portion of the robot (ignoring the wrist). Commercially, the Modular Prosthetic Limb from John Hopkins is the nearest mechanical equivalent with 12 DoC in the hand/wrist.

The focus of the 22 DoF Robotic Hand project was to recreate an equivalent workspace of the human hand while not being confined on actuator location or number of actuators. The purpose of the project was to find what mechanical requirements are necessary to allow for abduction, adduction, circumduction, and individual control of finger joints. Actuators were then predetermined to be later added in either a “forearm space” or an actuator rack beneath the hand.

Design:

The Robotic Hand was originally sketched on paper and then designed through multiple iterations in AutoCad Fusion 360 to be entirely 3D-printable, excluding electronics and cables for actuation. The design is made to be modular with attachment slots for future modifications or sensors. The current design has 52 (28 parts excluding connection pins) and allows for completer articulation and control of each joint. The next iteration will focus on removing the need for pins as well as fitting actuators within the hand itself (See Version 3 for further details on future iteration).

The current design is shown on the next page.

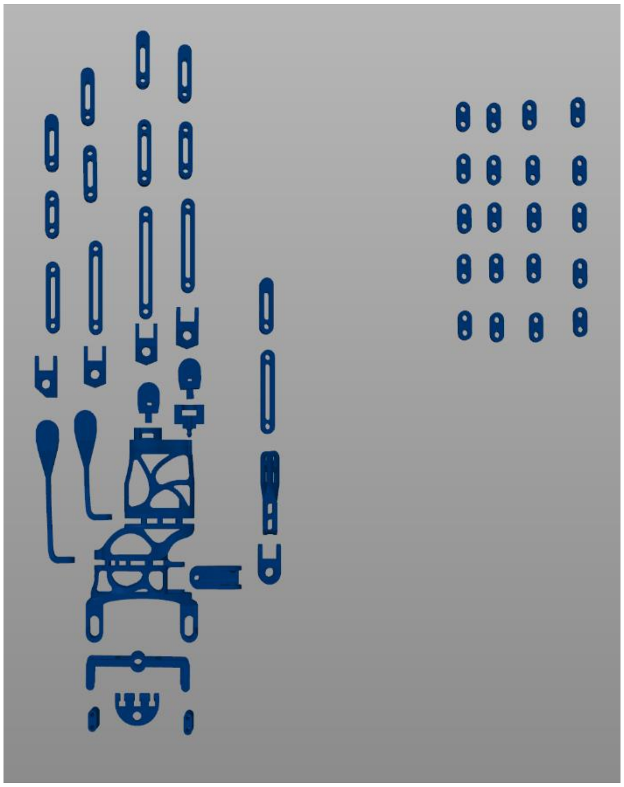
Original Sketches Can be seen in Appendix A.

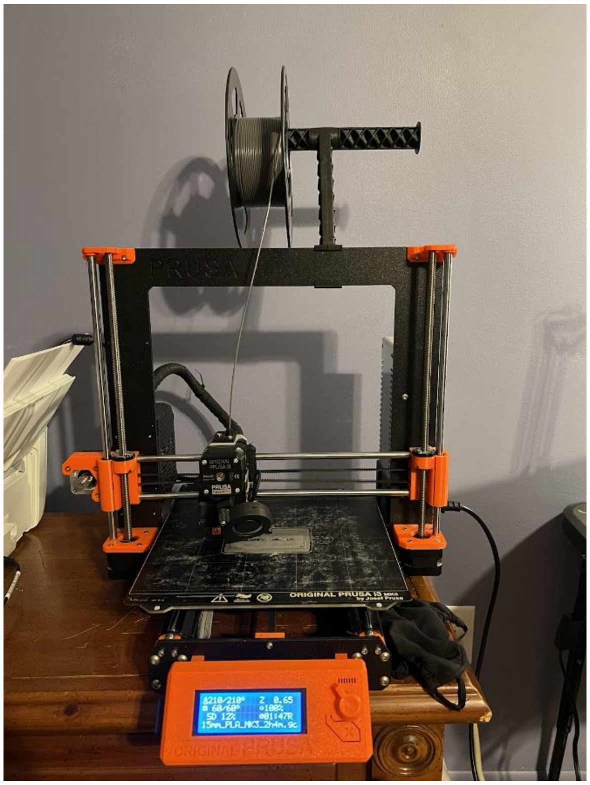
Results:

The Robotic Hand project has gone through 3 prototypes before being put on pause due to funding. The project focused on the mechanical structure needed for articulation without actuator restrictions. In the end, it was discovered that articulation should have a passive tension mechanism for both compliance as well as being able to return to position. Actuator cables should also be more organized in layout and design using guided actuator channels to allow for less stress on parts and smoother actuation. Further, the wrist joint in the hand is one of the most structurally important parts of the hand and emphasis should be made to make this area structurally stable and of high enough strength to support the high-tension forces acting on it. The first three prototypes focused on the mechanical structures needed for articulation without articulation restrictions; therefore, the next version should focus on articulation restriction with the restrictions and observations discovered in earlier prototypes. The goal for the next design is to have all articulation fit in the forearm or the palm of the hand itself while incorporating the design specifications above.

Fabrication:

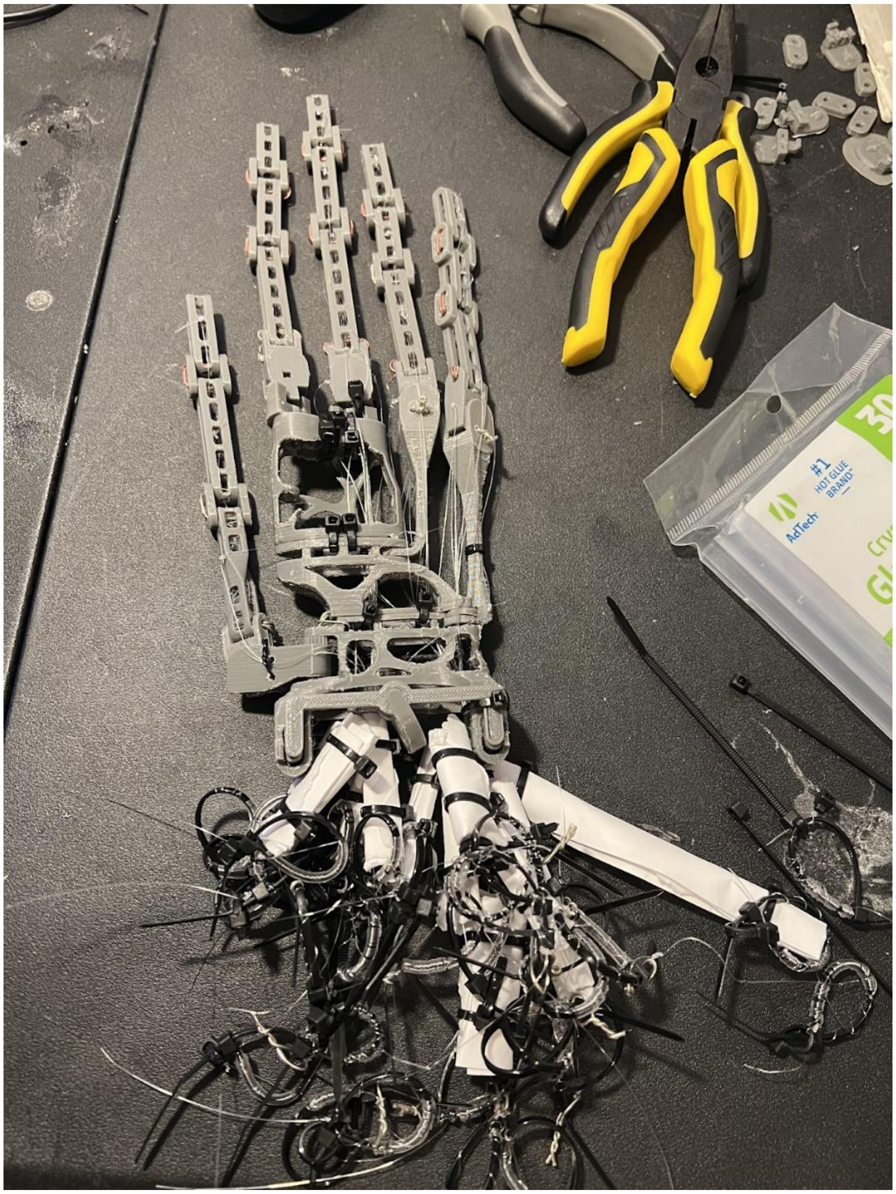
The 3D models of the parts for the Robotic Hand were converted to GCode using PrusaSlicer 2.4 and were then printer using a Prusa i3 Mk3 3D-Printer. An image of the Slicer parts layout and the 3D Printer Setup can be seen below.





Version 1:

After all the 3D Parts were printed, they were then assembled into the V1 Prototype. Version 1 included just the printed-out hand with manual actuation with 10 lb. fishing line. However, this version showed multiple redundancies (with 27 DoF) in the connection joints between the finger and cent structure of the hand. The fishing line also proved to be too weak and kept snapping both the line and parts (as can be seen with missing bridge in the palm structure. Version 2 would focus on removing the 5 redundant DoF as well as improving the strength of the actuator cables.



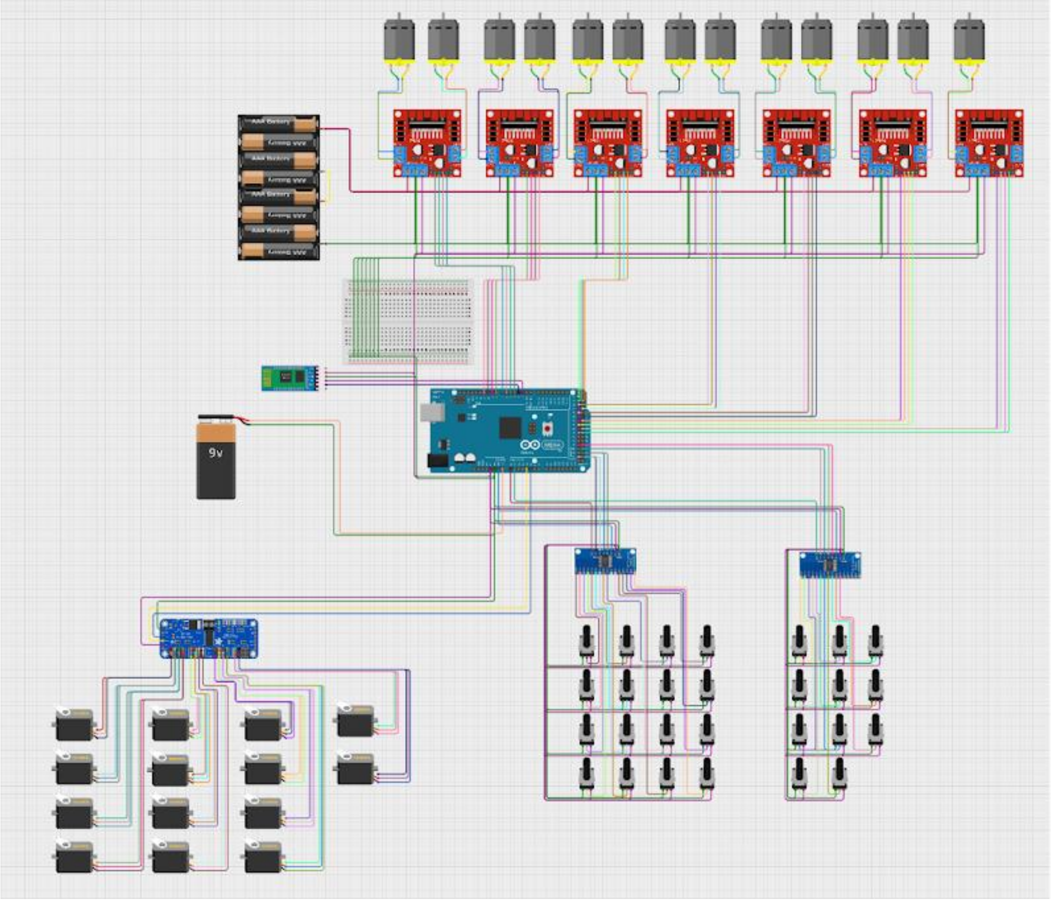
Version 2:

Version 2 is a similar model from version 1, except with the redundant joints removed (making the design 22 DoF). The fishing line was also improved to 50lb fishing line for actuation. The V2 Robotic Hand was also installed into an actuator rack to control all the joints. The model showed that the servo configuration did not have enough passive strength/torque to hold the actuator cables in tension. The tension in the actuator cables also proved to be too much for the 15% infill PLA parts, so version 3 will improve upon part strength where necessary. Also, the tensioning mechanism of having two cables per pulley also was a major source of failure of actuation in the hand, the next version would focus on a passive retuning mechanism for actuation.

Full assembly of Version 2

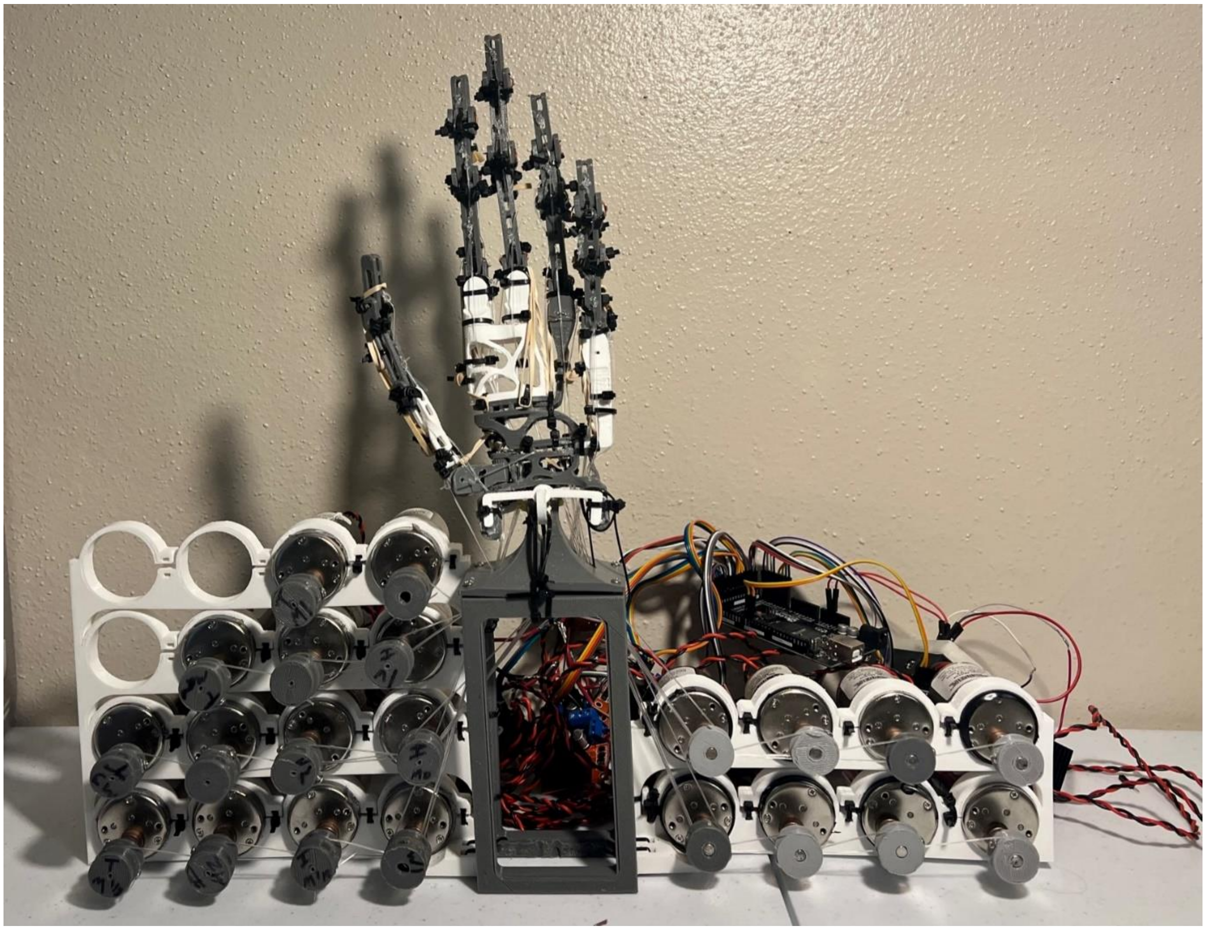
Wiring Diagram for Version 2:

Version 2 is controlled by an Arduino Mega connected to a 16 channel Servo Controller as well as 7 L298N Dual H-Gates for DC Motor control. There are also two 16 channel multiplexers connected to potentiometers to use a future positioning system for kinematics. However, the current design is hard-coded inputs until the controller system is operational.

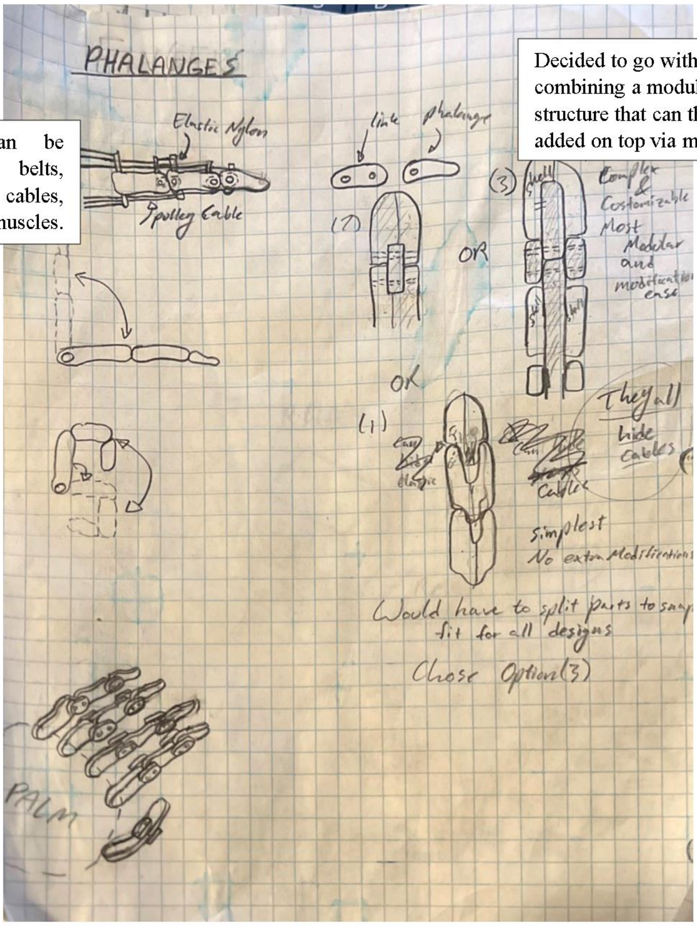


Version 3 (Current Design):

Version 3 uses the same base structure and mounting mechanisms as version 2. However, parts that failed in version 2 have been replaced with the higher density infill white parts for a higher material strength as shown below. The actuator racks were also replaced with a stronger motor mount system that offers more stability as well as strength to support against the tension in the actuator cables. The servo system was also fully converted to DC motors, allowing for full articulation control. Rubber bands were also installed as a passive returning tension mechanism for articulation, halving the number of cables in tension for the robotic hand. This design is the current design and can run a basic hard-coded diagnoses movement, articulating each joint separately and in order. However, there is still a strength issue in the wrist mounting mechanism, the part is under too much stress and snaps under the forces (hence the zip tie holding the wrist in position. Unfortunately, funding for the project ran out so the project is put on hold for the moment. Version 4 will focus on redesigning the hand to have routed channels for the articulation cables and passive tension returning system, to help reduce stress on parts. The next version will also focus on redesigning the wrist to be more structural stable, as well as focusing on actuator requirements. The first three prototypes focused on the mechanical structures needed for articulation without articulation restrictions; therefore, the next version will focus on articulation restriction with the restrictions and observations discovered in earlier prototypes. The goal for the next design is to have all articulation fit in the forearm or the palm of the hand itself.

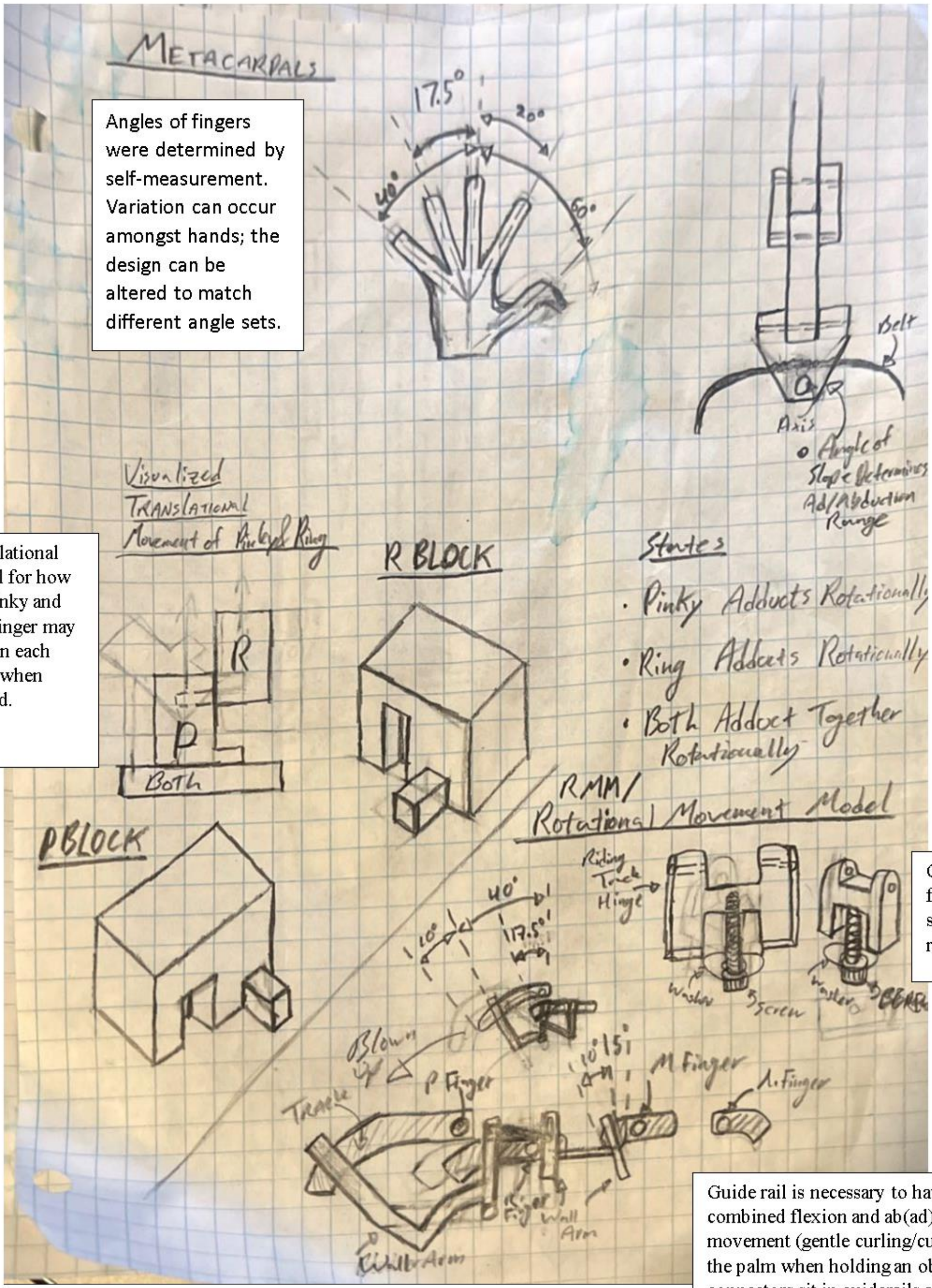


Appendix A: Original design sketches



Phalanges can be actuated via belts, pulleys, TCP cables, or pneumatic muscles.

Decided to go with a combination of design 2 and 3, combining a modular forward design with a “skeleton” structure that can then have an artificial shell or skin be added on top via magnets or some other method.

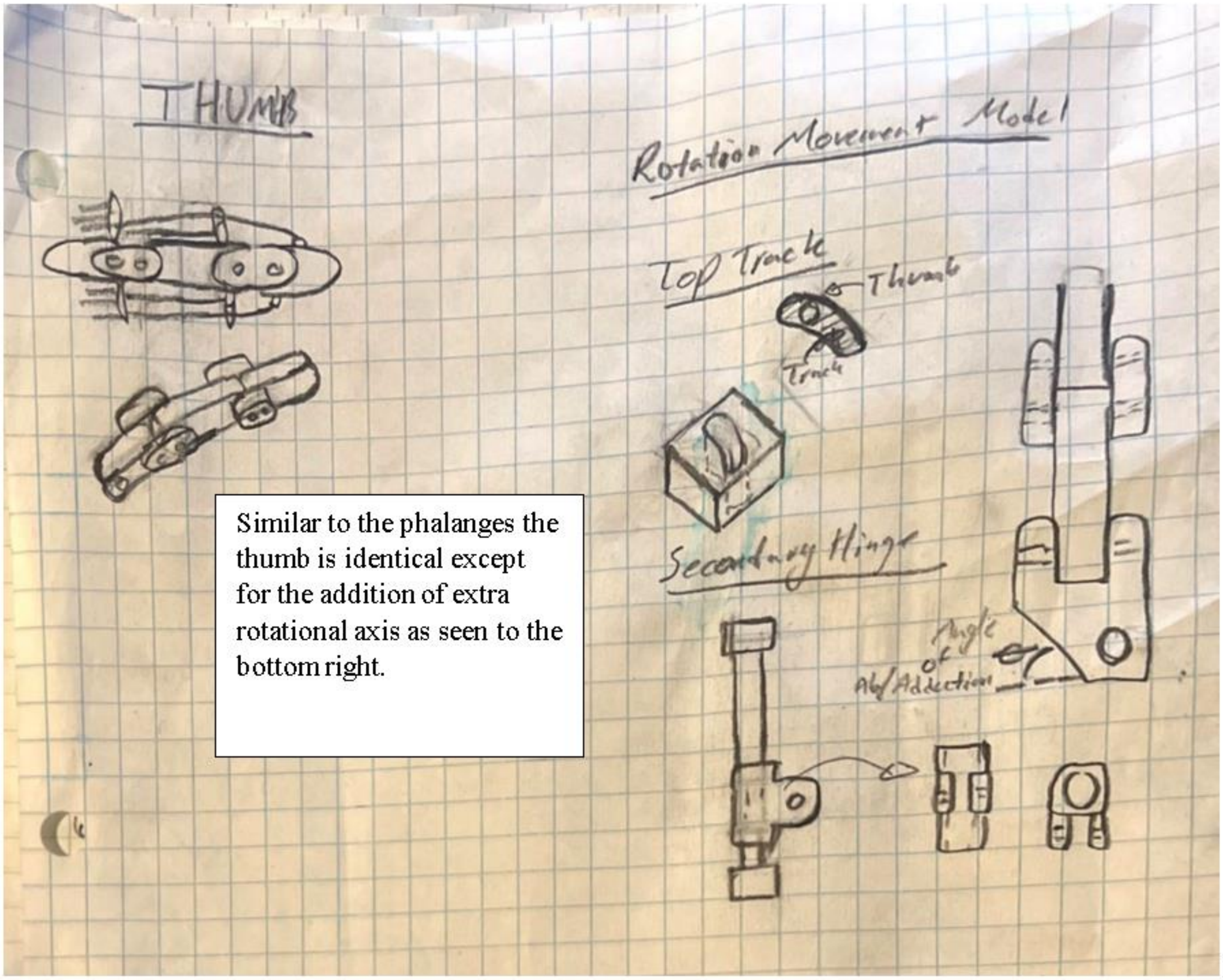


Angles of fingers were determined by self-measurement. Variation can occur amongst hands; the design can be altered to match different angle sets.

Translational model for how the pinky and ring finger may pull on each other when moved.

Connector of finger to palm, sits on guide rail.

Guide rail is necessary to have a combined flexion and ab(ad)duction movement (gentle curling/curving of the palm when holding an object. The connectors sit in guiderails and move lever arms that inhibit or push the other connectors (fingers) to mimic real movement. Mechanically encoded hard stops and linked movement.



Similar to the phalanges the thumb is identical except for the addition of extra rotational axis as seen to the bottom right.

To scale drawing of hand with the phalange models, and the empty space that may house the actuation mechanism of the hand. The empty space will be more defined, given a 3d model, and will be resolved upon assembly.