DARM

Dexterous Anthropomorphic Robot Manipulator
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[PROGRESS REPORT 1]

LINK MECHANISM AND CAD MODEL

Progress Checklist

- [x] ~~Anatomy of the human hand~~
- [x] ~~Mechanics model of the hand~~
- [x] ~~Links and Joints mechanism design~~
- [x] ~~Link mechanism CAD model~~
- [ ] Muscle mechanism design
- [ ] RL control [Direct Torque]
- [ ] Motor selection and modelling
- [ ] Multibody-dynamics analysis
- [ ] CAD model update
- [ ] Stress analysis (FEA) and design
- [ ] Software (ROS)
- [ ] RL Control (Software)

End-of-Design

Anatomy of the Human Hand

[April]

I spent most of April understanding the anatomy of the human hand and wrist. This include learning about the bones (links) that make up the system, the joints - the joint interfaces and the degrees of freedom at each joint, the muscles (actuation system) - origins, insertions and their actions, and ligaments - motion constraint at joints and function as sheats guiding the muscle tendons.

I started writing a detailed report on that as a documentation. Though it's incomplete now, I'll finish it up soon. Link - Anatomy and Mechanics Model of the Human Hand.

Mechanics model of the hand

[May]

I spent the most of May exploring concepts of mechanics models of the different subsystems of the hand - the links, actuation and joints. I created models in SIMULINK to verify the feasibility of the concepts. A couple of things I pre-conceived changed during the process.

The most notable change was with the model of the joints. The initial concept used rolling motion at the inner contact surface of two eccentric cylinders (DIP, PIP joints) or spheres (MCP joints). This represented the real joints with a higher fidelity. But the following issues were prevalent.

- Contacts were extremely difficult to model and simulate by simulation tools. It often gives unexpected results.
- Stemming from the issues with contacts, and rigid body assumptions, modelling ligaments was impossible with SIMULINK.

While the concept itself might be feasible without a model, it will be impossible to design and develop a controller for the system.

The following changes were made to the joint concept:

- DIP and PIP joints were modelled with simple revolute joints. [Fig. 1]
- A universal joint was used to model MCP joints (2-DOF). [Fig. 2]

- Saddle joints (CM joints) were modelled with a modified universal joint allowing for axial rotation, and non-coincident rotation axes for flexion and adduction. [Fig. 3]
- Ligaments were replaced with hard stops acting as motion constraints. [Fig. 4]

A detailed record of the mechanics model for the links, joints and actuation system will be updated in this same document at the end of the Muscle mechanism design phase. Link - [Anatomy and Mechanics Model of the Human Hand](#).

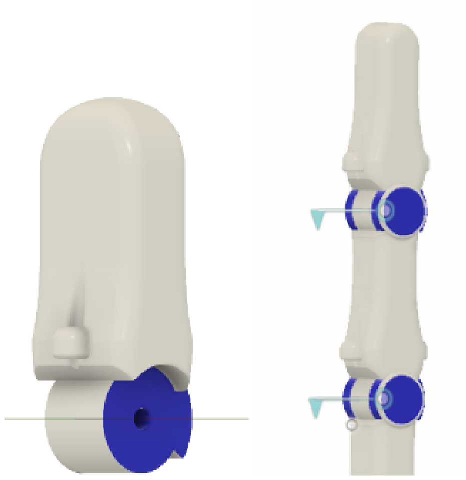

Fig. 1 Revolute Joint at the DIP and PIP Joints

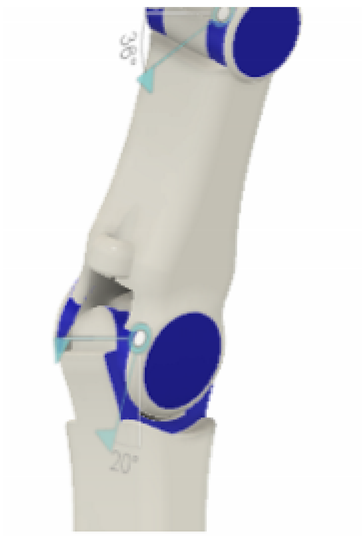

Fig. 2 Universal joint at the MCP Joints

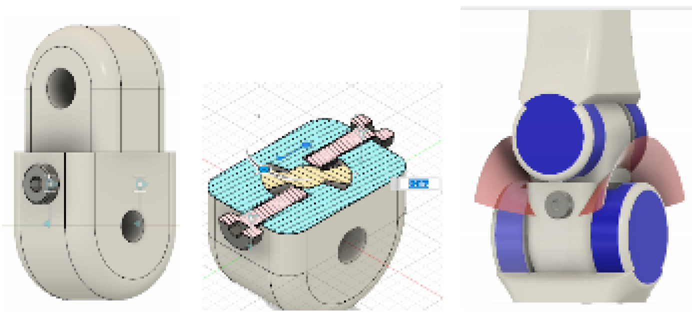

Fig. 3 Saddle Joint of the CM Joints

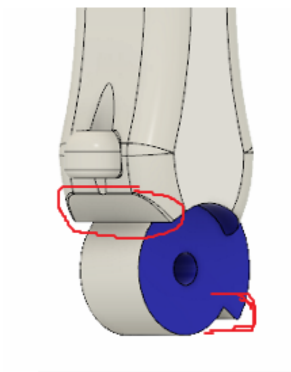

Fig. 4 Hard Stops at all joint interfaces

Links and Joints Mechanism Design

[June]

The design of the links and joints mechanism started in SIMULINK. The objective was to obtain the link lengths and joint origin transforms from a scanned hand reference.

A skeleton mesh obtained from the CT scan of a normal human body was the starting point. The CT scan is from the [Visible Human Project®](#).

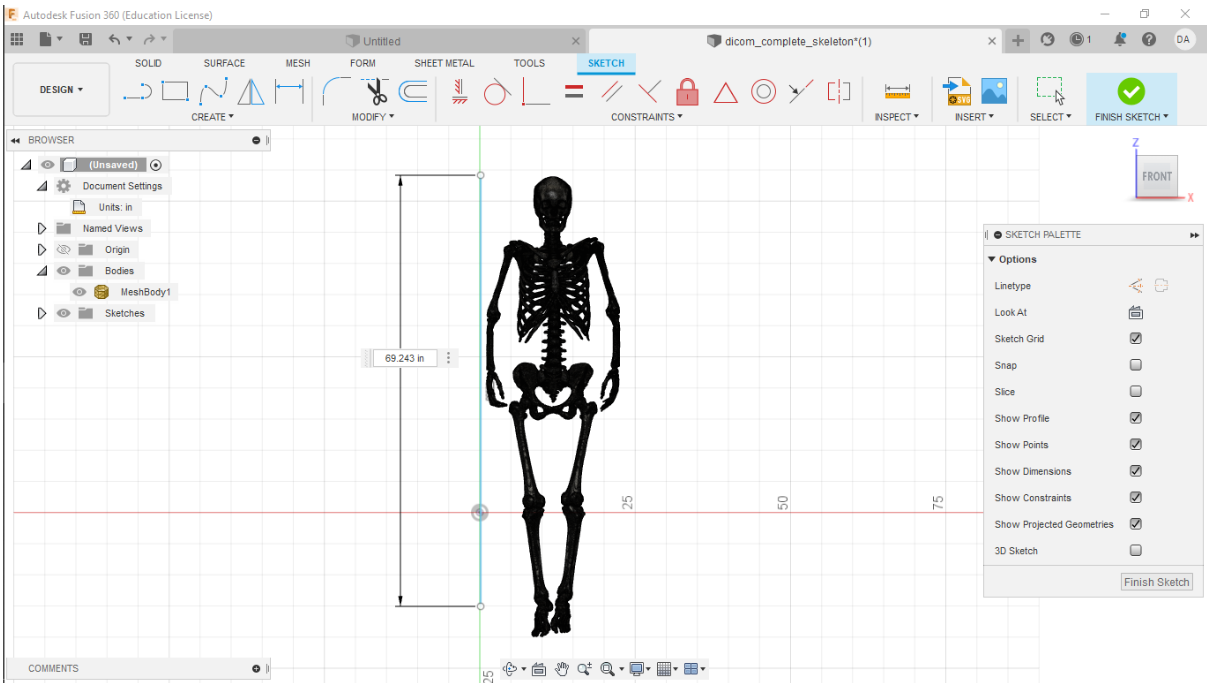

Fig. 5 Mesh from the CT scan of a human body

A section of the ***right hand*** starting from the middle of the forearm to the hand was imported to SIMULINK for analysis and design.

The bone lengths and joint origin transforms (CM and MCP joints) were obtained using this scan as a reference. [Fig. 6]

Models of the joints were also created and the motion of the links was verified in simulation to be similar to that obtainable in the human hand.

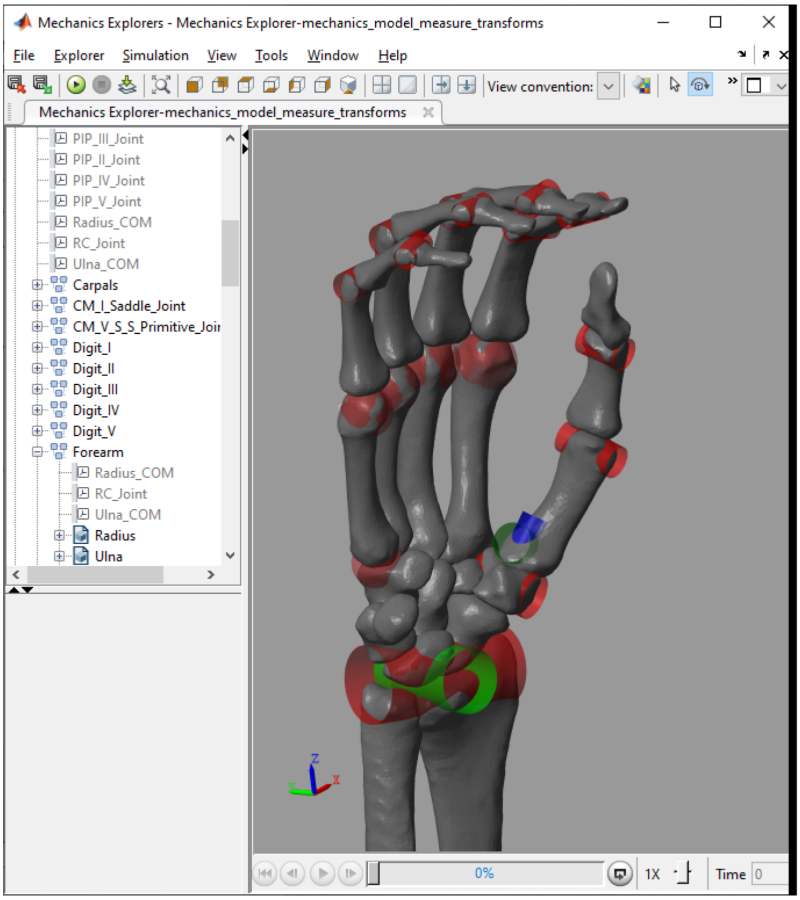

Fig. 6 Hand scan as a reference for link lengths and joint origin transforms

Data from this analysis was exported to Fusion 360 for CAD design of the links and the link mechanism.

Link Mechanism CAD Model

[June, July]

The CAD model of the links and their assembly was created in Fusion 360. Data from the analysis in SIMULINK was used to parameterize each link's length, and the transformations of MCP and CM joint origins from the wrist.

The following images outline the evolution of the design.

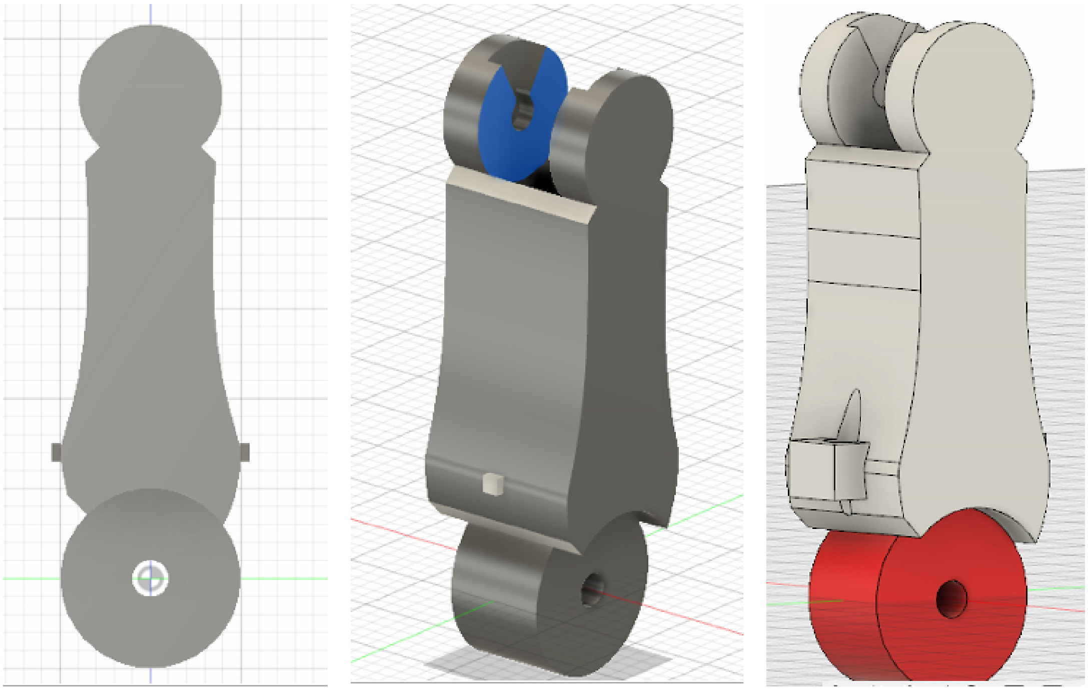

Fig. 7.1 CAD model of the ***Middle Phalanx*** link. Snap locks are used to keep joints in place. Block at the lower end of the link is the insertion point for muscles.

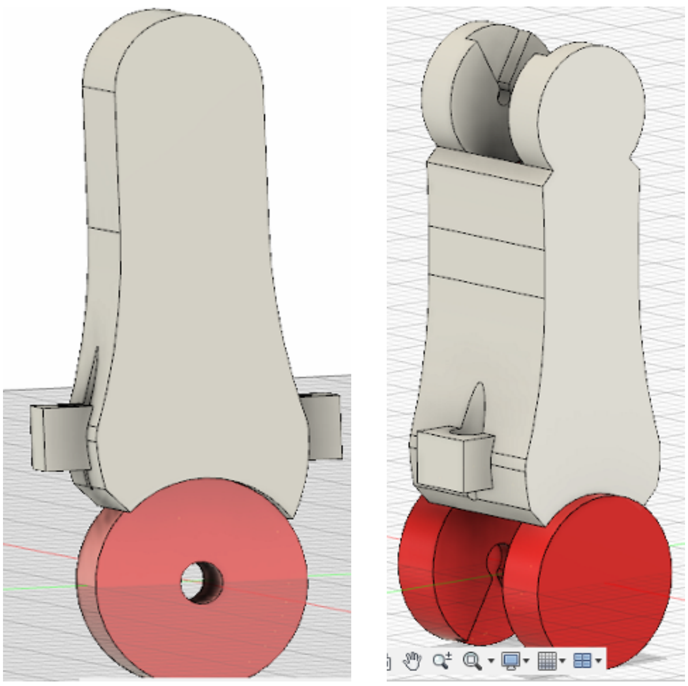

Fig. 7.2 CAD model of the ***Distal Phalanx*** and ***Proximal Phalanx*** links

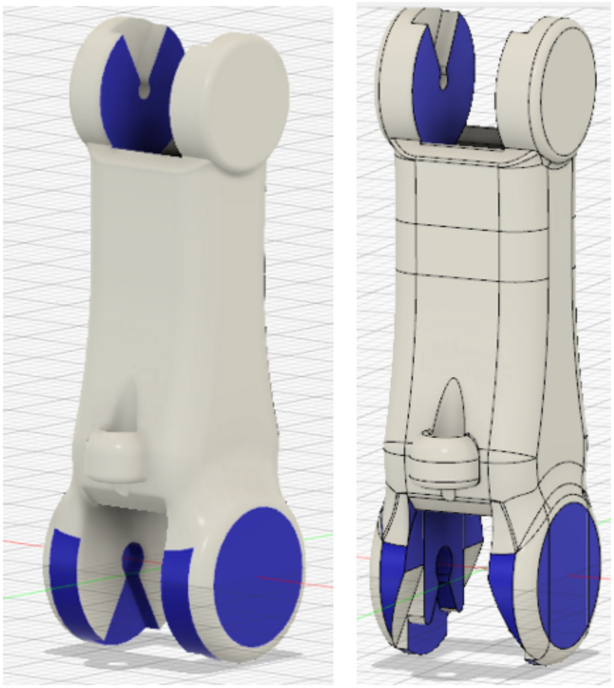

Fig. 7.3 Updated ***Proximal Phalanx*** with allowance for ***adduction/abduction*** motion

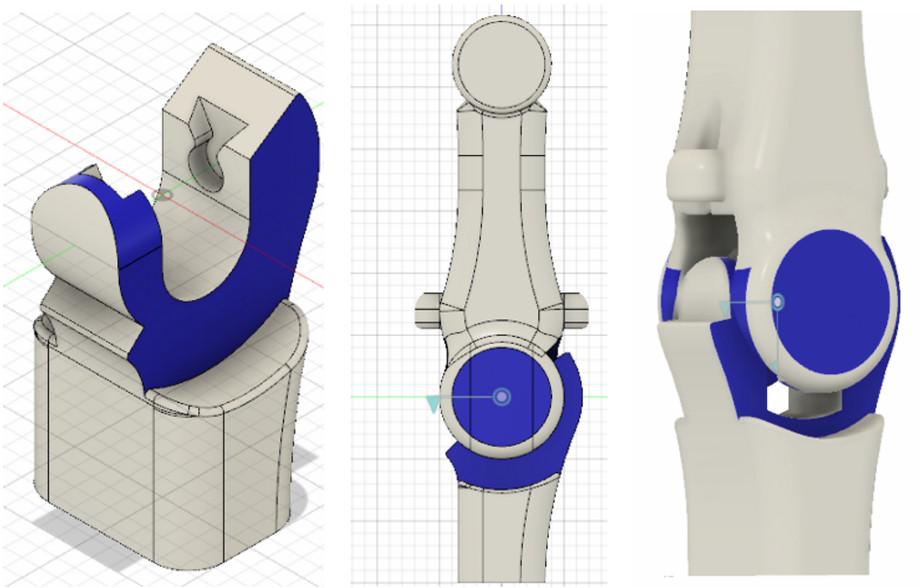

Fig. 7.4 ***Metacarpal Head*** and ***MCP Joint*** Assembly

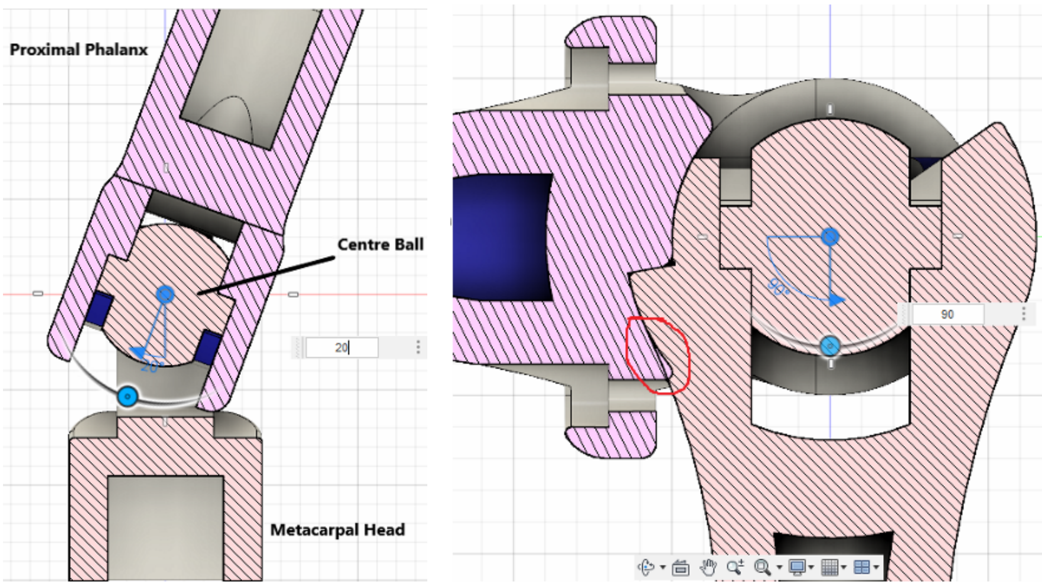

Fig. 7.5 ***Adduction/Abduction*** and ***Flexion/Extension*** motion at the ***MCP Joint.*** Hard stops control the range of motion.

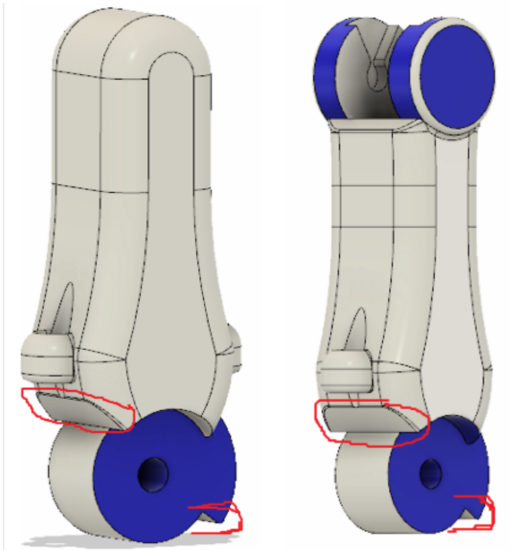

Fig. 7.6 Updated ***Hard Stops*** at ***Distal and Middle Phalanges***

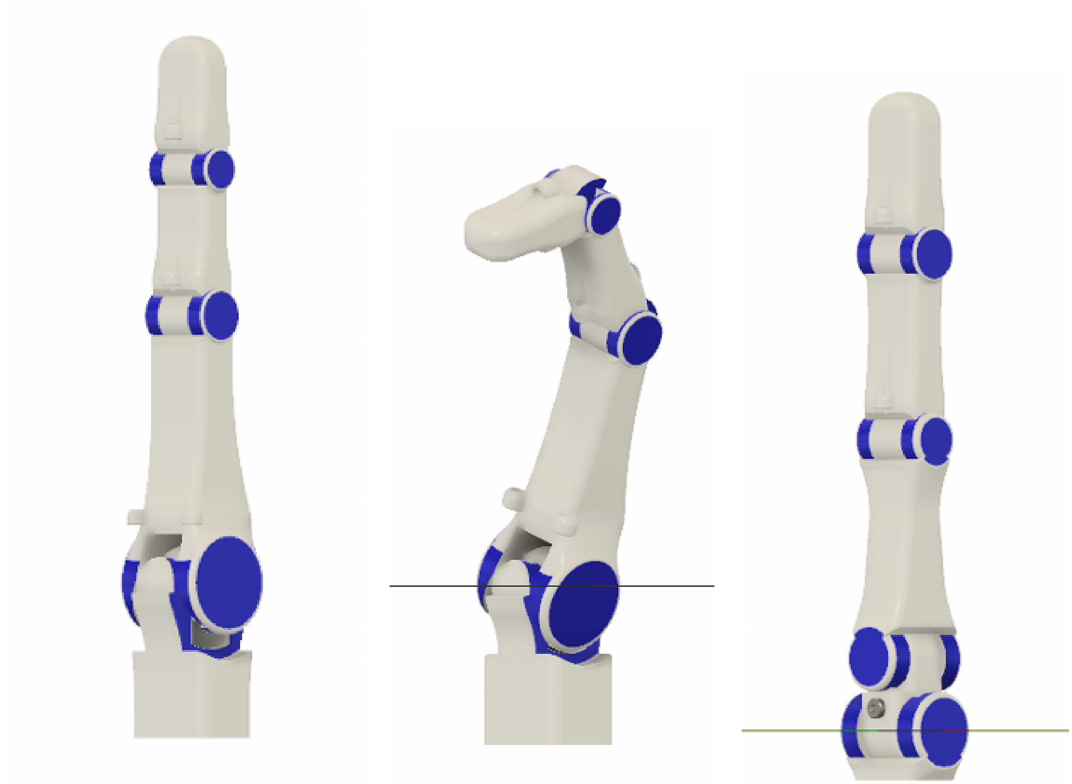

Fig. 7.7 Index and Middle Finger and Thumb Assembly

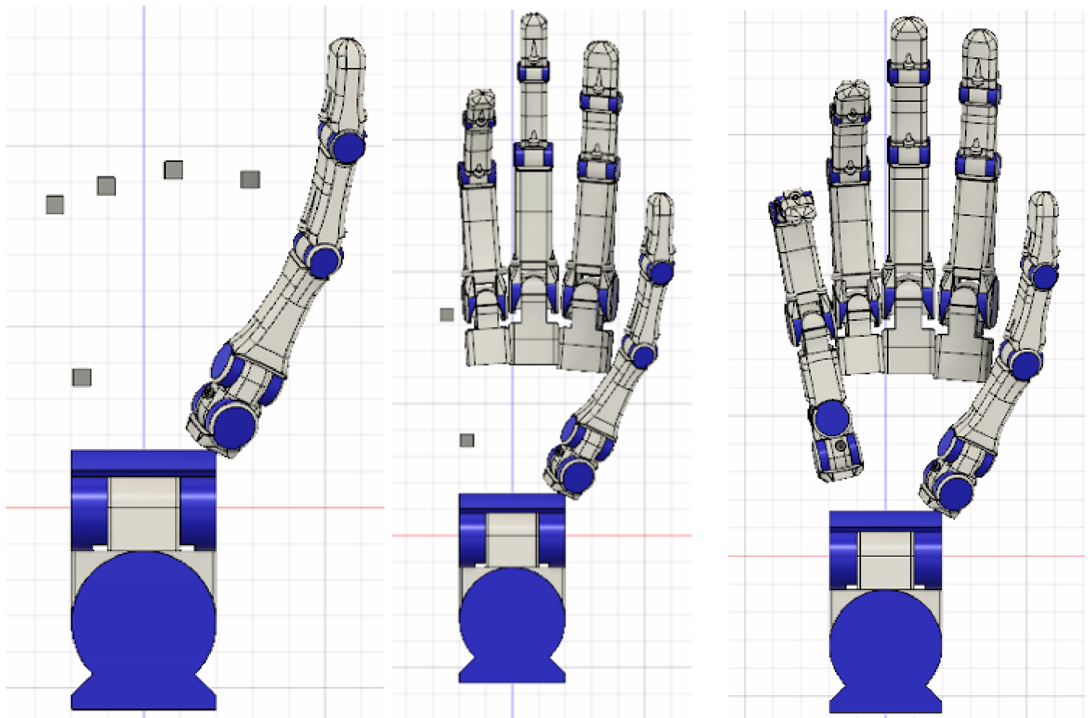

Fig. 7.8 Digits and Wrist Assembly

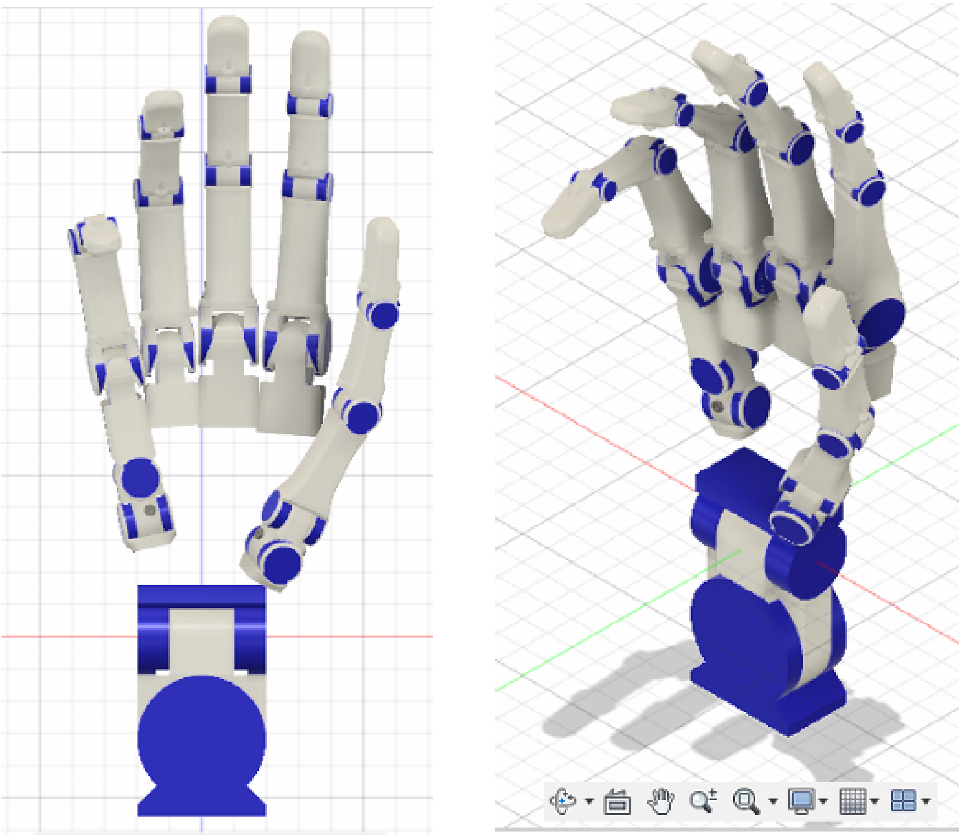

Fig. 7.9 Digits and Wrist Assembly

The next few steps involve the CAD model of the carpals-metacarpals link (occupying the palm region), and the link of the forearm.

Research Papers

I went through a couple of research papers in the process. I've found the following papers where a similar problem was solved very useful:

- Xu, Zhe, et al. "[Design of an anthropomorphic robotic finger system with biomimetic artificial joints.]" 2012 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob). IEEE, 2012.
- Xu, Zhe, Vikash Kumar, and Emanuel Todorov. "[A low-cost and modular, 20-DOF anthropomorphic robotic hand: Design, actuation and modeling.]" 2013 13th IEEE-RAS International Conference on Humanoid Robots (Humanoids). IEEE, 2013.
- Xu, Zhe, and Emanuel Todorov. "[Design of a highly biomimetic anthropomorphic robotic hand towards artificial limb regeneration.]" 2016 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2016.

These papers are from the same group of researchers. But they have done the most beautiful work that I've seen so far.

The adoption of design choices like snap joints which enhance modularity and easier prototyping are from the works in these papers.

They have adopted a pneumatic actuation system for their work. Pneumatic systems are pretty big in size and can render the hand immobile for a typical use-case. I have chosen a motor actuation, where the motors don't actuate the joints directly but via a pulley-tendon mechanism. If this design choice works as expected, it will add the useful feature of mobility to the system.

Next Steps

Once the CAD model of the hand is completed, the next couple of weeks will be spent on Muscle mechanism design. The CAD models will be imported to SIMULINK for the design of the actuation mechanism using a pulley-tendon mechanism.

The design of the actuation mechanism will serve as the basis for

- analysis of the range of torques required at each joint for actuation,
- dynamic force analysis in the system for a detailed design for stress.

Data from the range of torques required for actuation will also feed the motor selection process.