FINGIE

Fully **I**ntegrated **N**europrosthetic **G**rasp **I**nterface and **E**ngine

Outline of Design Principles

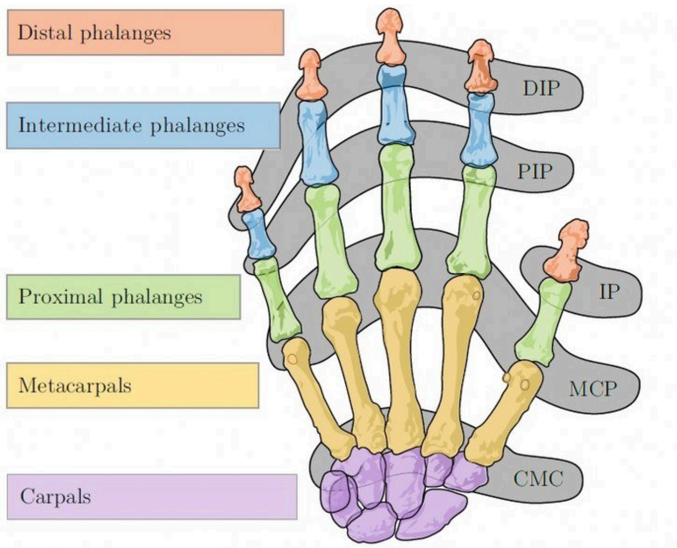
- Joint Actuation Design
  - DIP, PIP Joints
    - Flexion uses tendons running from a tube connected to the middle of the proximal phalanges, carrying a taut cord from the forearm, actuated by servos.
      - Spring-mounted pulleys in the intermediate phalanges enable ‘bulging effect’ for increased high-flexion torque mentioned in biomimetic paper
    - Extension is underactuated, as it uses springs embedded in distal and intermediate phalanges similar to section 3.1.3 in the PUT Hand
      - Could also use extensor hood like the biomimetic approach
  - Finger MCP Joints
    - Two parallel rod-crank mechanisms are used to achieve both degrees of freedom in each joint similar to section 3.2.2 in the gestural hand
      - Instead of the SEA system, use two linear actuators (or) embedded into the metacarpals
      - Unidirectional actuation (actuators moving in the same direction at once) actuates flexion and extension
      - Bidirectional actuation (actuators moving in the opposite direction at once) actuates abduction and adduction
      - Components
        - Use 2 motors with 1:30 gearbox (PUT Hand used one with 1:75, but we have 2 so we can reduce by approx. factor of 2).
        - Thrust bearings on each side of screw connected to shaft of motor
        - Ball bearing linear guide connected to the screw and the finger attachment point
          - Expensive and space constraints - might just use notchines built into hand body (have them poke out of back of hand)
  - Pinky and Ring Finger CMC Joints

        - A double rod-crank mechanism is used to achieve palmar rotation similar to section 3.2.3 in the gestural hand with SEA since there is rarely rigid grasp requirements in this dimension
            - The linear actuator is mounted between the pointer and middle finger metacarpals (which do not move), and connect via rod-crank to the metacarpals of the ring and pinky finger
    - Thumb CMC Joint
        - Rotation around the trapezium is achieved through a worm drive embedded parallel to the motor used for palmar rotation in the pointer and middle finger metacarpals, in contact with a spur gear in the thumb metacarpal similar to the method used in the PUT Hand
            - The motor has a 1:298 ratio with an additional 1:20 reduction from the worm gear
        - Adduction and abduction will be performed using a worm gear oriented lengthwise inside the thumb metacarpal and in contact with a spur gear near the bearing bar that comes up from the spur gear used for trapezium rotation. This area can be seen in the palm of the PUT Hand
    - Thumb MCP, IP Joint
        - Both MCP and IP joints are actuated separately, using tendons running from tubes that enter into the middle of the metacarpal and proximal phalanges, respectively
        - Similar to the underactuated design of the digits, there will be springs embedded in the distal and proximal phalanges to enable passive extension
    - Radiocarpal Joint
        - There is a horseshoe-shaped metal piece that connects at the bottom of the U to the forearm and at the top, to the carpals in two locations
            - The locations attached to the hand are responsible for flexion and extension. These locations are mounted to a thin cylindrical servo motor mounted below the
            - The location attached to the forearm is responsible for adduction and abduction. This location is mounted directly to a servo motor.
        - Supination and pronation will be actuated using a forearm- and carpal-mounted flat disc servo motor (to enable minimal cross sectional occupancy in the forearm)
- Forearm Design

- Finger Actuators
  - There are six servo motors used for finger actuation (four used to actuate the digits and two for the thumb)
    - These will be oriented in two revolved groups of three servos, all connected to a central hub that can swivel around the wrist supination/pronation pivot point
    - The hub is connected to the forearm body via two sets of ball bearings (one at front and one at back of body)
  - The tendon sheaths will be mounted via electronic screw port into exterior of the base of the forearm
  - The servos will use a hub-mounted spool to coil the tendon
- Wrist Actuators
  - There are two servo motors used for wrist actuation in the forearm
    - These will be located nearest the wrist, connected via the central hub to the other servo motors
    - The first controls the adduction/abduction movement and the bottom (i.e. closest to the other servos for finger actuation) is connected to the body of the forearm to enable rotary actuation and thus supination/pronation
- Control & Power Units
  - All control (a RPI or Jetson Nano) and Power (Li-ion battery) will be mounted to the back of the forearm, not mounted to the rotary hub
  - To enable easy charging (which is an issue for the OSL as it has to be partially disassembled each time), external charging port will be present on the forearm
  - To enable easy connection to the controller, USB and Ethernet ports will also be accessible externally

- Sensor Array Design
  - Joint Position Feedback
    - Surface Mounted IR sensors using Color Gradient Method used in the gestural hand
      - Can also use rotary resistive encoders similar to the PUT Hand
      - Can also use linear encoders similar to the PUT Hand
  - Fingertip Force Feedback
    - Strain gauge sensors will be embedded under the distal phalange grip
      - Could also use piezoresistive or capacitive force sensors
- Exterior Design
  - Soft Tissues

        - Thenar web should be filled to enable natural feeling grasping like [the biomimetic hand]
        - Joint space should be covered to prevent pinching and tendon (wire) snagging
            - Use Flexible/elastic SLA printing (tried this a couple years ago and it tends to dry out or tear over time) or laser cutting thin rubber sheets
    - Tendons
        - The sheaths will be routed through the void space, starting from the bottom of the forearm and inserted into electronic screw-lockable ports in the phalange bodies
        - All sheaths insert into the proximal phalanges, except the one that inserts into the thumb metacarpal to actuate the MCP joint.
            - The sheath that inserts into the proximal phalange of the thumb will route through a ridge in the top of the thumb metacarpal in order to avoid interference with grip surfaces
    - Palmar Surface
        - To enable flexibility in grasping studies, the palmar surface is designed to be interchangeable with electronic screws holding it in place
        - The two surfaces developed are
            - Flexible resin (SLA printed) to enable high-friction and compliant grip patterns
            - Standard PLA material to enable low-friction and non-compliant grip patterns
        - The grips will be independently located along the pinky and ring finger metacarpals, dependently located along the middle and pointer metacarpals, independently located on the metacarpal of the thumb, and independently located on each section of ventral phalange (along with finger tip caps attached to the grip on the ventral distal phalanges)



Existing Robotic Hand Research

- Mechatronic Design of a Self-Contained Dexterous Robotic Hand for Gestural Communication
    - Uses a lot of SEA (with weird spring connections)
    - Self-contained in hand
    - Weak power, used just for gestures
    - Good anthropomorphic analysis
    - Full DoF
        - Interesting SEA for palmar CMC joints (ring and pinkie finger only). Assuming that this range of motion can be weak
        - Interesting MCP joint for full DoF using double rod-crank mechanism. Need to adapt to make stronger without SEA (figured out with PUT hand linear actuators)
    - IR Color Gradient Method for position sensing (avoids encoders in joints)
- PUT-Hand—Hybrid Industrial and Biomimetic Gripper for Elastic Object Manipulation
    - Not full DoF
        - Interesting worm drive for CMC joint (thumb movement wrapping around palm)
        - Interesting idea to adapt the MCP joint (here is only done in one dimension), but it does use linear actuators
            - Thus, adapt using two linear actuators embedded in palm for each finger, then do same as gestural hand with double rod-crank mechanism
        - Interesting idea for proximal and distal joint underactuated behavior
            - Use tendon (cable) going through, starting at proximal, then use extension springs in bone locations

    - Self-contained in hand
    - Good literature review
    - Suggests I might need to engineer driver boards embedded in hand or forearm
    - Has good hand dimensions
- Design of a Highly Biomimetic Anthropomorphic Robotic Hand towards Artificial Limb Regeneration
    - Highly biomimetic design
    - Interesting approach to having tendon sheaths (can 3d print or laser cut from rubber sheet) to reproduce skin-like behavior. Could use small electronics screws and screw them directly into small holes in 3d print
    - ‘Bulging effect’ from moving pulley points inside finger enables higher torques at bent orientations than straight due to lowered moment arms
        - Suggests we could use a pulley mounted to a spring inside the fingers that replicates this behavior
- Design and Development of a Linkage-Tendon Hybrid Driven Anthropomorphic Robotic Hand
    - Omits abduction and adduction of middle finger for “limited motion in humans” which is false but they don’t seem to have room for the servo
    - Interesting analysis of ‘workspace’ of fingers
    - Almost all linkages happen outside the bounds of the palm/fingers, so it is bulkier than human hands
- Design of the Passive Joints of Underactuated Modular Soft Hands for Fingertip Trajectory Tracking
    - Has a lot of the necessary elastic/kinematic calculations used for the underactuated tendon joints
- RoboRay
- ILDR