Preliminary Literature Review

Robotic Prosthetic Hands

- *Ten guidelines for the design of non-assembly mechanisms: The case of 3D-printed prosthetic hands* [2]
    - This article talks about how 3D printed prosthetic hands could be useful in developing countries, as they would be much more accessible than prosthetic devices that are manufactured, especially if that hand was fully assembled and did not need any post-processing steps. The article explains ten design considerations for additive manufacturing with non-assembly mechanisms, supporting the argument with a design case that resulted in a fully functional prosthetic hand. Only about 5% of the 40 million amputees in developing countries have access to prosthetic devices, so if we were able to make a fully assembled and functional 3D printed hand, it could be useful for this audience, since elimination of post-assembly steps increases the accessibility of these devices. Through the discussion of additive manufacturing techniques and fused deposition modelling, the article lists design considerations that should be followed in order to achieve fully functional non-assembly devices. Some requirements the hand should meet include functioning like a real hand in its ability to grasp, look cosmetically appealing, be low weight and waterproof. The article also discusses the main design and functioning principles behind how the fingers on the hand move, which will be helpful when we design our hand and make sure it functions properly.
- *Dextrous Hands: Human, Prosthetic, and Robotic* [3]
    - This article begins with a discussion of the structure of the human hand, including the musculoskeletal system, range of motion, sensory structures, and dexterity, as well as the commonly used hand-finger grip patterns. While the anatomy of the hand might not be incredibly helpful, gaining a better understanding of the muscles and how they change with different grips will help us allow our hand to behave like a real one. Various types of prosthetic hands are discussed, including passive aesthetic hands, body-powered, and electric-powered hands, with various terminal devices replacing the "hand" part itself, some shaped to look like a hand, while others have more of a hook-type configuration. Various types of robotic hands are also discussed, including clawlike grippers and anthropomorphic hands with fingers and joints. Anthropomorphic hands are designed to perform equivalent to those of the human hand, and the article gives insights into different versions of this type of robotic hand. This information will be helpful for our project, regardless of whether we end up making a prosthetic or robotic hand.

- *A Method for the Control of Multigrasp Myoelectric Prosthetic Hands* [4]
    - This paper discusses testing of a multigrasp myoelectric controller, where 5 nonamputee subjects utilized the controller to command the motion of a virtual prosthesis between random sequences of target hand postures in a series of experimental trials. For comparison purposes, subjects also utilized a data glove to command the motion of the virtual prosthesis for similar sequences of target postures during each trial, since the purpose of the study was to improve the degrees of freedom of a prosthetic hand and increase the grasping capabilities. Information in this paper related to concepts in ME480, as they discussed a control system that used a two-electrode EMG interface as user input, as well as the creation of a finite state model to model the inputs which are indicated by measured EMG at two electrode sites (flexion, extension, co-contraction, and rest). There was a lot of information similar to what we learned in ME331, as the data glove was used to track the movement of the human hand using variable resistance flex sensors attached to a flexible slip-on glove. The article discussed the creation of a data glove and virtual prosthesis, which will be useful to use when we get to the design step.
- *A practical 3D-printed soft robotic prosthetic hand with multi-articulating capabilities* [5]
    - This article discusses the benefits of robotic hands made of 3D printing soft material which incorporates membrane enclosed flexure joints in the finger designs, synergy-based thumb motion and cable-driven actuation system, aiming to improve the mobility and quality of life of upper limb amputees. Requirements that must be taken into account when designing a prosthetic hand include light weight, intrinsic actuation system embedded in the hand structure, robust finger design and compliance, powered thumb for multiple grasping types, and ease of manufacture and personalization. These requirements could be easily met by 3D printing the entire hand from soft material, and then embedding the actuation and control systems into it, using flexure joints (hinges) in the finger, which proved to be successful at grasping a wide range of objects.
- *Biomimetic actuators in prosthetic and rehabilitation applications* [6]
    - Biomimetics attempts to replicate the flexibility of natural structures in engineering structures. In biomedical mechanisms, this focuses on using soft compliant structures, which is analogous to muscle emulation in actuation terms, with the goal of combining the power, accuracy, and endurance of mechanical drives with the safety, controllable compliance, and efficiency of natural muscle. This article discusses the use of pneumatic Muscle Actuators (pMA) in the design of prosthetic hands. The portion explaining the closed loop control system will be helpful to us as we progress through controlling our robotic hand.

- *Affordable 3D-printed tendon prosthetic hands: Expectations and benchmarking questioned* [7]
    - This article discusses how 3D-printing prosthetic limbs provides affordable options for amputees in developing countries, since fused deposition modeling (FDM) printers have allowed enhanced low-cost prosthetic hands. Currently, very few 3D-printed hands allow space for microcontrollers that electrically power the prostheses and allow greater dexterity, by actuating each finger independently. In affordable designs, the motion of the joints in each finger are linked with nylon threads running into sheaths (these are analogous to the tendons in the human hand). This makes assembly and maintenance simple, and this actuation transmission makes it easier for the hand to take the shape of the grasped object. This also allows the motors to be located remotely. The article explains testing methods to analyze the performance of prosthetic hands, including the Southampton Hand Assessment Procedure (SHAP) is a tool to assess the effectiveness of hand prostheses, which is a tool we can consider utilizing in judging our design. By reviewing and evaluating the mechanical design of several prosthetic hands and discussing materials used in these designs, our team has great insight into ways to pursue 3D printing a prototype of our design.

Vaccine/Drug Manufacturing (Biomedical Materials Hazardous to Touch With Actual Hands)

- *Medical Robots for Infectious Diseases: Lessons and Challenges from the COVID-19 Pandemic* [8]
    - Identifies the need for medical robots in mitigating the spread of infectious diseases as well as providing care of a patient who has an infectious disease. The range of possible uses includes: disease prevention, screening, diagnosis, treatment, and home care.
        - Our idea of the robotic hand could be particularly useful for the identified need for medical robots in screening for infectious diseases, because someone could remotely operate a screening exam to test for infectious disease. For example when covid tests first came out and a medical professional had to stick the swab up your nose in full PPE while potentially exposing themselves to the virus, that could be done with a robotic hand instead which was controlled by a professional who is safely far away from the patient.
- *Robots in the Chemical Industry* [9]
    - States useful applications for robots in manufacturing processes. Highlights robots as being useful for manufacturing in the pharmaceutical industry for protecting the integrity of the product and keeping workers safe from potential exposure to

dangerous chemicals. Identifies a challenge for making robots for these industries is they must be extremely precise which in turn makes them more expensive.

- *Arduino Robotic Hand: Survey Paper* [10]
    - Discusses creating a robotic hand with an Arduino, flex controllers, and servos.

Physics/Mechanics of Robotic Hands

- *Underactuation in Space Robotic Hands* [11]
    - This robot claw has a very interesting and effective design. If we are to build a more claw type robotic hand, this is definitely something that we should look into. Relative to the other papers researched, this one has amazing diagrams regarding the geometry of each claw segment in order to maximize the grip strength and surface contact of each individual claw. The paper includes a valuable visual that compares the grasping force of the claw with the provided input torque.
- *Robotic hand developed for both space missions on the International Space Station and commercial applications on the ground* [12]
    - This paper goes into more detail about the more dexterous and practical side of using robot hands in commercial applications as well as in space, this link goes more in depth about the dimensions and inner workings of the robotic hand designed to work in space. Multiple simulations of this robotic hand are run to see the amount of power it takes to grip an object with a certain amount of strength and it functions as a good baseline to work off of in the future.
- *Biomechatronic Design and Control of an Anthropomorphic Artificial Hand for Prosthetic and Robotic Applications* [13]
    - This paper features a more prosthetic type hand design with three fingers (thumb, index, middle). It includes many important values for experimentation like the weight, dimensions, max grip strength at varying parts of the fingers. The time it takes to close and open the fingers is something important to consider as well. CAD models of the production and design process are included so those may be worth looking into too. The schematics, control systems, and equations used to design a prosthetic hand in this paper should most definitely be used in our own calculations.
    - This paper discusses a way to design an artificial hand to mimic the natural motion of the human fingers, which can be applied to prosthetics and robotics. CAD tools were used to obtain a finger model to study the robotic hands kinematics and dynamics(and degrees of freedom). Prosthetic applications of artificial anthropomorphic hands have requirements including cosmetic appearance, the size and weight of the hand, and its embeddable control system. Commercial prosthetic hands are simple flippers with few DOFs and only one actuator able to exert high grasping forces. The control is simply a couple of commands sent by the user control gripper opening and closure. Control

algorithms for more advanced prosthetic hands were discussed, where feedback from electromyographic signals from electrodes applied to the skin over the user's residual muscles allos the prosthetic to change its grasping movement and strength. This paper will be very useful for us, regardless of whether we decide to go with the industrial robotic hand or the prosthetic hand, as it discusses the mechanics and control systems to make an underactuated artificial hand move and grip objects. By studying the basic capabilities and anatomy of the human hand, a control system was developed to allow robotic hands to operate as close to a real human hand as possible.

- *Intelligent Controller Design for Multifunctional Prosthetics Hand* [14]
    - Although this may be a decent bit more complicated than the sources above, it still has it's uses. It includes block diagrams of the PID controller that basically commands the prosthetic hand. There are multiple figures that go more into detail regarding the controller process and how it chooses how the hand moves. This paper has multiple useful equations to compute how the robotic fingers would work as well as transfer functions to validate how well the hand is working in general.
- *Low-cost and open-source anthropomorphic prosthetics hand using linear actuators* [15]
    - While less technical, this paper discusses more about the possible cost cuts of current prosthetics and making them more affordable to people living in developing or less developed countries. This paper still provides diagrams on how the hand would be designed ie: where to put the motors and cables, but the larger focus is on the best ways to keep it cheap and affordable without sacrificing too much quality. There are basic control diagrams to explain the basic function of the hand as well as multiple tables with materials to build the prosthetic hand out of (and their respective costs).

Clutching Mechanism and Hand Movement

- *iGrasp Hand: A Biomimetic Transradial Robotic Hand Prosthesis with a Clutching Mechanism* [16]
    - This article discusses the design of a hand robot. It goes in depth on how the fingers and thumb are made in order to grasp items. It is based on the real mechanisms of an actual hand. A PID controller was used to evaluate the position of the fingers and make sure they were in the correct position. The results of this study were pretty significant. The hand was able to hold objects with many different shapes and sizes. Some of the objects included a golf ball, pool noodle, and credit card. It does not seem as if they tried heavier objects but that can be something we look into.

Design and Control Implementation for Robotic Hands

- *Mechanical Design and Control Issues of a Dexterous Robotic Hand* [1]
    - In this paper from the University of Craiova in Romania, authors Berceanu Cosmin and Tarniţă Daniela discuss design and control issues of robotic hands, previous hand designs, as well as their proposed mechanical and control system design for a new dexterous robotic hand. The vast majority of robotic hand designs have been anthropomorphic, leading to difficulties relating to actuators, sensors, and controllers. Namely, the human hand has 19 degrees of freedom, meaning a robotic hand would need at least 19 actuators to be truly comparable to a human hand. However, the authors of this paper explain that a "simple yet viable solution" is to reduce the number of actuators while retaining functionality. The design presented by Cosmin and Daniela consists of five fingers and palm with six actuators. Five of the actuators are used to power the fingers in flexion or extension and the last is used to rotate the thumb related to the palm. This is advantageous as the hand retains much of its functionality while the amount of actuators and complexity is reduced. The control system for the hand is based in Arduino and utilizes sensors for proximity and force. Overall, many design and control decisions need to be made when considering robotic hands, and one of the most difficult parts is finding the proper balance between representation of the human hand and amount and complexity of actuators, sensors, and controllers.
- *A Soft-Robotic Approach to Anthropomorphic Robotic Hand Dexterity* [17]
    - Published in the peer-reviewed journal IEEE Access, authors Zhou et al discuss the value in utilizing soft robotics anthropomorphic robotic hand design. Soft robotics is a term used to describe the construction of robots using compliant materials. While soft robotic hands tend to be less complicated than more traditional ones, they achieve well in terms of human hand dexterity. Notably, these types of hands were most successful in object grasping exercises. The authors of this paper presented a design with 26 independent degrees of freedom, known as the BCL-26. The BCL-26 achieved high scores in different measures of dexterity, including grasping, thumb dexterity, and in-hand manipulation. The combination of high functionality paired with reduced mechanical complexity is fascinating, and could be very beneficial to pursue in this project depending on the application that is chosen for the design.
- *"Natural" Design prosthetic limb covers* [18]
    - This company provides life-like silicon covers for non-robotic prosthetic limbs. Not only does it give the user a more normal feeling and piece of mind, it is also built with products that can resist damage from UV rays. Originally designed in Berlin with simple molding producers, this company is not utilizing 3D printing to bring these artificial limbs to life.
- *Building Artificial Muscle With Hasel Actuators* [19]

    - This discusses the invention and development of hasel actuators and the science behind them. Hasel actuators work by providing some hydraulic pressure in a soft environment that is able to conform to a new shape due to the pressure difference. Hassle actuators properties are dependent on the voltage applied to the materials and can have more flexible and strain properties when slightly energized. Contienvnelt to us, they are being utilized to build artificial muscle that reacts and tenses based on the voltage and pressure applied to the internals.
- *John Hopkins Prototype Comparison of Upper Limb Prosthetics* [20]
    - This published journal discusses the findings of Johns Hopkins funded research on the development of robotic limbs for amputees, specifically arms. Two prototypes were built size by side, each to conform to different sponsor specifications. In this journal they discuss the pros and cons of each design outcome they encountered and how their research and prototyping has led them to better build a lightweight and user friendly robotic prosthetic for all different types of arm amputees.

Data Glove

- *Data glove with a force sensor* [21]
    - This describes a fairly simple scratch-built data glove, made using a rubber-tipped cotton work glove, and commercially bought strain gauges. It includes exact specifications, which may be mostly useful as reference, and it includes block diagrams which I think will be more useful.
- *3-D hand motion tracking and gesture recognition using a data glove* [22]
    - This paper describes a design for a data glove that uses 3-axis accelerometers to read and measure hand motions. The paper discusses the problems with force-sensor based data gloves, like the one above, as well as the difference between data gloves that use video tracking, and data gloves that use motion sensors like accelerometer or gyroscope sensors.