A. SIGNIFICANCE

Lower limb amputations(LLA) occur at the foot or more proximal, and upper limb amputations(ULA) occur at the wrist or more proximal. In the United States, It's estimated that about 158,000 people have undergone an amputation of upper or lower limb each year on average [3]. About 65% of all amputations are constituted by LLA with 38% are major, and 35% of all amputation cases are constituted by ULA with 8% are major [2]. In our project, we mainly focus on the loss of upper limb or the dysfunction of hands.

The approximate number of people living with limb loss is vast in the United States, and this number is increasing each year as well. Based on the research results reported in [2], there are 1.7 million people in the United States living with limb loss, and 50,000 to 100,000 new amputees occur per year. Moreover, the total number of amputations are estimated to increase from 1.6 million in 2005 to 3.6 million individuals by 2050 in the United States [3].

The incidence of limb amputations and limb deficiency can be caused by many various reasons, including trauma, malignancy, vascular disease, congenital deformities, birth anomalies, and Carpal tunnel syndrome [3]. The consequences of hand amputation or losses can severely impair not only the patient's emotional quality of life but also the functionality of their everyday life, including daily living activities, body structure and functions.

In recent years, a new type of ULP(upper limb prostheses) has emerged, commonly referred to as "bionic" prosthetic hands, as their design is based on multi-articulating fingers that allows the users to perform multiple grip patterns and gestures so also known as multi-articulating hand prostheses (M-AHPs). However, the price for this type of bionic prosthetic hands are expensive, normally ranging from 10,000 to 70,000 [5]. Due to the high cost of bionic prosthetic hands available in the market, we are motivated to design and produce a more cost effective and affordable 3D printed based prosthetic hand grasper, with the hope of allowing patients with limb loss to restore from most of daily living activities like normal hands.

B. INNOVATION

Existing solutions to upper limb loss include various hand prosthetics systems ranging from no actuation (silicone prosthesis) to fully automated robotic prosthetic devices (i-Limb Access) where each device on the spectrum has its setbacks [6]. The non-actuated simple prosthetic models are highly affordable and accessible; however, they lack any actuation and feedback so essential to replicate the amputated limb purpose [7]. On the other hand, high-end robotic actuated hand prosthetic systems are extremely complex, require prior controls knowledge for proper usage, and carry an astronomical price that most amputees are not able to afford [8,9].

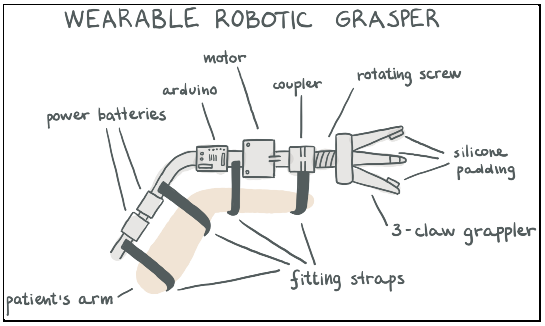
The design compromise is difficult to achieve due to high cost and high complexity of the actuation electronics and preferability of implementing finger mobility through actuation, sensing, and material mobility [10]. Previous work in the field of upper limb prosthetics has demonstrated the need for an affordable robotic system that carries similar functionality to the hand. Invention of such devices will boost the prosthetic industry and bring in more customers due to its affordability, user-friendly interface and completion of hand-dedicated tasks [11].

To address the current state of the art challenges, the group's focus was designing a cost-effective actuated hand-compensating system that provides haptic feedback. The robotic grasper fulfilled the purpose of an amputated hand with its fingers securely grabbing objects while being a relatively simple, affordable system. Cost efficiency was achieved through usage of simple electronics, such as Arduino, force sensor, and EMG sensor - components enough to implement a grabbing motion mechanism with haptic feedback [12]. 3D-printing the rest of the physical components proved to be highly cost efficient while allowing the design to be modeled according to the group's needs [13]. Furthermore, fabric used for attaching the system to the amputee's arm carried a low price and delivered the purpose of securing the system on a human body.

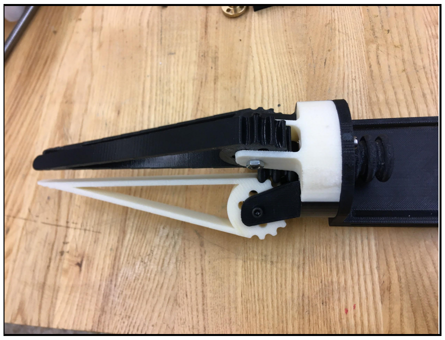
Additionally, the design introduced haptic feedback to the system that allowed the user to assess the force applied on the object by the grasping fingers. From related work, it was found that more than 70% of amputees that use prosthetic devices prefer to determine how much force is applied to the object [14]. A simple force/vibration sensor mechanism was implemented that was cost effective and provided feedback to the user. This method allowed the user to experience vibration on the spot of the sensor when a force threshold was exceeded. This haptic feedback provided the user with necessary information to handle the object carefully in accordance with the force sensor reading [15].

All in all, based on the two constraints of the design consideration, affordability and user feedback, the group came up with a hand grasper design that implemented a force sensing component with a 3D printed 3-finger grasping mechanism.

C. APPROACH



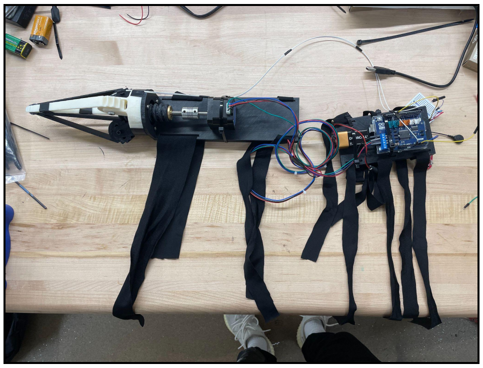
Design Philosophy. The main design drivers for this device were mobility, ease of manufacturing, simplicity, and low cost. The robotic hand must be accessible to a person with few economic resources (college students fit well into this demographic) and assembly must be simple, requiring either intuition or very simple instruction to create. Most of the complex components, those used in the end effector, base, and driving mechanism are designed with low-tolerance printing in mind, that is, ensuring the mechanism will operate when imperfection in the building process due to low-skill of the user or inexpensive additive manufacturing systems used. To keep the project simple, very few parts were used for the device as weight and cost-saving and also simplifying the system. Another design decision addressing simplicity was the use of a motor-leadscrew actuation method as it is simple to assemble and repair. Some drawbacks observed arising from the design decisions taken will be discussed in the last section of this report. The entire system can be divided into: end effector assembly, actuation assembly, and the electronics and controls circuit.



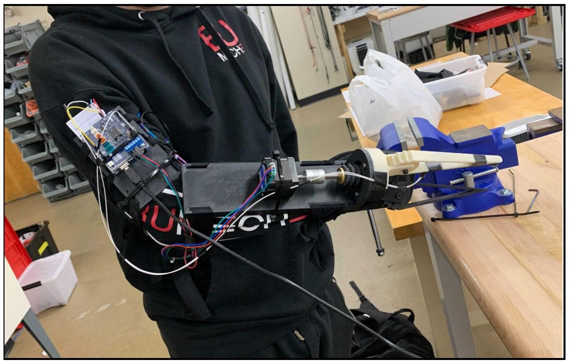
End Effector. We decided on a general end-effector design that consists of a rigid skeleton, optimized for the Stratasys FDM PC-ABS 3D printer, with a geared base that would interface with the actuation mechanism. For force feedback, a force-sensitive resistor (FSR) sensor is attached to the tip of a claw on the end effector. With the data provided by the FSR, the control, and therefore, the user knows when the robot is grasping an object. For weight saving, the rigid frame is hollow and the infill for the printer settings was set to low. The three end effector claws are hinged by holders spaced one hundred twenty degrees.

Actuation. Using high tolerance designs has the advantage of saving in cost but can sometimes introduce obstacles to overcome or constraints that limit certain aspects of the design. Expecting high friction on the printed mechanism, it was decided that a 12V stepper motor would be at the powerplant for the driving mechanism. A coupler transferred the torque from the motor to a lead screw that pushed a nut forward and backward depending on the motor rotation direction. The component that interfaces with the claw gears is connected to the leadscrew nut by heat-welding them using a soldering iron at 350 degrees Fahrenheit. The completed mechanism is able to open and close the end effector by using the base to align the components and join both the end effector and actuator assemblies.

Electronics. The electronics include sensors, batteries, and microcontrollers. For the “brains” of the system, we used an Arduino UNO and a motor shield to guard the Arduino from overcurrent due to the dual 9V battery required to drive the stepper motor. The Arduino is mounted in the main section of the device (which also holds the actuation assembly and mounts to the patient's forearm) while the battery bay has its own platform on the shoulder of the user. The sensors and feedback circuit are comprised of the end effector's FSR for force control, an electromyography (EMG) sensor used to activate the device using the user's muscle electrical signals, and a vibration motor that will provide tactile feedback (to some extent [very limited one]) to the user.



Controls. Keeping in line with the simple goals of the system, the control system was also not developed to be too complicated. The control goals are to read the user's intent (EMG signal from arm muscle) to activate the robotic arm, and activate a motor sequence that will close the end effector until the FSR passes a force threshold or the claws reach the maximum closed state. Activated again by the EMG, the process will reverse and the motor will turn in the opposite direction, opening the end effector until it reaches its maximum open state. In parallel, the vibration motor will rumble when the FSR detects it is holding an object when closing the end effector so that the user does not have to have a view of the robotic arm to know the state of the gripping action.



Tests. The system was stressed to reveal any and all success and failure conditions. Grasping several soft and hard heavy and light objects was attempted. The high friction from the tolerances on the manufacturing process were offset by the shear power of the 12V stepper and it became a nonissue when actuating. The gripper can successfully retain small soft objects but cannot carry a particularly large load as the claws are too long and there is severe backlash on the geared base (due to the high tolerance manufacturing strategy).

Results, Challenges, and Future Work. Even if the system developed served as a good concept to explore, our implementation was far from imperfect (if even actually functional). Several roadblocks and time constraints cause the system's full implementation plans to be cut short. Manufacturing and design of a functional mechanism that can be accessed by anyone and produced cheaply and easily was successfully proven. The implementation of the electronics and controls, however, was not as successful, unfortunately. The FSR sensor used had a very limiting response curve due to its very low quality, this made force sensing unreliable at times. The EMG sensor was not free of fault either. The quality was poor and heavy processing of the incoming data was needed to activate the system as much noise was common. Through the project, though limited in final functionality, many lessons were learned about prosthetic design. The hard nature of the components and materials made it uncomfortable to use when mounted. A next generation design would seek to integrate soft materials wherever there is interface with the user. The previous point of comfort as well as low energy storage in the batteries meant that the device, even if fully functional, could only operate for a limited amount of time before having to replace the batteries. An improvement in this front could be using a less demanding power plant for the actuation mechanism. A 12V motor was chosen because it was accessible and provided torque overhead to overcome the forces of friction that arise from misalignment and low tolerance printed parts. Looking into electropneumatics could be a step in the right direction for weight reduction. Finally, the most pressing improvement lies on the end effector itself. The designed claws do not mimic at all real human hands and thus their use in day-to-day activities. Grasping objects in a human-like manner is impractical and sometimes close to impossible (taking opening a door and grabbing a can of soda as an example). A complete redesign of the claws is in order first and foremost if this model is to be improved upon as future work.

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