ECE 44x
Senior Design

Team 16
Neural Prosthetic Hand

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Design Impact Statement

1.0 Public Health, Safety, and Welfare Impacts

From a research conducted by Johns Hopkins University, it was found that while prosthetic limbs improves the quality of life for amputees, it was also reported that a prosthetic without any kind of feedback system makes it difficult to use during their daily lives, since they have no way to gauge the how much pressure they are exerting when using the prosthetic [1].

A common way to produce prostheses for children is to 3D print them. This allows for customization of the hand to give the children something special that they will enjoy and feel happy wearing. Some designs even include Iron Man hands [2]. This can lead to improved mental health among young amputees.

2.0 Cultural and Social Impacts

A cultural impact of our 3D printed hand comes from the use of PLA. PLA is a 3D printing material made using corn. Corn is a staple food for many people around the world and now that food source is being used to make plastic. One source pointed out that this brings up the ethical question of should corn be used to make plastic or be sent to feed people who are going hungry around the world [3]. The PLA that is made from corn will likely be disposed of as trash instead of recycled (covered more in the next section) which will lead to more plastic waste. The question then becomes, how many people could you have fed with the same amount of corn that was made into this same plastic waste?

3.0 Environmental Impacts

The biggest environmental impact of our project is that it promotes the use of 3D printed prosthetics but does not cover the proper disposal of these prosthetics when the user has grown out of them or designed a new one. All the plastic used can then be recycled. The problem is that most people don't know you cannot put PLA (the material we used) into a regular recycling bin. Recycled plastics are weighed to separate them into different types and PLA, a plant based plastic, ends up combined with PET plastics which reduces the quality of the PET that is resold [4].

4.0 Economic Factors

A major economic impact of our project is that it will lower the costs of having a prosthetic. An upper limb prosthesis can cost anywhere from $3,000 to $30,000 [5]. Part of the reason for this high cost is the parts that are used to build the prosthetic. In our case, we used 3D printed materials and lower cost electronics to make our hand cost less than $800. Another factor that lowers the cost of our hand was the use of surface electrodes.

Project Timeline

Main Goal: This project will be to create a prosthetic hand that responds to an Electromyography (EMG) sensor's recording. The goal is to create a hand that will work with ongoing research in the Information Processing Group at OSU. The project strives to create a hand that is capable of grasping objects, carrying weights, and has the ability to respond to EMG with movements.

Fall term

Timeline: Start—Oct. 5, 2020 End—Jan. 30, 2021

Tasks:

1. Block Division and assigning tasks (Group)
    a. Determine the number of group members (2 or 3)
    b. Make Block diagram with all components
        i. Individual
        ii. Group
    c. Determine the individual responsibilities for each block
        i. Which block has priority

    Timeline: Start—Oct. 5, 2020 End—Nov. 5, 2020

2. Build the Hand (Sienna)
    a. 3D print molds and parts from design
    b. Casting the molds with silicone
    c. Order the parts - (shafts, screws, nuts, silicone, tendon? filament)
    d. Motors
    e. Wires
    f. Pressure sensor
        i. Test each individually first
    g. Accelerometer
        i. For orientation
    h. EMG sensors?
    i. LED
    j. Camera and Raspberry Pi?
        i. For future use

    Timeline: Start—Oct. 19, 2020 End—Nov. 23, 2020

3. Initial testing of what we have (Lindsey)
    a. Test pressure sensors (receiving)

    b. Test accelerometer
    c. Test EMG reading, translating, and transmitting

Timeline: Start—Nov. 5, 2020 End—Dec. 11, 2020

4. Requirements finalized and approved by project partner (Group)
   Timeline: End—Week 8

5. Have final project partner approved block diagrams and Project Charter. Have one or more blocks of your system design 'done' (Physical Implementation) - (Group)
   Timeline: End—Week 10

6. PCB (Sienna)
    a. Power Calculations
        i. in/out
        ii. Pressure sensors
        iii. Accelerometer
        iv. Motors
    b. Amplifiers for EMG?
        i. Homemade vs bought (accuracy issues for individual finger control)
    c. Motor driver
    d. LED indicator
    e. On/off switch
    f. Make it on Eagle
    g. Send design for manufacturing

   Timeline: Start—Dec. 11, 2020 End—Jan. 30, 2021

Winter and Spring term

Timeline: Start—Jan. 4, 2021 End—Apr. 12, 2021

Tasks:

1. Block 1 (checkoff Week 13)
    a. Lindsey - work on the sensing block
        i. Accelerometer transmitting orientation in space
        ii. Pressure sensors registering when pressure is applied
    b. Sienna - work on the EMG signal transmission block
        i. Should have already be able to read from the sensor (Fall term)
        ii. Work with current research EMG sensor board and start translating EMG signals with the controller

   Timeline: Start—Jan. 4, 2021 End—Jan. 18, 2020

2. Requirements Lock (Reminder)
   Timeline: End—Week 15

3. Block 2 (checkoff Week 16)
   a. Lindsey - power supply (may need to do over winter break so Sienna can have it for PCB)
      i. Calculate input voltages and currents to determine the appropriate capacity of the battery needed for the system.
   b. Sienna - Calculation of the finger positions based on motor steps
      i. Research motor encoder and how to calculate positions based on number of steps counted by the encoder.

   Timeline: Start—Nov. 23, 2020 End—Dec. 11, 2020

4. Block 3 (checkoff Week 19)
   a. Lindsey - work on decoder block
      i. Integrate with IPG code and test out usable parts. Interface with MuJoCo if needed/desired.
   b. Sienna - work on the controller/code block
      i. Integrate all existing code into one program and make any adjustments necessary to work with the controller of the system.

   Timeline: Start—Dec. 11, 2020 End—Mar. 12, 2021

5. System Review 1 & 2 (Starts Week 20) - (Group)
   a. Combine whole system and start testing
   b. 8 out of 12 engineering requirements done for the first system review (By March 12th). Finish the rest of the engineering requirements for the final system review (March 26th).
      i. Carry object
      ii. Cheap
      iii. Current research
      iv. Duration
      v. All power supplies in the system must be at least 65% efficient
      vi. The final system must contain two of the following: a student designed PCB, a custom Android/PC/Cloud application, significant utilization of a specialized software required by the project
      vii. The project must meet the required 'Work-level' of 56
      viii. The system may not include a breadboard
      ix. Individual finger control
      x. Natural hand movement

xi. Usability
xii. Responsiveness

Timeline: Start—Mar. 8, 2021 End— Apr. 12, 2021

6. Have a good complete draft of the project poster.
   Timeline: End—Week 20

7. Have the project closeout packet drafted
   Timeline: End—Week 24

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	Fall Term WEEKS 1	2	3	4	5	6	7	8	9	10	11
Project Design															
Block and Task Division	All	10/5/20	11/5/20	30											
Requirements Creation	All	10/8/20	11/26/20	48											
Block Diagrams	All	10/29/20	12/3/20	34											
Build First Hand	Sienna	10/19/20	11/23/20	34											
Initial Sensor Testing	Lindsey	11/5/20	12/11/20	36											

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	Winter Term WEEKS 1	2	3	4	5	6	7	8	9	10	11
Block Checkoffs															
Block 1: Sensing	Lindsey	1/4/21	1/30/21	26											
Block 1: EMG	Sienna	1/4/21	1/30/21	26											
Block 2: Power	Lindsey	1/30/21	2/21/21	21											
Block 2: Hand Assembly	Sienna	1/30/21	2/21/21	21											
Block 3: Arduino Code	Lindsey	2/21/21	3/14/21	23											
Block 3: Decoder	Sienna	2/21/21	3/14/21	23											

TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	Spring Term WEEKS 1	2	3	4	5	6	7	8	9	10	11
Block Checkoffs															
Initial System Testing	All	3/29/21	4/22/21	23											
Final System Testing	All	4/22/21	5/13/21	21											
Reassembly of Hand 2	Sienna	4/22/21	5/13/21	21											
Code	Lindsey	3/29/21	5/13/21	44											
Decoder	Lindsey	4/22/21	5/13/21	21											

Scope and Engineering Requirements Summary

Name	CR	ER	"Verification Method"	"Test Process"	"Test Pass Condition"	"Evidence Link"
Carry Objects	The system needs to be able to grab and carry objects	The system needs to hold a 800 g rigid object including a glass jar and a plastic container in various orientations at 0 degree, 90 degrees, and 180 degrees with 20 second duration.	Test	1.) First, the tester will grab an object weighing no less than 800 g from a surface. 2.) Then, the user will hold the object with the palm facing sideways to the right (left-handed) for 20 seconds - this is defined as 0 degrees 3.) Next, the user will rotate the system counter-clockwise to 90 degrees - palm is facing up, perpendicular to the ground, and the object needs to be held for 20 seconds 4.) Lastly, the user will rotate the system counter-clockwise to 180 degrees - the palm is facing sideways to the left, perpendicular to the ground, and the object needs to be held without dropping for another 20 seconds.	If the system holds a 800 g rigid object including a glass jar and a plastic container this condition passes.	https://drive.google.com/file/d/1u7Yz5B4rJ6O74qBIpOBvQKihorpdx4Rp/view?usp=sharing
Degrees of Freedom	The system has to specify the range and number of different types of motions (degrees of freedom)	The system will have 5 different degrees of freedom - one for each finger that must vary from 0 degrees (open hand) to 90 degrees (closed fist) with a tolerance of +/- 10 degrees.	Test	With each finger, bend to maximum and minimum and measure with a protractor. 1.) The test starts with one finger fully extended, measuring from the knuckle and the back of the hand this is defined as 0 degrees. 2.) Next, the finger will retract to its fully closed position, the proximal phalanx (the segment of the finger attached to the knuckle) will be perpendicular to the knuckle and the back of the hand at 90 degrees. This will be measured by a protractor. 3.) Repeat for each finger.	Each finger that must vary from 0 degrees (open hand) to 90 degrees (closed fist) with a tolerance of +/- 10 degrees.	https://drive.google.com/file/d/1Lgx_5gCW1XawveCNsXI0PeIotW-N1wId/view?usp=sharing
Durable	The unit has to be durable	The system must be withstand a transverse force of 4.9 N five times and still operate normally.	Test	An object that weighs 0.5 kg will be dropped from 1 meter above onto the system while it's resting on a solid surface. 1.) Find an object that weighs 0.5 kg and measure 1 meter above the system (positioned palm up) that's resting on a solid surface such as the ground. 2.) By using the force equation, F = ma, this will give a force of 4.9 N when it hits the system. 3.) Pick up the system and inspect if there is any visible damage. 4.) Connect the system and test to see if all subsystems are working as stated in other requirements. 5.) Repeat 5 times, dropped by the same person, from the same height, in a row.	If the system still operates after a transverse force of 4.9 N impact this condition passes.	https://drive.google.com/file/d/1ovDBu3KdolC4xDExs60h4QM6uf9qjoHF/view?usp=sharing
Individual Finger Control	The subsystems on the system should be controlled by signals from muscle movement	The system will distinguish between individual finger contractions and respond by moving the correct finger(s) of the system confirmed visually by a user 4 out of 5 times.	Test	The fingers on the system will match the movement of the tester's (not amputee) hand. 1.) First, the tester will first hold their hand in a fist, the system will follow. 2.) Next, the tester will move each finger individually (one at a time, there will be cross-movement in the tester's hand that will be shown on the system). An inspector will look at the system and determine if the correct finger was moved on the system. 3.) Testing each finger 5 times.	An inspector must visually confirm each individual finger contraction from a tester moves the correct finger(s) of the system 4 out of 5 times.	https://drive.google.com/file/d/1jSblYfHwCDXsXtjQo-OOTVny9OfqlKGr/view?usp=sharing
Inexpensive	The system needs to be inexpensive	The full system (excluding the EMG sensors or any equipment related to current research) will be kept less than 800 dollars.	Analysis	Keep track of all purchased items and what type of filaments are being used for the system. Record how many grams of material were used and calculate the final cost to print the hand. The total budget is 800 dollars, $300 from ECE 441, and $500 from Dr. Mathews research lab. 1.) For all 3D printed parts, create an excel sheet to record what type of filament was used and how many grams of material was needed. 2.) For all purchased items, record the website from which we purchased the items as well as the price. 3.) For all time spent on the project, including meeting, researching, testing, assembling will be tracked and calculated. 3.) Finally, a list of all costs will be compiled into one spreadsheet and the total cost will be calculated.	If the system components sum to less than 800 dollars this condition passes.	https://drive.google.com/file/d/1KctaRjI2AMW7gqr_pISw-zV_PD4Tw6Wf/view?usp=sharing
Pressure	The system must have a feedback system for pressure	The system must have a pressure sensor enclosed inside of the finger tips and output to a row of 5 LEDs corresponding to each finger within 0.5 seconds.	Inspection	1.) The feedback system inside the socket will have five LEDs, starting the left most LED, it corresponds to the thumb, then index finger, etc. 2.) Starting from thumb, a user will apply pressure to the finger tip by pressing against a flat, hard surface. The corresponding LED will light up. An inspector will record the process with an iPhone with the LEDs in frame as well as the finger. 3.) Repeat for all fingers. 4.) The footage will be reviewed frame by frame. The time at which the finger is pressed and the time at which the LED lights up will be recorded in a spreadsheet. 5.) The time difference between the two responses will be calculated and recorded for each finger.	The system must have a feedback system to sense pressure exterted onto the fingers. The socket must have a row of LEDs that will light up corresponding to each finger and it must respond within 0.5 seconds to the pressure change.	https://drive.google.com/file/d/1IScAN3DdE6PjOTWvThiKLIh54PGP8CLc/view?usp=sharing
Responsiveness	Design must be able to process quickly enough to ensure minimal delay between muscle movement and prosthetic hand movement	The system will move the sub-system within 1 second of the user moving their finger with +/- 50 milliseconds margin of error	Test	A timer should be used to precisely record when the tester's finger has moved to when the system is responding. The system and the testers hand should be captured with an iPhone camera which films at 60fps. 1.) The camera starts filming. Both the system and the tester's hand must be within the frame of the camera. 2.) The tester will move their hand and the system will respond accordingly. 3.) Camera stops filming. The footage will be transferred to a laptop. 4.) The footage will be reviewed frame by frame. The time at which the tester's fingers start moving and the time at which the system responds will be recorded in a spreadsheet. 5.) The time difference between the two responses will be calculated and recorded. 5.) Repeat the test 5 times and take the average of the time difference as the final result.	The system should respond within 1 second with +/- 50 milliseconds margin of error.	https://drive.google.com/file/d/1PesReXL16IwXiPdSU94qyibZPE8Ze8nf/view?usp=sharing
Usability	The system needs to be usable for amputees	The system must have a socket that is less than 4 inches in inner-diameter (on the residual limb end) and no greater than 11 inches in length to fit all electronic parts. It also must have a wrist that is able to rotate 360 degrees in-place along the z-axis (vertical axis - along the length of the socket).	Inspection	1.) Measure the socket from its widest inner points to ensure it has an inner-diameter of no more than 4 inches on the residual limb side (wider-end) and a length no greater than 11 inches. 2.) A user will rotate the prosthetic hand 360 degrees by hand along the z-axis (vertical axis - along the length of the socket).	The measurements of the socket must be no more than 4 inches in inner-diameter (on the wider-end) and no more than 11 inches in length of the socket. A user also must rotate the wrist in-place along the z-axis (vertical axis - along the length of the socket).	https://drive.google.com/file/d/10BHujP5YWzJZZQwNMWyU2mHJ7tHii5Q4/view?usp=sharing

Risk register

Risk ID	Risk Description	Risk Category	Risk Probability	Risk Impact	Performance Indicator	Responsible Party	Action Plan
R1	A team member getting COVID.	Timeline	10%	H	Becoming sick with a fever and/or testing positive for COVID through Trace or RiteAid. Trace testing happens every few weeks.	Lindsey	Retain
R2	Parts breaking due to overuse, carelessness, or lack of robustness.	Timeline/ Cost	60%	M	Any part that shows physical damage or any device that is not performing on basic checks.	Ranyu	Reduce
R3	Vendor delay for PCB and/or necessary parts.	Timeline	40%	M	Following the delivery tracker and noticing a change in arrival or email updates from the vendor.	Lindsey	Reduce
R4	Signal processing speed or the accuracy and tolerance of the parts not meeting standards.	Technical	50%	M	If each finger is responsive to testing and there is a minimum delay between the sensors and prosthetic hand. Responses should be within the acceptable error range.	Lindsey	Retain

R5	PCB design not working as expected.	Technical	40%	H	All components of the circuit are working as expected. Inspect the PCB visually before every use, as well as taking measurements of input and output voltages.	Ranyu	Retain

Lessons learned:

- Start testing out materials ahead of time
- Print 3D printed parts in sections to ensure each part fit each other before printing the full print
- PCB should be made for all connections to motors instead of protoboard to minimize time debugging the circuits
- 3D print orientation is crucial to the durability of the prosthetic hand
- The parts that broke most frequently are: wrist, palm, and thumb motor mount.

Risks we did not anticipate:

- PCB didn't match either pressure sensor
- Python code errors
- Computer died as soon as it was unplugged, luckily it lasted till the end of the project but it was concerning
- Things got pushed back and the coding side wasn't able to start until much later than anticipated
- Didn't realize how mechanical the project was going to be and how that side of things would keep coming apart or not working (ex. unsoldered wires)

Future Recommendations

Recommendation	Reason	Solution
Purchase a different type of silicone for the fingers, palm, and back of the hand.	Current silicone cures too hard, it causes the hand to be more slippery and it does not absorb the impact of an object falling onto the hand as much.	Only use silicone rated with Shore hardness of 2A. This is what we had used previously, and it worked much better.
Secure electrical components	During the testing the wires keep	Design a PCB for all the wired

better.	on breaking away from the protoboard. This added a lot more time to debug and it became one of the biggest issues we've had.	connections to the motors or solder them to jumpers instead of directly to the protoboard.
Design a PCB for the pressure sensors	The pressure sensors we have purchased should be in working conditions. But since we didn't design a PCB for them, and the PCB we found was not working properly, we couldn't use the pressure sensors we had bought.	Design a PCB for either the MPL115A1 pressure sensors or MPL115A2 pressure sensors.
Add battery that could sustain the system for 8 hours	Because of the time constraint, we couldn't add batteries to the system. If batteries were added, this prosthetic can be more useful since it can be used outside of a lab setting.	Find batteries that can last long but not bulky, since we have limited spacing in the socket. Rechargeable Lithium-ion batteries is a good starting point.
Start testing each sections earlier	Because the project is 80% mechanical, we found a lot of areas that we weren't familiar with, such as finding the right type of silicone, filament, and how all mechanical parts work together. So a lot of time was spent debugging the mechanical components and figuring out how to make things run better with a lot of changes that takes quite a bit of time.	Start each section early and test every individual part well before putting the system together. Including the code and all electronics parts. Ideally, one month in advance.
Communicate with professor and/or grad students better, ask for help earlier, especially the decoder portion.	For the decoder, we ran into a lot of problems and a lot of errors from trying to run a code that is written by someone else. And because the code was also programmed by two different people, there were a lot of back and forth and waiting to hear back.	Communicate early and start this section early overall. Because it's a section that we weren't familiar with, we should've started this section earlier than we did and communicate with the research group earlier on the issues we were facing.
Changing the design of the hand	A huge issue that we ran into with the mechanical design of the hand was that a lot of intricate parts didn't quite fit together well. One example is the sockets for the motors. Even with the	Increase spacing between the motor brackets. Enlarge the socket for the gears. I found printing 7% than the original design helped, but maybe even increasing to 9% or 10% would

	printing parameters the project specified, the sockets are still too small for the gears and therefore causing the motors to stall. In addition, the brackets that hold the motors would snap off very easily.	be better.
Changing the design for the wrist	One of the problems that we didn’t see coming was the wrist design. Because we have the twisting motion for the wrist, that causes the wires to become twisted and sometimes breaks the soldered wires.	The wrist will need a way to stabilize the wires or change to a different rotating mechanism. In addition, if the ball-joint design is kept, the part that screws on top of the ball joint can be made thinner to allow a greater degree of freedom for the rotation.

References

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