Fabricating a flexible force-adaptive EMG-controlled upper-limb prosthetic

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Introduction

Upper-limb prosthetics have been around for decades, but their cost, adaptability, and availability have resulted in half of upper-limb prosthesis users abandoning their devices (Biddis & Chau, 2007). One major hurdle that prosthetic development has encountered is the lack of adaptability of the device. While modern hands can do several complex movements, a very basic yet fundamental movement is a power grip. Recent prosthetics have achieved this grip by creating flexor "tendons" out of a wire and then using dc motors to wind up the "tendon", thus flexing the finger. One major drawback of this grip is that it can damage objects that have different structural integrities without a proper force regulator. Making the power grip adaptive to use different amounts of force is critical for continuing the development of upper-limb prosthetics. In more recent years, a design strategy called soft prosthetics has gained popularity and utilizes flexible filament. While there might be some potential drawbacks, like structural integrity or the wear and tear of the material, the flexible approach to the prosthetic allows for a more controlled, compact, and lightweight design that is not a burden on the users (Mohammadi et al., 2020). This project attempted to design and produce a flexible, force-adaptive, muscle-controlled upper-limb prosthetic through the integration of soft prosthetics and a user interface.

Materials and Methods

Figure 1 (above): Final model as shown in Fusion 360. Included are the manual supports added in between the thumb joints and the servo holders.

The design goals of this project were broken down into five major points. The first was seamless transition between grip strengths. The second was the provision of immediate feedback to the user. The third was myoelectric control. The fourth was the ease of production. The final goal was flexible design with an intrinsic actuation system. The project involved the simultaneous development of three components: the physical hand, printed circuit board (PCB) design, and code. The hand was designed in Fusion 360. The model implemented monolithic soft structures which acted as the joints of the fingers. Once designed, test pieces were produced, and any necessary changes were made. When the model satisfied all requirements, the final product was produced using thermoplastic polyurethane (TPU) and acrylonitrile butadiene styrene (ABS). The final fusion design can be seen in Figure 1 with the TPU in black and the ABS in white.

Materials and Methods (continued)

The hand required two PCB's, each with a different purpose. The first, produced by Backyard Brains, read the electromyography (EMG) sensors and translated the reading into a value. The second controlled the servos, the liquid crystal display (LCD), the force sensors, the button, and the potentiometer to create a user interface (UI) that generated immediate force-feedback and actuated the hand. This board, as shown in Figure 2, was designed using Autodesk Eagle and produced using a PCB printer. The code for this project involved two parts. The code for the EMG PCB was retrieved data from the Backyard Brains website and was slightly altered to include I2C. The code for the User OS was built with three separate functions. The first was a calibration phase, the second enabled manual movement with the use of a potentiometer, and the third was the main control loop using the EMG signals. The logic map for the code can be seen in Figure 3.

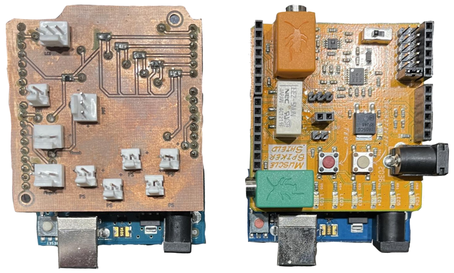

Figure 2 (above): Both PCBs completely soldered and attached to Arduino UNOs. The left PCB is the UI shown with a Molex connector for each pressure pad, LCD, button, potentiometer, and both servos. The PCB on the right is the EMG PCB.

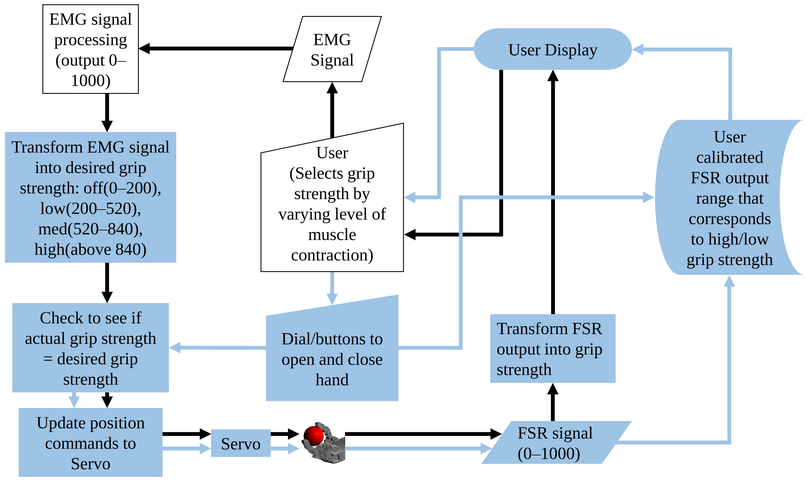

Figure 3 (above): Code logic map. The blue boxes represents the actions that the User OS accomplishes, and the clear boxes represent the actions that the EMG PCB accomplishes. The blue arrows represents the calibration loop, and the black arrows represent the main control loop.

Results

Figure 4 (above); Final hand completely printed. Shown without pressure and grip pads.

The hand underwent a series of tests that corresponded to each of the design goals. The tests gauged the hand's ability to change the amount of force being used, the accuracy of the myoelectric control, how fast the LCD provided feedback, and the overall design of the hand. The functionality tests included grasping a paper cup, an egg, and a water bottle and then placing each object down carefully before immediately grabbing the next object without altering the device. Based on the results of the tests, the hand was given a pass/fail for each of the five design goals. The final model did receive a pass in all five categories, thus resulting in a pass overall. The final model can be seen in Figure 4 and the testing breakdown can be seen in Table 1.

Force Adapt.	Force Feed.	Myoelectric	Production	Actuation	Overall
Pass	Pass	Pass	Pass	Pass	Pass

Table 1 (above): Results of testing for the prosthetic. All 5 design goals received a "pass" therefore resulting in an overall result of "pass" for the prosthetic.

Conclusions

The purpose of this project was to design and produce a flexible, force-adaptive, EMG-controlled upper-limb prosthetic. The purpose of the project was met, because the final product received an overall grade of "pass". While this device did meet the set standards for the project, the overall concept and execution is still rough for a public product. Any future projects should focus on cleaning up the hand design, optimizing the control, and combing the PCBs to reduce needed wires. That being said, this project does show that developing an adaptive hand that can switch between force levels is achievable and is the next step in making prosthetics suitable replacements for missing limbs.

References

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