Design and Development of a Cable-Driven Wrist Prosthesis

Student: Corey Huffman / Mentors: Javier Sanjuan De Caro, Mohammad H. Rahman
University of Wisconsin-Milwaukee, College of Engineering and Applied Sciences, Biorobotics Lab

Introduction

A prosthetic is a device used to replace lost limbs or parts of the body that serve a vital part in daily functions, such as an arm or a leg. While missing limbs can be tolerable, it is far from optimal, so the general population prefer to have at least a basic prosthetic to substitute for that missing limb. This is especially true for those in a more labor-intensive occupation, such as a farmer or construction worker. As prosthetics have progressed, studies and innovations have been done that incorporate active robotics into the design process. These prosthetics use electromyography (EMG) waves from the muscles of the patient's body to command the prosthetic to perform actions akin to what a living limb would accomplish. While these devices are advanced, the cost for one is generally very high (upwards of over $50,000), which most of the populous would have trouble affording. Even without motor functions, a prosthetic limb can be thousands of dollars not including costs if the prosthetics need to be repaired or replaced.

Like many researchers in the engineering field, our project includes creating a more cost-effective prosthetic limb. This section primarily focuses on a cable-driven wrist prosthesis (CDWP) that will ultimately have the same range of motions as a normal wrist would have (flexion, extension, adduction and abduction) along with a rotation motion. This prosthetic would connect to a hand prosthesis on the distal end, and a brace that holds the CDWP to the living limb. Along with the wrist prosthesis, a performance index has been created that calculates the dimensions of the patient's limb in order to make the correct dimensions (height, length) for the wrist prosthetic. While a large-scale version of the wrist prosthesis has been made by Javier, this version is smaller and more realistic to what would be produced.

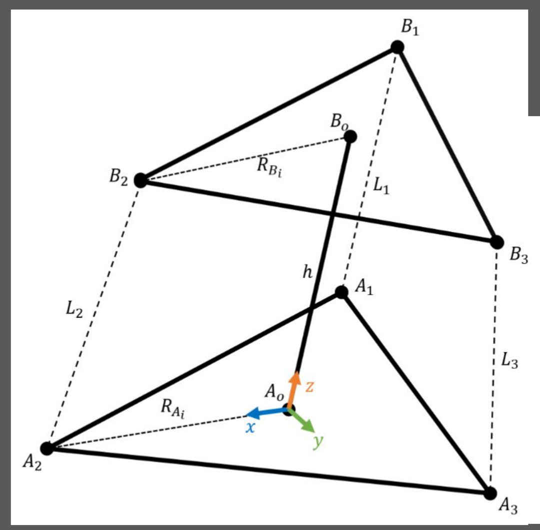
How the CDWP Works

Three strings of steel cable are connected to a mobile disk and to one motor each. When EMG signals are sent to the CDWP, it will move the cables connected to the top disk in a series of simultaneous motions. According to the code and EMG signals, the motors on the bottom later of the model will either reel in the cables or loosen the cables to force the top disk into a certain position. The pully wheels help keep the cable straight as it is reeled or released. A universal joint coupling allows for the disk to tilt at different angles, which allows for most wrist-like motions.

Goals & Considerations

By the end of this project, we are looking at a functioning wrist prosthesis that is sturdy, light, and affordable. It should be compact and not cumbersome, while also allowing for the same Degrees of Freedom (directions of movement) that a normal wrist would serve. During the process of creating the CDWP, many things must be considered:

• Production Time and Cost • Material Strength and Durability • Weight • Battery Life and Circuitry Location	• Weather and Temperature Exposure • Connection to Hand Prosthesis and Brace • Degrees of Freedom • Safety of the Material



$$L_i = \sqrt{\Delta L_{xi}^2 + \Delta L_{yi}^2 + \Delta L_{zi}^2}$$

Where the terms ΔL_{xi}, ΔL_{yi}, and ΔL_{zi} are presented as follows:

$$\Delta L_{xi} = {}^{b}B_{xi}\cos(\theta_y) - {}^{o}A_{xi} + {}^{b}B_{zi}\cos(\theta_x)\sin(\theta_y) + {}^{b}B_{yi}\sin(\theta_x)\sin(\theta_y)$$
$$\Delta L_{yi} = {}^{o}A_{yi} - {}^{b}B_{yi}\cos(\theta_x) + {}^{b}B_{zi}\sin(\theta_x)$$
$$\Delta L_{zi} = h - {}^{o}A_{zi} - {}^{b}B_{xi}\sin(\theta_y) + {}^{b}B_{zi}\cos(\theta_x)\cos(\theta_y) + {}^{b}B_{yi}\cos(\theta_y)\sin(\theta_x)$$

Fig. 3: The Kinetic Diagram for the CDWP and the equations for inverse kinematics, which is what the performance index is based on.

Method

The first step with this version of the CDWP was determining what the material the rod in the middle (where most the stress will be placed on) will be. It must be a light material that can withstand a decent amount of stress caused by both the prosthetic hand as well as the item being held. This was determined by calculating the bending moment (with a safety factor of 2) of the rod if the mass on one end was 20 kilograms simulating the mass of a held object along with the mass of the prosthetic hand. Once the rod material was determined along with the dimensions of the rod, the SolidWorks model from the first prototype was resized to fit the smaller specifications of the rod. Since the rest of the body is made of 3D PLA filament, numerous parts were 3D-printed out, with some parts resized and reprinted to correctly fit the model. A drill press was used to create 3 sets of holes on the rod, which connect the three layers of the model together. The physical model was then constructed with m3 bolts and washers.

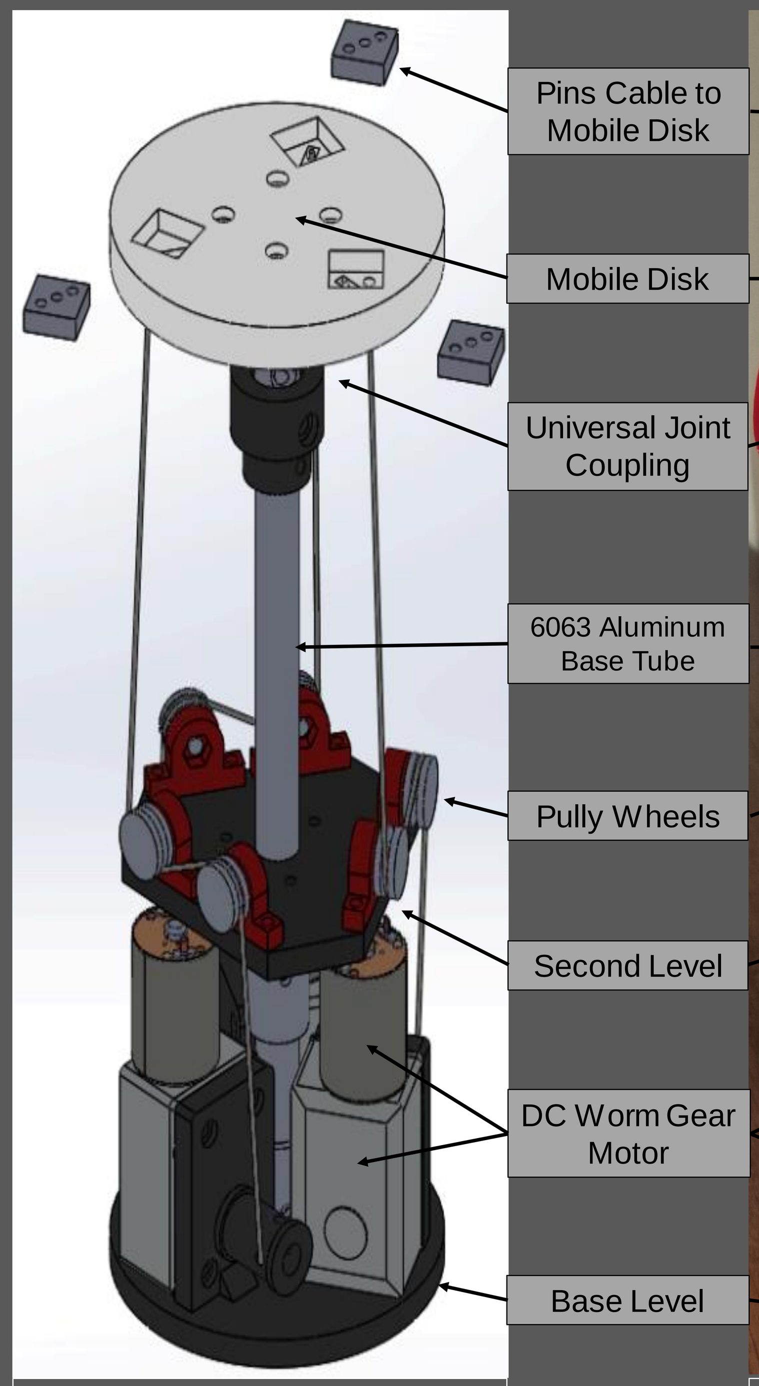


Fig. 1: SolidWorks model of the CDWP.

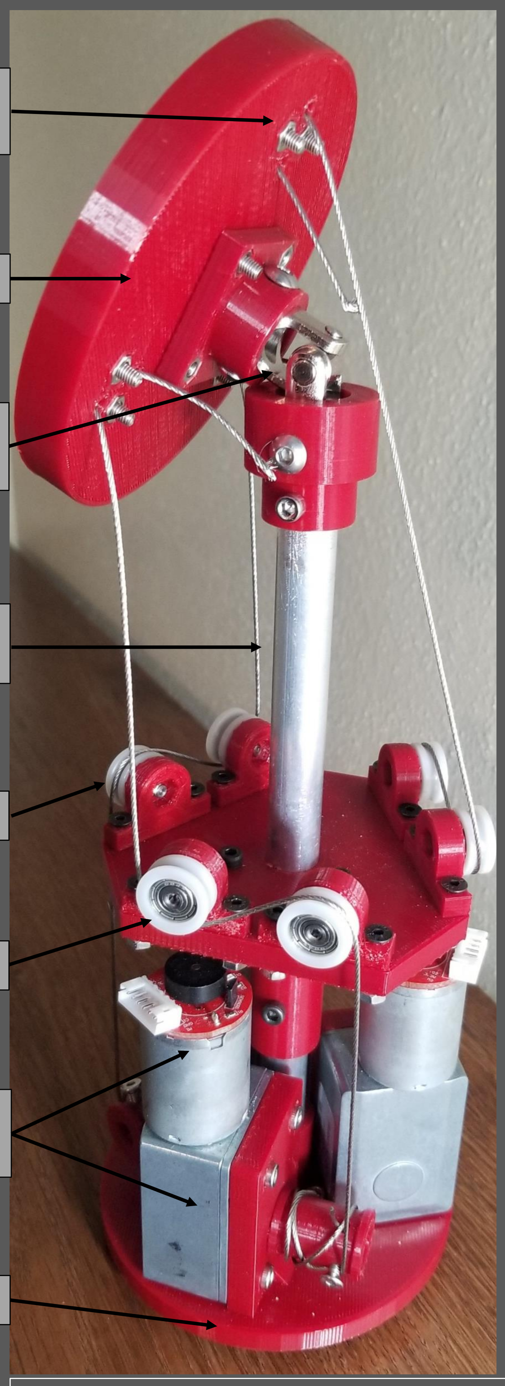


Fig. 2 : Physical model of the CDWP.

Results & Current State

As of April 2021, the physical model has been securely constructed. The optimal rod calculated for this model was a 6063-aluminum tube that had an outer diameter of 12mm and an inner diameter of 9mm. This base can hold the designated amount of weight given (20 kilograms) while also being the lightest out of the options given. The cables are properly fitted to the top disk and their respective motors, and the disk will not move unless the cables are removed. It's important that the disk will not move if the motors aren't in motion, so that the prosthesis will not give out or slip when holding an object. The next step is to create the circuitry and code necessary to move the motors and cable for the prosthetic to work properly. As of now, code originally created for the larger prosthesis is being reworked in accordance with the new model, and the circuitry is being compacted to fit within the space of the CDWP. Once the coding is ready the CDWP can be tested with weight and exposure to different temperatures and environments. As the model is tested, it is expected that design changes will happen depending on the problems that occur. For example, a section of the model may need to be wider if the constructed circuit board requires more room. The performance index has already been created by Javier , so we will be able to test the index once more when the model is complete.
Currently the model weighs about 0.75 kilograms, which is within the range of what most arm prosthetics weigh (which is between 0.5 kilograms and 2 kilograms). The total cost of the materials including the circuitry is under $200, which is due to the decision to use PLA filament for most of the structure.

Table 1: Cost of the materials for the CDWP currently.

Material	Cost
12mmODx9mmIDx300mm 6063 Aluminum Tube	$5
L293D	$1
Red eSUN PLA+ Filament (~210g)	$5
DC Worm Gear Motor 12V (30RPM) 3x	$75.30
1/16 In Stainless Steel Wire Cable (~6ft)	$1
U Joint Coupler	$8
Pulley Wheels Roller 6x	$12
Circuitry	$40
M3 Screws/Bolts	$10
Total (With model and circuitry)	<$200

Conclusion

Although there is a long process for constructing the prosthesis, it has been going smoothly during construction. It is at least confirmed that this model will structurally operate, however more work needs to be done to get the motors activated and cable moving.
When concerning weight and cost, this model has been meeting expectations. The CDWP is relatively light but will have to include the weight of the prosthetic hand and the circuitry when it is complete. The use of PLA filament reduces costs substantially, which will make it cheaper than its competitors.
Overall, the CDWP has been a successful prosthetic thus far, and there are high hopes for its use in the biomedical field if the rest of its development is successful.

References

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