Cable Management Device

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by

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1. Problem Statement

The cable management device's main function is to create a tangle free environment for any station needing multiple plug ins like any computer set up for office or home use. When using this device, it will attach to the bottom of cables then the cable management system will use a small manual crank mechanism to pull the wire to the desired length, in doing so this will reduce the space of loose cabling and will make it so the wires never are able to cross and get tangled together. This will also lead to safe and time efficient detaching so that if you need to move or replace anything in the setup it won't cause any unneeded problems. The product can also be used for cable storage and cable hot swapping, every part should be removable and interchangeable with new prints without the need for extraneous pieces.

2. Research

a. Background of the Problem

When computers and cabling were first introduced the need for things like a cable management system was never thought to be an issue because they usually only included up to 3 connecting peripherals for any system. Around the 1970-1980s the problem was first established with the rise of personal computers and professional set ups, at the time most electrical devices being used required coaxial cables which were a single thick cable that snaked through buildings, they were prone to interference and difficult to maintain and offered no clear solution outside of professional assistance like an I.T. or Electrician rewiring. After this period, the 1990s saw the development of industry-wide standards by organizations like the TIA and EIA. These standards defined cable types, connector specifications, and installation guidelines, ensuring compatibility and performance across different vendors' equipment and although these new standards revolutionized cable management for companies and business with a large quantity of set-ups, they didn't offer any solution for the removal of this equipment and was also not logical or affordable for any personal set-ups. [4]

From then until the present with custom builds becoming more popular and with things like headsets, mice, monitors, charging stations, external storage and other technology being introduced, it quickly became an issue of maintaining these connections without interference with the others while also needing easy access to them for removal or upgrades.[6] During the last 20 years many different solutions were made to try to combat against these concerns ranging from cable conduits to twist ties, and while these seemingly removed the problem of wire interference the issue of the removal of these products quickly arose. Recently, in 2023 the problem of maintaining a good cable management system was brought to the forefront. With the release of Nvidia's new graphics card, the RTX 4090, owners quickly found themselves with damaged wiring which led to fire hazards and permanent damage to the GPU and other connected components, costing upwards of $2000 in repairs and erasure of data. Although Nvidia did release a statement addressing these concerns, they never offered a real solution and while the cause of the damage was eventually found out there never seemed to be a plausible alternative to combat them effectively. [2]

With more and more interchangeable devices being introduced in the electronic peripheral market, and with the introduction of USB-C interchangeability becoming more common, it's led to more prebuilt and homemade computer towers to be less conscious about their cable management after initial installation. For the first time in computer history, even the most common user has become customed to prioritizing certain USB ports over others. With modern solutions only offering pre-installed wiring or unremovable solutions like cable clips, the need for cable management products to introduce hot-swapability while maintaining affordability and efficiency has never been greater.

b. State of the Art

- Cable Bushing
  - Bushings protect wires and their passage openings. By insulating these openings, bushings protect the wires from damage, for example, as caused by pulling, tugging or abrasions. However, they can be challenging to make adjustments to the cable routing without reinstalling them in new positions or removal of them all together when replacing the chord.
- Cable Clips/Clamps
  - Cable clamps secure long cables and wires that run between components outside of a housing, such as a data cabinet. When using an adhesive or Velcro mounted clamp, it can run alongside walls and furniture, this solution provides even more cable security than the bushing when it comes to any interference but still run into the same issue when it comes to removing or replacing them.[1]
- Cable Conduit
  - Conduit encloses, supports and protects cables. It can be rigid, or you can get flexible plastic conduit for cables. An example of a rigid material used to make conduit is metal. The benefit to this type of cable conduit is its grounding and bonding qualities, which minimize electromagnetic interference. However, they are only as durable as the amount you pay for them. Cheaper conduits only have about a 100-degree F limit while more expensive ones can go upwards of 300 degrees F. Whatever material you buy, they don't offer a solution for cable replacement or cross wiring interference.
- Cable Ducts
  - Cable ducts are useful as a space-saving routing system for your cables. It makes maintenance and repairs easier, while providing safety. Plastic cable ducts are the most popular option, as they provide a degree of flexibility. These arguably work the best

when you have a dense amount of wiring as they offer specific pathways for the wire to follow. However, this is a double-edged sword as they are also commonly the most annoying to try to remove.

- Cable grommets
  - Cable grommets are accessories that protect cables from damage and are used to manage and route wires. They can be made from plastic, rubber, or metal, and are often used when wires pass through a panel hole. They are often the smallest in cable management systems and offer easy access for reinstallation. They often run separately from the system they are attached to and are usually for one specific use. Although these offer a good solution, they often tend to get loose and don't offer any additional protection for the cable.
- Cable Ties
  - Cable ties are the most common type of cable management partly for how many different types there are but also because they offer the most adaptability from station to station. Cable ties are the most user friendly, but this does not make it the most reliable. Compared to the others, cable ties offer easy installation and provide whatever level of space needed between cables you need, they are also the least durable and provide no additional protection similar to cable grommets.[5]

c. End User

The target end user that will benefit from my Automatic Cable System is anyone that often requires reinstallation of cables due to their work or their own personal use. These can range from users of highly dense data centers to businesses that upgrade their equipment regularly to anyone with a personal smart device or tablet set-up who requires a more affordable solution to cable management. Theres no intended age range for the product but the users who will benefit from this research will be anyone between 16-40 who is reliant on using newer technologies and are informed of the requirements of maintaining them.

d. Applicable Standard

- ANSI/TIA-568- and all sub sections: This standard focuses on structured cabling for data communications.
- ANSI/TIA-942: These standard outlines the functional areas specific to the data center
- ANSI/TIA-569: for telecommunications Pathways and Spaces
- ISO/IEC 11801: This is the international standard for Generic Cabling for Customer Premises.
- All USB, DVI, and HDMI standards for computer systems.
- 340 mm of space maintained between power supply and other cables.
- IEEE 802.3: Ethernet Standards
- ISO/ASTM 52900-52904: General principles and requirements for 3D printing design
- ISO/ASTM 52920-52921: Classifications of 3D printing processes
- USB Standards from USB 1.0-USB 4.0
- USB-C

  [3]

e. Summary of Research

From our research we can see that with the increasing power and complexity of modern computer components, users require efficient cable management to prevent system failures, interference, and expensive damage. Poorly managed cables can lead to overheating, damage to hardware, and safety risks. As technology becomes more powerful and users demand easy access for upgrades and replacements, the importance of efficient and removable cable management systems has never been greater. While existing cable management solutions like conduits and ties help reduce interference, they make accessing and replacing components difficult, especially in modern setups with larger and more powerful components.

There is currently no affordable, user-friendly solution that addresses both interference and easy removal of components for upgrades or repairs. The cable management system aims to address these concerns while reassuring professionals, PC enthusiasts, small businesses using high-performance components, and any casual consumer using smart devices or laptop stations that they can use these newer products without worry of cable crossing or damaged wiring.

3. Quality Function Deployment

a. Survey Methodology and Results

Conducted a survey on the features for cable management products based on how important the features are in current technology and how important they think they should be for new products. Surveyed 12 participants on Reddit and 8 Engineers from Duke Energy.

Combined Results:

Customer Features	Average Score
Efficiency	4.2
Safety	4.1
Durability	4.8
Size	3.8
Design	2.8
Cost	3.6
Upgradability	2.2
Accessibility	4.1

b. Engineering Characteristics

Based on the survey results these are the Engineering Features that were decided upon:

1.) Length or Diameter (mm.)

2.) Heat Resistance (C)

3.) Wattage Accessibility (W)

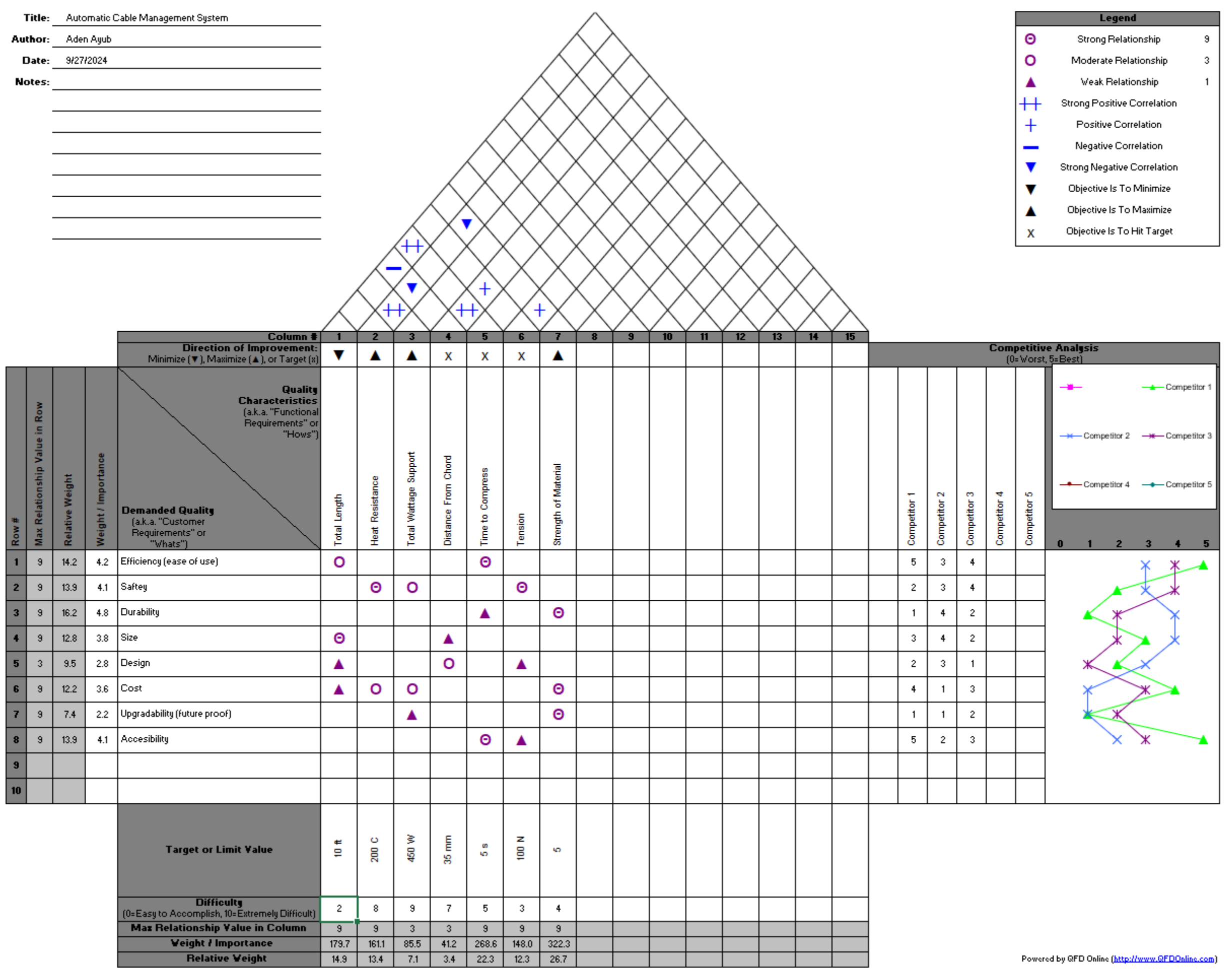
4.) Distance From Chord (mm.)

5.) Time to Compress (sec.)

6.) Tension in Chord (Psi)

7.) Strength of Material (psi)

House of Quality:



c. Project Objectives:

1.) Compression Time (22.3%)

a. To implement a compression time that is short enough that it won't take up too much time will require a motor or a handheld mechanism that ensures that the required speed will be obtained without damage to the chord or user in the process.

2.) Strength of Material (26.7%)

a. The product needs to be strong enough to endure heavy usage but not too strong so that the removal process diminishes in ease of use.

3.) Heat Resistance (13.4 %)

a. Based on speculated future technology and based on applicable standards, the product needs to be resistant enough to handle upwards of 200 degrees C, otherwise the product needs to be changed from universal use to external use.

4.) Tension (12.3%)

a. Tension needs to be implemented in order for the wire to remain in the same place without placing too much strain on the chord. Too tightly wound will result in damage to the chord and will lead to other issues like heat concerns, wattage support and overall efficiency.

5.) Total Length or Diameter (14.9%)

a. Length or Diameter of the product needs to leave at least 35 mm between chords to comply with applicable standards but also leaves room for multiple devices to be plugged in whichever port desired.

6.) Wattage Support (7.1%)

a. Wattage Support will be one of the easiest to account for since most modem cables have been built in protection to combat against crossing or spikes in voltage however, we still need to maintain applicable standards for newer cables like 12VHPWR.

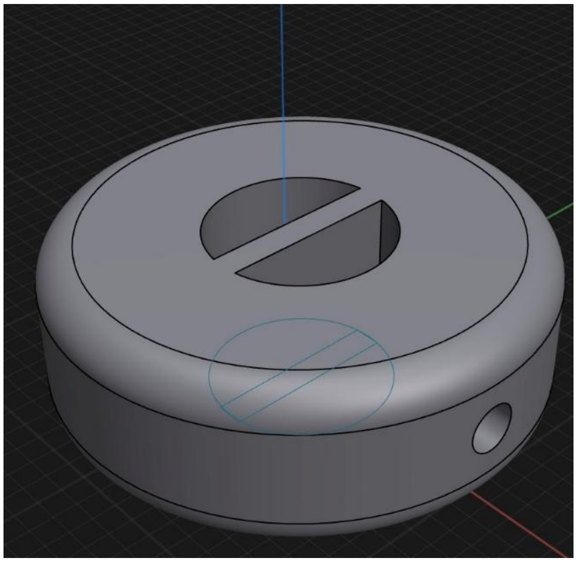
7.) Distance From Chord (3.4%)

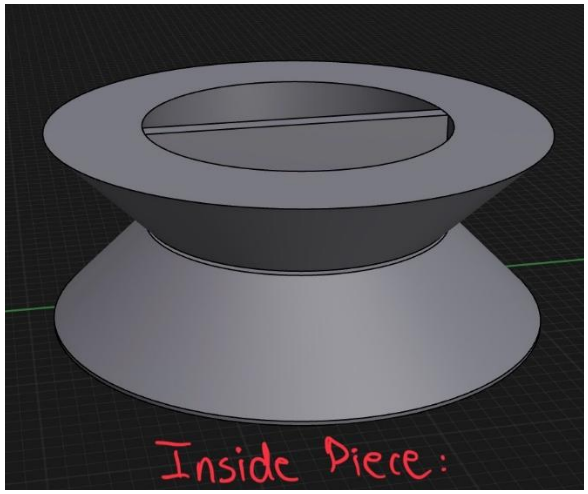
a. Distance needs to be minimized but also support things like data centers and business set-ups, this will be achieved by having a max distance value on 10 ft and compressing it to whichever length the user actually needs.

4. Concepts Design

Based on the QFD Process we want to design a product that is user friendly and safe for any type of wire or chord a customer will need, along with being strong enough both in material strength and wire compression for the wire to have the smallest amount of volume occupied without losing functionality, the product needs to be easily removeable and must occupy the required amount of distance between the appliance and output device. Minimum requirements for distance are 35mm in diameter and 10 ft in length,

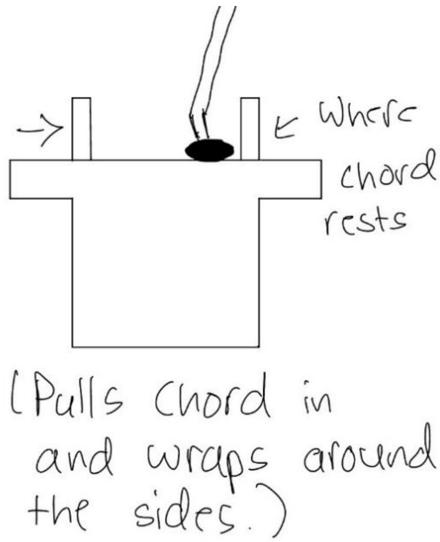
a. Concept 1:





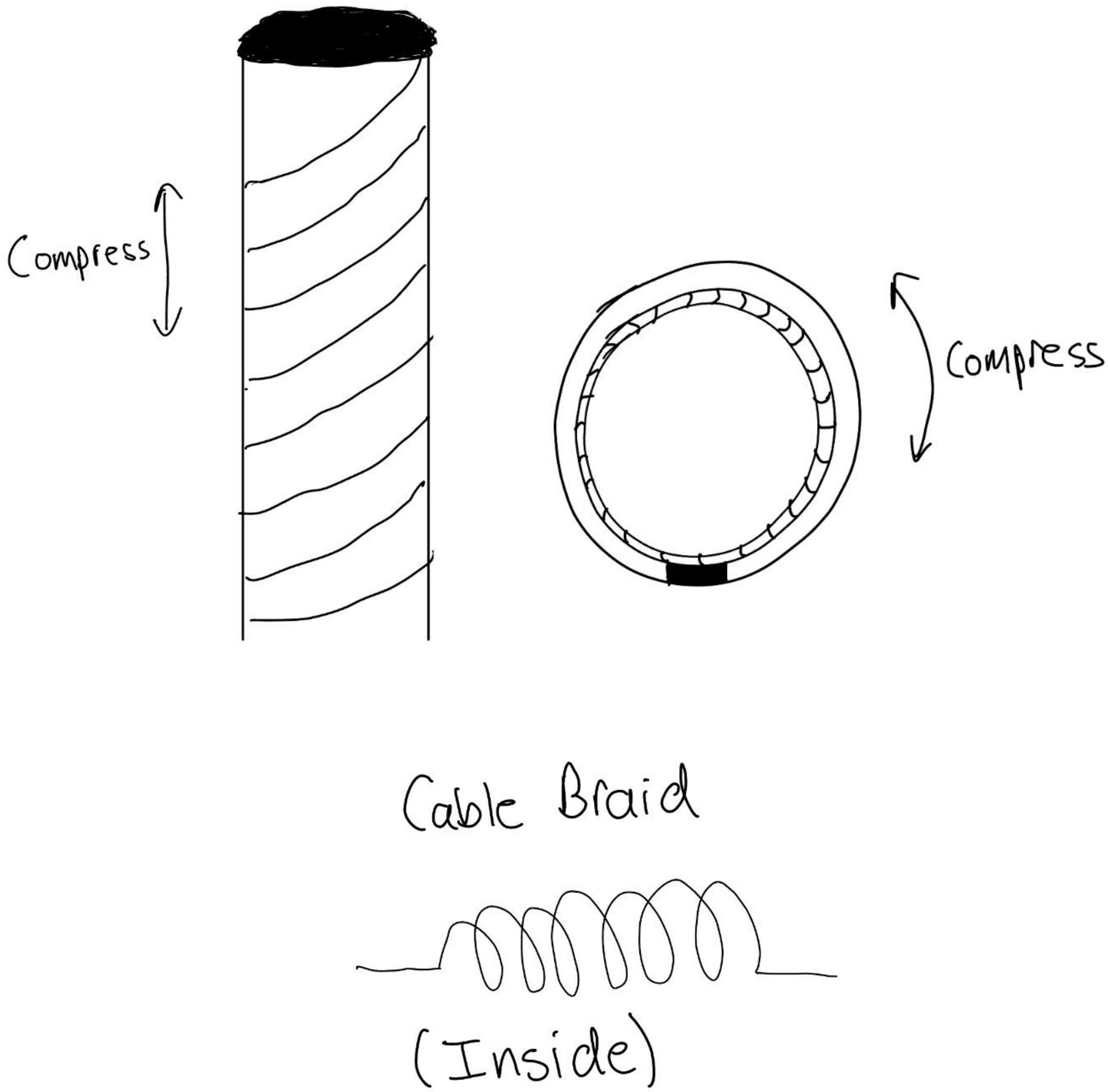
My first concept takes the fundamental mechanism found in outdoor real extension cords. Attaching to the midpoint of a wire or chord, the wire will be inserted in the two corresponding holes on the outside and once closed the top spinning mechanism will pull up the chord to fit inside the base and a latch will be implemented to keep them secured. The top section will be comprised of a rubber material to allow any size wire to fit inside but the latch will be metal to ensure it won't move. The main body and housing unit will be made of plastic if the testing doesn't run into any heat concerns. The product will be attached to the midpoint of the chord, but the distance needs to remain universal horizontally.

b. Concept 2:



The next concept will be slightly different to concept 1 and will use a servo motor or something similar in power instead to attach to the top of the chord (the side connected to the device) and will use a lever system to pull up the chord to the desired height, afterwards the servo will reverse direction and add a zip tie to the outside to ensure it won’t move during use. A housing unit will hopefully not be needed for the servo since the twist ties need to exit from there, but the attached lever mechanism will be made up of metal or plastic if strong enough.

c. Concept 3:



For the final concept we are using a completely different approach, instead using tension to store the cable, this design will be using compression instead. The Cable sleeve will first compress to the desired length you want, then after inserting the cable in the slot (black area on top view) the cable will be threaded along the walls to create a cable braid which will not remove any functionality but will only be the length that the user selects. This method will be made of a flexible material that maintains its shape once moved and will allow the cable to follow its path, once released the product will return to its original length while the cable will need time to straighten out before being able to re-enter the sleeve.

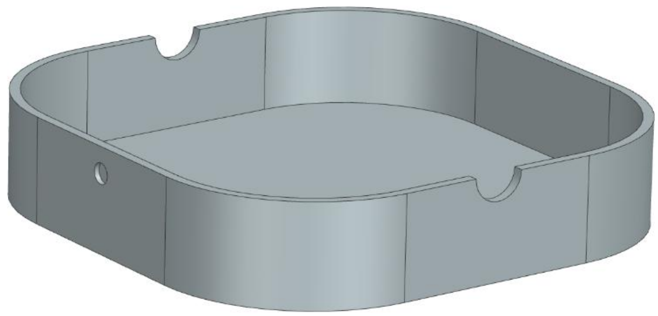
5. Design

a. Design Selection

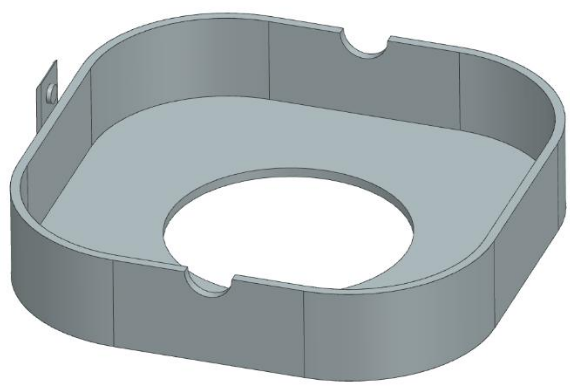
I selected concept two as my final design. Concept 1 would have been more efficient in reducing the time needed in order to compress the length of the wire, however it was more open to other issues like heating concerns and tension concerns. Even though it could have been potentially faster, you would need to specify the desired distance you wanted the wire to be otherwise the system would be prone to going further than that distance without the addition of a force stop option or an abort button, this would also cut the power entirely and cause the entire system to shut down. To combat this, we would need to spend about twice the initial budget for wiring and timing concerns with the motor and coding. Since affordability and hot-swapability were some of our main concerns to address I have decided not to select design 1 instead because it achieves the same final destination but with manual inputs instead, this allows the main features to be customer specific instead of fixed. I decided not to choose concept three because the material selection needed in order to implement the design would be very expensive. The material used in creating a moving mold for the wires is only seen in high level engineering dealing with hydraulics or gears like cars, airplanes, etc. With all this in mind, although concept 2 wasn't the most efficient when it came to reduced distance or time to reduce, and although concept 3 utilized the wires greater compression strength vs tensile strength to a greater degree, concept 1 still allowed us to stay in budget and maintained the final project statement to still be addressed.

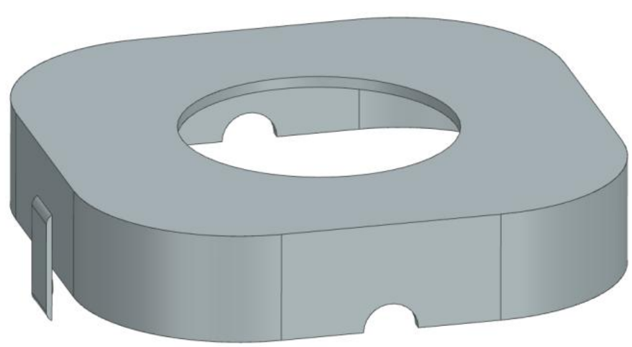
b. CAD Drawings

- Bottom Section:

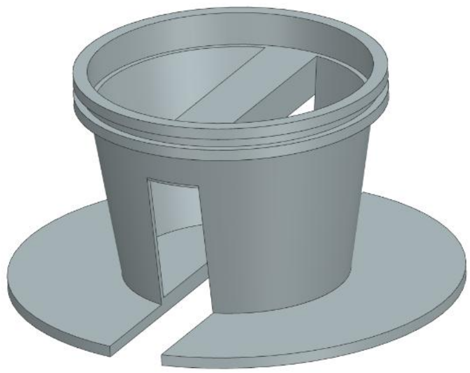


- Top Section:

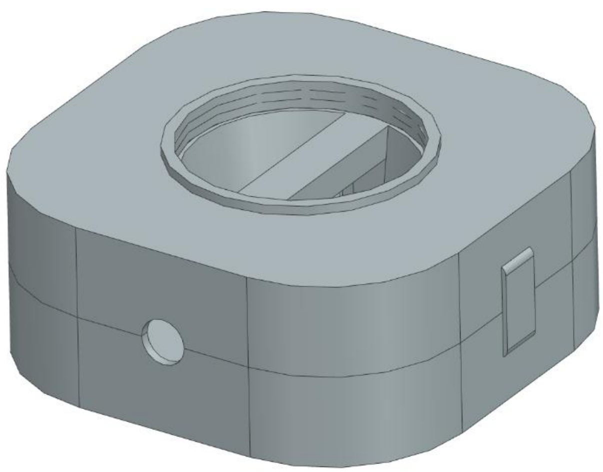




- Main Mechanism:



- Final Assembly:



c. Design Analysis

- Bottom Section:
  - This is the main housing portion of the device. It includes the area where the wire will coil up for storage and will be made of PLA material to ensure a steady foundation for the product to rest at any angle and in any required position. As seen in the image, the drawing also includes a latch indent for the piece to be connected to the top portion. It ensures that the wires will not pop up but still allows the need for efficient removal.
- Top Section:
  - The top portion of the assembly functions the same in a lot of ways as the bottom section however, the main latch component is located in this region. Another difference compared to the bottom section is that this is where the main mechanism will be attached, thus the need to include the exposed hole through the center of the device. This portion will also be constructed of PLA material.
- Main Mechanism:
  - The main mechanism is the region where the compression of wires will take place and also where the user will manually crank in order to reach the desired length of exposed wires. This section will be made of TPU material, allowing for greater tensile strength and more flexibility allowing us to maintain the desired strength of materials. This section includes grooves where the system will attach to the top portion and is the region of the assembly where any adjustments will be made.
- Final Assembly:
  - The final assembly when aligned will allow the wire to pass through the side hole, into the extruded section of the main mechanism and pass out through the other exposed hole. After the device is aligned correctly with the wires and the latching system has been closed, the user cranks the top rectangular piece of the main mechanism to reach the

desired length of exposed wires. The system's rotation works as intended but with NX limitations, the wire length reduction and compressions storage was not able to be shown in Simulation.

d. Loading Conditions

Since this specific configuration has variances for wire length, wire diameter, rotation speed, distance reduced, wire material, and tensile strength it is impossible to give all the specific loading conditions. Instead, we will be looking at the industry standard values and seeing if the factors of safety for PLA and TPU materials will cause any issues for the total build. These values will all be in ranges but to make sure we have no design faults we will be using the maximum properties to ensure availability with as many wires as possible even though every single cable ranges in total length.

- 5mm diameter wires:
  - Compression:
    - 5–15 MPa
  - Tension:
    - 5-10 MPa
- 10 mm diameter wires:
  - Compression:
    - 10–20 MPa
  - Tension:
    - 10-15 MPa

e. Factors of Safety

- PLA Material
  - 5 mm diameter Wires:
    - 57 (Mpa)÷15 (Mpa)=3.8

    - 10 mm diameter Wires:
        - 57 (Mpa)÷20 (Mpa)=2.85
- TPU Material:
    - 5 mm diameter Wires:
        - 70 (Mpa)÷15 (Mpa)=4.6667
    - 10 mm diameter Wires
        - 70 (Mpa)÷20 (Mpa)=3.5

[7]

f. Component Selection

For the product being constructed, since we will be using 3D printing to build the device, I firstly will be requiring filament and a 3D printer in order to achieve this. The 3D printer on campus will be used for the construction of the base and two different types of filaments will be used. One will be a PLA filament that is probably the most common type of filament used in 3D printing and is a durable and unflexible material. This will be used for the base and closing portion of the device to maintain the least variance in movement. Another filament type I will be using is TPU for the main mechanism of the assembly, this is a more flexible material and allows the compression of wires to be a non-factor when thinking about the strength of materials. TPU has a much larger maximum strength compared to PLA and this allows leeway for the wire's movement since it's not a fixed compression each time. Another component to look out for is a docking system when the product is being placed. This will be addressed with the use of magnets, sticky tape, or Velcro. Since we are very underbudget at the moment and these prices are negligible, I've ordered all three and will implement the most effective one in the final design.

6. Project Management

a. Product Budget

Proposed:

The first items included in the total budget would be the mold and material in order to make the first assembly. This can range from $20-$50 based on manual molds or simply 3d printing filament. This will range from concept to concept for the purpose of the section we'll call it $35. Next piece of material we need to order would be the latch and binding materials for the chord to keep shape. Metal pieces like this usually can be ordered in bulk for around $10. Again, we want the motor and casing which will be the hardest to price out since our concepts have a lot of different requirements. Once again, we can use motors ranging from a servo to a $10 to an AC motor which can go for upwards of $100. For the sake of this section and focusing on concept 1 we will include this for $20 and add it to the budget if this ends up taking too long. Finally, we want to include the rubber pieces we can mold which can be another $15. The total of our budget ranges from $50-$200 based on which concept we implement first and if we use manual process or something streamlined like 3d printing. One of the main requirements is to maintain affordability so we will initially try to minimize as much as possible and add on as necessary.

Actual:

TPU Material:	$25
PLA Material:	$15
Miscellaneous (magnets, silicone tape, etc.):	$15
Total:	$55

Comparing our actual budget to the proposed budget, you can see given the concept we chose to design we are on track to stay within the budget. Implementing either the first or third concept would dramatically increase our budget but given a 3D printer being available and the material being the most expensive component we have stayed within our budget. This also allows us to spend a little more on miscellaneous items like magnets and Velcro while still staying within budget and allowing more variability in the testing phase. The filament will last three to four design iterations as well so any additions needing to be made are already accounted for in the final total budget.

b. Project Schedule

Proposed:

Order Components	1/01/2025
Components Arrive	1/18/2025
Begin Molding and Assembly Process	1/19/2025
Finish Assembly	1/31/2025
Begin Testing	2/01/2025
Error Correcting	2/16/2025
Finalize Testing	3/01/2025

Actual:

Begin Assembly	1/06/2025
Begin Testing	1/17/2025
Finalize Edits	1/31/2025
Repeat Steps 1-3 for February and March	2/01/2025-3/14/2025
Finalize Report and Presentations	3/31/2025
Tech Expo	4/08/2025
Final Adjustments	4/24/2025

7. Fabrication Process

a. Iteration Process

- Iteration 1

For the first iteration I used the model created in the design portion. All testing was conducted using USB-C cables with differing lengths of 1m, 1.5m, 3m, and 5m. After the initial print, I examined that even after the 1m cable, the PLA already began to crack after multiple uses. The hinges also snapped when moving the housing unit in the horizontal direction. This is an issue because the mouse wires actively move, and any slight collision with the product could cause deformation with the hinges. So, before I began the next print, adjustments to the model were made including increasing the shell thickness to 2mm instead of .5mm as it was previously and increasing the diameter of the latch and hinges by double.

- Iteration 2

After the first iteration, I instantly saw a better success in the shell's durability with the increased thickness. The 1m reduced in length as intended but the hinges still proposed an issue with any slight movement in the horizontal direction. Keeping this in mind, for the next iteration I kept the model the same but tried to print the entire body out of TPU instead of separating between PLA for the housing unit and TPU for the rotating mechanism.

- Iteration 3

Following the testing from iteration two, I immediately ran another print and although the TPU allowed the hinges more flexibility in the horizontal direction, the hinges were no longer separable from each other, and the latches wouldn't connect. Even though the hinges no longer broke, the product couldn't properly close, so the device was no longer removeable or hot swappable. This was due to the

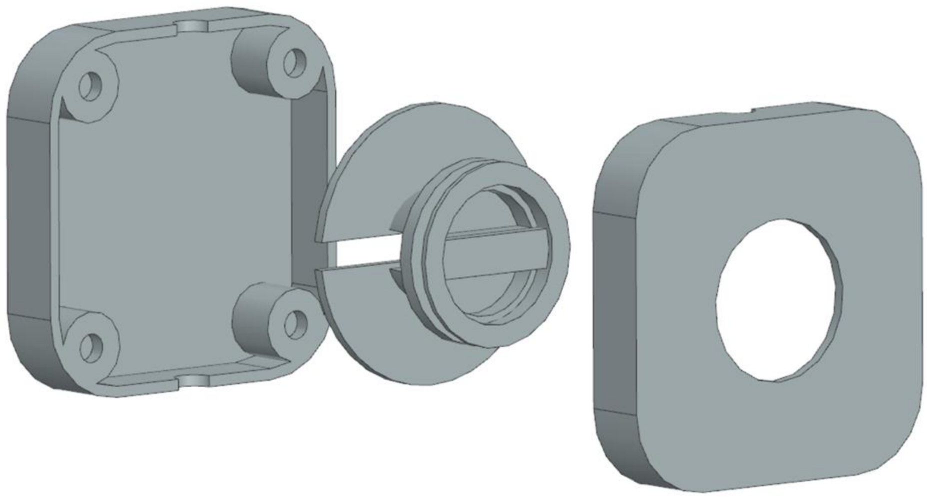
TPU filament extruding thicker than the PLA filament. Instead of dealing with the hinge issues further, I decided to make the device connect using magnets between the top and bottom.

- Iteration 4

In iteration four I finally had a product that worked as intended. The magnetic connection worked as imagined and both the 1m wire and 1.5m wire both successfully reduced in length. Durability was also maintained throughout multiple tests. Issues only arose with wires that were longer than 1.5m in length, although the 3m and 5m chords reduced initially, the volume of the inside was filled after 1.5m due to the magnet additions and any subsequent rotations would end up damaging the chords. Since I didn’t include a feature for the chords to lock in place, the only resolution that I found in the given time duration was to increase the size of the .stl file before uploading to the printer.

- Final Iteration

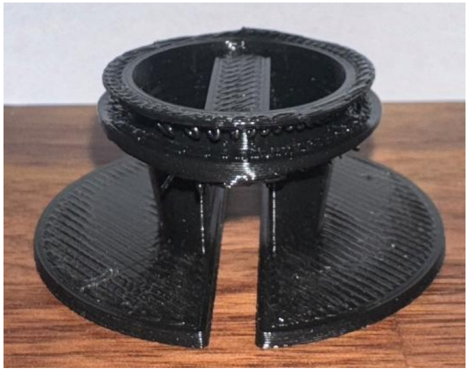
Final adjustments were made after some recommendations from our judges. They proposed adding a feature on the bottom to attach to the device. I also had this idea initially with Velcro attachments, but after success with the magnetic connection, I instead created the same magnetic connection that was used in the center of the device and mirrored it to the bottom. Some minor adjustments were also made including decreasing the rotating mechanism indent diameter for a more efficient detachment, having more precise supports in the printing file for a more uniform product, and filling hollow portions in the center of the main mechanism.

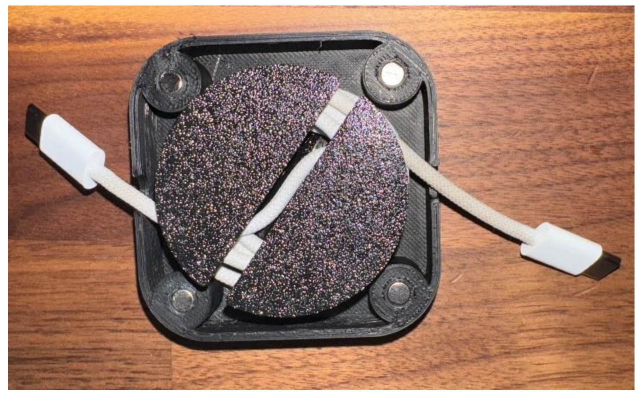


(final assembly model)

b. Conclusion

After the final iteration was printed, assembled and tested, a conclusion can be made that the product reached the desired objective of reducing the length of any USB type wire. For this iteration, the maximum distance that can be reduced is 1.5m in length and up to 5mm in diameter. Longer chords up to 3m in length can be accommodated by doubling the scale factor in the .stl file before printing. This also increases the hole diameter up to 10mm, but this is the maximum diameter the product can compress, any larger will result in the PLA material in the housing section and the TPU material of the middle rotating mechanism to start deforming. Chords longer than 3m can be reduced up to that length but once the volume of the housing unit is at maximum capacity the wires will start to cause damage to the main mechanism.



c. Future Ideas

Although I completed most of the goals that I initially assigned, there were some additions that couldn’t be made in the given time constraints. The first addition was creating a locking feature for the inside housing portion to keep the wires from freely moving once the desired length has been reduced, this could’ve accommodated for the chords that were longer than 3m without needing to increase the scale factor of the .stl file, but a clear method to include them without interfering with the compression wasn’t obtained. Another feature that was recommended by the judges from the Tech Expo was to include a stronger magnetic connection between the top and bottom portion, since the magnets I ordered were initially meant to create a docking feature between the base of the station and the device, the connection wasn’t intended but can be changed by a simple increase in diameter in the CAD model, the model for this was created but the magnets did not arrive in time to test. The last recommendation for future work I received from the judges was to create the device using metal material machining to create a more standardized product that can be sold commercially.

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