Automated Exercise Equipment for Accessibility:

Elevating Your Workout

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Abstract

Gym equipment is not required to follow ADA guidelines to ensure they can be used by people with disabilities. We have adapted one half of a dual-pulley machine to allow our sponsor, a paralympic athlete, to demonstrate these issues and push for change because the components used to alter these machines are often inaccessible. The height adjuster changes the angle between the weight and the user, allowing them to focus on different muscle groups, but if a user cannot reach the mechanism, they cannot use the machine, so we have automated and motorized that aspect. The weight stack requires users to move a small pin to a very specific position, so creating a raised system with linear guides to make that easier will allow users with hand dexterity issues to use the machine on their own. We hope these changes will make exercise more accessible for all.

1. Background

There were almost 1 billion people worldwide with chronic lower limb disabilities in 2017 (Ellapen et al.) This includes 2.7 million full-time wheelchair-users in the U.S., in addition to the many others who use wheelchairs part time or while recovering from medical issues (ADA Inspections). Yet, common spaces such as gyms often fail to accommodate them. The Americans with Disabilities Act (ADA) is the law that requires public accommodations for people with disabilities. This act was most recently updated in 2010, but several specific updates have been planned for 2023 (Hutton). Since gyms are often excluded from certain ADA requirements, a similar update may require more compliance in the future if enough need is demonstrated. Therefore, projects to demonstrate both problems with gym accessibility and to create solutions to those problems may inspire the ADA to increase accessibility requirements for gyms.

1.1 Gym Equipment Accessibility and ADA Requirements

Current ADA requirements around gyms focus on ensuring that the spaces are accessible to navigate. 2010 ADA Standards 206, 206.21, 206.5, 307, 401, and 404 ensure people with disabilities can enter gyms by requiring parking and entrances to be accessible by requiring accessible ramps and routes for people with visual impairments and wheelchair users (ADA Inspections). This is good for disabled people trying to get to gym spaces that are standardized for accessibility such as large indoor spaces like basketball courts (covered in 2010 ADA Standards 206.2.2 and 302.1) and swimming pools (covered in 2010 ADA Standards 242 and 1009) (ADA Inspections).

However, there are still many issues with standard gym design that are not addressed by these standards. Gyms are not required to train staff to safely transfer wheelchair users to equipment, to modify gym equipment to be accessible to users with disabilities, or to create accessible activities programming (Rimmer et al). Gym equipment is also not required to be accessible; 2010 ADA Standard 205, which requires all machines to have accessible user interfaces, has Exception 8, which specifies "[e]xercise machines and exercise equipment shall not be required to comply" with this standard (Department of Justice).

Therefore, gym equipment is not designed to meet 2010 ADA Standard 309: Operable Parts, which lays out requirements for anything people need to interact with to engage with a space (Department of Justice). This means that equipment is not required to have gaps large enough for wheelchair users to approach machines and maneuver around them as defined by 2010 ADA Standard 305 (Department of Justice). Additionally, access button panels, handles, and other mechanisms can be found at heights unreachable to wheelchair users because these systems do not have to comply with 2010 ADA Standard 308 (Department of Justice). Finally, mechanisms to adjust settings can be difficult to operate since they do not have to follow 2010 ADA Standard 309.4 which prohibits mechanisms that require more than one hand to use "tight grasping, pinching, or twisting of the wrist," or more than 5 pounds of force (Department of Justice).

Since exercise equipment does not need to meet these standards, very little gym equipment is manufactured with these standards in mind leading to barriers to fitness for many people with disabilities (Cunningham et al., Rimmer et al., Sharon-David et al., Turnock). Since manufacturers focus mostly on designs that work for gyms, physical therapy centers and disabled athletes with home gyms must pay higher prices to get more accessible, custom devices to fit their needs (Cunningham et al., Rimmer et al., Sharon-David et al., Turnock).

1.2 A Need for Specific Solutions in Strength Training

Standards around gymnasiums and swimming pools ensure aerobic exercises are available to people with disabilities including those in wheelchairs, but strength training requires equipment which is often much less accessible than these spaces (Rimmer et al., Turnock). This is an important distinction because strength training has specifically been linked with a variety of factors which can improve quality of life across multiple types of physical disabilities (Cunningham et al., Ellapen et al., Sharon-David et al.). For example, increased muscular strength can lead to full-time wheelchair users gaining the ability to lift themselves out of their chairs and move to another seat, increasing independence (Ellapen et al.). Low cardio strength training has also been shown to reduce pain, increase cardiorespiratory function, and improve wheelchair functionality (Ellapen et al.).

Strength training equipment often poses specific challenges for people with disabilities because of the aforementioned lack of ADA requirements. Many wheelchair users have trouble navigating through messy gym floors and scattered weight equipment to get to the user interfaces of machines, which are then out of reach (Cunningham et al., Sharon-David et al., Turnock). This need for help can create a mental obstacle which prevents people from working out (Sharon-David et al). While there are easy gym layout changes which would increase accessibility, many issues stem from the initial design of gym equipment, which is often created without accessibility in mind. Therefore, it is important to develop prototypes to determine if there are any difficulties manufacturers may need to overcome to make more accessible strength training equipment, or if simple solutions can create a large impact.

1.3 Our Design

This team was initially made aware of many of these issues by our sponsor, Steve Ferreira. Steve is a Paralympic athlete, influencer, and disability advocate with a passion for making working out more accessible. Since Steve has cerebral palsy and uses a wheelchair in his everyday life, our redesigns focus on ensuring that equipment follows ADA guidelines for wheelchair accessibility and motor dexterity.

We adapted a dual pulley functional trainer because of this strength training device's versatility and accessibility limitations. Pulley-based functional trainers allow users to change settings for the height of the pulley handle and the weight pulled, allowing users to customize their workout's intensity and affected muscle groups. Additionally, users can change out the handle grip to work out with one or both hands.

Current models for dual pulley systems do not accommodate disabled athletes, as the components used to alter the machine settings require users to have high hand dexterity, grip strength, and range of motion. The components that are most difficult and unsafe to use are the cable height adjuster and the weight resistance adjuster. Cable exercises requiring large angles place the device at unreachable heights, so the redesign of the system features a motorized lead screw application that can be used to automatically adjust the cable height from a position on the machine that wheelchair users can access. The redesign of the weight selector system stabilizes the weight pin using two linear guide rods, restricting pin movement horizontally and ensuring that the user only needs to move the pin vertically. We hope our efforts to demonstrate the difference our modifications bring will inspire gym equipment manufacturers to produce accessible equipment at accessible prices as this project continues into its second year.

Figure 1: Top: The unmodified dual pulley system. Bottom: The modified dual pulley system.

2. Accessible Weight Selection

The intensity of a pulley machine workout is determined by the weight setting on the machine. Dual pulley machines have piles of large, metal plates collectively called a "weight stack." Users move the large pin from a hole in one plate to another in the weight stack with one hand to change the weight lifted by the pulley. However, this pin has a tight tolerance to its hole, so there is very little wiggle room to slot it into place. Additionally, the machine requires the handle to be moved to a tight angle at the top of the machine for this pin to be moved, which requires users to reach the top of the machine.

These design parameters were chosen by the manufacturers to ensure stability of the device and to ensure the weight settings are not changed while the device is in motion, however, they also pose accessibility issues. The tight tolerance on the pinholes prevent the weight plates from shaking during a workout, but also makes the pin difficult to slot into place manually. While the pin's handle is small to prevent it from protruding too much, it is difficult to maintain a stable grip since users can only manipulate it with one hand. Additionally, the tight angle requirements on the pulley ensure the weight settings are not changed while the device is in use, but require users to reach the top of the machine to set up. Finally, the weight stack rests directly on the ground, putting many weight plates needed to change settings very low to the ground.

2.1 Our Solution

Our solution to these accessibility issues consists of two major changes: replacing the small pin with the pin assist subassembly as shown in Figure 2 and raising the weight stack's minimum height.

2.1.1 Pin Assist Subassembly Design

The pin carrier shown in Figure 2 consists of two main sub-assemblies: a pin carrier and linear guides. The pin carrier has a large handle which can be grasped with one or two hands. This allows users with grip strength issues to easily hold the pin in place. The linear guides allow the pin carrier to slide up and down when the pin isn't inserted into a block while restricting horizontal and rotational movement. This reduces the precision and motor dexterity required to insert the pin by keeping the pin aligned with the holes, therefore making our system compliant with 2010 ADA Standard 309.4's guidelines for motor dexterity requirements for devices (Department of Justice).

The pin carrier sub assembly consists of thirteen parts created via CAD then fabricated via manual mill, manual lathe, drill press, and 3D printing by team members, with tight tolerances chosen to ensure the parts would work with the existing dual pulley system. The pin carrier was tested and refined to ensure its pin moves smoothly in and out of the blocks, the pin assist subassembly moves smoothly up and down the linear guides, and the selected weights move smoothly with the pin assist system when the machine is in operation. Additional drop testing confirmed the system remains aligned within tolerances when in sustained operation at the maximum selectable weight.

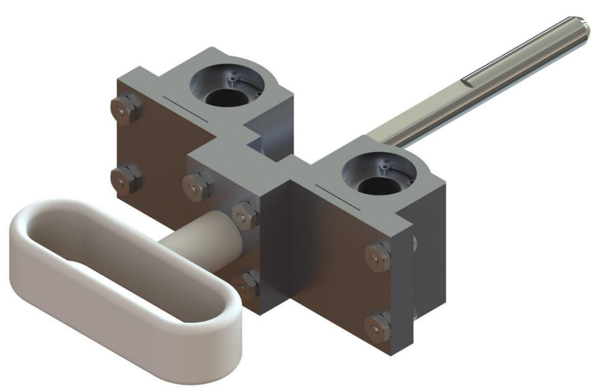

Figure 2: Top: The modified weight selector pin carrier, with large handle. Bottom: The full pin assist system.

2.1.2 Raised Weight Stack Design

The raised weight stack base was affixed to the machine at a height of 15 inches so every weight plate is reachable by a wheelchair-bound user as defined by the 2010 ADA Standard 308 accessible height range of 15-48 inches (Department of Justice). This is additionally helpful for users who may have difficulty leaning close enough to the ground to reach the lowest plates in the original configuration.

The raised weight stack base was machined by team members and then welded to the base of the machine. Drop testing confirmed the system remains aligned within tolerances when in sustained operation at the maximum selectable weight.

3. Accessible Height Selection

The height of the pulley grip handle on a dual pulley machine determines which muscle groups are used in a workout. This machine is designed to allow for workouts with a grip at up to 80 inches above the ground, far outside the reach range for many users with disabilities as well as shorter users. The height adjuster also allows users to do seated exercises with the machine while the grip is at less than six inches above the ground, which is outside the reach range for wheelchair-bound users and requires all users to lean close to the ground. This creates accessibility issues when the machine is left at a setting its next user cannot reach and therefore cannot adjust.

Additionally, the height adjuster requires multiple fine motor movements with two hands to change settings. Users have to hold the carriage in place while manipulating a pin with large pinch points where it slots into the carriage. Then, users must firmly grab the carriage and slide it to the right height while sustaining a tight grip on the pin to keep it out of the carriage. This design poses several accessibility issues since it requires sustained and rapid movement along with the use of both hands.

3.1 Our Solution

Our solution to these accessibility problems is to automate the height adjuster system.

Our modified height adjuster allows users to change the height of the pulley grip handle with the push of a button on a centralized panel within the 2010 ADA Standard 308 accessible height range of 15-48 inches, so the pulley grip handle's height will not make the system unusable to those who cannot reach the handle (Department of Justice). Additionally, the modifications result in a user interface that meets 2010 ADA Standard 309.4 by requiring no fine motor movements (Department of Justice). To automate this system, we modified the mechanical parts of the system by replacing the standard bar with a lead screw as shown in Figure 3, then motorized it.

3.1.1 Mechanical Design

Mechanically, the automated height adjuster consists of several important parts: the pulley, the carriage, the lead screw, the linear guide, and the couplers. The pulley was not modified in our design, but it set important design parameters such as required linkages, so it was important to consider the pulley as a part of the lead screw subassembly. The carriage is the part that moves up and down, adjusting the height of the pulley grip handle. The lead screw was chosen to convert the rotational motion of the motor into linear motion to move the carriage vertically. The linear guide helps keep the carriage on track and reduces wobbling in the system. Finally, the couplers attach to the ends of the lead screw to allow it to connect to the dual pulley machine and the motor.

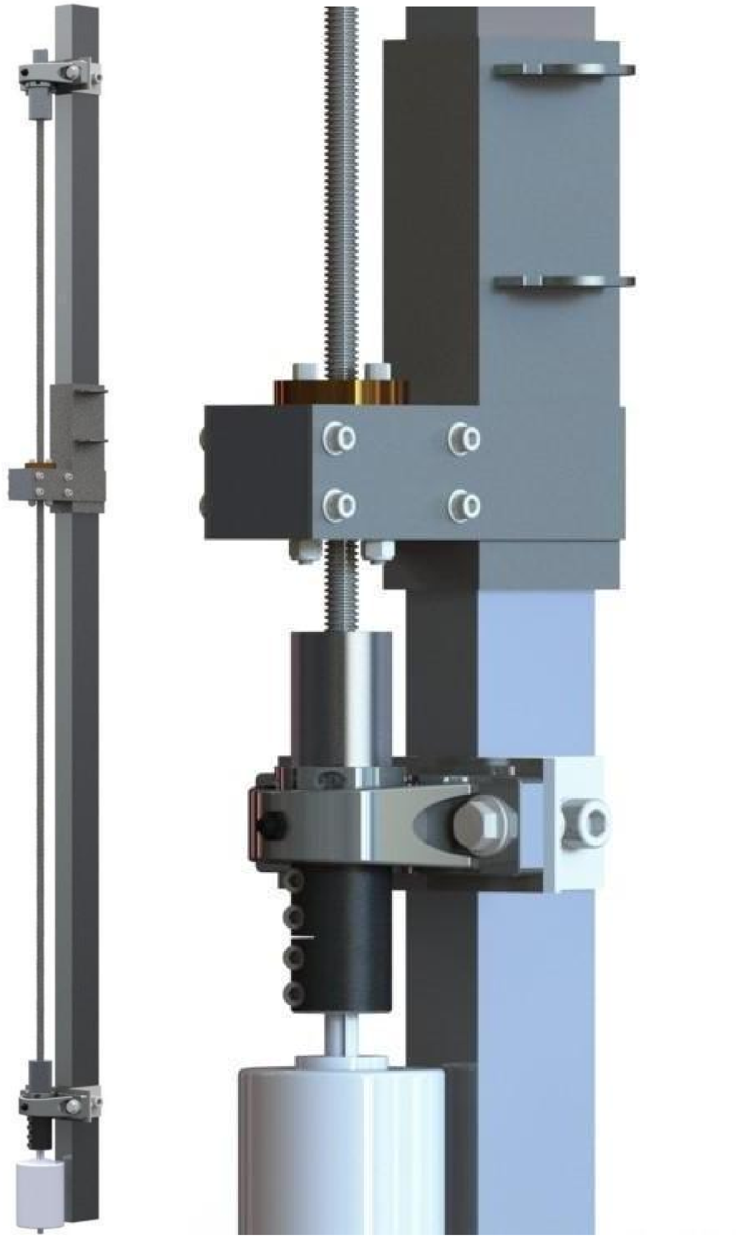

Figure 3: Left: The modified weight cable adjuster assembly in full. Right: Close-up of the modified cable adjuster.

An important part of our design is that the carriage needs to be able to move when users change the height of the pulley grip handle but must stay fixed in place during a workout. Therefore, we picked a self-locking lead screw, which is able to move the carriage when the motor forces the lead screw to overcome static friction, but locks both the lead screw and carriage into place when the motor stops.

Our modified cable adjuster's lead screw was chosen for its ability to resist buckling and shear stress with a high safety factor for our mechanism. The carriage was designed to be attached to the height adjuster subassembly, then machined by team members. Further calibration each time the dual pulley machine is reassembled reduces wobbling in the carriage's movement and ensures all parts are assembled to tolerance, but is not required between uses of the machine.

3.1.2 Electrical and Software Design

A control scheme is used to automate and monitor this machine as shown in Figure 4. The peripheral Arduino microcontroller uses a custom printed circuit board (PCB) to receive input from the button panel. These buttons include preset height settings and smaller height adjustments. Additionally, the standby button on this panel ensures that the height cannot be changed while the machine is in use by preventing input from being received without pressing it first. The main Arduino microcontroller uses its PCB to receive information from the peripheral Arduino, the limit switch, and the motor encoder. The limit switch at the bottom of the lead screw tells the microcontroller when homing calibration is complete. telling the system when the carriage is at its minimum height. The encoder tells the microcontroller the direction and amount of rotation the motor has completed so the device always knows where it is. Finally, the microcontroller uses all of this data to compute the number of rotations the motor should travel to move the carriage to the correct height setting.

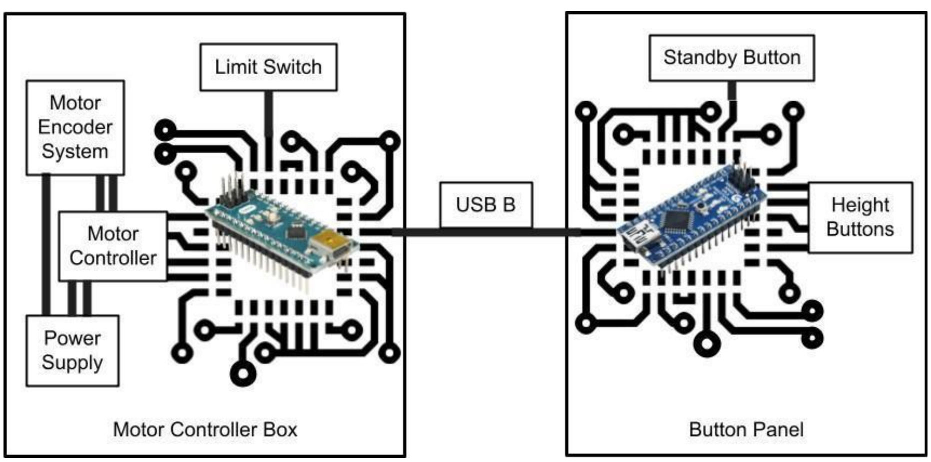

Figure 4: Electrical layout schematic.

The motor was chosen to ensure the torque requirements for the motion are met. It is able to move the carriage from the maximum to minimum height smoothly in under twenty seconds. The motor's controller communicates with the Arduino in its own serial language and transfers power to the rest of the system from a power supply which can be plugged into a standard wall outlet.

Power requirements drove the need to have two Arduino microcontrollers; since the button panel is about six feet from the motor controller box, it was essential that more secure serial communication via modified USB B cable was used between the PCBs to avoid voltage drop. The final electrical system is contained in two boxes with accessible buttons.

4. Future Directions

While the current team will not be continuing work on this project, there are currently plans to potentially continue this project if there is enough student interest and funding. We believe there are many directions this project could work towards, as the goal of increasing accessibility awareness in gym settings is very broad and important. We hope that the project is picked up again by future capstone teams so this project continues to attempt to inspire change in the fitness industry.

4.1 Further Safety Testing and Features

Our project was designed to be a lab prototype of this machine and was therefore tested under lab conditions for its ability to accomplish specific functions. However, more testing is needed to ensure this project is safe to be used in commercial settings. This testing should include ensuring the system meets the American Society for Mechanical Engineers standards for gym equipment, American National Standards Institute UL 961 (Standard for Electric Hobby and Sports Equipment), and American Society for Testing and Materials F2216-17a (Standard specification for selectorized strength equipment) so we can be confident this equipment is safe to use in the home (Malloci). Additionally, the team should analyze the wear on electrical parts like the motor and power supply to determine machine lifetime for components. Finally, adding more safety features to the system such as a casing around the lead screw would reduce the number of pinch points on the machine.

4.2 Developing an Accessible Pull-Up Bar

Many gyms only include pull-up bars outside of the 2010 ADA Standard 308.2.2 recommended obstructed height range of 15-48 inches (ADA Inspections). Since these are usually fixed, comparatively inexpensive gym equipment, we believe future work could include encouraging gyms to include pull-up bars at multiple heights or creating a mechanical solution that would allow users to select the height of their pull-up bar. This could be an automated system like our pulley height selector or a more analog process, but we believe that working to ensure pull-up bars are at heights accessible to all will greatly increase gym accessibility.

4.3 Partnerships

Since the goal of this project is to demonstrate the need for additional accessibility in the fitness industry, future work should include reaching out to fitness centers and gym equipment manufacturers to give this work a wider reach. We hope that future work will include demonstrating to these corporations that increasing accessibility may lead to increased gym usage, improved public perception, and increased profit. Ensuring our work is open source and accessible for physical therapy centers will also help to standardize these modifications for increased user safety.

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