Modifying a Standard Pushrim Wheelchair to move with Bicep Flexion

John Fitzpatrick
Mechanical Engineering
Senior Project 07-08
Advisor: Professor Rapoff

INTRODUCTION

Approximately one half of a percent of the American population outside of institutions are confined to using a wheelchair on a daily basis. Of these the vast majority use the standard tubular pushrim wheelchair for daily mobility, approximately 90%, who are called manual wheelchair users or MWU. A problem arises when a person must rely on using an on average thirty seven pound wheelchair to accomplish every day tasks instead of utilizing what humans have evolved to use for mobility, their feet. This problem is rapid muscle fatigue and inevitable long term muscle and joint problems.

The reason for these problems is due to having to perform a non-natural, repetitive movement that was designed to propel the wheelchair every day to be able to retain some degree of mobility. Approximately 900,000 people of the 1.6 million Americans who use wheelchairs are over the age of 65. As the human body gets older the amount of force one can apply diminishes, this is why senior citizens have the most trouble operating their wheelchairs for a substantial duration.

Seniors will often resort to other methods to propel their wheelchair to stay mobile such as having a nursing assistant push their chair or using their feet to slowly walk forward while remaining seated. Railings have also been mounted on the walls of the majority of nursing homes. Oftentimes seniors' alternative to using the tiring pushrim is to pull themselves forward with the use of the railings. A reason that seniors result to this last method of propulsion is that it utilizes muscles in the body that are more adapt to perform this repetitive motion instead of the muscles required in using a standard pushrim wheelchair. The motion used for the wheelchair relies primarily on flexion of the triceps and extension of the biceps. However the triceps muscle group is inherently smaller than the bicep muscle group, which means that they tire more quickly.

When these muscles tire it makes ascending hills much more difficult. For an operator to climb a hill they not only have to produce enough energy to overcome the static and kinetic friction forces in a wheelchair, but they also must produce enough energy to overcome the gravitational forces which oppose the ascent of the chair. To do this the user mush make shorter strokes in rapid succession on the pushrim to avoid rolling downhill. This means the user is does not have the ability to stop and rest while ascending a hill and will therefore become tired faster than when negotiating level terrain.

The goal of this project was to alter the design of a standard pushrim wheelchair so that it requires less energy put forth by the operator than the current wheelchair design. This design will utilize a different method for propulsion of the chair than the current method of flexion of the triceps. This would allow greater mobility, decrease the prevalence of long-term joint and muscle problems, as well as increase the handicapped person’s independence. This design does not require the use of a battery or a motor in anyway to propel the system meaning that the whole system will not add significant weight to the current model. Another aspect of the project was to design a mechanism which makes it easier for an operator to ascend steep hills and allows them to rest part way up the hill without descending.

BACKGROUND

Pain in MWU

Wheelchair users have a much higher risk of developing shoulder joint problems due to the repetitive nature of wheelchair propulsion. In one study 64% of the study group reported some sort of upper-extremity pain. Of the individuals who reported pain 32% reported that their pain was primarily in their shoulder. After five to twenty years of use they experienced up to an 85% increase in shoulder pain. This repetitive nature has been shown to alter the components of some of the stabilizing components of the shoulder. Along with shoulder pain wheelchair users can also develop wrist pain. Carpal tunnel syndrome has developed in 49% to 73% of manual wheelchair users. Some implications of these repetitive strain injuries are expensive medical interventions, loss of ability to perform activities of daily living, and disruptions in roles and routines. This increase in pain is understandable since the shoulder joint was not designed for wheelchair propulsion. An advance in wheelchair technology that would reduce the strain on the shoulder and wrist joints would result in a decline of the prevalence of repetitive strain injuries in manual wheelchair users.

Current Designs

There have been a number of advances in wheelchair technology since the modern wheelchair was created in the nineteenth century. These range from specific purposes such as a wheelchair for a one armed individual to the first foldable wheelchair in 1932. There have been advances in wheelchair technology but they mainly revolve around triceps flexion and bicep extension. Those that do not involve adding a system of motors and batteries that considerably increase the weight and can possibly decrease the mobility.

Most prevalent of the advances is the invention of the fully electric wheelchair which relies on a motor and a battery to operate. These batteries do have a large battery life and propulsion of the wheelchair needs virtually no energy to be supplied by the user. Another positive aspect of this particular design is that a person who only has one useable hand can still have mobility. One large drawback is the shear weight and size of the motor and batteries causing it to be cumbersome when trying to load into a car. Solutions to this problem deal with decreasing the unloaded weight while still providing a supplementary torque.

A pushrim activated power assisted wheelchair (PAPAW) is one of these solutions. When a torque is applied upon the pushrim the motor turns on supplying a supplementary torque. This allows a user with relatively weak triceps to navigate a variety of surfaces for long distances and reasonable speeds compared when they are using a standard pushrim wheelchair. There are a few negative aspect of the PAPAW, it weighs more than the simple wheelchair design, it relies on the triceps group for propulsion, and it uses batteries which are heavy and must be charged. Getting rid of the motor and battery would greatly reduce the weight but would completely negate all positive aspects of this design.

Recently in 2004 a new patent was approved for MagicWheels, a two gear wheelchair drive. This invention allows the operator to change from a one to one gear ratio to a two to one gear ratio with the rotation of a hand operated switch, figure 1. In the lower two to one gear ratio less force is required to propel forward, however, for every rotation of the pushrim the drive wheel rotates one half of a revolution. Although this design does not require the use of a motor and is therefore light weight, approximately ten pounds, it is very complicated, therefore expensive, and still relies on flexion of the triceps for propulsion.

Figure 1. MagicWheels Wheelchair

ALTERNATIVE DESIGNS

There were three main possible methods of propulsion were considered during the initial stages of the project. One was a simple alteration while the other two were complex and would require the user to get used to the new system which would be different from any current wheelchair. Figure 2 shows the commonly mass produced tubular wheelchair that the majority of MWU own. Attached to the larger wheel in the back is the pushrim where the axel should be almost directly below the shoulders of the wheelchair user.


Figure 2. Standard tubular pushrim wheelchair

Alternative Designs

The first method that was considered was altering the pushrim on a standard wheelchair to be a pullrim. This would be accompanied by moving the pullrim forward on the wheelchair to make the movement more ergonomical. Figure 3 shows the approximation of where the pullrim, in green, would be attached to the wheelchair. To have the drive wheel propel the user forward when the pullrim is being used there would need to be a reverse in the rotational direction. Installing a couple of gears would allow for this change in rotation direction. Power from the pullrim must be transferred to the drive wheel by either using a dive chain similar to that on a bicycle or a drive belt which are commonly found in cars. This method is simple and would only slightly cause a difference in the MWU's operation of the wheelchair.

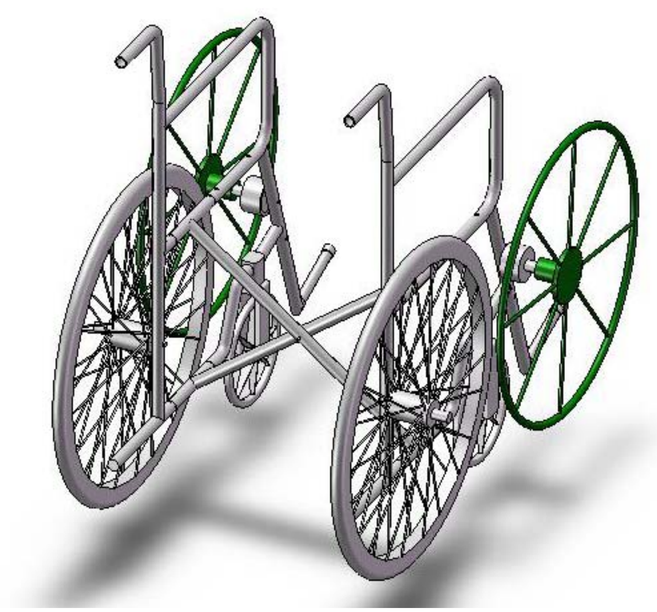

Figure 3. Wheelchair with pullrim

The second method that was considered to lessen the repetitive strain injuries that manual wheelchair users develop was to divide the necessary forces between the biceps and the triceps muscle group. A way to do this would be to use a combination push-pull mechanism. A complication this adds is that the wheelchair’s drive wheel would need to be able to freely rotate even when external forces are not being applied to the push-pull mechanism. To accomplish this a freewheel would need to bee added. A freewheel disengages the drive shaft when the drive wheel is rotating faster than the drive shaft. Another complication added is that if the wheelchair is driven by a push-pull mechanism there would need to be external breaks to allow the user to stop the wheelchair when desired.

A third design that was considered was instead of using the arm muscles to propel the wheelchair forward the user could utilize their larger leg muscles. This would only be applicable for a small portion of the wheelchair using community since a large majority of users have little or are completely lacking the ability to move their legs. However there is still a portion of the community that has mobility in their legs but are wheelchair bound for other reasons, such as those in nursing homes who result to walking their chair forward instead of using their arms. This design would also require that an external break be mounted onto the wheelchair to allow the user to quickly come to a complete stop.

The first design possibility has a number of positive aspects. Not many parts would be added thus decreasing the overall price increase that the purchaser would incur over a traditional wheelchair. It would also decrease the potential for a piece malfunctioning. The overall weight of the wheelchair would not change drastically from the average thirty seven pounds of most wheelchairs so there would only be a slight increase in the amount of work necessary to move forward in the chair. A final positive aspect is that it would change the repetitive motion used by the operator thus it might decrease the severity or delay the onset of repetitive muscle strain which causes problems like carpal tunnel syndrome and shoulder pain. One aspect of this design that would not be ideal is that the pullrim will impede the operators interactions with other people due to its position and size.

The other two design possibilities have similar positive and negative design characteristics. They would both require a number of parts which could drastically increase the weight of the chair thereby increasing the power necessary to operate. Adding external breaks, such as the ones used on bicycles, would also complicate the mechanics of operation. Since the major benefiting group of this project would be senior citizens that are wheelchair bound, complicating the mechanics would make it exceptionally difficult for them to operate. Another problem with either of these designs would be reversing. Seeing that the push-pull mechanism uses a forward and reverse stroke for propulsion then there would need to be another mechanism to engage if either of the drive wheels is to rotate in the reverse direction. The final negative aspect that they both share is that in adding all these components it would increase the footprint of the wheelchair, therefore decreasing the mobility of the user. Positive aspects of the push-pull design would be decreasing muscle fatigue by dividing the necessary input power between the triceps and bicep muscle groups equally. A positive benefit of the third design would be that a person's leg muscles would be used for propulsion which evolved to be able to handle more repetitive motion and produce more force.

Comparing the pros and cons of each design the final design that was chosen was the simplest; the push rim would be removed and replaced with a pullrim that was moved forward on the wheelchair. Keeping the design relatively simple allows for and easier fabrication and reduces the total number of moving parts on a wheelchair. Since they are used day in and day out the less movable parts the better because it will reduce the possibility that a part will malfunction and therefore decrease the life of a wheelchair. If a part did malfunction the user would have to consider repairing the part or purchasing a new costly wheelchair which might deter possible buyers in the first place.

Another addition to the modified wheelchair would be replacing the current wheel lock with an anti-rollback system where the operator can easily ascend a hill without rolling back down the hill. The wheel lock stops the drive wheel from moving in either direction when it is engaged. The anti-rollback system would only stop the chair from moving backwards when engaged allowing a user to climb steeper inclines and completely rest part way through the ascent. A study by an Edinburgh company determined how the amount of forced required when climbing slopes of varying degrees. Their findings can be found in table 1.

Ramp angle	90 kg load (50th percentile)		123 kg load (95th percentile)	
	Start force	*Sustained force*	*Start force*	*Sustained force*
4.8° [1]	78 N	74 N	107 N	101 N
12°	188 N	184 N	257 N	251 N
16°	248 N	243 N	339 N	332 N
20°	306 N	302 N	419 N	413 N
24°	363 N	359 N	497 N	491 N
28°	419 N	414 N	572 N	566 N

[1] Maximum angle recommended in inclusive mobility access guidance (Richardson and Yelding 2003)

Table 1. Calculated forces (N) for transporting 90 kg and 123 kg loads up ramps with various angles

They then took this data and compared it with data comparing an operator's weight and the forces that are acceptable to both males and females. This data can be seen in table 2.

Kerb	Ramp angles	Passenger percentile	Forces acceptable for…	Level of risk
Yes	11 – 17°	50th % ile	90% of males 50 – 75% of females	Low for males Moderate for females
		95th % ile	50 – 75% of males 25 – 50% of females	Moderate for males High for females
No	17 – 29°	50th % ile	25 – 75% of males 10 – 25% of females	Mod – high for males High for females
		95th % ile	10 – 25% of males <10% of females	High for males Very high for females

Table 2. Ramp angle compared to operator's weight and acceptable forces

It is evident from this data that as the ramp angle increases to anything greater than seventeen degrees the operator will have a difficult time ascending the ramp. If they were to have the anti-rollback feature installed on their wheelchair then if they were not able to climb the hill they would not be at risk for rolling back uncontrollably. Also they would be able to stop and rest part way through the climb, regain some strength, and try to finish ascending the incline.

FINAL DESIGN

Final Choices

With the final design chosen decisions needed to be made about what parts would be used in the assembly. The wheelchair is to be regular, tubular, folding Everest & Jennings base model wheelchair. This is one of the most widely produced wheelchairs available which is ideal so that few altercations need to be made to the majority of chairs to implement the design. Other parts that had to be determined were what type of gears to use, what type of power transmission to use, and which type of bearings to use to allow for lowest possible friction.

There are three types of gears that would be suitable for the application at hand. In this application the gears will be mounted on parallel shafts. The three ideal gear types that can be mounted on parallel shafts are spur gears, helical gears, and herringbone gears which are similar to helical gears which are depicted in figure 4. Each type has positive and negative aspects.

Figure 4. Three possible gear choices

Spur gears are cheap compared with helical gears due to the machining process necessary to create each type. Also unlike helical gears when engaged there is no axial thrust associated with them. Due to the angle of the teeth in helical gears when they are in use the right hand side and the left had side produce opposite thrust loads which need to be accounted for so the gears do not slip off the bearings. One way to account for this thrust is to use thrust bearings instead of regular ball or roller bearings. Spur gears are also more efficient than helical gears which would cause the drive wheel to slow less quickly than when a set of helical gears are used. Two major benefits of using helical gears over spur gears are the noise level, and the increased time of contact between the two gears. Due to the increased contact time there is a smoother transition from one tooth to the next also it drastically decreases the noise since the faces interact by one sliding across the other instead of rapidly coming into contact.

Herringbone gears are equivalent to one left handed and one right handed helical gear welded together. This type of gear has the same benefits as the helical gear, it is quiet, it can tolerate higher loads, and the smoother transition between teeth. Unlike helical gears, however, when herringbone gears are used the right and left handed sides produce equal and opposite thrusts therefore eliminating the total thrust and the need for thrust bearings. The only downside with using herringbone gears is that they are more expensive to produce than either spur or helical gears. Despite this one drawback herringbone gears are ideal for this implementation.

There are two main possibilities to transfer power from the pullrim to the drive wheel. One possibility would be to use a system of sprockets and a drive chain similar what is found on a bicycle while the other is to use a drive belt with pulleys, which are commonly found in cars. While a drive chain is made out of metal and usually heaver than drive belts it has advantages that outweigh this one disadvantage. Over an extended use belts can stretch causing them to be more susceptible to slippage, unlike chains which cannot slip. This would result in requiring more than one revolution of the pullrim to result in one revolution of the drive wheel. Also drive belts degrade faster than chains. The third advantage of chains over belts is that drive chains are narrower than belts allowing them to be put into tighter spaces reducing the increased footprint of the modified wheelchair. For these reasons, and the fact that a new drive chain can be purchased at a local bicycle store, a drive chain will be used to transfer power from the pullrims to the drive wheels.

The last design variable to chose was which type of bearings to use for the gears and the sprockets. Since large radial loads will not be acting on the bearings and their rotations per minute will not be high any type of bearing would suffice. One design constraint that does exist for the bearings is that they need to be double sealed so that particulate does not enter the bearing slowing it down due to the extra friction. Another constraint is to have a small profile allowing the gears and sprocket to be of a smaller size. Ball bearings and roller bearings both fall in with both of the constraints. Another type of bearing is the sleeve bearing which do reduce the amount of friction but not as much as roller or ball bearings. Double sealed needle roller bearings were chosen based on their small profile and their ability to keep out harmful particulate.

The Design

A model of the final design can be seen in figure 5, this is a too scale model of a Everest & Jennings wheelchair excluding the seat, backrest, and the foot rests. The large green wheel is the pullrim that was detached from the drive wheel and moved to its current location. The four maroon parts are the sprockets that will be used with the drive chain to transfer power from the pullrim to the drive wheels. In this model the sprockets available for download through SolidWorks were slightly oversized.

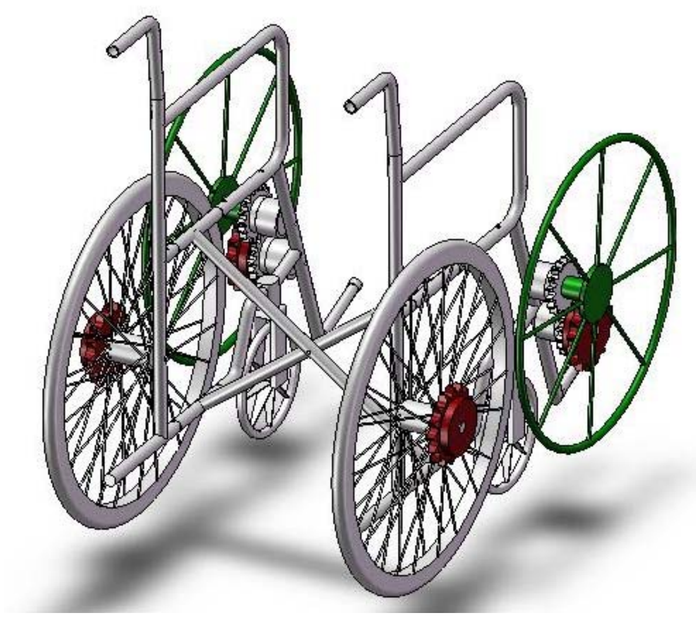

Figure 5. Final design

A close up of the gear assembly in the front can be seen in figure 6. SoilidWorks drawings of herringbone gears were not available near the required diameter so a spur gear represents where each herringbone gear would be attached, point 2. Point 1 is where the pullrim attaches to the front gear assembly. The herringbone gears, the sprocket and the pullrim would all be attached using set screws drilled into a shaft extending from the needle bearings.

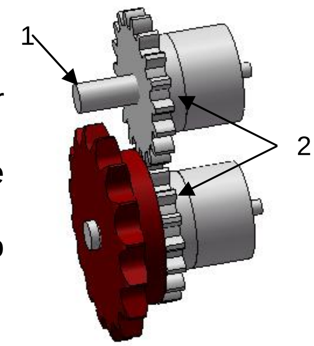

Figure 6. Gears and sprocket

During research for the project a patent was found that accomplished the anti-rollback for a standard pushrim wheelchair. This mechanism replaces the current wheel lock mechanism, outlined in red on figure 2, with the anti-rollback mechanism. this mechanism that was patented includes a handle to engage it which holds a small egg shaped cam onto the drive wheel. This cam can rotate in one direction freely but not in the other direction thus limiting the movement of the drive wheel to rotating in one direction when the mechanism is engaged. The operator can use this system to either allow the wheelchair to only move forward or only move back. This can be seen in figure 7.

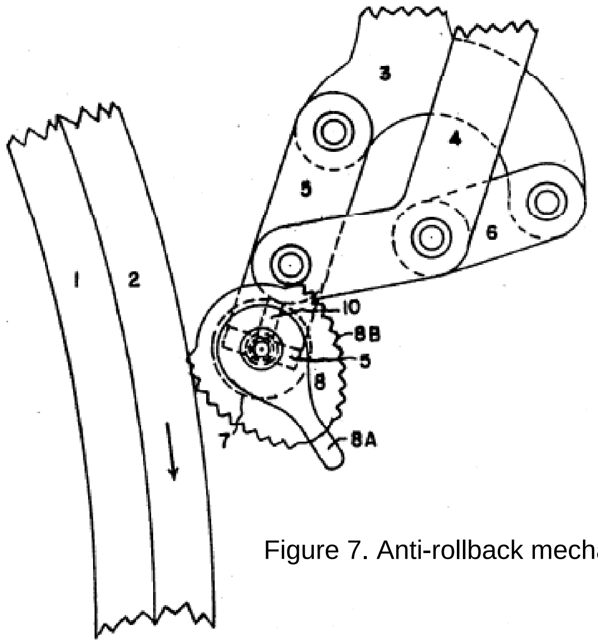

Figure 7. Anti-rollback mechanism

Future Work/Conclusions

Future work would involve ordering the parts necessary for completion, creating the anti-rollback mechanism in SolidWorks, and constructing the modified wheelchair. Due to the relatively low speeds and low radial forces being applied to the sprocket and herringbone gears almost any size could be used. An outside diameter of two inches for both the sprocket and gears would suffice and have a sufficient factor of safety. Any size of the needle rollers could be used and the only factor affecting that choice is the bore sizes for the gears and sprocket. After completion, the wheelchair would ideally be brought to a rehabilitation center to undergo testing for a few hours by an outpatient who would return constructive criticism and further ideas to improve the modifications.

Bussmann, Postma, Sluis, Bergen, and Stam. "Validity of the Detection of Wheelchair Propulsion as Measured with an Activity Monitor in Patients with Spinal Cord Injury." Spinal Cord (2005).

Cooper, Fitzgerald, Boninger, Prins, Rentschler, Arva, and O'connor. "Evaluation of a Pushrim-Activated, Power-Assisted Wheelchair." Arch Phys Med Rehabil (2001).

Digiovine, Cooper, Boninger, Lawrence, Vansickle, and Rentschler. "User Assessment of Manual Wheelchair Ride Comfort and Ergonomics." Arch Phys Med Rehabil (2000).

Middleton, Harvey, Batty, Cameron, Quirk, and Winstanley. "Five Additional Mobility and Locomotor Items to Improve Responsiveness of the FIM in Wheelchair-Dependent Individuals with Spinal Cord Injury." Spinal Cord (2006).

Middleton, Harvey, Batty, Cameron, Quirk, and Winstanley. "Wheelchair Use by Veterans Newly Prescribed a Manual Wheelchair." Spinal Cord (2006).