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Wheelchair Fatigue Reducer

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My name is Dennis Andre Norfleet, and I am a graduating senior in the Chancellor's Honors program with a Biomedical Engineering major and concentration. I was in a senior design group with Slater Pennington, Aaron Miller, and Matthew Wilson and our senior capstone design project was to create a fatigue-reducing wheelchair design. The proposed design system was to provide mechanical power assist proportional to user input torque. In the scope of the design it was my role to come up with the algorithm that would signal motor power assist once the user input crossed a pre-determined torque threshold. I was also responsible for coming up with the system of wiring that would make signal communication possible through an Arduino MCU, a motor driver unit, and a single-side hub motor.

My name is Aaron Miller and I was the team leader for the Senior Design Team "Atlas Design" during this last year. I am graduating this year in the Chancellor's Honors Program with a major in Biomedical Engineering. Our senior design project this year was to design a device that would reduce muscle fatigue in people who regularly use wheelchairs. I served as team leader and worked on conceptual design and computer modeling of the part, manufacturing of the design components, and assembly of the design. The final product was a design that provided mechanical propulsion via an electric motor that was activated when users reached a predetermined torque threshold. The following paper is our teams report of the project.

Executive Summary:

Our designated stakeholder has identified that he wishes for the design team to conceptualize a system for wheelchair uses that reduces fatigue and decreases the chance for chronic musculoskeletal issues. Some of the alternatives designs that were considered included a lever-arm type extension to allow more efficient power delivery for the user to the hand rim with the added benefit of ergonomic improvement and the incorporation of a speed control algorithm that increased speed command with respect to a greater torque input form the wheelchair user.

The design that we chose to implement is advantageous because a pre-determined torque threshold may be set and adjusted to prevent the wheelchair user from sustaining injury from over-straining muscles and because the torque threshold prevents the motor from being continuously activated. This not only saves battery power but also ensures that wheelchair users do not experience muscle degradation from lack of use. The designed electromechanical system consists of an electromagnetic hub motor, a driver that supplies power to the motor, an Arduino microcontroller unit, a breadboard for electronic connections, and 5 strain gauges. The proposed system will have the features of signal communication from strain gauges to an Arduino MCU, where the signal is to be processed and sent to the motor driver upon the strain signal exceeding a certain threshold. The motor driver will provide the hub motor with electrical power, which will activate it and allow it to provide mechanical work to assist the wheelchair user with propulsion. The ability of the system to meet manufacturing specifications will be confirmed by simulation in Solidworks and Simulink. The results of the coordinated system featured real-time strain measurement from the gauges situated on the aluminum faceplate. The next step in the process is the coordinate the serial data from the receiver to the Arduino MCU and making physical connections between the MCU and the hub motor.

Background:

The stakeholder requested that the designed product had the effect of reducing fatigue experienced by wheelchair users, while also straying away from the concept of a completely electric wheelchair. The literature associated with the conception of such a system included journal articles from clinical trials that estimated the amount of force exerted by a wheelchair user when propelling a wheelchair and the creation of an algorithm that provides torque from existing power assist e-bikes. The Alber e-motion power assist wheelchair delivers power to the wheelchair to assist users in all propulsion scenarios so the user gets the fatigue reducing benefits of the wheelchair but the motor is consuming more battery power so it is constantly being engaged. Alber emotion reviews have stated complaints of a snapping hand rim and user tipping backwards/forwards.

Figure 1: Alber e-motion power assist wheelchair. [2]

The Quickie Xtender wheelchair accessory addresses the fatigue of wheelchair users by using electrical power assist to increase user propulsion power by as much as a factor a four. Even though the Quickie Xtender has received generally positive reviews from wheelchair users who have tried the device its cost and design subject the product to some degree of constraint. The Quickie Xtender assist system cost around $5000-7000 and the device is limited to use on Quickie wheelchairs.

Figure 2: Quickie Xtender Wheelchair. [3]

The system we are proposing seeks to eliminate some of the problems associated with these competing wheelchairs. The novelty of our design arises from the adjustable torque threshold for wheelchair users and the ability to be fitted to a variety of wheelchairs.

Problem Definition:

The purpose of our motor and algorithm design is to alleviate the physiological stresses that are associated with high muscle straining and reduce fatigue felt by wheelchair users. A large consideration of our design included the design of a power assist wheelchair that is both novel and less expensive than those that are currently on the market. Current power assist wheelchairs, such as Alber e-motion M12 and M15 power assist wheelchairs, range in price from $3000-7700 (USD), so one of the intended goals of the design process was the choose materials and create a design that optimized costs. The designed system will be expected to output between 600-1200 watts of power that is directly proportional to the input power from the wheelchair user. The strain gauges to be incorporated operate between -20 and 60 ℃ and have a resolution of 16 bits. They sample strain/torque measurements between 1 sample/hour and 512 Hz. The motor driver is capable of receiving a 1.5-4.2 V throttle signal, which will have the expected response of a motor power/torque command that is directly proportional to the throttle value from the Arduino MCU.

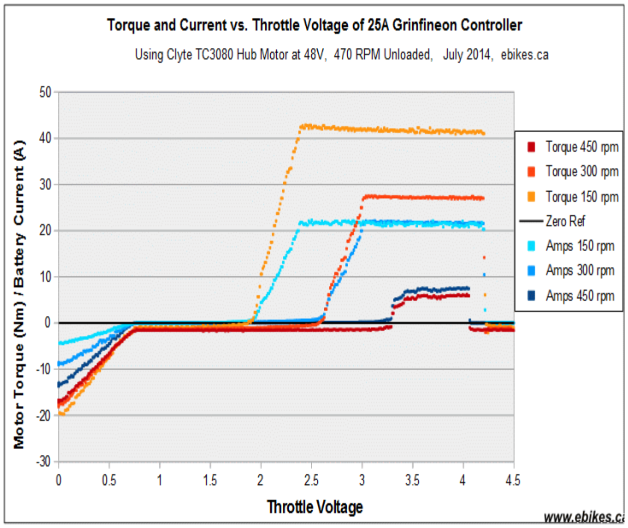

Figure 3: Relationship between driver throttle voltage and motor torque/battery current. [1]

The Arduino MCU will provide a throttle voltage via pulse-width modulation and the magnitude of the voltage signal will be determined by the duty cycle of the pulse-width modulated signal. The pulse-width modulated signal is the passed through a RC low-pass filter to convert it to an analog signal and passed to the motor driver. In order to ensure that the designed product meets performance qualification requirements the motor will be operated at its upper and lower limits of power consumption. This means that an object of comparable weight to a wheelchair user will be placed in the wheelchair and the algorithm controlling the Arduino/Motor driver system will be modified to deliver maximum and minimum power to the hub motor. This process will also reveal whether or not running the motor at maximum power introduces system overheating in either the hub motor itself or the motor driver. The maximum current input accepted for the Infineon NC-7225 motor driver is 25 amps and the maximum power output for the hub motor is 1200 watts. Maximum power output situations may also be tested by setting the pulse-width modulated duty cycle at 100%. To ensure that the attached aluminum faceplate and spokes do not break under high mechanical loads the product will be subjected to similar loads to those present during propulsion under high torque situations (i.e. climbing a steep hill).

To ensure the accuracy of the algorithm to operate in real world situations the strain measurements will be shown on a computer and the activation of the motor upon reaching the strain/torque threshold can be manually observed. Correct motor activation dynamics will be validated by attaching known weights (i.e. 10, 15, and 50 lbs) to the wheelchair handrim and observing whether or not the motor is activated. Torque calculations will be done by multiplying the value for the attached weight by the radius of the wheelchair handrim. The aforementioned processes may be reapplied when changes are applied to equipment, packaging, etc.

The ability of the designed system to meet societal expectations will be determined by wheelchair users themselves. They will be responsible for confirming that the system possesses ease of use, lack of jerk reactions, activation at physiologically stressful torques, deactivation below physiologically, and a noticeable power assist behavior that proportionally corresponds to increasing user input torque.

Some of the key sources that were used to integrate the power assist system include: The Arduino website, ebikes.ca, GRIN technologies, Dr. Paul Frymier, Dr. Daniel Costinett, LORD Sensing Solutions, Dr. Matthew Nalepa, Solidworks, and C++ formatting language.

Concept Development:

Our initial design would essentially follow the design for a traditional push-rim activated wheelchair, but would contain an adjustable lever along with a motor to create mechanical advantage for the patient. One goal of the wheelchair is to increase patient comfort using ergonomic principles. We planned to increase mechanical advantage by attaching the lever to the wheel and positioning it to optimize moment arm length while decreasing the amount of force and strain on the patient's shoulders, back, etc. This would act to effectively increase the patient's power output while decreasing range of motion. We planned to use to patient's power output to generate electrical energy, which can then be used to be the wheelchair motor. Our goal was to give the patient the option to switch between manual and motor-propelled locomotion in hopes of reducing his/her average metabolic consumption in daily use. Unfortunately, this design has already been implemented by multiple companies. These companies have not only made wheelchairs with this design, but also adjusted the design to accommodate several different lever styles. As seen in Figure 1 below, the lever can be attached to either the wheel as we proposed or in front of the user, much like a rowing machine.

Figure 4: Lever Propulsion Wheelchair [4]

From our initial design, we decided to try and keep our new idea of using a motor to propel the user, but we needed to come up with a new way for the user to generate the force needed to activate the motor. Thus, we decided to design a system that would allow the user to operate a wheelchair as they normally would, however the motor would allow our design to prevent the user from exerting too much force, thus causing bodily harm to their upper body. As seen in Figure 2, we intended for our design to use the force input from the user to activate the motor. The motor coupled with the user input will generate enough power to propel the wheelchair.

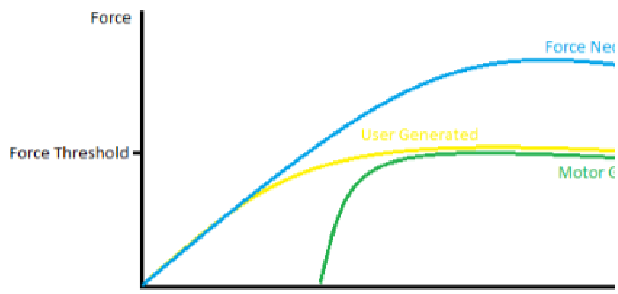

Figure 5: Graph of Expected Force by User Along with Motor

Thus, we were then tasked with developing a design in which our system would be able to detect how much force the user was exerting. As such, we came up with the idea to build a hub component that would house a system to measure the force being exerted by the user. Our design was a circular, hollow hub that would hold strain gauges that would detect the deflection of the hub when the user put force on the hand rim. The strain gauges will then be wired to a wireless transmitter that will be contained within the hub. The transmitter will then send the data wirelessly to a receiver on the motor, which will activate said motor when the measured strain reaches above a certain threshold. As seen in Figure 3, the strain gauges and transmitter will be housed in the large cylindrical center of the system.

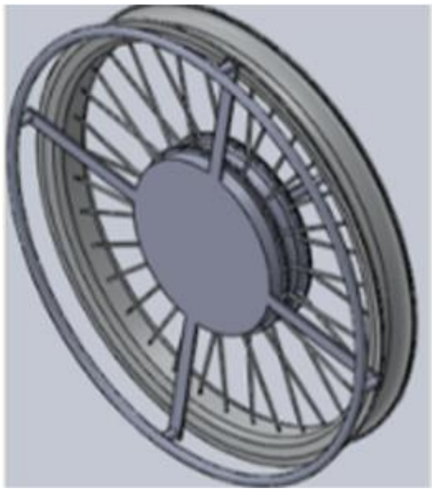

Figure 6:Design of Our System

Product Description:

As has been mentioned many times previously, the design has four primary components. These are the wheel, the motor, the hand-rim device, and the control system. For the purposes of this semester our team only developed the hand-rim device. The wheel and motor are available for purchase online and should be capable of connecting to the final product with relative ease. The control system is heavily involved with computer engineering and programming, so it is beyond the scope of our abilities as biomedical engineers. As such, the primary focus of our design process was the hand-rim.

The hand-rim device consists of three components itself. There is the material component that acts as a casing and a housing for the system, the strain gauges which were mounted to the system and are capable of recording stress and strain data, and there is the hub/node combination which transmits the information from the device to the onboard computer. Transmitter

The material assembly was made out of 6061 aluminum alloy. It was manufactured using two machines, which were a lathe and a water-jet cutter. Specific components were cut out using the machines and then were welded together in the MABE machine shop. The result was the device shown in the figure below.

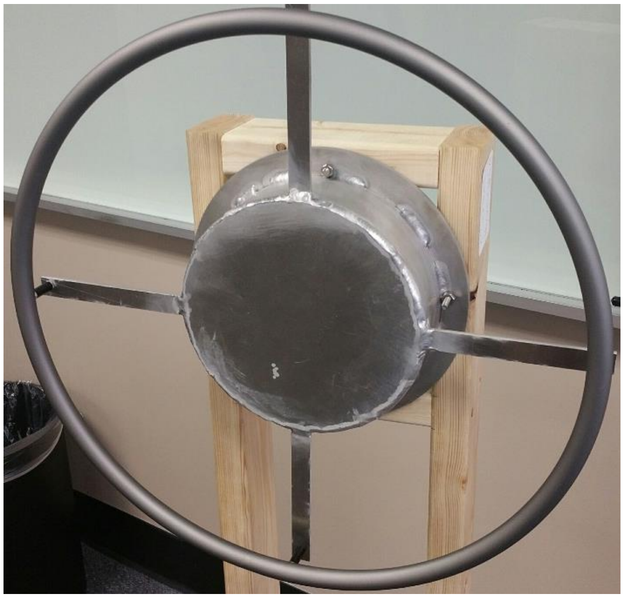

Figure 7: Completed Hand Rim Device

The next component was the strain gauges. The strain gauges that were chosen were rosettes that have been rated for aluminum. The rosettes were mounted in such a way that a full Wheatstone bridge was created across the part. The way the rosettes were mounted and wired allowed for the collection of average strain data across the whole part. This was beneficial for our use because it ensured that there was not one "hot spot" that would provide more assistance that any other location. A picture of the mounted rosettes can be seen in the figure.

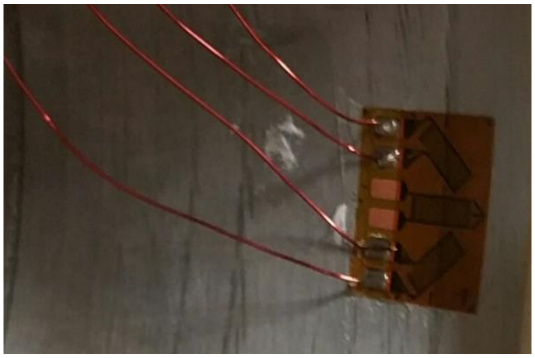

Figure 8: Mounted Strain Gauge

The last component was the wireless transmitter. This was necessary because a motor has a stationary and rotating component. In order for our device to function, one of the components would have to transmit data without being in physical contact with the other components. The method we chose to accomplish this was a wireless transmitter. The transmitter and the node that receives the data can be seen in the figure below.

Figure 9: Wireless Node by LORD MicroStrain

For the purposes of this part, the only components the user would interact with would be the hand-rim. The user, being a wheelchair user, would use the hand-rim to propel themselves forward, just as they would in their everyday life. In our future work, we will discuss a design that allows the user to adjust the amount of assistance they receive as well as the amount of tolerance between the wheels that will be allowed. This would add another component to the user interface, but as of now, no such system has been implemented. The limited user interaction with the majority of the components of our design is beneficial in that it should prevent the failure of our product due to user error. If the only interaction the user is having with the device is the hand-rim, then there is little room for error. The components all come together in an order of operation that is shown by the diagram below.

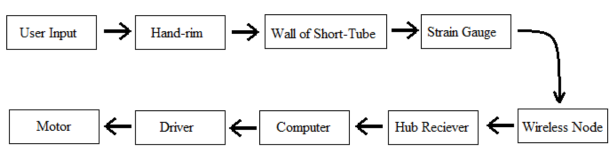

Figure 10: Order of Operations

Our device supports two novel concepts that are at the very least, new to the concept of wheelchair assisted motion. The first novel concept was our initial method for measuring torque. This method of using strain gauges to measure torque in cylindrical devices is certainly not a new concept. However, the idea that the concept could be integrated into a wheelchair power assist design is entirely new. The benefits of this design with regards to the previous designs are numerous. The first is the accuracy of torque measurement. Previous designs relied heavily on one sided torque measurement systems that didn't allow for accurate measurements of strain or torque. The second benefit is fatigue life. Many of the systems we encountered had moving components which would greatly decrease the lifetime of the part and the accuracy of the device over time as the part is used. Our design was stationary and as strain gauges have an extremely high cycle fatigue life, there would be no reason to fear that our design would fatigue. Another flaw in previous systems that our device addressed was the exposure to potentially harmful environmental hazards. Being on a wheelchair, all devices will be exposed to the weather, water hazards, heat and cold, physical trauma, and many other hazards, however, our part accounted for each of these possibilities. The casing that contains all the components would be waterproof and would protect the part from any physical trauma. In these ways, our novel idea far surpassed the systems we had seen implemented in the past.

The second novel idea we had was transmitting the data wirelessly. This idea came of necessity because the device we were building could not function while being fully wired. The concept of wirelessly transmitting data is, once again, not a new concept, but it is a new concept for wheelchair assistance that opens up a lot of possibilities for wheelchair devices in the future. All the systems we encountered were wired from their sensors to the controller. Not being wired gave us a couple benefits. The first was that it allowed us to use a torque sensing device that was considered much more accurate and effective than previous installments. The second is that the device can always be adapted for more uses in a wireless world. This opens up possibilities for the future of the device, such as communication with cell phones. There are some downsides to wireless transmission, such as the loss of data, time delay, and interference issues, but we feel as though the benefits outweigh the downside.

<u>Design Evaluation:</u>

There was only one test conducted thus far on the wheelchair fatigue reducing prototype. This test was to evaluate the use of strain gauges, placement inside the aluminum hub, and the overall design of the outer hub to attach to an already acquired motor. First to cover the use of strain gauges. Through the research they were shown to be the best device to measure the strains associated with the hub when a torque is applied to the hand rim. Solidworks simulation with a 10-pound load showed that there were strains throughout the hub. This became the location for the strain gauges and were determined to be placed in a 4 node Wheatstone bridge arrangement around the inner face of the hub. The strain gauges were wired in to a wireless transmitter to avoid tangling wires when rotating in a real world scenario.

The test was conducted as a multiple series of applying torques to the hand rim to see what sort of signals are being transmitted. The ideal signal would be displayed as a single baseline when the system is at rest, a positive direction of strain when a force is applied in growing magnitude, and a negative direction when the force decreases from a reduction in magnitude. The testing was done multiple times with various individuals and different magnitudes, ranges, and intervals of force application. One instance of torque can be seen below, where the decrease indicates a decrease in recorded current due to increased resistance.

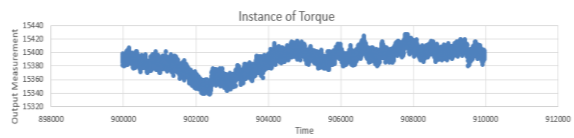

Figure 11: Instance of Torque

Several observations were made during testing. First noise was seen from the start which could have been attributed to a large amount of actual noise in the testing area. Next was when initial testing began the data showed large spikes that did not truly appear to return to a baseline but rather showed increasing jumps to higher and higher levels after the initial spike showing that the strain gauges were reading an applied torque. After a period of time the system actually leveled out to the previously defined constant baseline. After this was established the strain gauges began to accurately represent the forces and torques of the system. This included being able to identify when the torque was applied at different intervals and with increasing magnitude as shown by the width of the “curves” produced. A final observation was that a signal was generated when the arms were pulled or pushed parallel to the axis the wheel will sit on.

The next part is to look at potential failure modes of the current design. The first would be the welds made to hold everything together. Over time welds can weaken especially when under repeated stress associated with large torques. This could lead to a catastrophic failure where the hub and the hand rim are removed from the wheelchair which could seriously injure the user. The second failure mode is the wires of the strain gauges. They are wired up to the transmitter with very thin wire and soldered to the strain gauges. Any form of a jostle such as striking a large bump unaware could remove the wires from the strain gauge. Third is the size of the hub specifically the thickness of the walls. If the walls are too thin or long the torque could cause the part to fail resulting in larger values for the same input torque as time and use progress. Fourth is the structure of the arms and effect on strain gauges. Similar to the hub, the arms could also warp from use. Since the arms are connected to the hub any weakness could result in the torque not being effectively applied and cause the user to have to exert more force before the power can be applied to the motor.

The prototype cost in this experiment was around 400$. 125$ of that came from the strain gauges. The metal used in the design, the cost of using lathes and waterjet cutters, and mounting hardware as well as welding would be a variable cost of where the work is coming from and how much is used. The wireless transmitters and software cost could be variable based on exactly what is desired in additional prototypes such as low cost simple transmitters and very basic software which could be used for multiple prototypes so it could be considered negligible.

Overall this prototype met what was wanted for a prototype design and confirms the legitimacy of this system. A signal was generated when a torque was applied that did match up to the force being applied up until a certain point where any more force did not really move the line but the strain did return to a base line when the force was removed. This proves that the strain gauges are a viable option compared to existing techniques such as springs which can be easily damaged.

Recommendations and Future Work:

The above section mentions all of the features that prove this option can perform very well when compared to the other designs. The whole system can be bolted on to an existing motor with a few modifications to the motor casing. This also allows the hub to be easily accessed to work on the transmitter, strain gauges, and wiring should anything arise. The hand rim will be removed from its normal position on the wheel to be attached to the arms on the hub using the same hardware. Portions of the arm nearest to the hand rim need to be filled down and optimized to be sure the user does not injure themselves.

Recommendations and future work would be first to start testing with different techniques and designs of the hub assembly including dimensions and materials. This testing will further investigate the best design to optimize strains without sacrificing structural integrity or longevity of the system. Next would be to find the proper placing of the strain gauges to ensure that the only measurement being detected is the torque and not the effect of the arm's movement parallel to the axis of the wheel axle.

The next steps in the process after finding the best combination of factors to get the best results out of the strain gauges and the transmitter. Signals in the software can then be used through several tests for known forces and known torques to get a range of values that can be used to send signals to the controller to tell the motor to turn on and what the power output should be based on how strong of a torque is being applied to the rim.

Once the process has been determined and all of the computational parts are finalized then there leaves assembling the final product. The hub component will have to be attached to the motor assembly. While this is being worked on the design of the wheel should also be determined. Such as if the whole assembly should be made from scratch or if there is a way to make it a bolt-on style of motor that can attach to the existing factory issue wheel. The motor casing would have to be redesigned to allow the hub to attach securely. The final piece of the puzzle is to see how the signals interact with two signals. In addition, tests should be done to look at what kind of signals occur when braking or turning to enhance user control over the system.

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