Modification on the Torque Sensor Based Electrically Assisted Wheelchair with Dedicated Solar Charger Kit to Enhance Performance in Association with the Center for the Rehabilitation of the Paralysed

By

Pronob Sarker
15121025
Nafis Al Bari
15121035
Ishtiak Ahmad Zim
15321022
MD. Abdullah Al Mohaymen Rafi
19121150

A thesis submitted to the Department of Electrical & Electronics Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical & Electronics Engineering

Department of Electrical & Electronics Engineering
Brac University
April 2019

Declaration

This thesis is based on the modification of an existing electrically assisted wheelchair with torque sensor technology and hence, is based upon the work of a previous thesis group. However, we hereby declare that the research and modification work done for this thesis is completely our own work and has not been presented elsewhere for assessment. All external material used for this thesis paper has been properly acknowledged and referred.

Student's Full Name & Signature:

Pronob Sarker 15121025	**Nafis Al Bari** 15121035
Ishtiak Ahmad Zim 15321022	**MD. Abdullah Al Mohaymen Rafi** 19121150

Approval

The thesis titled "Modification on the Torque Sensor Based Electrically Assisted Wheelchair with Dedicated Solar Charger Kit to Enhance Performance in Association with CRP" submitted by

1. Pronob Sarker (15121025)
2. Nafis Al Bari (15121035)
3. Ishtiak Ahmad Zim (15321022)
4. MD. Abdullah Al Mohaymen Rafi (19121150)

of Spring, 2019 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical & Electronics Engineering on April 25, 2019.

Examining Committee:

Supervisor:
(Member)

Dr. A.K.M. Abdul Malek Azad, PhD
Professor, Department of Electrical and Electronics Engineering
BRAC University

Program Coordinator:
(Member)

Dr. Saifur Rahman Sabuj, PhD
Assistant Professor, Department of Electrical and Electronics Engineering
BRAC University

Departmental Head:
(Chair)

Dr. Shahidul Islam Khan, PhD
Professor and Chairperson, Department of Electrical and Electronics Engineering
BRAC University

Abstract

For millennia, physically challenged people have had to find different means to live their daily lives. In the early times, most of the used methods were very inconvenient and needed constant aid of other people. With time, however, these methods have been improving constantly and with the dawn of the revolutionary wheelchair, the hardship of physically challenged people was reduced a great deal. Although it is uncertain, the first known wheelchair is said to be made in 1595 in Spain, and since then with the advancement in technology, the wheelchair has come a long way and today's sophisticated wheelchairs make life for physically challenged people very convenient. However, these sophisticated wheelchairs are also very expensive and unaffordable by the financially unprivileged people of the third world countries. Hence, an idea was proposed to produce an electrical wheelchair with integrated torque sensor technology which would ensure longer battery life and cut down overall costs and therefore, would be more affordable and convenient for the unprivileged people globally. The wheelchair was successfully produced, however had certain limitations and inconveniences. This thesis paper is about the modification works done on the existing torque sensor based electrically assisted wheelchair with dedicated solar charger kit to enhance performance.

Keywords: physically challenged; wheelchair; financially unprivileged; torque sensor technology; dedicated solar charger kit; modification;

Acknowledgements

Sincere appreciation and gratitude goes to our thesis supervisor, Dr. A.K.M. Abdul Malek Azad, Professor, Department of Electrical and Electronics Engineering, BRAC University, for his constant guidance, mentorship, support and supervision over the thesis. Furthermore, we also appreciate all the help of our Project Engineer, Shafiul Amin, for all his support and assistance. We also express gratitude to BRAC University for giving us a platform to conduct the project and allowing us to use some necessary components from the laboratories. Last but not least, we appreciate the assistance we have received from some of our friends during this project.

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Chapter 1

Introduction

1.1 A brief history of wheelchairs

There are millions of physically challenged people around the globe and with the passage of time and the developments in technology, life has been becoming less and less difficult for them in terms of movement and many other aspects. Even in the ancient times there were certain ways that were used for the movement of paralyzed people; these ways improved bit by bit over a long time and eventually led to the wheelchair. The manual wheelchair was a major breakthrough in this field and gained worldwide popularity and was used everywhere on the planet. However, with further development in technology, people thought of improving the manual wheelchair more and more as the original manual wheelchair was very energy consuming for the user as they had to rotate the wheel by their own hands. These issues led to further research and with the advent of the electrical wheelchair, life for physically challenged people has become mucheasier in comparison to how it was before.

Physical disability in human beings dates back to prehistoric times and people have always found ways of dealing with it. Recorded history does not quite tell us when and where the very first wheelchair was made or at least where the idea originated. As far as known, an image of a wheelchair-like vehicle has been found carved on a Greek Vase back in 525 BC [6]. Later, sometime in the 6th century, pictures of wheelchair-like transportation vehicles were found carved into stones in China [6].

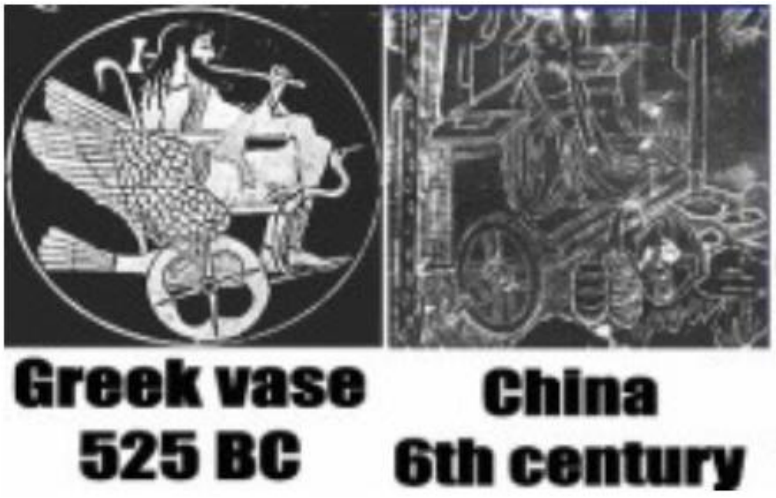


Figure 1:Pictures of wheelchairs carved in vases and stones

Recorded history says the first wheelchair was made in Spain in the 16th century (1595) for the Spanish king Philip II [8]. However, the inventor of this wheelchair remains unknown to the world. It was a very simple wheelchair with normal wheels attached with a normal chair and a distinct place for placing the feet. It also had an adjustable backrest. The chair could not be propelled by the user and was called “An invalid’s chair” [8]. Not too long after that, in 1655, a paraplegic German watchmaker named Steven Farffler invented a wheelchair for himself[8]. He was only 22 at the time of invention. His chair was a tri-wheeler with handles that could be self-propelled. Afterwards, in 1783, a wheelchair with two large wheels in the back and a small wheel in the front was invented by John Dawson in England[7]. The wheelchair was named “The Bath Wheelchair” after the name of the town Bath. The first motorized wheelchair was attempted in 1912 that consisted of an engine attached to a tricycle[7]. Later in 1916, the first power wheelchair to go into commercial production was manufactured in London [7].

In 1932, for the first time, the earliest version of the modern folding wheelchair was made by Engineer Harry Jennings [8]. He designed it especially for his friend Herbert Everest who was paraplegic. It was a tubular steel wheelchair that ruled over the market for decades. Harry Jennings and Herbert Everest co-founded the Everest and Jennings Company that kept on selling this wheelchair and made quite the name and fame in the contemporary wheelchair industry [7].

George Klein, a Canadian inventor, along with his engineering team, invented electric powered wheelchairs to assist injured veterans after World War II [7]. The Everest and Jennings Company mentioned earlier went into mass production of electric wheelchairs in 1956. Since then, with advancements in modern technology, wheelchairs have been becoming more and more sophisticated. Today's wheelchairs can stand up on two wheels, travel up and down stairs and can even be controlled by the mind using brain computer interface.

1.2 An overview of the original wheelchair to be modified

Although the electrical wheelchair was a revolutionary invention, it was very expensive and therefore not affordable to most people in the developing countries. Hence, a modification on the electric wheelchair was proposed which would improve both the battery's performance and longevity and also cut down overall costs. The proposition was to implement torque sensor technology on the existing electrical wheelchair so that the users could rotate a torque sensor pedal and this energy would be converted into voltage and be fed to the motor as an additional input with the main battery [1]. This technology has shown remarkable improvements on the battery performance and longevity as the energy consumption from the battery is reduced because of the additional muscular energy input [1]. The vehicle covered a longer distance than before and the state of charge remaining in the battery was higher [1]. The basic structure and measurements of the original tricycle are shown in the pictures below.

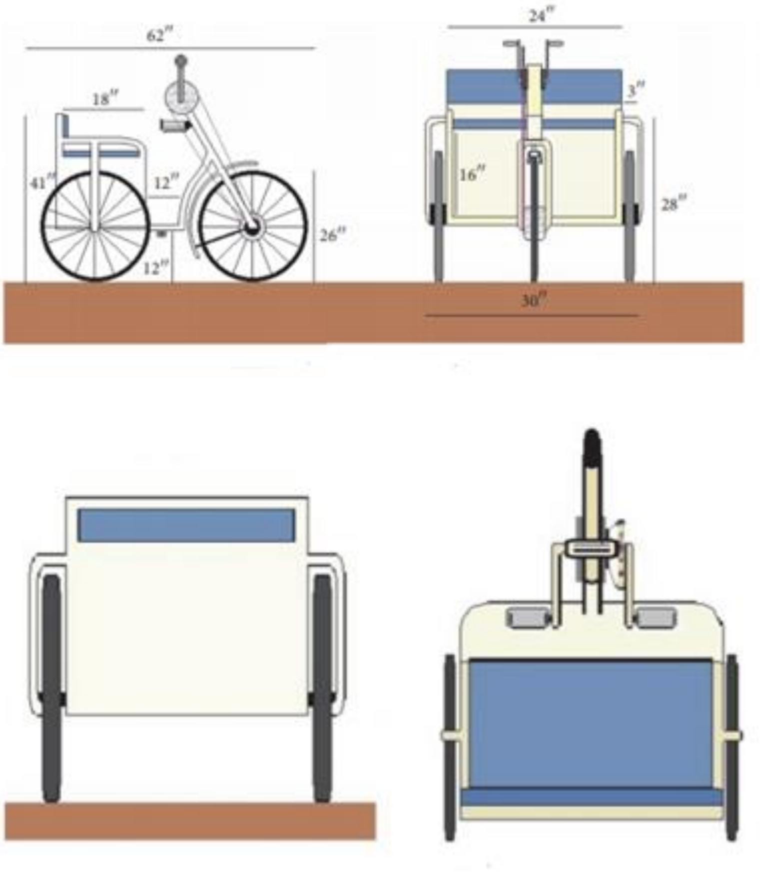


Figure 2: Side, front, back and top view of the original wheelchair [1]

Also, a picture of the actual wheelchair built with the above design is shown below.

Figure 3: The original wheelchair [1]

A set of three rechargeable 12V, 12Ah lead acid batteries were used to power the electric wheelchair [1]. The batteries were connected in series which made it a 36V system [1]. The battery set weighed 13.75 kg and each one had dimensions of 6x4x3.56 inches [1]. When fully charged, one battery gave about 12.7V or above and hence the set of three batteries showed about 38.1V across the terminals [1]. Solar energy was used to charge the batteries which ensured the process was clean and the environment was not being polluted. Also, it is advantageous as solar energy is a renewable energy source. 3 solar panels were used, each of which was 75 watts, and therefore gave a total of 225W. Two charge controllers were used, one for the wheelchair and another for the solar charging kit. The charger for the solar charging kit was rated 36V, 20A and the one for the wheelchair 36V, 25A [1]. The wheelchair charge controller was of LVD (Low Voltage Disconnection)type and it disconnected (LVD) at 36.3V (50% SOC), and reconnected (LVR) at 37.4V (75% SOC) [1]. Pictures of the batteries, solar panels and charge controllers are shown on the next page.

Figure 4: Battery set of the original wheelchair [1]

Figure 5: Solar Panels provided with the original wheelchair [1]

Figure 6: Solar charge controller for solar panel (left) and for wheelchair (right) [1]

One 250W Hub Motor was used in the front wheel of the wheelchair. The motor was connected to the batteries via a motor controller unit that controlled all the associated electrical connections. A throttle was connected to the controller unit as well. A major component of the wheelchair was the torque sensor module. It is basically a device that detects any circular rotating motion and measures the torque involved. It, then, converts this torque into voltage and feeds this voltage to the output circuit, which in this case is the hub motor. A torque sensor pedal was installed near the throttle and it was connected via a chain sprocket system to the hub motor in the front wheel. The output voltage of the torque sensor is directly proportional to the torque applied, meaning simply that the faster the pedal is turned, the faster the motor is going to rotate because of the extra voltage being fed to it. The wheelchair also had a horn system next to the throttle and a hand clutch brake system in the front wheel [1]. Pictures of the hub motorand the torque sensor pedal and module is provided below.

Figure 7: Hub Motor [1]

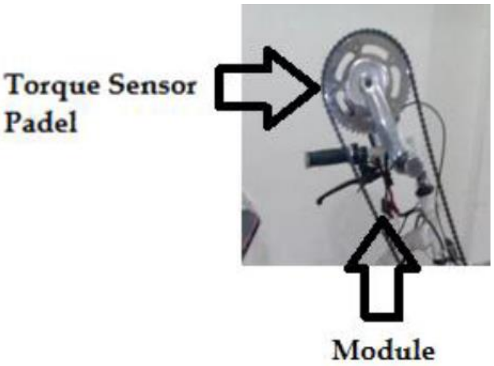


Figure 8: Torque Sensor Pedal & Module [1]

Due to certain mechanical inadequacies, a second version of the wheelchair was produced with few improvements on top of the original one. The seat of the original wheelchair was a bit too high and the back-rest was too low. Hence, the newer version had a lower seat and the back-rest was made taller. The cushions were also made comparatively more comfortable and the back rest was tilted a little bit and also the shape of the back rest was made a little curvy. The chain connecting the torque sensor pedal to the front wheel was covered with a metal layer because the exposed chain could cause injuries when it comes to contact with the patient while turning the pedal. Arm rests were also installed on both sides and mud guards were put on the back wheels. Two push bars were put in the back of the wheelchair in case someone needed to push it from the back in emergency situations. Two hand rims werealso put on the wheels for the user to push the chair forward if necessary. Metal bumpers were also put around both wheels in the back to protect the body from collisions on the road.The overall metal body of the wheelchair was made a bit more fashionable for aesthetic purposes. The second version of the wheelchair is shown in the picture below.

Figure 9: Wheelchair version 2.0

Besides the mechanical changes, some of the electrical systems were changed as well. The 36V battery system was changed to a 48V system. One extra 12V 12Ah lead acid battery was connected in series. The 36V 250W hub motor in the front wheel was replaced with a 48V 450W hub motor. A headlight was also put on the second version.

1.3 Motivation

Bangladesh is a third world developing country and although the poverty rate has been decreasing over the decades, a large proportion of the population still lives under the poverty line. Furthermore, Bangladesh is well known as one of the most densely populated countries in the world and on average, families living below the poverty line usually have more members than well-off families, which adds to the overall poverty of the country. Under these circumstances, most physically challenged people living beneath the poverty line are deprived from modern wheelchairs due to financial obligations. Most of them have to rely on normal manual wheelchairs that require a lot of muscle strength to propel and are also very inconvenient for outdoor movement. Thousands of disabled people are glued to their homes only because of the lack of a suitable outdoor wheelchair that they can afford. The upper-class and some middle-class families are able to afford the modern highly sophisticated electric wheelchairs for their disabled family members but for the majority of the lower-class people of our country it is only a dream. This electric wheelchairwith integrated torque sensor technology and solar battery charging kit is highly affordable compared to the modern imported ones. This wheelchair can give our lower class disabled people a better chance to live a day-to-day life where theycango outside by themselves with ease and even earn a living by working. According to “The Daily Star”, as of October 2018, there are about 1.6 million disabled people in our country [9].A large proportion of these 1.6 million people are financially underprivileged and this wheelchair can provide them with an alternative lifestyle.

1.4 Literature Review

Torque sensors are devices that sense and read the torque of a rotating system and convert this mechanical energy into electrical voltage. These devices have a wide range of applications in science and engineering and the potential of even more applications. In a poor third world country like Bangladesh, a lot of transportation vehicles still rely completely on human energy, e.g. the rickshaw, manually driven vans, bicycles etc. Electric rickshaws were introduced a few years ago but the government put a ban on them in certain areas because charging the batteries of these power rickshawswas putting too much pressure on the national grid. Consequently, it was considered to charge the batteries using solar energy which would relieve the pressure from the national grid. Quite a few researches were conducted on different types of electric battery-run vehicles with solar charging options and torque sensors were used in these projects. The torque sensors were beneficial in the way that it increased the duration the vehicles could run after fully charging the batteries once. The torque sensor pedals were also much easier to turn compared to manual pedals because of the additional electrical input to the motor. So, with one turn of the pedal, the vehicles would move quite some distance, comparatively much longer than manual pedals. And it also takes less energy to turn these pedals compared to manual ones. Some of these researches using torque sensors and solar battery charging system are discussed in this section.

In the summer of 2015, a research was conducted which was based on improving the manual rickshaws into electrically assisted ones with a solar charging system and implementing torque sensor. Khan, F. R., Rahman A., Aurony, A.T. (2015),“Power Conservation for Electrically Assisted Rickshaw-Vans with PV Support, Torque Sensor Pedal and the Solar Battery Charging

Station- A Complete Off-Grid Solution” [2], focuses on how rickshaws are an essential part of our daily transportation and the hardship rickshaw-pullers have to go through driving these vehicles manually. They state that technological advancement on rickshaws would cause an overall improvement in the standard of living and would significantly reduce the amount of physical stress of the pullers. The torque sensor reduces the use of the battery bank, hence ensuring a longer battery life and the duration the rickshaw travels on full charge. The solar panels help reduce the load on the national grid. The motorized rickshaw-van, as they called the product, had one BLDC gear motor and four 12V 25Ah lead acid batteries. Pictures of their vehicle are shown below.

Figure 10: The motorized rickshaw-van [2]

As it can be seen, the solar panel is mounted on top of the vehicle and directly charges the batteries through a charge controller, ensuring a totally off-grid system. The torque sensor pedal is positioned in the normal foot pedal position in manual rickshaws. And the module is connected next to it as shown in the following picture.

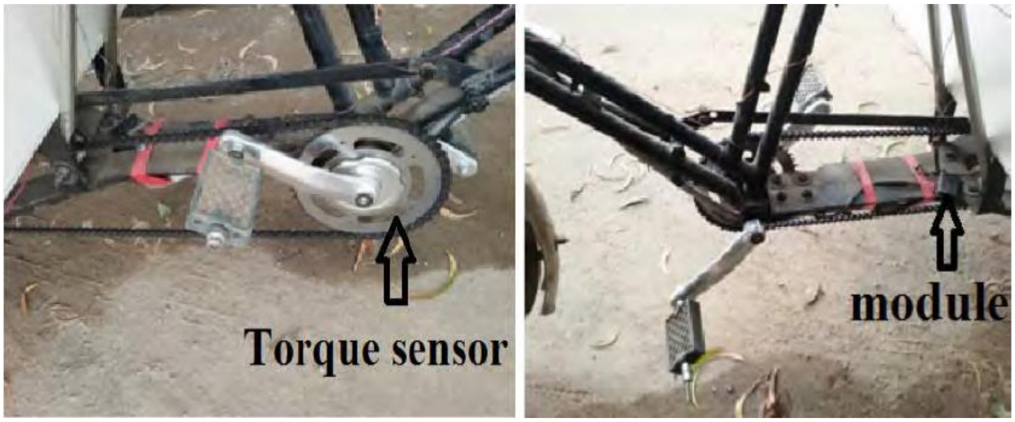


Figure 11: The torque sensor pedal and module in the motorized rickshaw-van [2]

Tarek, R., Anjum, A., Abrar-Ul-Hoque, MD., Rahim, F. A. (2015), "Solar Electric Ambulance Van to Assist Rural Emergencies of Bangladesh - A Complete Off-Grid Solution" [3] was a similar research that also used the torque sensor technology. A lot of people die in the rural areas of Bangladesh for not being hospitalized in time. Due to the unavailability of good roads, it is difficult for modern automobiles to travel in the village roads and therefore the villagers mostly depend on manually driven rickshaw vans or sometimes boats to transport patients and these means of transportations are very slow, especially when it comes to saving a life. Hence, a research project was conducted that proposed a solar ambulance van for such areas that would run on the village roads like the normal manual rickshaw vans but at a faster and more convenient rate so that the patients can be taken to the nearest medical institutions as quickly as possible. Similar to the motorized rickshaw-van, the torque sensor relieves the pressure on the battery bank and a solar PV is placed on top of the vehicle which slowly charges the battery. The batteries can be charged from Solar Battery Charging Station and thus are totally independent of the national grid. The ambulance contains a 500W BLDC gear motor and eight 12V 25Ah lead acid batteries. A picture of the ambulance is shown below.

Figure 12: Solar Electric Ambulance Van [3]

The ambulance has a siren, a stretcher and a first-aid box to serve the medical purposes and the torque sensor pedal is also connected similar to the motorized rickshaw van.

Another research has integrated the torque sensor technology into the battery-run, motorized e-bike.Hossain, R. I., Saleheen, I. I., Islam, S., Mahmood, I. (2018), "Inception of Electromechanical Bike Incorporating Torque Sensor Technology and Solar Charging Kit" [4], state that their torque sensor based e-bike will help save energy because of the solar energy input and the torque sensor would provide assistance in pedaling and reduce strain from the batteries. The paper establishes the significance of riding bicycles in Dhaka because of the immense benefits they provide in our traffic jam. Dhaka traffic is one of the worst in the whole world and a large part of our days are wasted stuck in traffic signals. Bicycles are narrower and can squeeze through the traffic and help save a lot of time and also keeps us healthier compared to using cars or other vehicles. The e-bike has two 12V lead acid batteries that run a 250 BLDC motor. The motor is mounted on the back wheel using chain sprocket system and the torque sensor pedal is placed in the normal foot pedal of bicycles. The batteries are put in a box and placed on the back carrier of the bicycles and can be charged from solar energy using the Solar Battery Charging

Station. Similar to the motorized rickshaw van and the solar ambulance van, the torque sensor module senses the amount of torque applied on the pedal and turns it to voltage, thus assisting the battery bank by putting an extra human energy input to the motor. Pictures of the torque sensor based e-bike are shown below.

Figure 13: Torque Sensor Based e-bike [4]

Figure 14: BLDC motor on Torque Sensor Based e-bike [4]

Figure 15: Torque Sensor Pedal and Module of e-bike [4]

As it can be seen, the torque sensor module has been attached to the rod above the torque sensor foot pedal. The researchers used MATLAB/SIMULINK to simulate the mathematical model of the torque sensor based e-bike.

One of the prime features of all these projects is the fact that they are all clean and non-polluting and also runs on a renewable energy source- the Sun. The human body energy input through the torque sensor pedal is also a renewable and clean source. Even though the option of charging from the national grid is kept in the vehicles for emergency purposes, it is always advised to charge them using solar energy, hence maintaining the renewable and non-polluting image.

A research team had proposed a solar charging station that would charge batteries for these vehicles just like normal fuel stations or petrol pumps.Islam, R., Hossain, S., Showrav, A. A., Ayon, A. A. (2014), “Solar Battery Charging Station with Automated Switching System” [5], presented a station where two 200W solar panels would be set up and different sets of batteries would be charged from the panels. The station would also have a backup charging system from the national grid just in case of emergencies or in case of certain days when the solar radiation intensity is low. The paper says that the geographical location of our country ensures plenty of sunlight throughout a day and implementing such stations would greatly benefit our energy crisis by relieving the national grid from a lot of pressure. The concept of Solar Battery Charging Station (SBCS) is simple. Rickshaws and other solar vehicles would come in with a drained battery set, take it out and put it to charge, take in charged batteries and would be good to go, and so on. The concept is shown below.

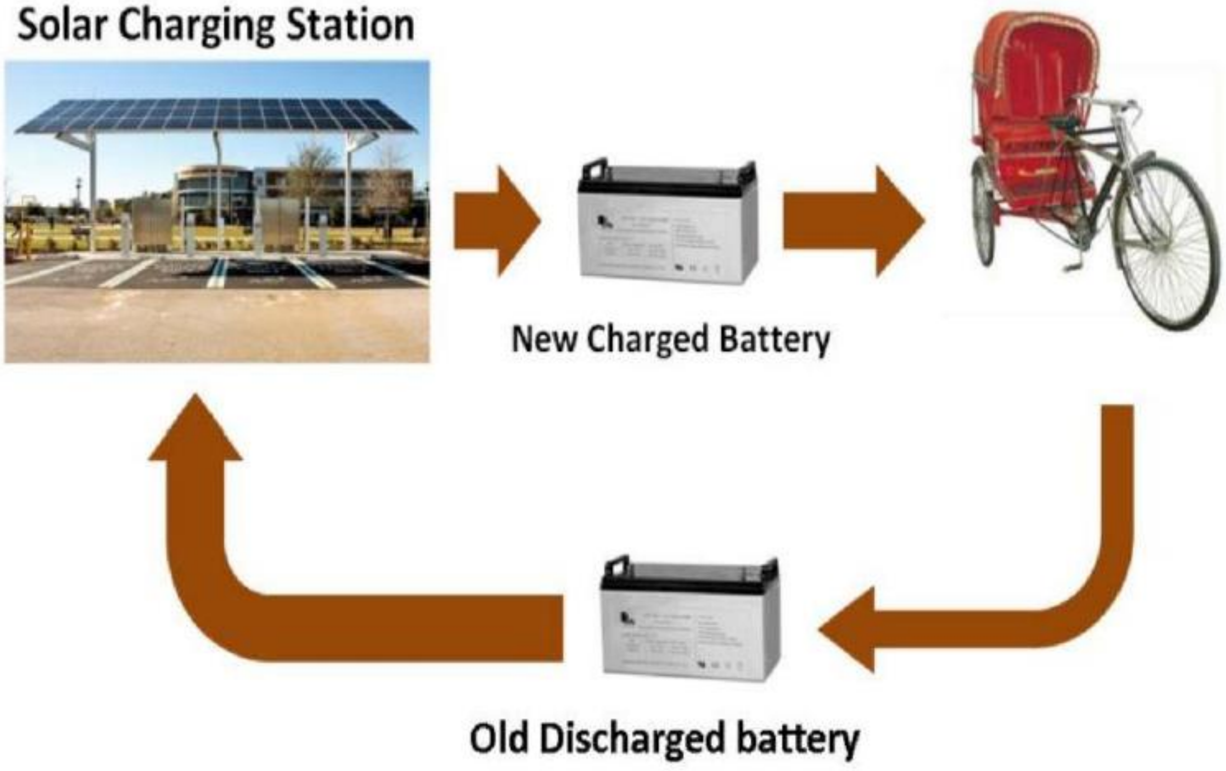


Figure 16: Solar Battery Charging Station [5]

Chapter 2

System Overview- Components, Design & Construction

2.1 Introduction

Since this project is based on the modification of an existing electric wheelchair, most features of the system remain as they were in the original wheelchair. However, there have been some major alterations which will be discussed in this section. It is important to mention that the original wheelchair was manufactured by Beevatech Limited [1], a company that makes electric vehicles. The physical structure of the wheelchair has not been changed much, other than the fact that the front wheel and the main body of the wheelchair (seat and back wheels) have been made detachable. The wheelchair has a steel body and the material is lightweight. The details about each component, whether it was altered or modified, are going to be discussed in the following sub-sections. The major components of the tri-wheeler are a set of four 12V, 12Ah lead acid batteries, two brushless DC (BLDC) motors and two motor controller units, a torque sensor pedal and a torque sensor module, a throttle, a power key, a front wheel brake system, etc. It should also be mentioned that the solar charging station is also available for the batteries to be charged from the solar panels, so the wheelchair can even be used in villages where the national grid supply is not available yet.The pictures of the completed product are shown below.

Figure 17: Version 3 Electric Wheelchair

2.2 Batteries

There are a total of four 12V, 12Ah rechargeable lead acid batteries in the supply system which are divided into two sets connected in series. Each series connected set is connected in parallel and therefore supplies 24Vto the BLDC motors. The dimensions of each battery are 6x4x3.56 inches and each individual battery weighs approximately 4.5 kgs. The original version had a 36V battery system (three 12V batteries), which was later changed to a 48V system (four 12V batteries) in the second modified version as mentioned above in 1.2. The batteries can be charged in two ways. The option of charging them directly from the national grid is available. A charging port has been installed near the footrest of the wheelchair and using a suitable charger the batteries can be charged through that port. Furthermore, the batteries can also be charged from solar panels in a dedicated solar charging station. Charging the batteries using solar energy is encouraged because it ensures a 100% off-grid solution and also a clean renewable source. It ensures that no extra pressure is put on the national grid and no environmental pollution is caused. Because of this, an extra pair of battery sets is also going to be provided so that one pair can be charging from the panels during the day while another pair is being used in driving the wheelchair and then they can be swapped. The swapping system of the batteries has also been made very user friendly. The batteries have been put inside metal drawers that are placed under the seat of the wheelchair. Once the user-friendly electrical connections of the batteries are opened, they can be taken out of the wheelchair from the back (just like a drawer opens). After removing the batteries and replacing the charged batteries, the drawer can just be put back in and the electrical connections re-attached. Each individual battery shows at least 12.7V or above once fully charged. Pictures of the batteries are shown below.

Figure 18: Batteries

Figure 19: Battery drawer

2.3 BLDC Motors& Motor Controllers

The original wheelchair had one 36V 250W hub motor attached to the front wheel and no motors in either of the back wheels. In the second modified version, the motor was replaced with a 48V 450W hub motor in the front wheel because the battery system was changed to 48V. However, similar to the first version, there were no motors in the back wheels. This proved to have some problems during climbing ramps and going over obstacles on the road because of inefficient torque provided by the motor. Hence, the system was further modified and two 24V 250W BLDC motors were installed in the two back wheels of the wheelchair. This ensured that enough torque is being provided for the tri-wheeler to climb ramps and overcome obstacles on the road, because the motors are placed where most of the weight of the wheelchair exists, in the back. The motors have been mechanically attached to the wheels using chain sprockets and placed underneath the wheelchair seat against the wheels. The motor controllers are also attached under the seat next to the batteries and the motors. Pictures of the motors and the controllers are shown below.

Figure 20: BLDC Motor

Figure 21: BLDC Motor mounted inside wheelchair

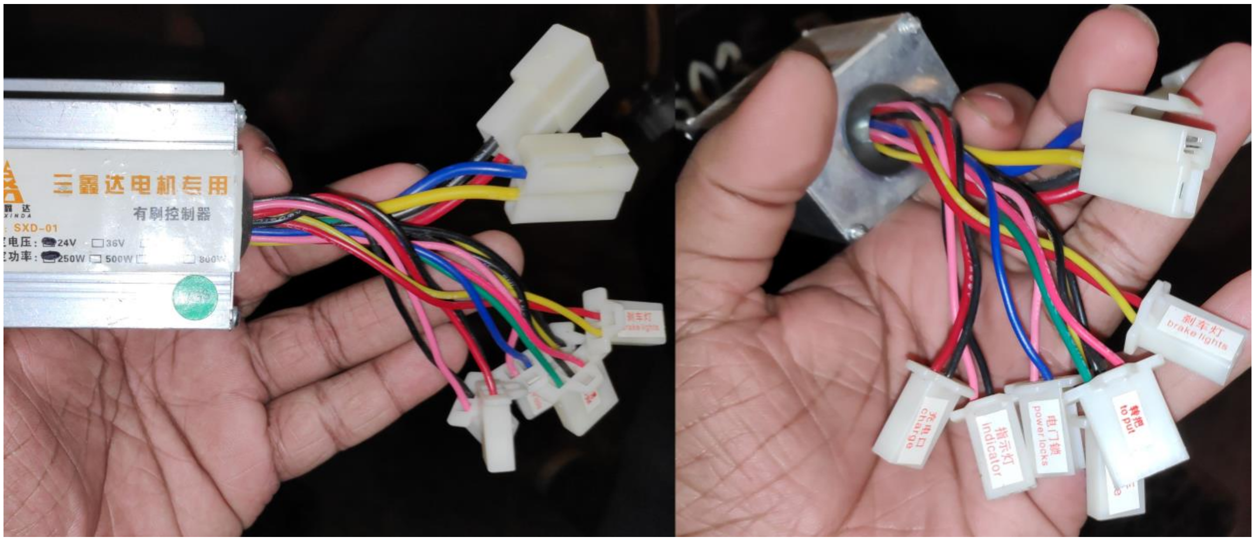


Figure 22: Motor Controller

2.4 Torque Sensor Module and Pedal

As the name suggests, the torque sensor is a device that senses the applied torque in a system and converts it into electrical energy. Going back to the law of conservation of energy, we know that energy can neither be created nor destroyed; it can only be converted into different forms. The tri-wheeler has a torque sensor pedal, which is basically just like a normal pedal with a sensor attached to it which reads the applied torque when the user rotates the pedal. This torque sensor pedal is electrically connected to the torque sensor module. The torque sensor does the beautiful conversion of mechanical energy into electrical energy. The module needs a 5V biasing voltage and its output is directly proportional to the amount of torque applied. A torque adjustor circuit is also included in the system. The adjustor circuit provides the 5V biasing voltage to the module and the output of the module also goes to the motor controller via the adjustor circuit. Besides the solar energy used to charge the batteries, the torque sensor introduces another clean and renewable energy source into the wheelchair system- the human body energy. One manual rotation of the torque sensor pedal provides more than enough electrical voltage to the motor and the motor turns independent of the throttle. It is fairly very easy to turn the pedal. Due to the support from the motors, it does not take a lot of energy to turn the pedal. Pictures of the torque sensor system are shown below.

Figure 23: Torque Sensor Pedal & Module [17]

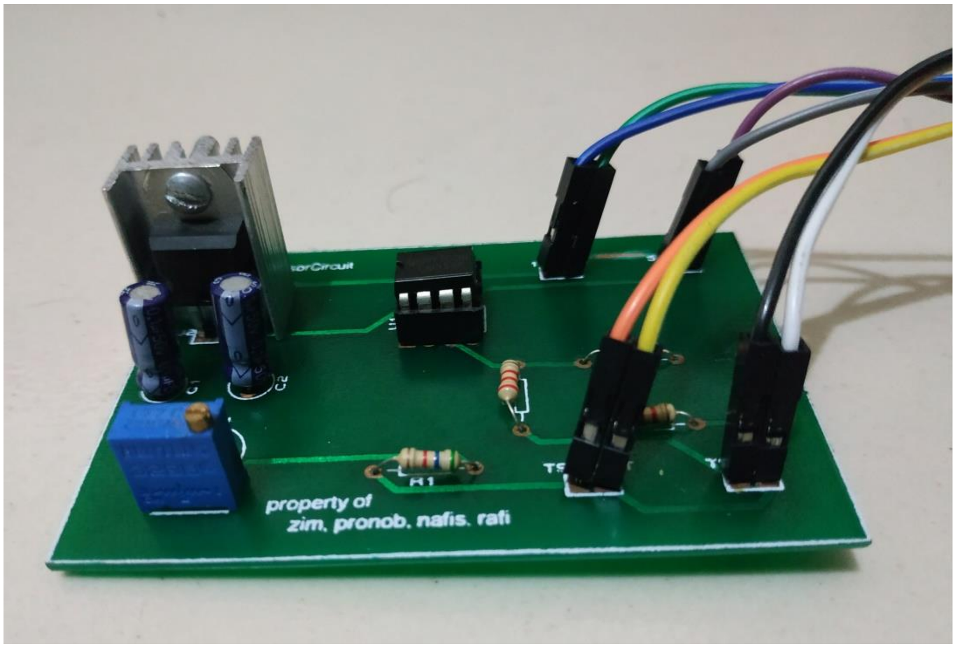


Figure 24: Torque Sensor External Adjustor Circuit

2.5 Throttle

The throttle works just like a normal motorbike throttle. It is basically a special potentiometer and the resistance is controlled by turning the throttle. 5V are provided by the motor controller to bias the throttle and the output of the throttle depends on the angle to which it has been rotated, which ultimately means the resistance the potentiometer provides. This output voltage is fed to the motors through the motor controllers. The speed of the motors directly depends on this output voltage. A picture of the throttle is as follows.

Figure 25: Throttle

2.6 Solar Panels and Charge Controller

4 solar panels, each of 100W (total 400W) are provided with the wheelchair and the batteries can be charged from these panels via a charge controller. Each panel outputs 12V. So, only two panels can charge the ‘four battery set’, but for faster charging all four panels can be used to charge the four batteries in series. The charge controller helps protect the batteries from sudden current surges, overcharging and discharging in absence of the Sun. Pictures of the panels and the solar charge controller are shown below.

Figure 26: Solar Panels and Solar Charge Controller

2.7 Horn System

Since the wheelchair is meant for running on the road, a horn system has been installed into it. The horn switch is placed next to the throttle. The horn is placed in the front of the vehicle and is electrically connected through the motor controller. It requires 5V to operate, which is provided by the battery whenever the switch is pressed.

2.8 Brake System

A brake system is connected to the motor through the motor controller which contains a small bar attached to the throttle. When the bar is pressed, output voltage from the motor controller to the motor is cut-off and the motor comes to a stop. This is an efficient brake system as it brings the motors to an instant halt. Furthermore, a manual hand brakesystem is attached to the wheels.

2.9 Proposed Design

The software model of the proposed design of the version 3 tri-wheeler is shown below. As it can be seen, the front part of the wheelchair including the front wheel, the throttle handle bar and the torque sensor pedal has been attached to the main body with stainless steel pipes.A screwing mechanism was proposed that could be used to attach and detach these pipes from the main body. Hence, the front part can be made detachable from the body for indoor use and during outdoor travel the front part can just be attached back on. The small free wheels that can be seen on the model diagram are for the stability of the wheelchair when the front part is detached.

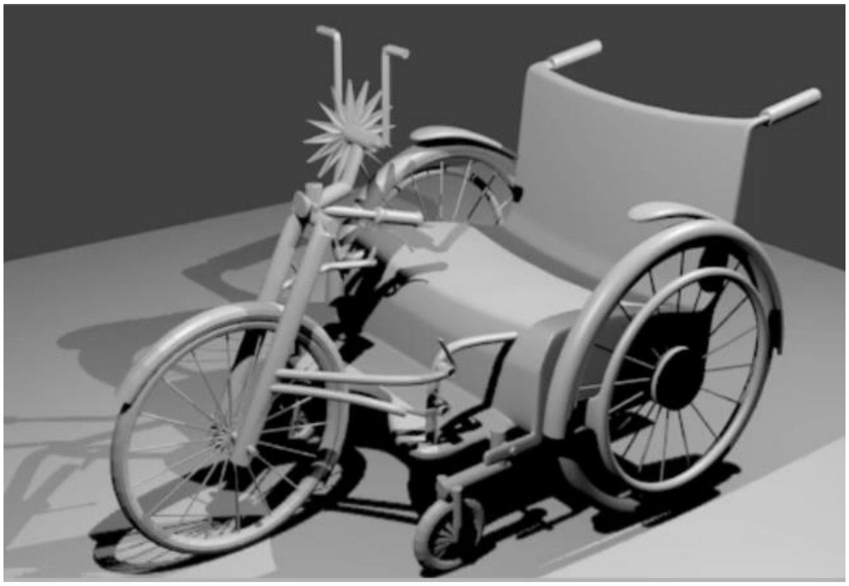


Figure 27: Proposed Blender model of the version 3 wheelchair

2.10 Construction

The changes in the construction of the body of the wheelchair are discussed in this section. The back rest and arm rest metal sheets have been removed and replaced with cloth and metal pipes respectively. Cloth has been put in the back rest as opposed to metal according to the recommendation of the Center for the Rehabilitation of the Paralysed (CRP). According to CRP, the cloth helps better posture maintenance and reduces sores. The arm rests have been replaced with metal pipes as this helps the patients exercise lifting movements sitting in the wheelchair. Two small free wheels have been attached underneath the footrest for supporting the chair when using indoors with the front part detached. A drawer door has been installed in the back of the wheelchair where the battery drawer can be taken in and out of the wheelchair. The door has a hinge system and it can be locked.The wheels in the back were rusted and broken at places and therefore a new set of wheels have been attached in the back. The front wheel was also too big for convenience of the detachable mechanism and hence a smaller wheel of 16 inch diameter was installed in the front. Furthermore, the original seat cushion was not comfortable for disabled patients and therefore a doctor’s recommended contour seat cushion was put into the new version. The contour seat cushion was provided by CRP. A few pictures during the construction stage are shown below.

Figure 28: Construction pictures

Figure 29: New back wheels

Figure 30: 16-inch diameter front wheel

Figure 31: Contour seat cushion

2.11 Electrical Connection of the Wheelchair

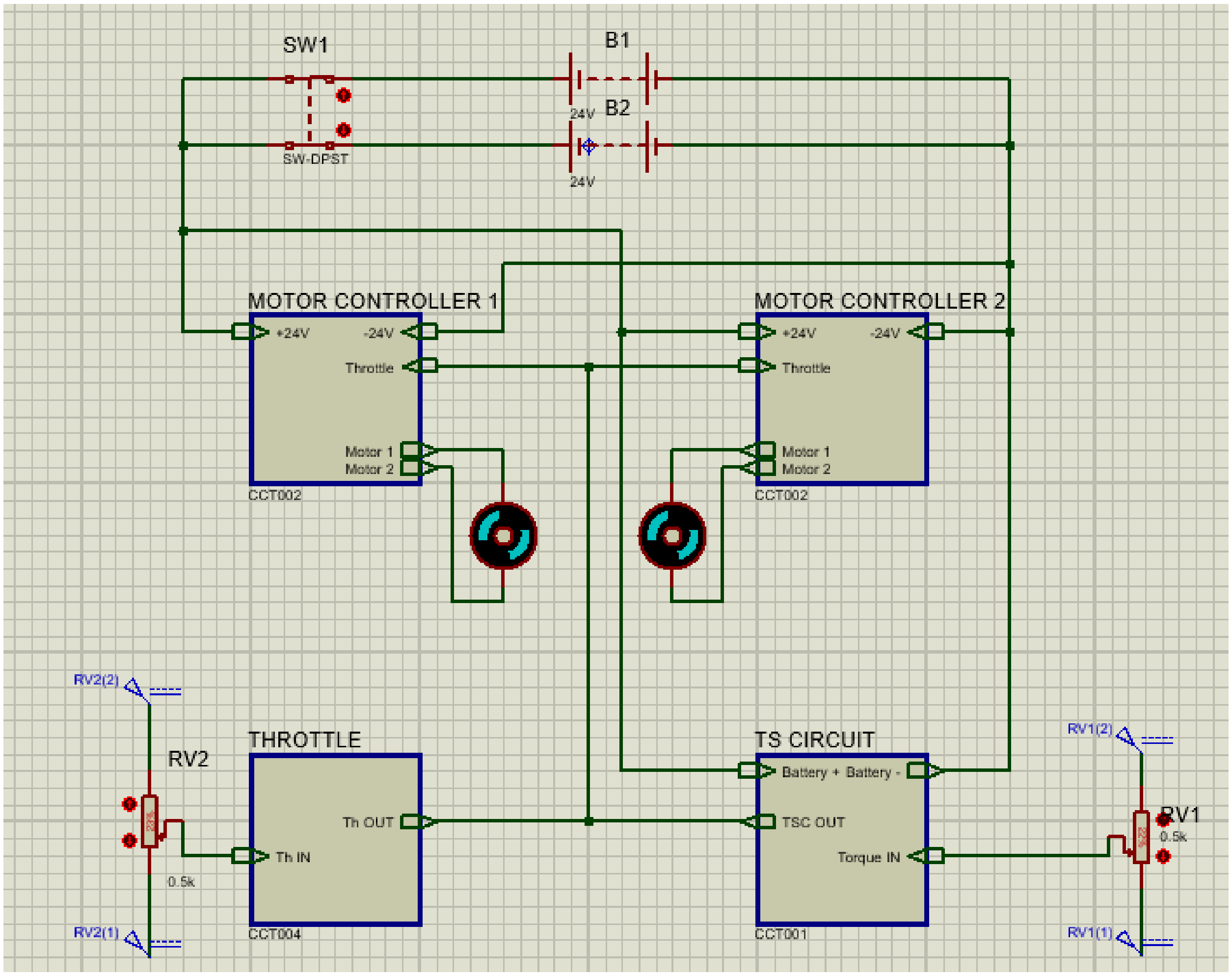


Figure 32: Electrical connection diagram of the wheelchair

The schematic diagram of the electrical connection diagram of the electric wheelchair is shown above. Two sets of batteries are connected to the two motors through two motor controllers. The throttle and the output from the torque sensor adjustor circuit are fed into both the motor controllers using parallel connection. Hence both motors turn at the same speed using both the throttle and the torque sensor pedal.

Chapter 3

Integrating the Torque Sensor

3.1 Introduction

This section particularly targets and describes all of the features and aspects of the Torque Sensor (TS) to aid in better understanding of the overall system, including the points about its operation, electrical connection, power management, mechanical implementation, and results found in laboratory and field tests.

The Torque Sensor or Torque Transducer is a device that measures torque on a rotational system, such as in an engine, rotors, pedals, crankshafts, etc [11]. The module itself requires 5V DC bias to operate and in response, it outputs DC voltage corresponding in proportions to the torque applied on the crank/shaft/pedal it is attached to. The torque itself is measured using strain gauges in the sensor, and in our system, this input torque causes the output voltage to vary linearly within its operating region.

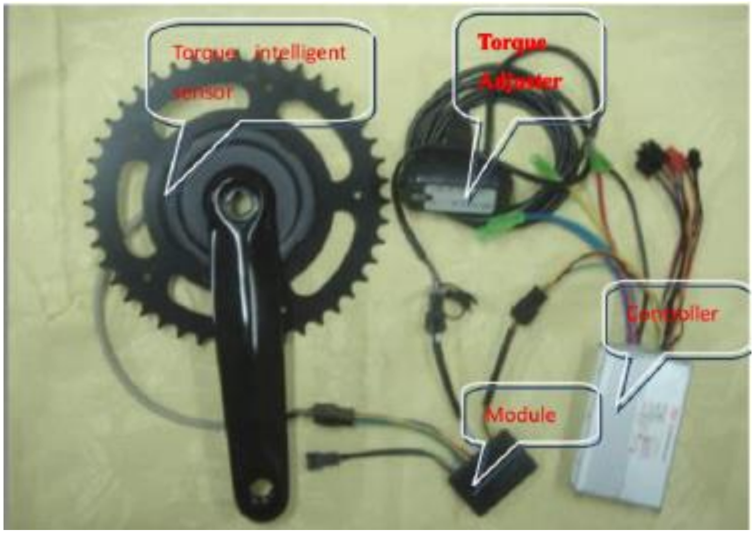


Figure 33: Torque Sensor pedal, module and controller

The Torque sensor system implemented in our project is purchased from Suzhou Victory Sincerity Technology Company Ltd, which is a high-tech enterprise located in Suzhou, China. The company hosts a group of experienced experts, who are adept at designing and developing various e-bike components, mostly torque sensors and other relevant parts. The torque sensor is their national patent product. Only the sensor and module are used in our system.

3.2 Torque Sensors and Transducers- Types & Technical Parameters

Several types of torque sensors are mentioned below [12]:

- Brushless Rotary Torque Transducers
- Flange Torque Sensors
- Shaft Torque Sensors
- Multi-Axis Torque and Axial Force Transducers
- High Capacity Torque Transducers (>5000Nm)
- High Speed Rotary Torque Sensors (>55000rpm)
- Low Capacity Torque Transducers (<1N)
- Rotary Slip Ring Torque Sensors
- Miniature Torque Transducers
- Square Drive Torque Sensors
- Static / Reaction Torque Transducers
- Wireless Radio Telemetry Rotary Torque Transducers

Figure 34: Torque Sensor pedaland module

Technical Parameter Data [10]:

- Vcc = 5.15 V (+/- 0.15 V)
- Output torque >15 Nm
- Output, linear, zero-start, 0.5~4.5 V
- Delay time < 50 ms

3.3 Torque Sensors and Transducers- Features & Applications

Features of Torque Sensor [10]:

- Compatible with brushed, brushless and hub motor controller
- Easy to install, since it can be mechanically fitted directly along the regular chain wheel crank
- High signal sampling rate allows instantaneous response from torque sensor
- Aluminum body parts for low weight

Torque sensor possible applications [12]:

- Automotive & Motorsport
- Aircraft Component Testing & Development
- Engine Test Stands
- Marine
- Production Process Monitoring
- Pump Development
- Steel Manufacturing
- Torque & Power Measurement on Drive Shafts
- Torque Wrench & Tool Testing / Calibration
- Wind Turbine Development

3.4 Mechanical Fitting and Setup

The whole torque sensor system is built to be easily compatible to fit with any structure that can attach a pedal, such as bicycle or rickshaw. For the tri-wheeler, the torque sensor pedal is attached to the chain to run the front wheel, which in turn is attached over the front handlebars and fork of the detachable segment to be run with the user's hands. The device also comes with an inbuilt lock pin to keep the circuitry steady, to measure the torque applied by flexing the pedals.

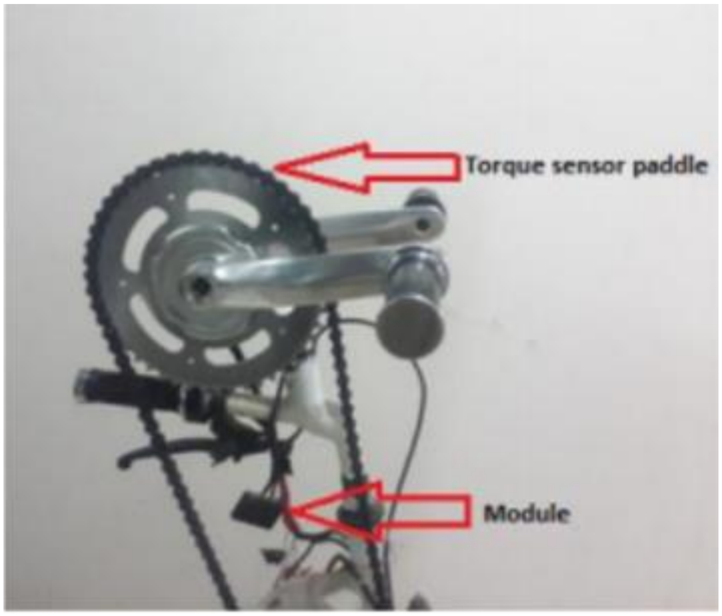


Figure 35: Torque Sensor pedal and module installed in the vehicle

3.5 Electrical Connections

The electrical connection diagram of the whole system was provided by the manufacturing company, including the module, controller, torque adjustor, etc. However, we only utilized the torque sensor and its signal-generating module. Separate connections were required for input from the controller, which is pointed out in the diagrams provided by the manufacturer. Rather, in our project, we have incorporated our own circuit with the sensor. From the main diagram, we have included that independent operation connection diagram.

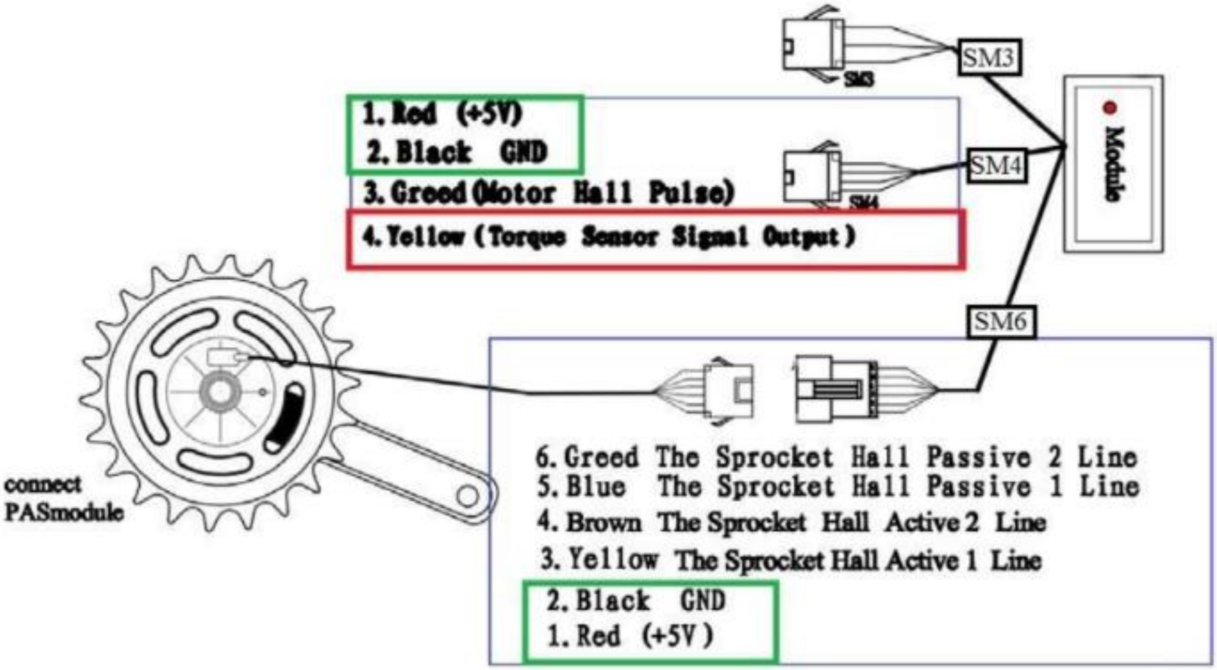


Figure 36: Electrical connection diagram of torque sensor circuit

As the figure above indicates, the Red and Black wires (marked as '+5V' and 'GND' respectively) are the terminals for the input bias, from SM6. The output from our modified Torque Sensor Circuit goes as input voltage to the module through the yellow wire at SM4. This wire provides output voltage corresponding to the torque applied on the pedals, relative to common GND. This signal is the output that is to be fed to the modified external control circuit.

3.6 Power Management

The tri-wheeler is designed to be operated on a set of batteries, which is our only power source for the entire system. Four 12V batteries are equipped for the wheelchair. The modified torque sensor circuit that has been used requires +5V to power all of the devices attached. A DC-DC buck converter has been attached to step down 48V to 12V, which then passes through the

LM7805 (implemented in the modified torque sensor circuit) to further step it down to a steady 5V to be fed to an amplifier as bias.

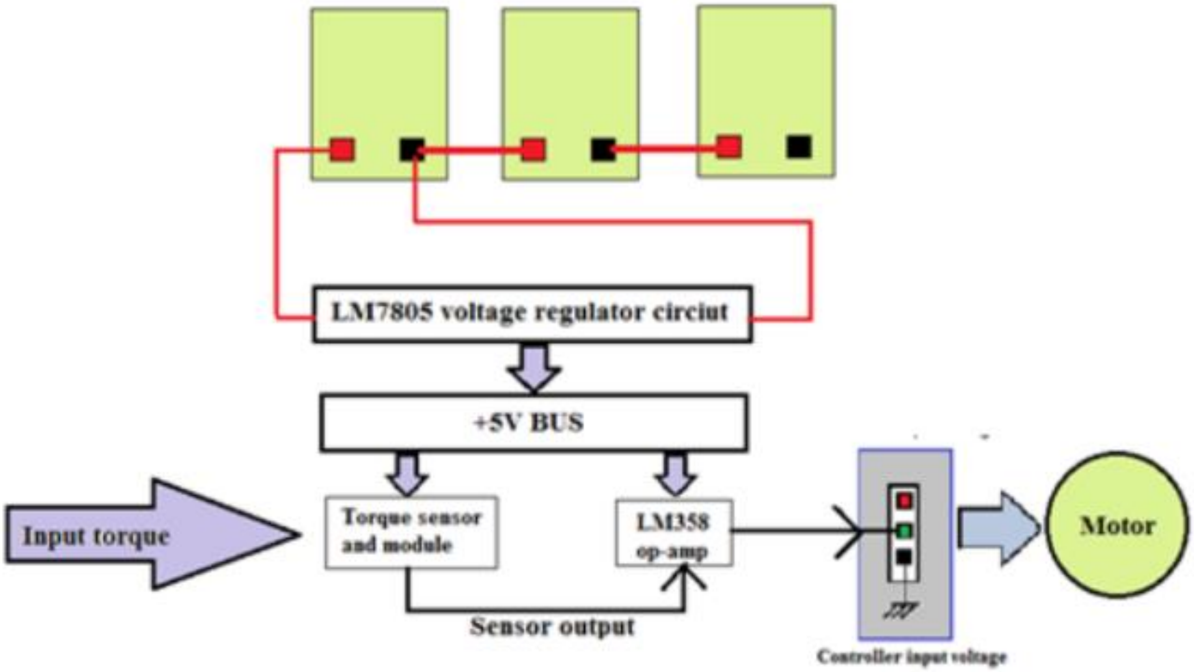


Figure 37: Block diagram of torque sensor circuit

The figure attached shows the signal flow in the system. The +5V biasing voltage enables the amplifier circuit which amplifies the output voltage sent from the Torque Sensor Module. Upon applying pressure to the pedals, if a threshold is exceeded, the sensor will sense and convert it to a certain voltage, which in turn is supplied to the amplifier.

3.7 Customized Torque Sensor Circuit Features

In the customized torque sensor circuit that was implemented, a voltage divider has been added. It was done to attenuate the voltage from torque sensor by a factor of 0.6 instead of feeding the voltage to the amplifier directly. This ensures accidental high voltage input would not get amplified to unsafe levels for the motor, and also limits the overuse of motor by pedaling. During our practical tests, the voltage generated was sometimes able to reach pretty high-voltage (3~5V), even if momentarily. Thus, the voltage divider was added to minimize the surge, $V_{OUT} = 0.6*V_{IN}$.

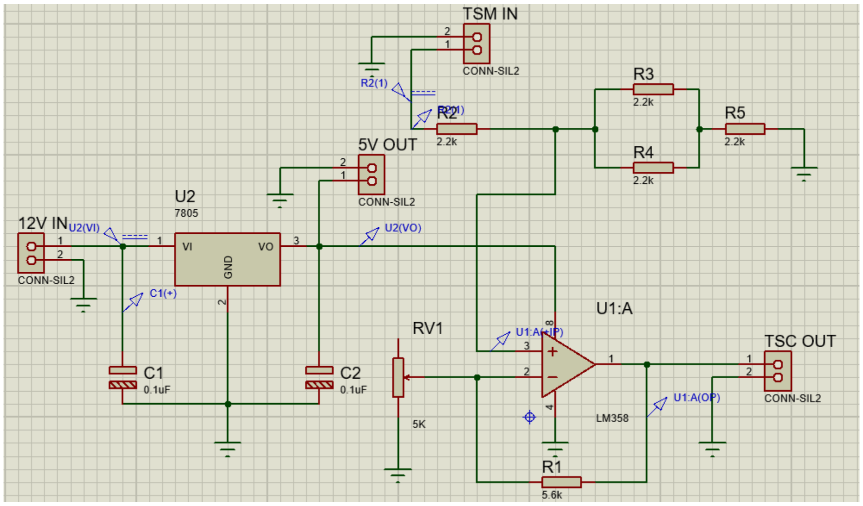


Figure 38: Schematic diagram of torque sensor circuit

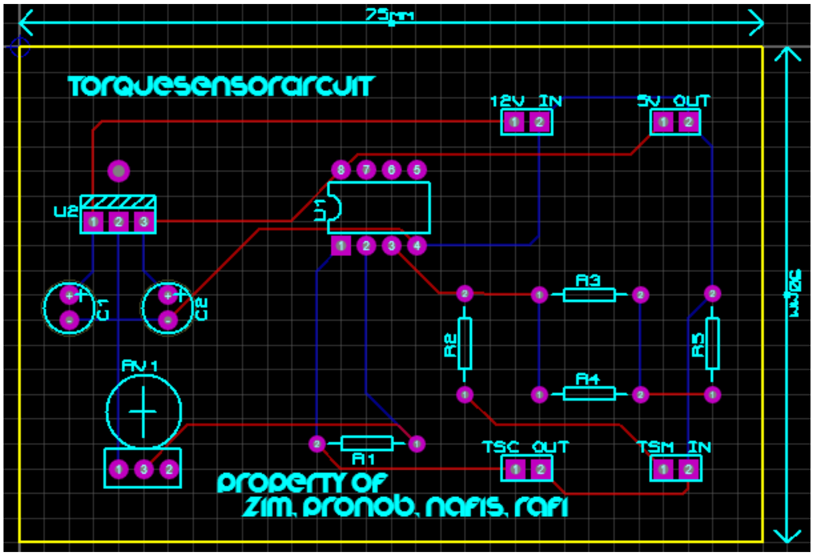


Figure 39: PCB order software diagram of torque sensor circuit

The amplifier outputs voltage corresponding to voltage from the torque sensor, which is directed to the Motor Controller unit, and ultimately to the motor itself, maintaining the ease of pedaling.

3.8 Hardware Implementation

During initial phases, a breadboard implementation of a tweaked design was prepared to ensure stability during field testing and ease of customization while avoiding wiring clutter. After satisfactory proof of concept and performance during initial trials, the circuit was developed to a custom PCB with the components soldered. The field tests were able to be conducted with ease due to securely placing the PCB with a user-adjustable notch of the potentiometer to easily vary the gain provided by the circuit, and consequently varying the motor output as required.

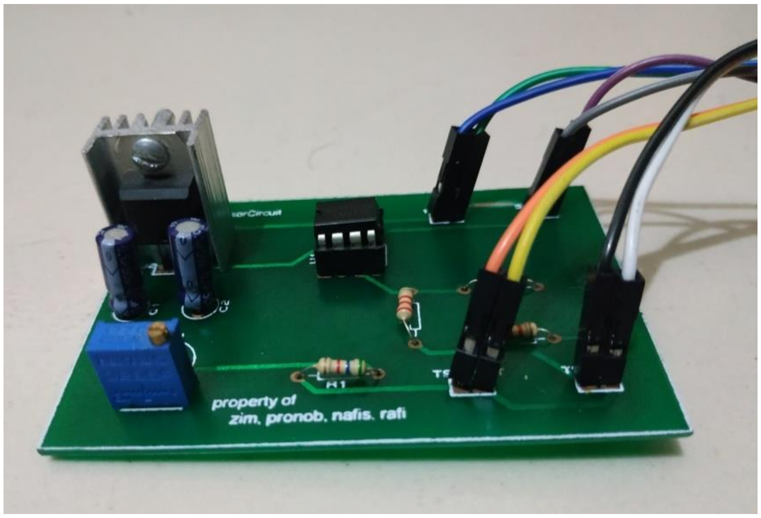


Figure 40: Hardware PCB of the torque sensor circuit

The system delivered proper performance within expected ranges during our laboratory tests. No issues were faced during and after the installation in the tri-wheeler vehicle, and hence it was declared fit for practical trials and field tests.

Chapter 4

Dedicated Solar Charging Kit and Battery Swapping

4.1 Introduction

The world has reached an era where even a single moment without electricity is unimaginable. Even though almost every kind development is dependent on electricity, Bangladesh is still unable to provide electricity all over the country. As of July 2018, around 95% of the population in Bangladesh has access to electricity [13]. Rural areas are the biggest sufferers and even urban areas face load shedding during peak-time. Thus, people are moving towards renewable energy and solar electricity system can be a great asset. Till April 2018, more than 4 million solar home systems have been installed around the world [14]. These solar home systems are proving greatbenefits during peak times even if it is by assisting with small amount of electricity. Governments are also taking bold steps regarding this issue and according to a plan, renewable energies will provide around 10% of the total generation capacity by the year of 2021.

Figure 41: Solar Charging Kit

4.2 Overview of Dedicated Solar Charging Kit

The main purpose of implementing a dedicated solar charging kit is to make it totally isolated from the grid. Even though the torque sensor pedal in the tri-wheeler helps in saving energy, the batteries still need to be charged at the end of the day. By setting up a dedicated solar charging kit, the batteries can be fully charged from sunlight through solar panel, which will make the whole system entirely independent of the national grid. This ensures that the wheelchaircan be used all over the country regardless of access to electricity.

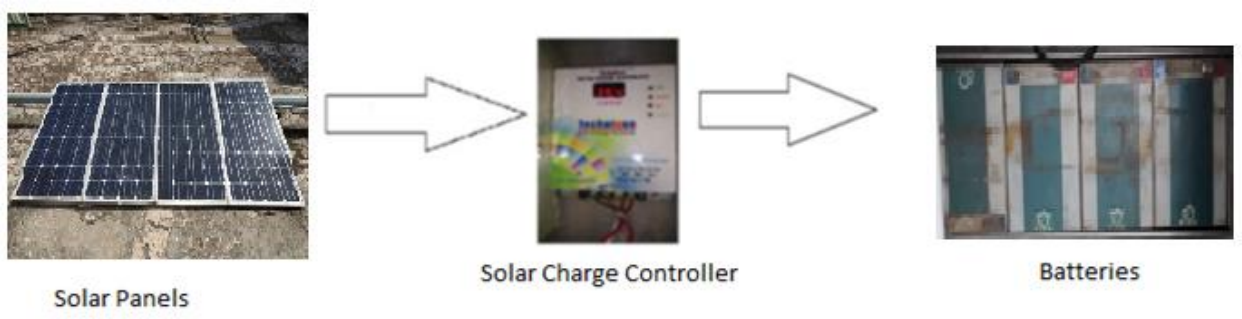


Figure 42: Flow diagram

4.3 Function of Dedicated Solar Charging Kit

A major reason for the dedicated solar charging kit to be included in the system is that people in rural areas where electricity from the national grid is not available yet can also use the tri-wheeler by charging the batteries using solar energy.Charging the batteries requires a considerable amount of time which may become an inconvenience in certain times of need. Hence, two separate sets of batteries are provided with the wheelchair so that one set can be charging while the other set is being used in the wheelchair. Once the battery set in use drains down to 50% state of charge (SOC), it can be taken out of the wheelchair from the back and put into the solar charging system. The battery set that has been charging all this time can then be replaced into the wheelchair. This helps ensure that the wheelchair can be at operating condition all the time.The solar charging it consists of the solar panels which are connected to the solar charge controller. The batteries are connected to the charge controller for the charging purpose.

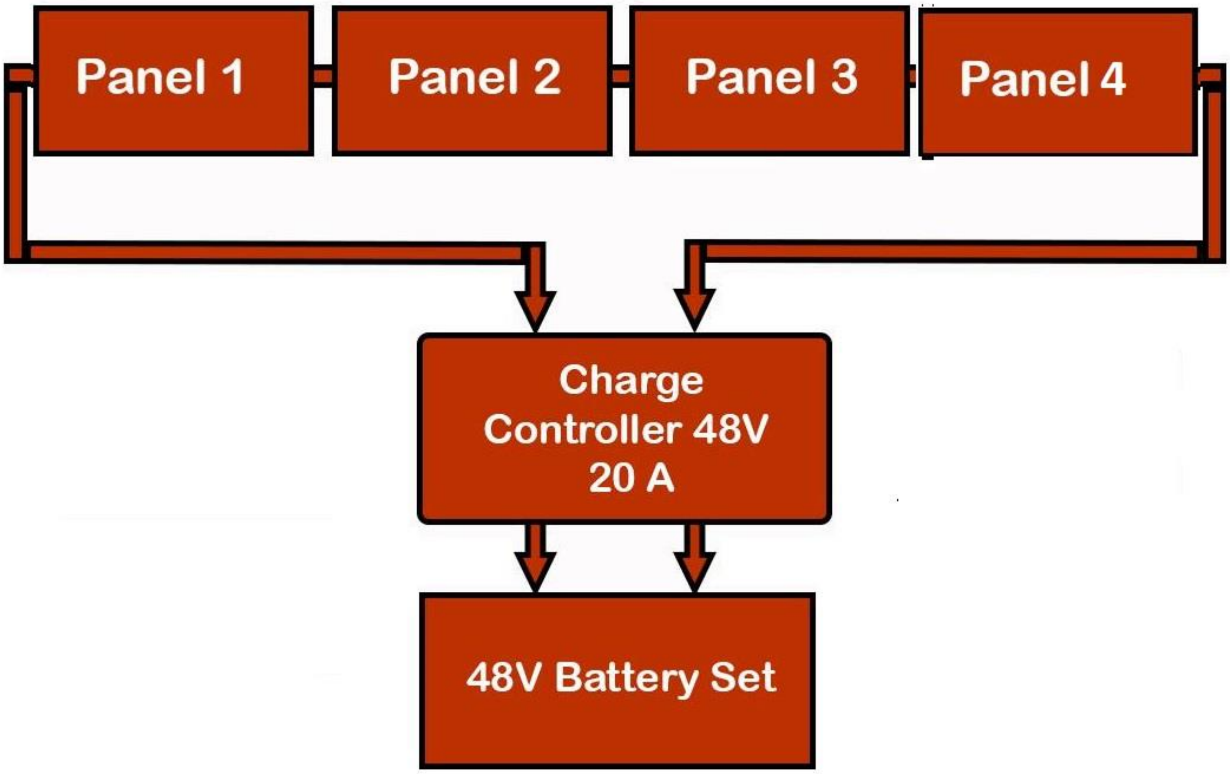


Figure 43:Block Diagram of a Solar Charging Kit

4.4 Components

The components of the solar battery charging kit are the solar panels, the solar charge controller and the batteries. A plastic box is provided for carrying the extra pair of batteries. And stainless steel drawers have been installed into the wheelchair to easily take the batteries in and out of the wheelchair body. The batteries are placed inside these drawers. Details of the components are discussed below

Solar Panels:

In total, there are four solar panels implemented in the system and they are all connected in series. Each panel is rated at 100W and hence the four solar panels together are at 400W. Each panel gives an output of 12V. The total output of the four solar panels connected in series is 48V. For faster charging, it is recommended that the four batteries are connected in series before putting them to charge but if in case it is preferred to charge the batteries maintaining their parallel connection, it is possible to charge the whole set of batteries from two series connected solar panels as the battery set connected in parallel requires 24V to charge.

Charge Controller:

A solar charge controller is included in the solar battery charging kit. It has no load connection in it and is rated 48V 20A. The solar charge controller can be put in the plastic box while charging the batteries from the panels. A picture of the charge controller is given below.

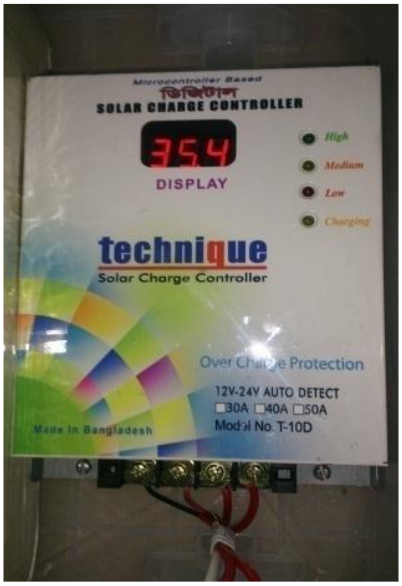


Figure 44: Solar Charge Controller

Batteries:

Four rechargeable sealed lead acid batteries have been used in the system, each rated 12V 12Ah. Since the modified version of the wheelchair contains two motors in the two back wheels, the four batteries have been divided into two parts.Each part contains two batteries connected in series and then these parts are connected in parallel, therefore supplying 24V to each individual motor via the controllers.The dimensions of a single battery are 6x4x3.56 inches. As it have already been mentioned, a total of 8 batteries will be provided with the wheelchair, because one set of batteries will be charging while the other set is in use. One set of batteries (four batteries) weigh about 18 kgs approximately. The batteries are placed underneath the seat of the wheelchair inside stainless steel drawers that can be pulled in and out through a door at the back.Each individual battery will show 12.7C across its terminals at full charge.

Chapter 5

Mathematical Model

5.1 Introduction

A mathematical model is an abstract model that uses mathematical language to describe the behavior of a system [15]. It portrays the scientific understanding of the overall system to be constructed or has been constructed through mathematical equations manipulation. Eventually it helps to analyze the working principles of the entire system and to identify if there is any error in the system. To develop a mathematical model through the mathematical interpretation, we need to build up a schematic of the physical systems showing the signal flow direction of the overall system which will eventually lead to get all the mathematical equations.

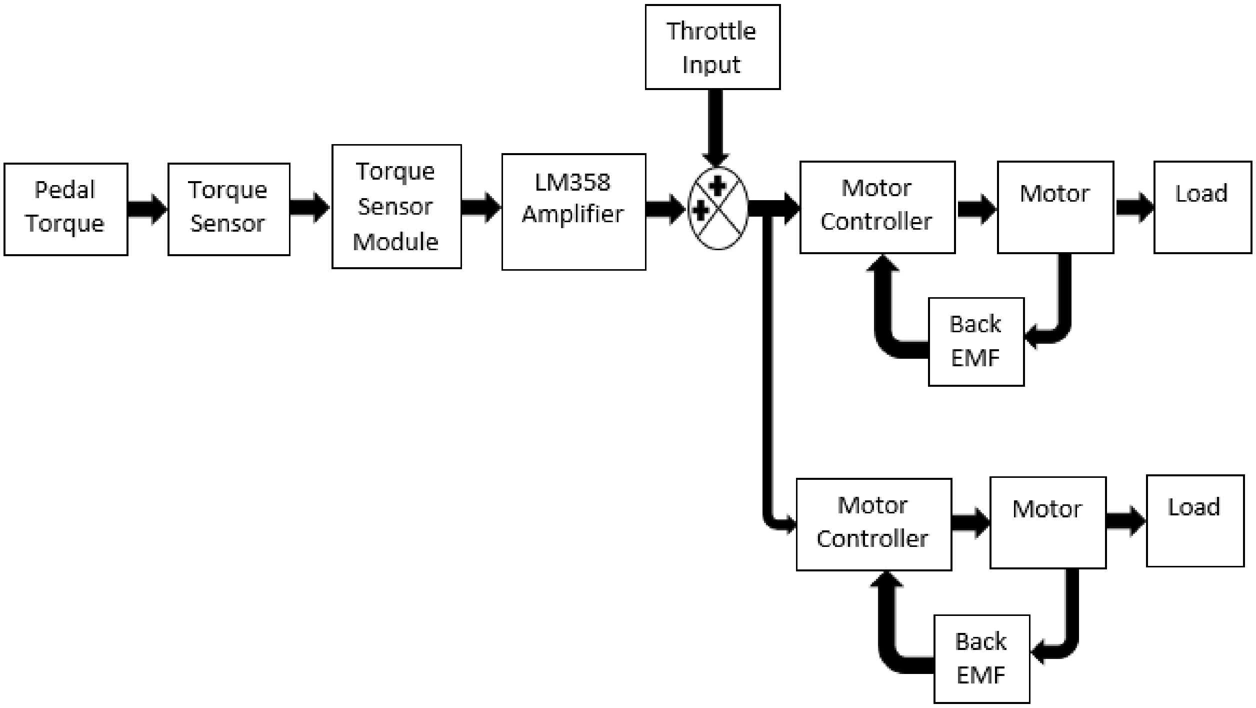


Figure 45: Block Diagram of whole system

This block diagram represents the behavior of the whole system with system inputs and outputs in a gist. This system includes torque sensor pedal and throttle as inputs and after processing these input signal an output is generated which drives the motors rotating the wheels.

5.2 Inputs and Outputs of the System

As mentioned, figure 45 portrays the operation of the wheelchair. A patient can choose one of two ways to drive the wheelchair; i) using the throttle and ii) using the torque sensor pedal. When the rider uses torque sensor pedal, the module connected to the pedal detects the rider's muscle power to sense the amount of applied torque, converts it into voltage and sends it to the torque sensor adjustor circuit. Then this voltage is amplified in the adjustor circuit and fed to the motor controller. The input from throttle here is directly fed to the controller. The motor controller reads these two input voltages and amplifies them and feeds them to the motors. Then the motor shafts start rotating the wheels using gear trainsand the vehicle moves.

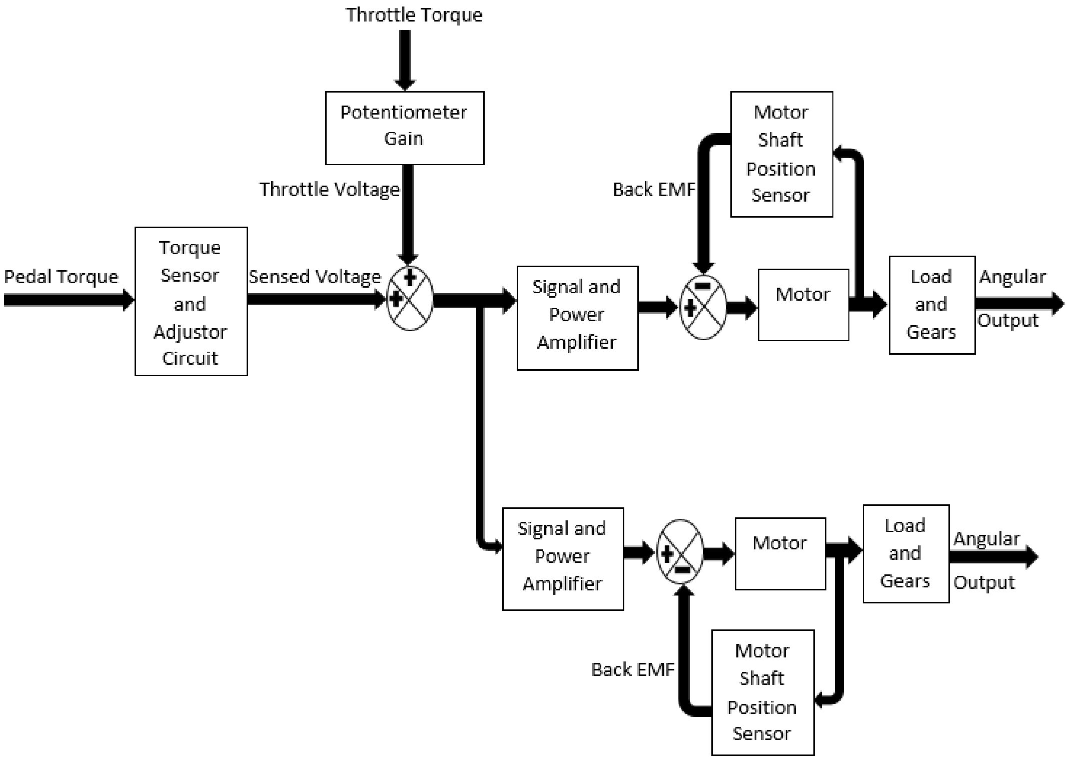


Figure 46: Detailed Block Diagram with labeled signals

5.3 Mathematical Representation

The basics of representing the system using mathematical block diagrams can be extracted from figure 46. Detailed mathematical representations of the overall system are as follows.

Torque sensor input:

Torque sensor or torque transducer senses the mechanical input, in this case the muscle power, or force applied to the torque sensor pedal and converts it into electrical energy. This conversion is done by the torque sensor module which gets its 5V biasing voltage from the battery via torque sensor adjusting circuit. The outputelectrical voltagesare then fed to the adjustor circuit. A minimum amount of torque needs to be applied for the sensor the read the torque. If the gain constant between the applied torque and the output voltage from the module is considered to be k_p, then the following equation is achieved.

$$k_p = \frac{output\ voltage\ from\ torque\ sensor}{torque\ applied\ into\ the\ pedal}$$[19]

If 15Nm of torque is applied and an output of 4.5V is received [19], therefore k_p= 0.3.

This output voltage is then sent to the torque sensor adjustor circuit and passes through voltage dividers to reach an LM358 Operational Amplifier. It takes 5V to bias the op-amp. The gain constant for the op-amp is K_{amp}, which is around 2.12 [4]. Before reaching the amplifier, the voltage from the torque sensor gets attenuated by 60% in the voltage dividers and the respective gain constant is K_a=0.6 [16,17].

The block diagram of the system is shown below.

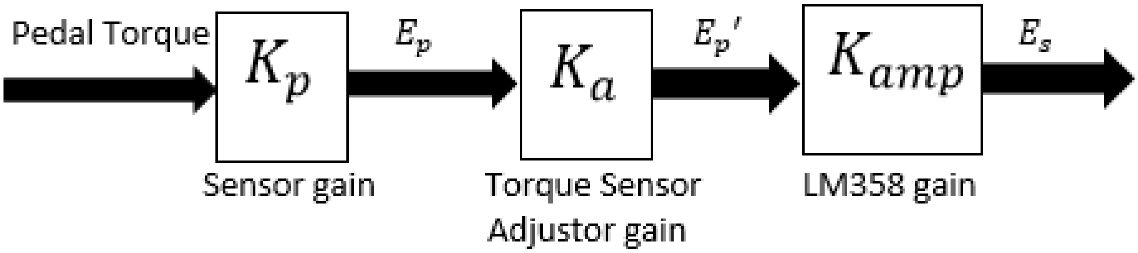
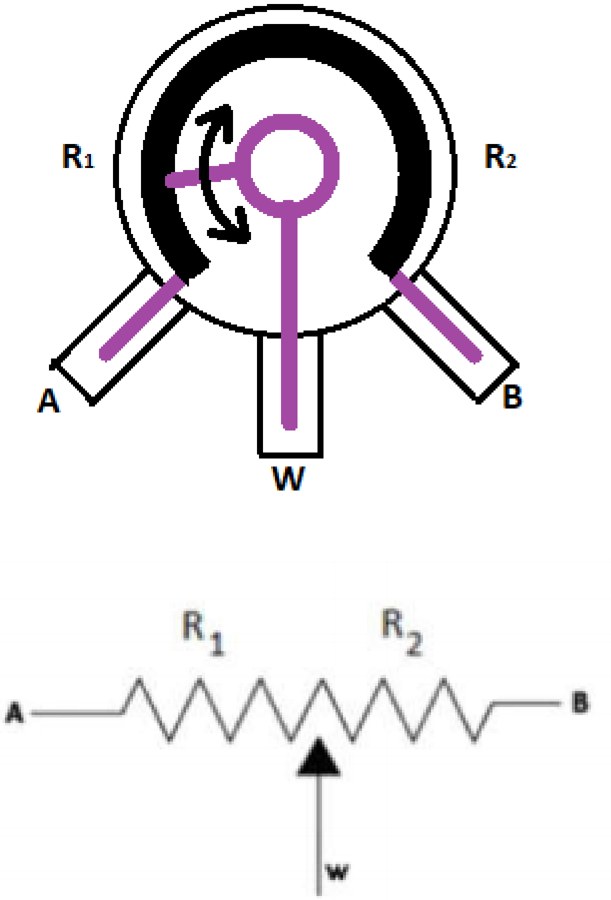


Figure 47: Torque Sensor Mathematical Modeling Block Diagram

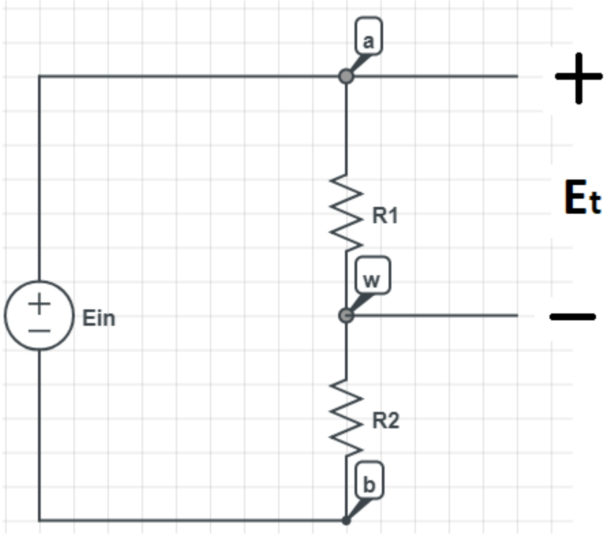
From figure 47, it can be seen that the torque sensor pedal torque constant, $k_{pedal} = k_p k_a k_{amp}$. After calculation the value of k_{pedal} is found to be 0.3816 [4].

Throttle input:

The input from the throttle reaches the motor controller along with the input from the torque sensor. Inside the throttle there is a potentiometer which adjusts the throttle gain through resistors R_1, R_2 and wiper W. Depending on the position of W, R_1 and R_2 change and the angle corresponding to R_1 changes as well. This angle determines the gain.



a) Throttle Diagram (Resistance value changes with wiper)



b) Throttle Circuit

Figure 48: a) Throttle Diagram b) Throttle circuit

The resulting equation is [19]:

$R_1 = \frac{\theta}{\theta_{max}} R_{total}$ .... (i)

Here, R_1 = resistance between A & W

R_2 = resistance between B & W

R_{total}= R_1+ R_2

As the throttle rotates from 0 to 70 degrees, the value of θ_{max} will be 1.22173 [19].

From fig 4(b) using voltage division rule we get,

$E_t = \frac{R_1}{R_{total}} E_{in}$.......................... (ii)

Manipulating equations (i) and (ii),

$$E_t = \frac{\theta}{\theta_{max}} E_{in}$$

Rearranging,

$\frac{E_t}{\theta} = \frac{E_{in}}{\theta_{max}}$.........................(iii)

According to Hook's law,

$T_t = K_s\theta$

Rearranging,

$\frac{\theta}{T_t} = \frac{1}{K_s}$ .... (iv)

The transfer function of the throttle input is shown below.

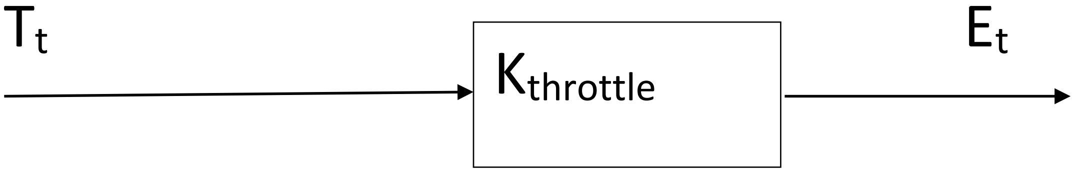


Figure 49: Throttle input transfer function

So,

$$K_{throttle} = \frac{E_t}{T_t}$$

or, $K_{throttle} = \frac{E_t}{\theta} \times \frac{\theta}{T_t} = \frac{E_{in}}{K_s\theta_{max}}$

Motor Circuit:

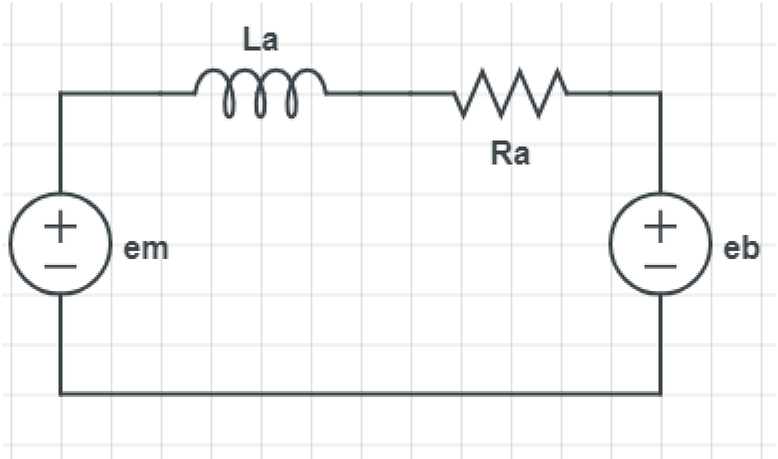


Figure 50: Motor circuit schematic diagram

The schematic diagram of the motor circuit is shown above [19].

Torque input from the throttle and torque sensor pedal are being fed to the motors. In this system there are two BLDC motors rotating two wheels of the wheelchair simultaneously and separately.

Before the electrical voltages reach the motors,they pass through amplifiers where they get boosted.

Let the motor amplification constant be considered asK_m

Armature Inductance asL_a

Armature Resistance asR_a

Torque sensor output voltage asE_s

Throttle output voltage asE_t

As it can be seen from the motor circuit of figure 50 [19],

$$R_a i_a + L_a \frac{di_a}{dt} + e_b = K_m(e_s + e_t)$$

Applying Laplace Transformation on the above equation,

$R_a I_a + L_a I_a s + E_b = K_m(E_s + E_t)$ .... (v)

Here, E_b is the back emf voltage of the motors which is proportional to rotation or angular velocity of the motor ω_m [19,20]

$$e_b \propto \frac{d\omega_m}{dt}$$

or, $e_b = K_b \frac{d\omega_m}{dt}$

Applying Laplace Transform on the above equation,

$$E_b = K_b s \omega_m$$

or, $\frac{E_b}{\omega_m} = K_b s$

From equation (v),

$$\frac{I_a}{K_m(E_s + E_t) - E_b} = \frac{1}{L_a s + R_a}$$

5.4 Motor Vehicle Dynamics

The motor vehicle dynamics can be represented as a T-i analogous circuit which is basically the relationship between an electrical system anda mechanical system [19].

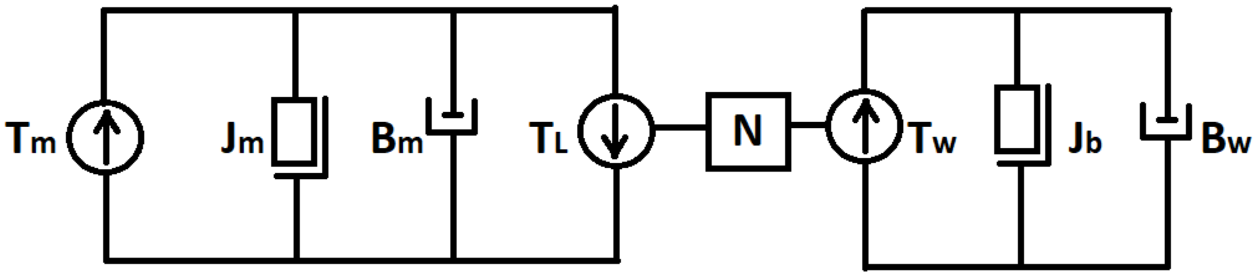


Figure 51: T-i analogous circuit of the motor and wheel

Here,

T_m= Motor Torque

J_m = Motor Inertia

B_m = Motor Damping/Viscous Coefficient

T_L= Load Torque (motor shaft)

T_W= Wheel Torque

J_B= Body Inertia

B_W = Wheel Viscous Coefficient

$N = \frac{T_W}{T_L}$ = Gear ratio

To establish the motor dynamics equation using Laplace transformation,the following can be written:

$T_m(s) = J_m s^2 \omega_m(s) + B_m s \omega_m(s) + T_L(s)$ .... (vi)

$T_W(s) = J_B s^2 \omega_W(s) + B_W s \omega_W(s)$

or, $T_L(s) \times N = J_B s^2 \omega_W(s) + B_W s \omega_W(s)$

or, $T_L(s) = \frac{1}{N}[J_B s^2 \omega_W(s) + B_W s \omega_W(s)]$

From the motor side,

$T_L(s) = \frac{1}{N^2}[J_B s^2 \omega_m(s) + B_W s \omega_m(s)]$ ....(vii)

Substituting equation (vii) into equation (vi),

$$T_m(s) = J_m s^2 \omega_m(s) + B_m s \omega_m(s) + \frac{1}{N^2}[J_B s^2 \omega_m(s) + B_W s \omega_m(s)]$$

or, $T_m(s) = [\left\{J_m + \frac{J_B}{N^2}\right\} s^2 + \left\{B_m + \frac{B_W}{N^2}\right\} s]\omega_m(s)$

or, $T_m(s) = [J_{eq} s^2 + B_{eq} s]\omega_m(s)$

or, $\frac{\omega_m(s)}{T_m(s)} = \frac{1}{J_{eq} s^2 + B_{eq} s}$..................... (ix)

where,

$J_{eq} = J_m + \frac{J_B}{N^2}$

$$B_{eq} = B_m + \frac{B_W}{N^2}$$

The approximate estimated mass of the wheelchair version 3 along with the user's mass is 150kgs. And the radius of the back wheels is 0.3302 meters. Using these values J_B can be calculated.

J_B= 0.5*150*0.3302= 24.75 $kg\ m^2$

Also, from the motor parameters table, $J_M = 0.0000173\ kg\ m^2$

Angular output of the motor, ω_m = 3500 rpm, equivalent to 366.52 rad/s.

At 78% efficiency, angular output of the wheel, ω_w= 366.52*(1/0.78)=469.89 rad/s

Hence, B_W= (150*9.81*0.3302)/469.89=1.03404 Nm/(rad/s)

From the motor parameters table, B_m = 0.0016 Nm/(rad/s)

Therefore,

J_{eq}= 40.705 $kg\ m^2$

B_{eq}= 1.70 Nm/(rad/s)

However, the motor torque T_m is proportional to the armature current,i_a [19]. Therefore,

$$T_m \propto i_a$$

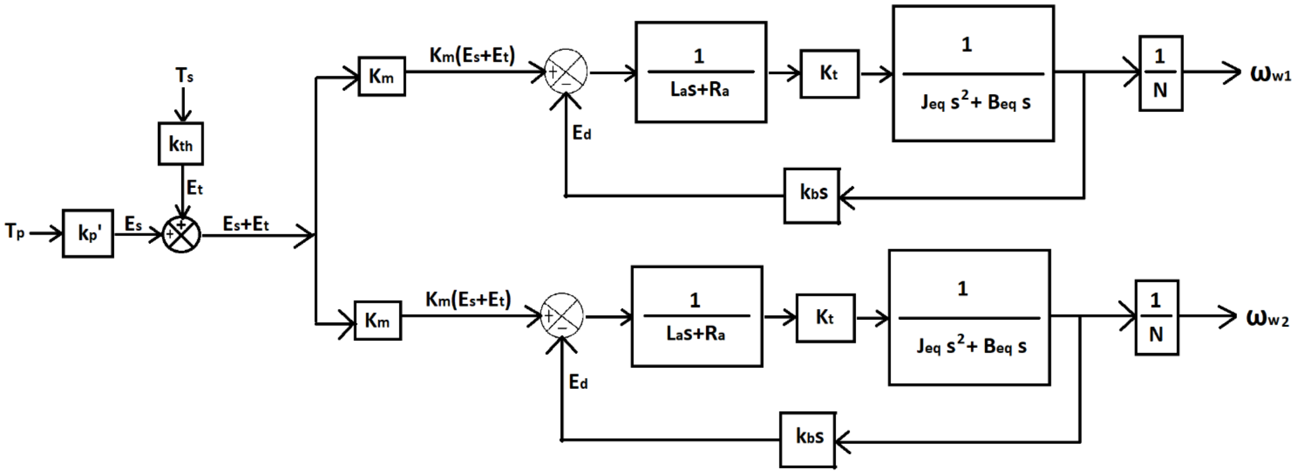
or, $T_m = K_t i_a$ ....(x)

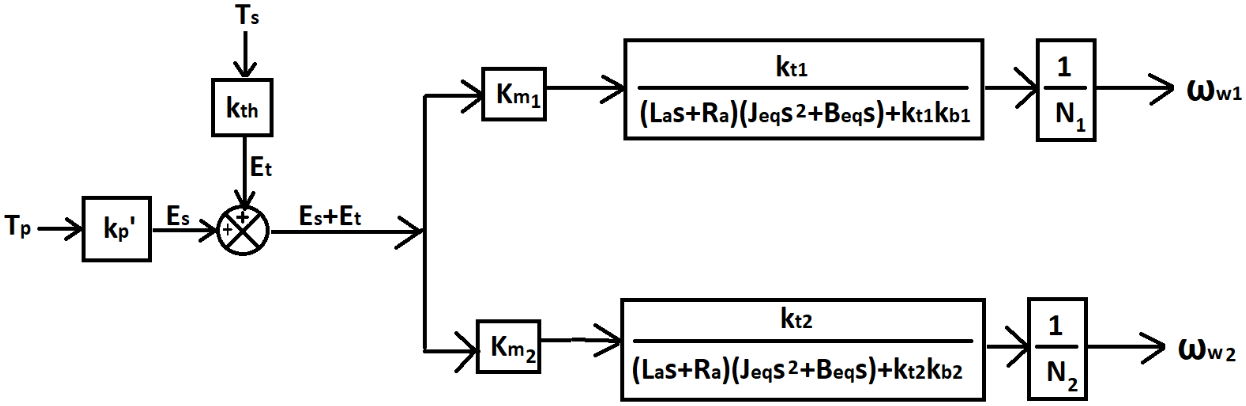
As it has already been mentioned, there are two motors in this system. However, these two motors separately run the two wheels as the wheels are not connected through any axle.

Furthermore, these motors run simultaneously to rotate the wheels at the same time at same velocity. So, the motor circuit equation for both motors along with motor dynamics equations for both the motors in this system will be the same.

5.5 Mathematical Modeling of the Overall System

All these equations and transfer functions lead to the mathematical modeling of the overall system which is shown below in the block diagram.





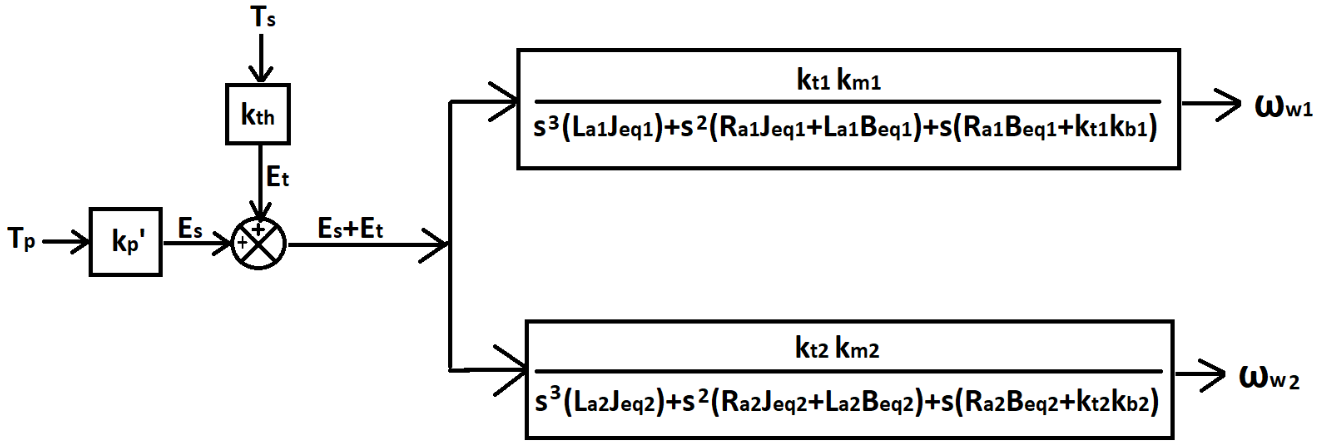


Figure 52: Mathematical modeling of the overall system

The overall system has two input signals along with two simultaneous output signals. For this reason, this model can be derived using the matrix formulation format of a Multiple Input Multiple Output (MIMO) system.

$$\begin{bmatrix} \omega_{w1} \\ \omega_{w1} \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \text{x} \begin{bmatrix} T_p \\ T_s \end{bmatrix}$$

From the matrix,

$\omega_{w1} = G_{11}T_p + G_{12}T_s$ -------------(xi)

$\omega_{w2} = G_{21}T_p + G_{22}T_s$ -------------(xii)

where,

$$G_{11} = \frac{\omega_{w1}}{T_p} = \frac{{}^{K_pK_mK_t}/_{N}}{S^3(L_aJ_{eq})+S^2(R_aJ_{eq}+L_aB_{eq})+S(R_aB_{eq}+K_{t1}K_{b1})}$$

G12 = $\frac{\omega_{w1}}{T_s} = \frac{K_{th}K_mK_t/_N}{S^3(L_aJ_{eq})+S^2(R_aJ_{eq}+L_aB_{eq})+S(R_aB_{eq}+K_{t1}K_{b1})}$

G21 = $\frac{\omega_{w2}}{T_p} = \frac{K_pK_mK_t/_N}{S^3(L_aJ_{eq})+S^2(R_aJ_{eq}+L_aB_{eq})+S(R_aB_{eq}+K_{t1}K_{b1})}$

G22 = $\frac{\omega_{w2}}{T_s} = \frac{K_{th}K_mK_t/_N}{S^3(L_aJ_{eq})+S^2(R_aJ_{eq}+L_aB_{eq})+S(R_aB_{eq}+K_{t1}K_{b1})}$

Substituting the values of the parameters,

G11 = $\frac{0.505}{4.07X10^{-3}S^3+2.85S^2+0.1217S}$

G12 = $\frac{265.67}{4.07X10^{-3}S^3+2.85S^2+0.1217S}$

G21 = $\frac{0.505}{4.07X10^{-3}S^3+2.85S^2+0.1217S}$

G22 = $\frac{265.67}{4.07X10^{-3}S^3+2.85S^2+0.1217S}$

Here G11, G12,G21andG22 are the transfer functions of the overall mathematical model.

Using (xi) and (xii),

$\omega_{w1} = \frac{.505}{4.07X10^{-3}S^3+2.85S^2+0.1217S}T_p + \frac{265.67}{4.07X10^{-3}S^3+2.85S^2+0.1217S}T_S$

$\omega_{w2} = \frac{.505}{4.07X10^{-3}S^3+2.85S^2+0.1217S}T_p + \frac{265.67}{4.07X10^{-3}S^3+2.85S^2+0.1217S}T_S$

Motor parameters table [4,21] :

Nominal output	250 W
Nominal torque	0.6 W
Nominal voltage	24 V
Speed	3500 rpm
Torque constant, Kt	0.043 Nm/A
Resistance, R	0.07
Inductance, L	0.0001 H
Rotor inertia, Jm	0.0000173 kgm2
Viscous damping, Bm	0.0016 Nms/(rad/s)
Back EMF constant, Vb	0.065 V/(rad/s)
Motor amplifier gain, Km	24

Equation parameters table:

Kp	0.3
Ka	0.6
Kamp	2.12
Kpedal	0.3816
Kthrottle	200.80
θtmax	1.22173 rad
Ein	5 V
ks	0.01711 Nm/rad
Jeq	40.705 kgm2
Beq	1.70 Nm/rad/s

5.6 Simulation in MATLAB/SIMULINK

The overall mathematical modeling diagram has been simulated using MATLAB SIMULINK including the necessary motor and equation parameters from the tables provided above.

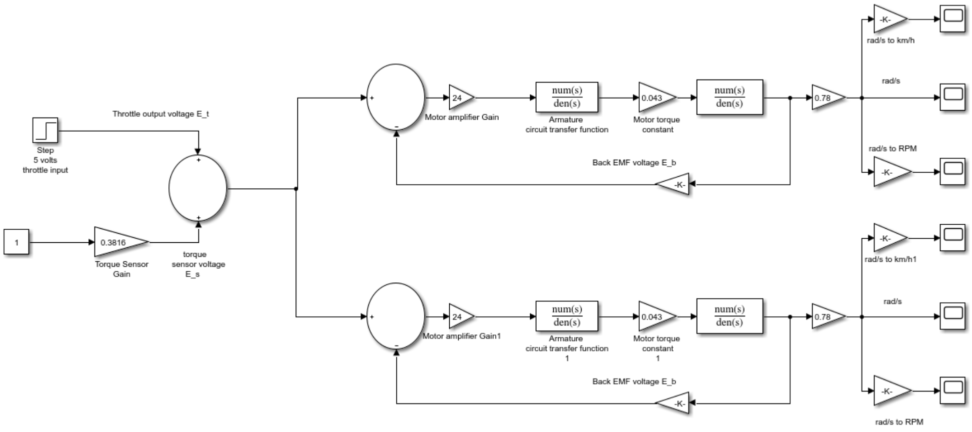
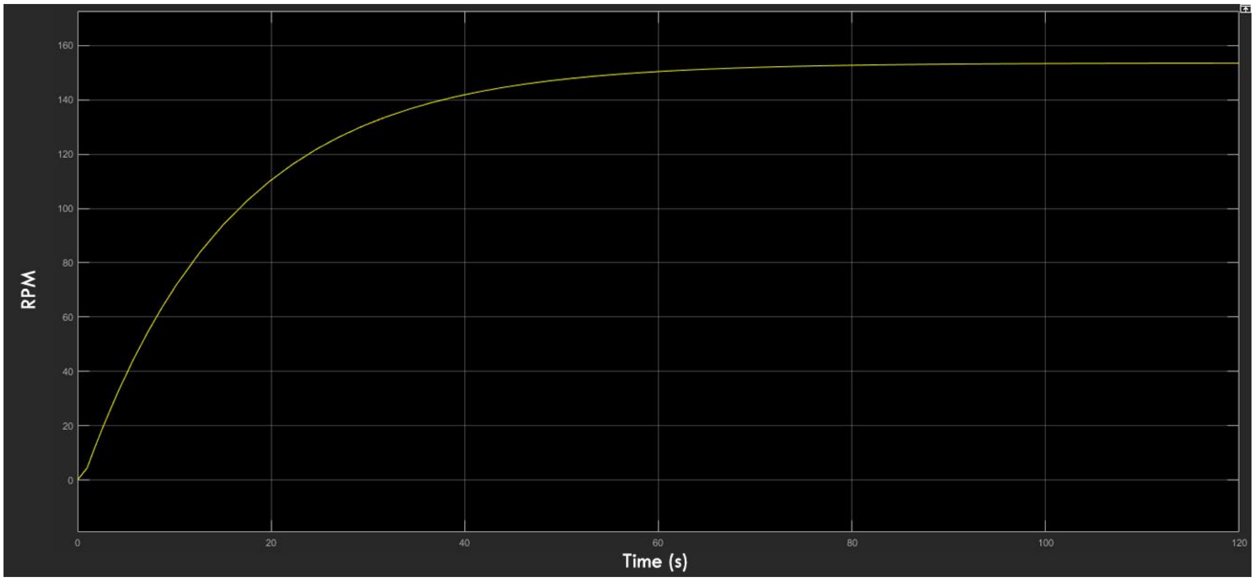
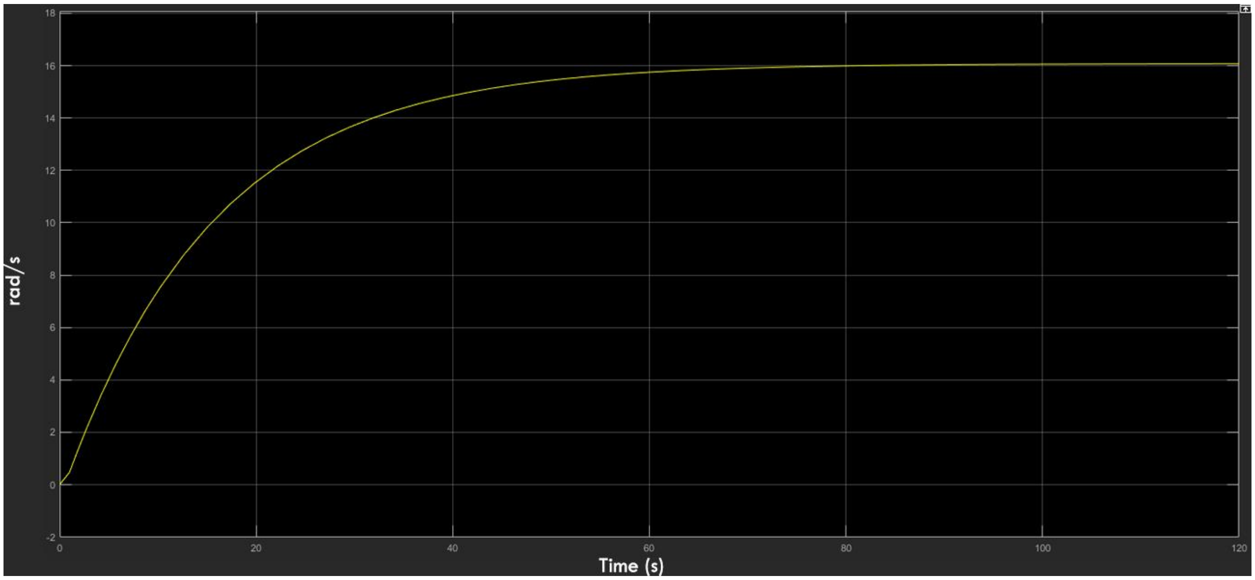


Figure 53: SIMULINK diagram of overall mathematical model

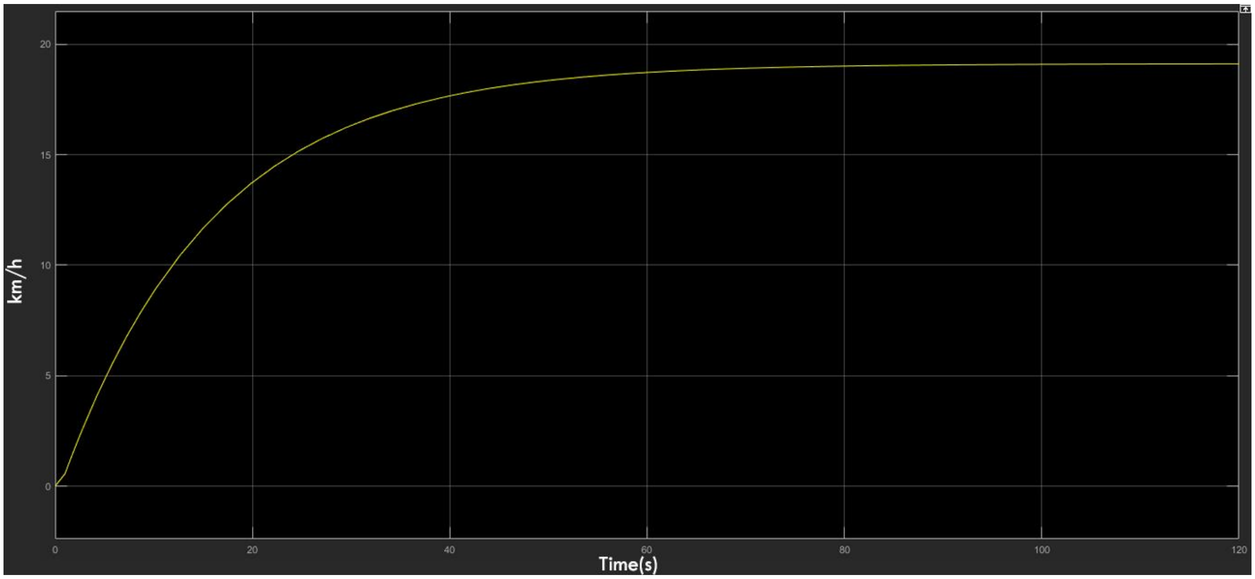
The following results have been found after running the simulations.



a) RPM VS Time



b) rad/s VS Time



c) km/hr VS Time

Figure 54: Simulation results a) RPM VS Time b) rad/s VS Time c) km/hr VS Time

Chapter 6

Field Tests

6.1 Introduction

The field tests have been carried out to find the voltage and current readings so that the power can be calculated and hence the energy consumed by the load can be found. The voltage readings were measured using a multimeter across the batteries and the current readings were taken using a clamp meter. Two other multimeters were also connected across the motor and the throttle to record the voltages across the motor and throttle with time.A picture of the multimeter setup during field tests is shown below.

Figure 55: Multimeter setup during field test

The meter readings were recorded by a camera and later extracted and graphed by taking the values after a certain time interval. Other than that, more field tests were carried out to confirm the improvement of the limitations of the original versions. Ramp test was done to observe if the wheelchair can move up a ramp and it was found to be successful. Overcoming threshold tests were also done by going over several speed breakers and the wheelchair went over them successfully.

6.2 Field test data analysis

The voltage and current readings recorded when driving the wheelchair using throttle is shown below in figure 55.

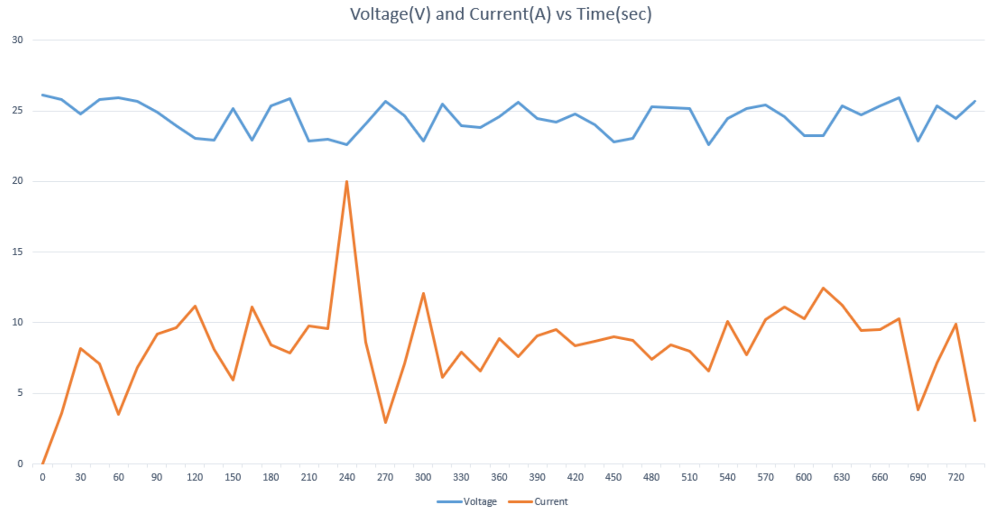


Figure 56: Voltage and current readings using throttle only

Power consumed by the load was calculated using these values and is shown below in figure 56.

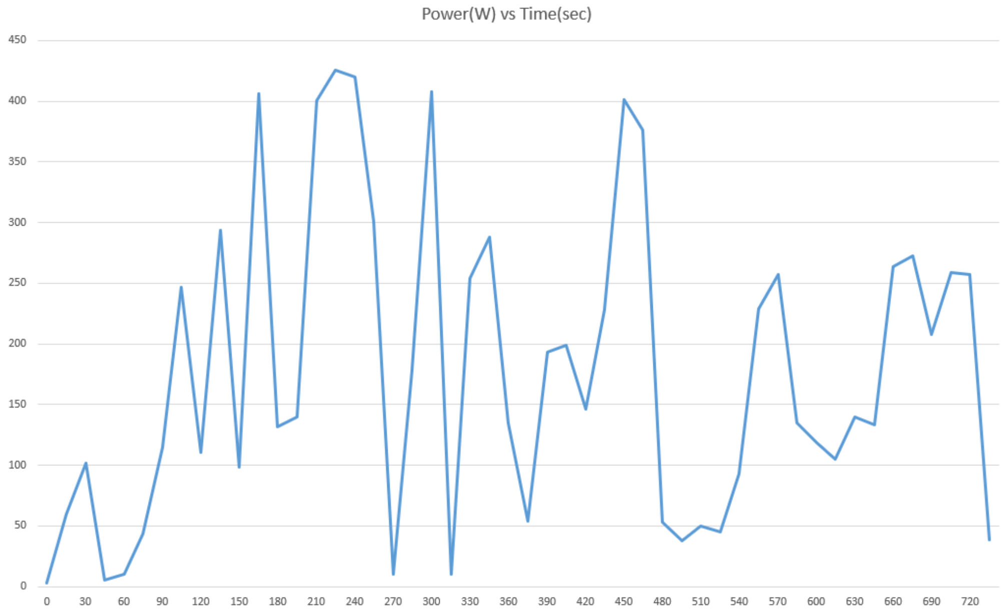


Figure 57: Power consumed by the load using throttle only

The energy consumed by the load was calculated from the power vs time graph by determining the area under the graph and the energy consumed was calculated to be 132979 Joules or 0.0369 kWh.Furthermore, the changes in throttle output voltage and the voltage across the motors were also recorded using multimeters and the graphs of these voltages against time are shown below.

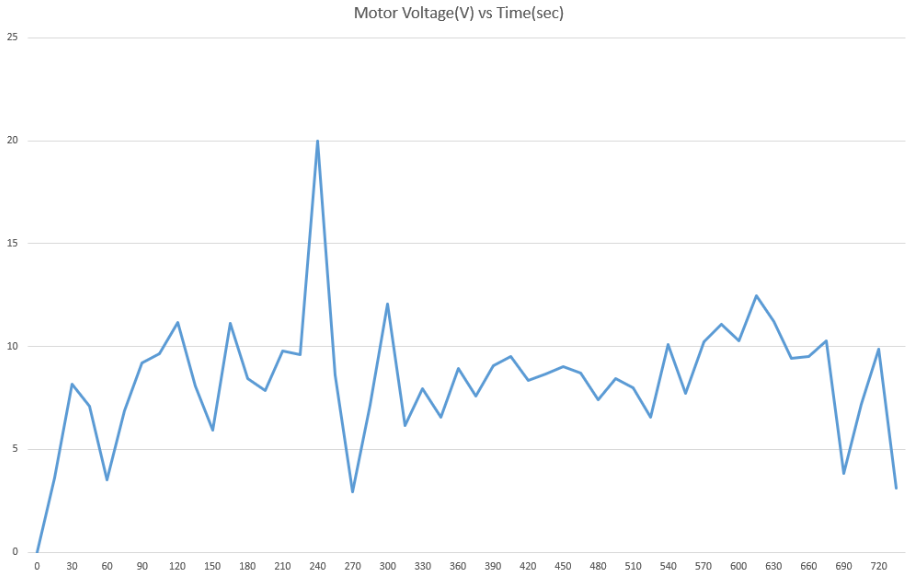


Figure 58: Voltage across motor against time

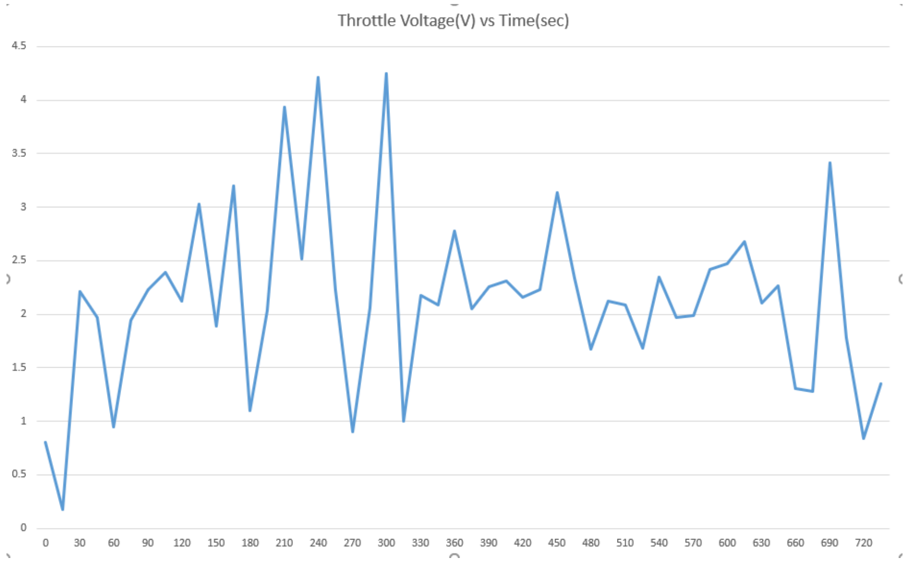


Figure 59: Throttle output voltage against time

6.3 Further tests in response to CRP requirements

Ramp test: One of the major feedbacks from CRP for the older versions was that the wheelchairs faced difficulty in climbing ramps. Hence a couple ramp tests were conducted and the wheelchair successfully climbed the ramps. Pictures are shown below.

a) Big ramp

b) Small ramp

Figure 60: Ramp test a) Big Ramp b) Small ramp

Threshold overcoming test: Another feedback from CRP was difficulty in overcomingthresholds. Hence, tests were carried out on the road and the wheelchair successfully went over speed breakers. Pictures are shown below.

Figure 61: Threshold test

Transfer test: The older wheelchairs had very little room for the patients to get on and off on the wheelchair and hence it was difficult for the patients to transfer to beds or other chairs from the wheelchair. Hence, a transfer test was done to show that enough space exists for the patients to transfer and the seat is also at a convenient level for transferring from the sides. Picture is shown below.

Figure 62: Transfer test

Detachable part test: A major requirement of CRP was to make the wheelchair front part detachable so that the vehicle can be used both for indoor and outdoor purposes. The detachable mechanism has been tested and it has been found to be extremely convenient and user-friendly. Two screws need to be taken off and then the front part is pulled and two long pipes are separated from the main body. Pictures are shown below.

Figure 63: Detachable part test

6.4 Torque Sensor Tests

Since there was no modification done with the torque sensor, all the data for the torque sensor field test have been collected from the thesis paper of the original version (version 1) of the wheelchair [1]. The battery voltage and battery current readings recorded against time while driving the version 1 wheelchair using the torque sensor is shown below.

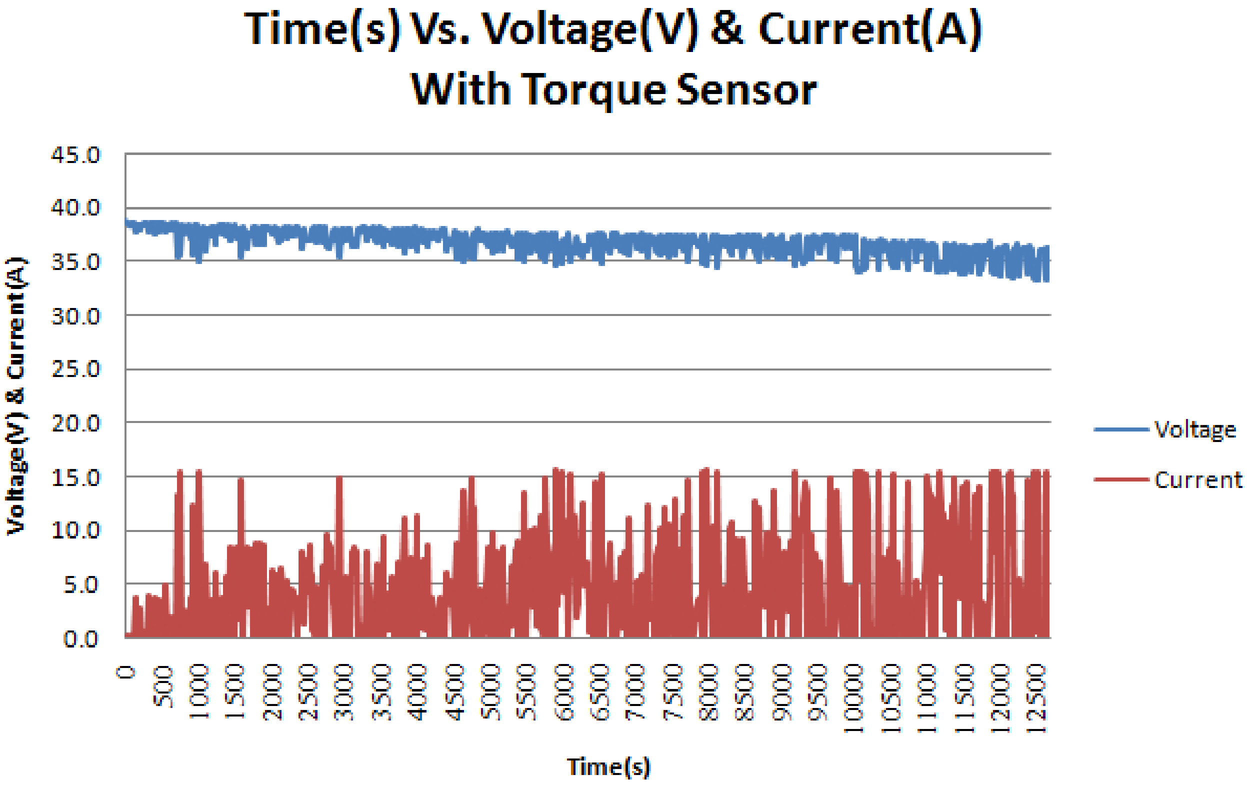


Figure 64: Battery voltage and current against time using torque sensor

Power has been calculated from these voltage and current readings and is plotted against time in figure 65.

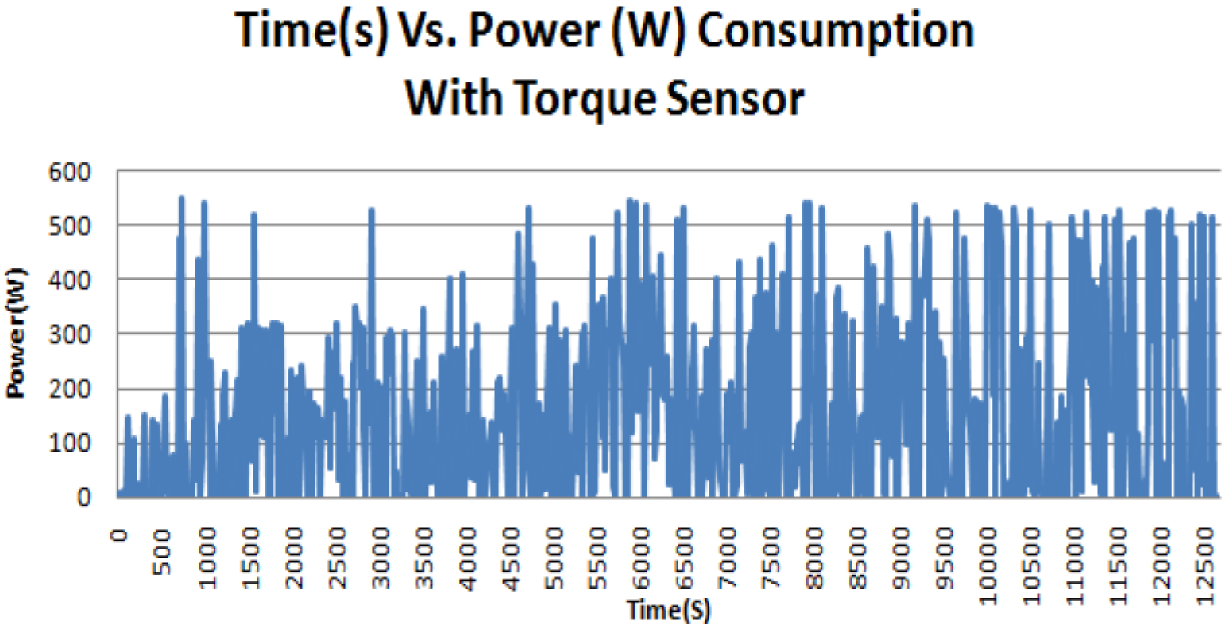


Figure 65: Power against time using torque sensor

The power against time graph can be used to find the energy consumed by finding the area under the graph. In this case, since torque sensor was used, the energy consumed by the load is a summation of the energy supplied by the battery bank and the energy supplied by the human body. The total energy consumed was found to be 2004674.3 Joules or 0.5569 KWh.

The following graph shows the torque sensor output voltage from the module and the input voltage from the adjustor circuit to the motor controller against time.

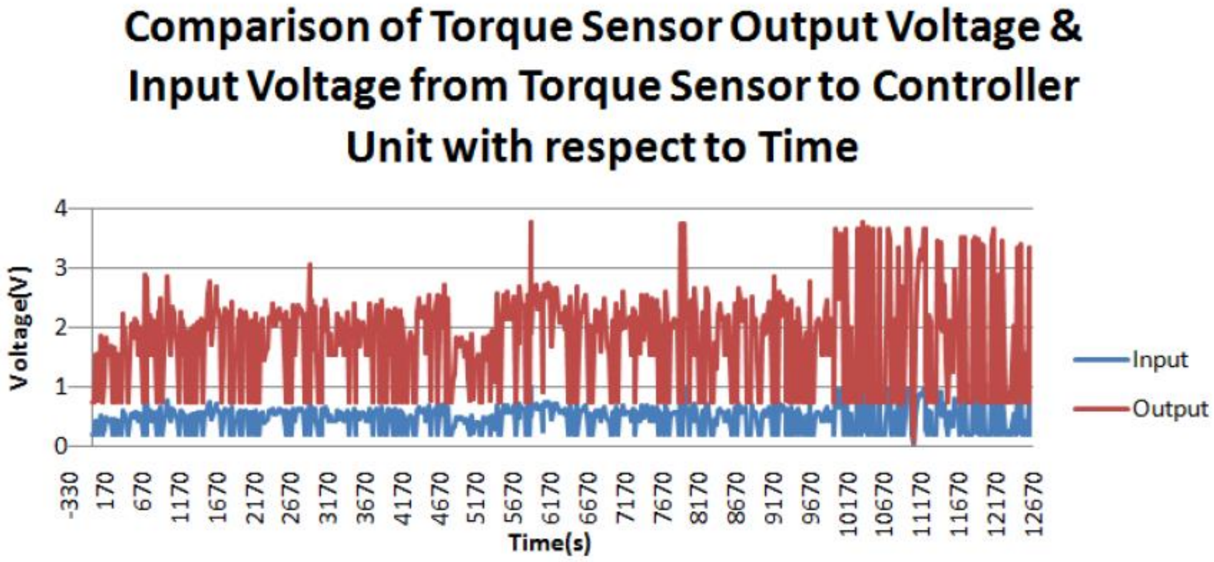


Figure 66: Torque sensor output voltage from module and motor controller input voltage from adjustor circuit against time

In the original version 1 thesis, another set of tests was carried out using the torque sensor, but with about 20 kg extra weight [1]. The test results for the extra 20 kg weight are shown below.

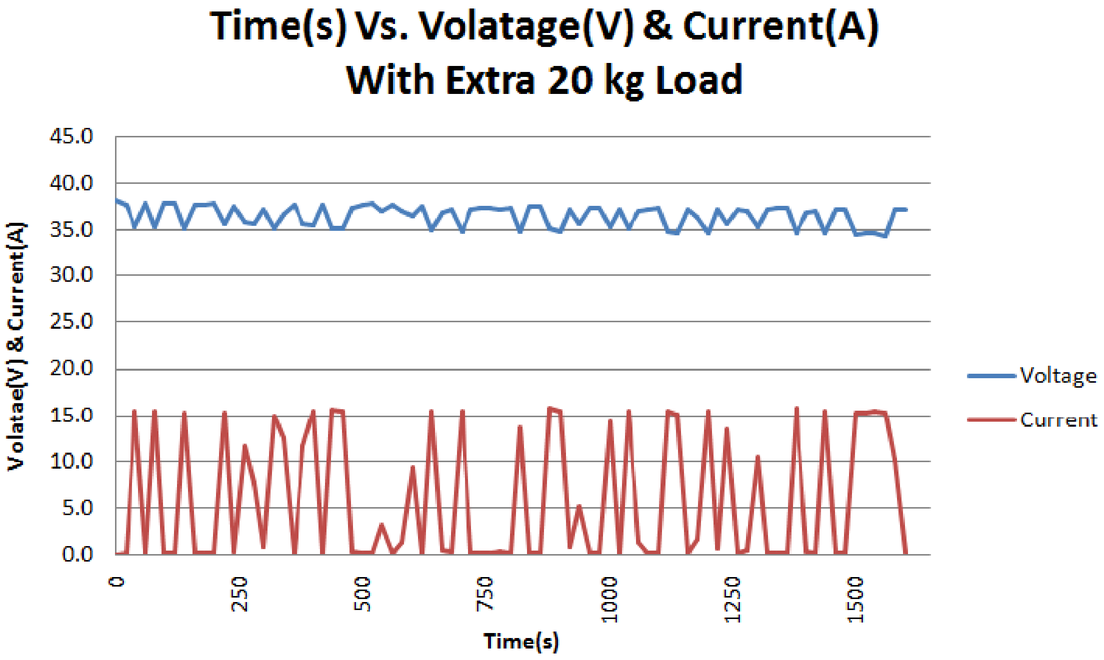


Figure 67: Battery voltage and current against time using torque sensor and extra 20 kg weight

Figure 67 shows the battery voltage and current readings graphed against time when 20 extra kg are put on the wheelchair and the torque sensor pedal is used to drive it. Again, the power is calculated using the voltage and current readings and graphed against time in figure 68. Energy consumed by the load is found from the area under the graph of power vs time and is found to be 334942.3 Joules or 0.0930 kWh.

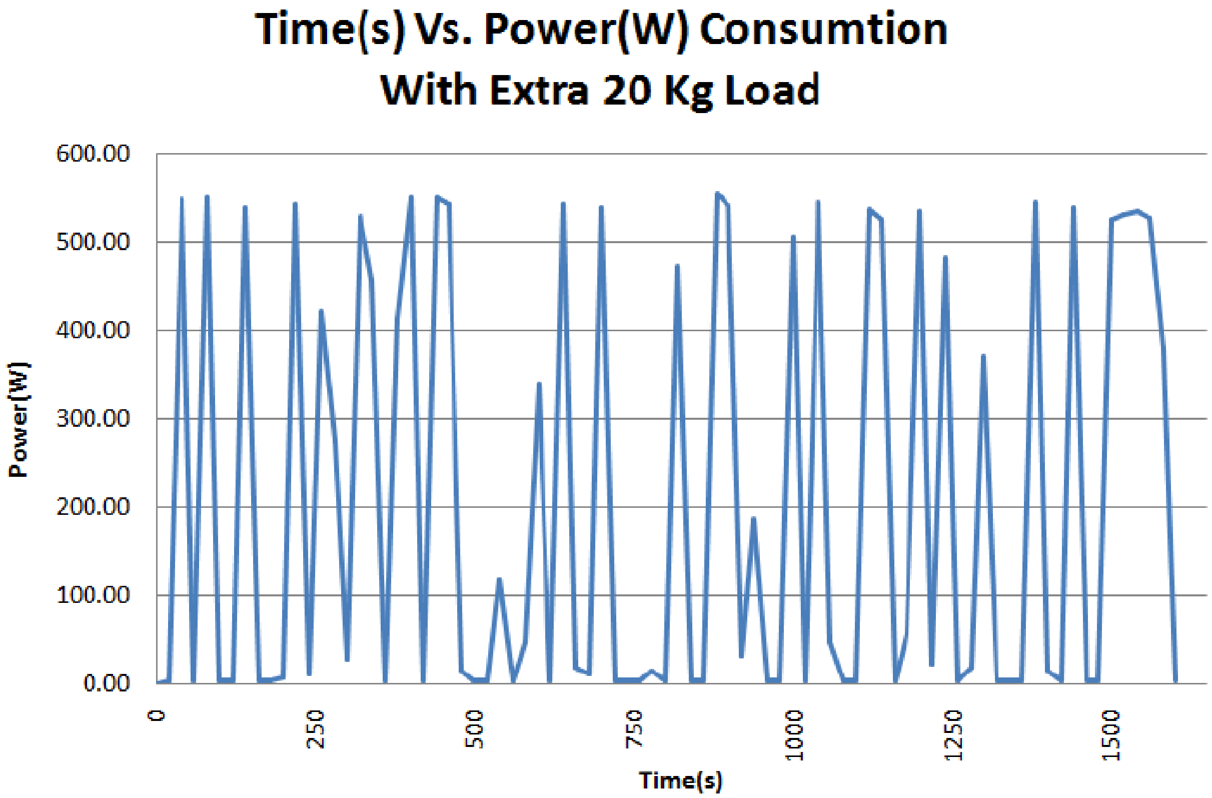


Figure 68: Power against time using torque sensor and extra 20 kg weight

It had been found in the version 1 thesis that when the torque sensor pedal is used, about 55% of the energy consumed by the load comes from the battery and the remaining 45% comes from the human body. Hence, it is highly recommended to use the torque sensor pedal as it saves around 45% of electric energy and increases battery life.

Chapter 7

Comparative Study and Analysis

7.1 Introduction

The comparative study of the electric tri-wheeler will be covered in this section, in two distinct segments per comparison. One segment should compare the differences of our version with the predecessors, v1 and v2, while the other segment will provide brief overview of the comparison with the existing and comparable detachable model developed by the Centre for the Rehabilitation of the Paralysed (CRP).

7.2 Comparison between iterations

Figure 69: Triwheeler version 1

Figure 70: Triwheeler version 2

Price:

All of the versions constructed were made as prototype units, hence their manufacturing prices don't exactly represent their mass manufacturing prices in bulk. However, excluding the Solar Charging Kit costs, each version costed about ~50,000 BDT. It also has to be taken into consideration that the third version was made by modifying the second version's chassis.

Version 1: 50,000 BDT

Version 2: 50,000 BDT

Version 3: 50,000 BDT

Distance travelled:

In the distance tests conducted, the units showed similar results between the versions. The distances measured are the distances the wheelchairs travelled after a full charge up until the state of charge of the batteries came down to 50%.

Version 1: ~20km/charge (without Torque Sensor), ~40km/charge (with Torque Sensor)
Version 2: ~20km/charge (without Torque Sensor), ~40km/charge (with Torque Sensor)
Version 3: ~20km/charge (without Torque Sensor), ~40km/charge (with Torque Sensor)

Safety Features:

Version 1:	Front Brake- V brake
Version 2:	Front Brake- V brake
Version 3:	Rear Brakes- Seatbelt

Charging time:

All battery charging times were measured after depleting the batteries up to 50% State of Charge (SOC). The time interval was measured up till the battery provided the rated voltage across the terminals

Version 1:	~2.5 hours
Version 2:	~3 hours
Version 3:	~3 hours

7.3 Comparison with CRP developed Detachable Tri-wheeler

The Centre for the Rehabilitation of the Paralysed (CRP) is a facility that provides therapy and rehabilitation for the physically disabled. Naturally, CRP also develop and manufacture various wheelchair models for the patients. One such model, in particular, is selected to be compared with the electric tri-wheeler for several key design feature similarity.

Figure 71: Manual detachable wheelchair by CRP

Figure 72: Triwheeler version 3

The key similarities include the Modular/Detachable front part segment, which can come off fully, leaving the backside as a four wheeled regular wheelchair. A pedal and chain sprocket connection is made to the front wheel, which is also smaller than the rear wheels similar to the electric tri-wheeler.

Despite the similarities of the basic outline and skeletal structure, there are major improvements on the electric tri-wheeler compare to the CRP Tri-wheeler. First and foremost, the electric tri-wheeler is motorized and runs on a 48V electrical system, while still retaining the option to manually turn the wheels when detached, hence massively improving convenience of the patients for both long distance travel or shorter day to day commutes. Secondly, the electric tri-wheeler is much more compact due to steeper placement of the front wheel fork and head tube, making it easier to maneuver around. Third, the electric wheelchair has smaller free wheels for the rear segment of the vehicle, reducing not only the inclination of the seat, but also the likelihood of scraping against the ground in rough roads, and even on speed bumps. And finally, the implementation of Torque Sensor on the manual pedal with chain sprocket connection to the front wheel, which improves mileage and battery life by significant margins. It achieves so by reducing load on the battery and also introducing electrical energy directly through conversion of chemical and kinetic energy from the patient’s muscles. And consequently, further reducing the carbon footprint coupled with the solar charging station.

7.4 Conclusion

The electric tri-wheeler (Current Version 3) having been refined from the previous versions, is much superior in terms of both design elements and performance statistics. It provides better distance coverage and travels at a safer speed as per recommended for patients, compared to the previous iterations.

Chapter 8

Conclusion

8.1 Summary

The torque sensor based electrically assisted tri-wheeler with dedicated solar charger kit has originally been produced with the hope of alleviating the hardship of disabled people as much as possible. It was a more economical alternative for the common people of this country who are unable to afford modern sophisticated wheelchairs. The wheelchair also promoted renewable energy and raised awareness against environmental pollution by encouraging the use of the dedicated solar charger kit, thus using the Sun's clean energy. Furthermore, the torque sensor technology implemented in the wheelchair harnessed human body energy and used it to drive the wheelchair, which is another renewable and clean source of energy. Due to some inconveniences in the first version, a second version was produced which was an improvement over the first one in certain aspects. However, for even further improvements and modification, a third version of the wheelchair has been produced, which has a lot more features compared to the first one and takes care of several problems that were encountered with the previous versions.

It is strongly hoped that this wheelchair comes to great benefit for the disabled people of this country. The wheelchair is designed for both indoor and outdoor use which promises the disabled people of a lifestyle where they can go out and earn a living.

8.2 Limitations and Future Scopes

Although utmost efforts have been put into making this tri-wheeler the best it can be, certain things could not be implemented due to various obligations. In this section, the limitations of the tri-wheeler version 3 and how they are intended to be upgraded in the future are discussed.

One of the major limitations of the tri-wheeler is its weight. The chassis had been made using metal sheets to give the wheelchair an overall attractive look. However, it resulted in the tri-wheeler becoming a little heavier than expected. In the future, it is intended to use more lightweight material for building the chassis of the tri-wheeler. Another major limitation is the unavailability of a back-gear in the system. Although it has been argued that it would be highly risky for a disabled person to turn back and drive the wheelchair backwards while maintaining his posture, it may still be an option in the near future to include a back gear in the system. Further limitations include the footrest not being adjustable. In the future, it is intended to make the footrest adjustable so that the user can move it up or down according to their comfort.It is also intended to modify certain features of the seat and back-rest so that the chair becomes more ergonomic.

Some major future scopes include the use of joystick controller to steer the tri-wheeler. The torque sensor based electric tri-wheeler has been designed for people who have strength in their arms so that they are able to turn the torque sensor pedal and drive the wheelchair. However, if there are certain patients with considerably less strength in their arms, they can still drive the wheelchair using the throttle only. However, even turning the throttle can require a minimum amount of energy and for these patients in particular, it is intended to implement a joystick controller system so that absolutely negligible strength is required in driving the wheelchair. Joystick controllers can be driven using about one or two fingers only and that would significantly benefit patients with less strength in their arms and hands.

Further proposed future scopes include implementing “Internet of Things (IoT)” into the system. IoT implementation can have quite a few advantages. For example, GPS tracking can help locate the user in case of any emergency or certain measures can be taken in case the wheelchair needs to be controlled from another place.Basically, the IoT would greatly benefit in monitoring the patient/user. Future scopes also include implementing suspensions and shock absorbers to make the wheelchair even more comfortable for riding in Bangladesh roads.

8.3 System specifications

Batteries : 12V 12Ah sealed lead-acid batteries (8 units, 2 sets)

Motors : 24 V 250W BLDC gear motors (2 units)

Solar Panel : 225W (3 units)

Tire Size : 26 inches

Seat : Cushioned and waterproof

Braking system :Motor break using controller and manual hand break

Steering system : Throttle handle bar and torque sensor pedal

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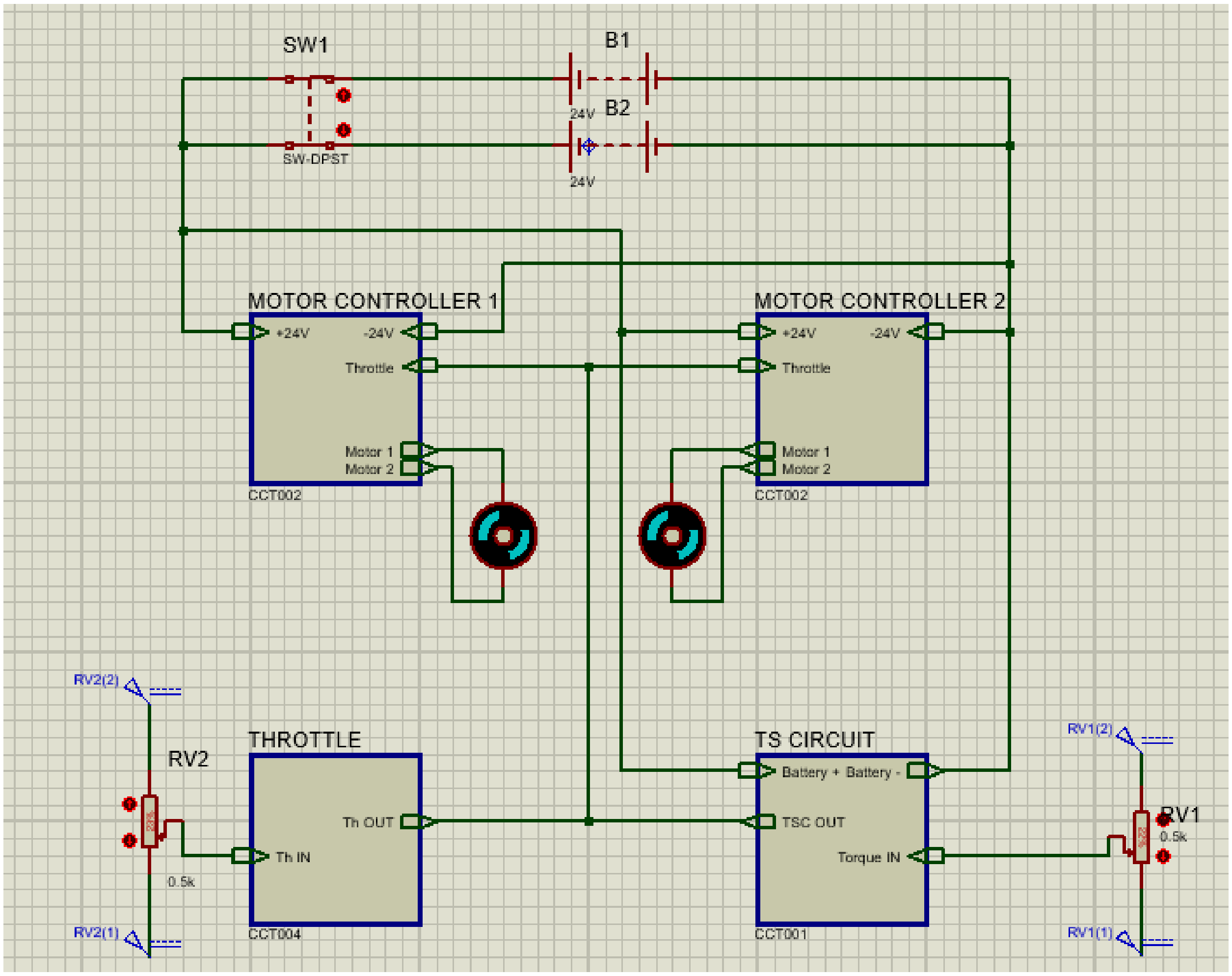
Appendix A

Electrical Connections



Appendix B

Field Test Data Using Throttle

Time (s)	Battery Voltage (V)	Motor Voltage (V)	Throttle Voltage (V)	Battery Current (A)
0	26.1	0	0.8	0.1
15	25.82	3.61	0.18	2.3
30	24.8	8.18	2.21	4.1
45	25.8	7.09	1.97	0.2
60	25.9	3.53	0.95	0.4
75	25.69	6.86	1.94	1.7
90	24.88	9.18	2.23	4.6
105	23.94	9.66	2.39	10.3
120	23.04	11.17	2.12	4.8
135	22.95	8.1	3.03	12.8
150	25.18	5.95	1.89	3.9
165	22.95	11.11	3.2	17.7
180	25.35	8.45	1.1	5.2
195	25.87	7.85	2.03	5.4
210	22.89	9.78	3.93	17.5
225	23	9.61	2.52	18.5
240	22.6	19.97	4.21	18.6
255	24.06	8.62	2.23	12.5
270	25.67	2.92	0.9	0.4
285	24.67	7.12	2.06	7.2
300	22.89	12.08	4.25	17.8
315	25.46	6.14	1	0.4
330	23.96	7.95	2.18	10.6
345	23.79	6.55	2.09	12.1
360	24.59	8.91	2.78	5.5
375	25.63	7.59	2.05	2.1
390	24.43	9.06	2.26	7.9
405	24.23	9.5	2.31	8.2
420	24.75	8.37	2.16	5.9
435	23.99	8.68	2.23	9.5
450	22.81	9.02	3.14	17.6
465	23.07	8.72	2.34	16.3
480	25.32	7.39	1.67	2.1
495	25.22	8.45	2.12	1.5
510	25.13	8	2.09	2
525	22.59	6.57	1.68	2

540	24.45	10.09	2.35	3.8
555	25.16	7.71	1.97	9.1
570	25.43	10.23	1.99	10.1
585	24.58	11.09	2.42	5.5
600	23.27	10.26	2.47	5.1
615	23.25	12.48	2.68	4.5
630	25.37	11.23	2.1	5.5
645	24.69	9.43	2.27	5.4
660	25.37	9.5	1.31	10.4
675	25.93	10.26	1.28	10.5
690	22.87	3.85	3.41	9.1
705	25.35	7.17	1.78	10.2
720	24.49	9.89	0.84	10.5
735	25.64	3.1	1.35	1.5