Electrically Assisted Wheelchair For Physically Disabled People With Torque Sensor & Dedicated Solar Charger Kit

A Thesis Submitted to the Department of Electrical and Electronic Engineering of BRAC University

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DECLARATION

We hereby declare that our research titled "**Electrically Assisted Wheelchair For Physically Disabled People With Torque Sensor And Dedicated Solar Charger Kit** ", a thesis submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelors of Science in Electrical and Electronics Engineering, is our own work. The work has not been presented elsewhere for assessment. The materials collected from other sources have been acknowledged here

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ABSTRACT

Mobility of the physically disabled people is a great concern of the society. It is really difficult to realize the problems and sorrows of a physically disabled person who is partially or fully dependent on others or confining himself in a wheel chair with limited mobility. We have developed a electric three wheeler for especially physically disabled people of CRP. In this paper it is discussed that how electric tri-wheeler will help to reduce the effort of physically disabled person. All the designs specification considered after analyzing the problems from the physically person of CRP. Comfort of the person in the electric tri- wheeler is an important and we have given importance to it. The main content of the tricycle is Solar PV panel, hub motor, Charge controller and battery. This paper will discuss about the main idea of this project and to get a larger picture on what is the problem in the current technologies, what that we want to achieve in this project and the area that will cover on this project.

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LIST OF ABBREVIATIONS:

WHO-World Health Organization

CRP-Centre for Disability in Development

ACWF -Autistic Children’s Welfare Foundation

LVD -Low Voltage Disconnection

LVR-Low Voltage Reconnect

SOC- State of Charge

DOD- Depth of Discharge

CARG-Control and Application Research Group

CHAPTER 1

INTRODUCTION

1.1 Introduction to Wheelchair:

Countless barriers and hassles are engaged with the day to day movements of the physically challenged people in our society. Moreover, in spite of achieving independence through valiant struggle and supreme sacrifice, Bangladesh, as a nation, is not very much successful to invent feasible assistive devices for physically disabled individuals who became disabled from liberation war as well as from numerous accidents and diseases. This unfavorable situation has compelled many of our physically disabled individuals to use some assistive devices like crutches, artificial limbs or legs and manual wheelchairs for their usual movements.

Fig 1.1: Crutch

Fig 1.2: Artificial limb

In our country, physically disabled people basically use some assistive devices like crutches, artificial limbs or legs and manual or electric wheel chairs. Different types of wheelchair had launched at different times in the market of Bangladesh which are still available as assistive products for use.

Among them, mostly common is four wheelers wheelchair which is generally known as folding wheelchair as anyone can fold it whenever it is not necessary to use. This is completely a manual wheelchair which offers its user to use both of his/her hands to rotate rear wheels for movement.

Fig 1.3: Manual Wheelchair (Folding)

Another type of wheelchair is often called "Joystick Wheelchair" which has got similarity with the physical feature of folding wheelchair. But this joystick wheelchair is electrically powered by battery and a motor is deliberately connected. The term "Joystick" easily reminds anyone of its joystick controlling feature with the precise implementation of algorithms inside it and perfectly allows user to operate the wheelchair using only one hand on joystick. Problem which could not be resolved with this joystick wheelchair is the user needs to do a lot of mental work for proper controlling of it.

Fig 1.4: Joystick Controlled Wheelchair

These above mentioned wheelchairs are mainly used for indoor purpose. The other type of wheelchair is paddle wheelchair which is seen frequently on the roads of Bangladesh. Street beggars and poor class disabled people are the main users of it. This wheelchair consists of three wheels, one is the front wheel and the other two are rear wheel and all three wheels are in same size. A chain can either be connected in front wheel or in back wheel. This wheelchair is driven by hand using paddle. But, most of these above mentioned wheelchairs are very simple or inadequate in designs which are not fit for the outdoor use as well as common territory in our country.

Fig 1.5: Three Wheeler Wheelchair

1.2 Main Concern to Physically Disable People of Bangladesh:

The World Health Organization has defined health as "a complete physical, mental and social well-being and not merely the absence of disease or infirmity." According to this organization - disability is an umbrella term, covering impairments, activity limitations, and participation restrictions.[1]

Bangladesh is a developing country and is the home to approximately 160 million people. According to CDD's (Centre for Disability in Development) report44.3 % of the population living below the poverty line, inadequate health, education and social security services, low employment and at high risk from natural disasters, particularly flooding. CDD's estimates indicate that 10% of the population that means 16 million people is living with a disability and these are one of the most vulnerable groups as they receive little or no assistance where government and nonprofit organizations deliver development programs to address the situation in the country but still only reach a small proportion of the population.[2] Here, we should mention the WHO's estimation that 10% of any given population are disabled.[1] It is found from a study of the causes of disability in Bangladesh which showed that, 46 percent had suffered from their impairments since birth (such as caused by an injury to their mother during pregnancy or a birth defect), 29 percent reported impairments due an illness, 17 percent due to accidents, 3 percent caused by malnutrition and 5 percent due to other external shocks or stressful social situations such as divorce or family feuds.[4] A figure showing the statistics is given below. It is learned from Autistic Children's Welfare Foundation (ACWF) that out of every 94 boys, one is affected by Autism. And for girls, it is one in every 150 girls where in Bangladesh, no research has been carried out but it is assumed that about 3,00,000 children are affected.[3] These people need wheelchair or other sort of instruments to run their life. This project mainly targets these 16 million disable people.

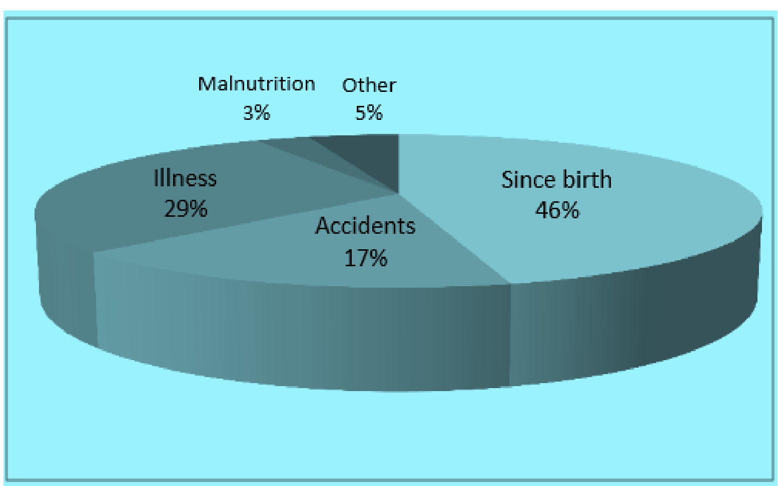


Fig 1.6: Disability Percentage shown in Pie Diagram [4]

1.3 Motivation:

The majority of physically disabled persons of countries like Bangladesh either use crutches or manual wheelchairs (folding) for their moving. Undoubtedly these devices are the blessings for disabled people but in the long run these things may make their life more miserable as commonly found manual wheel chairs have a basic problem that the occupant must use physical force to turn the wheels. Moreover, using conventional energy sources has some bad impacts on the surroundings and environment, like depleting limited energy resource, damage of ecosystem, environment pollution, global warming and so on. Because of physical weakness, many wheelchair users cannot control the wheelchairs properly by using their hands as it takes lots of muscle work. Electric or motor based wheelchairs are not available everywhere in Bangladesh. Again, physically weak users also face problems to control joystick wheelchair as it needs lots of mental works. Interaction of these wheelchairs with the users is not easy to adapt. Apart from that, these above kinds of wheelchair are mainly for indoor purpose or to move around in the local area. These are not fit to run on roads around the country as most of the roads are rough and narrow. Even, the city roads are not very smooth to run properly as there is no lane for the wheelchair. Roads of village are also of rough condition in Bangladesh where people mainly use bicycles, rickshaws etc.

There are some NGOs like, Centre for Disability Development (CDD), Centre for the Rehabilitation of the paralyzed (CRP), Hope for Life etc. working for the physically challenged people and producing some wheelchairs and assistive device for the crippled people. These should be mentioned that we visited CRP as well as their factory of wheelchair in Savar and they helped us to think more critically. Their valuable suggestions helped us to choose the right design for our electric wheelchair.

In respect to overall prevailing situation, Electrically Assisted Wheelchair with Torque Sensor & Dedicated Solar Charger Kit for the disabled person is a vital effort where the advantages of solar energy are taken into account. Solar powered wheelchair could be a standalone system where it will be self-operated as well as will be helpful during manual operation for the presence of torque sensor pedal while there will be an option to take unending solar energy from the sun through the solar charger kit.

This action is physically stressful, can result in muscle and joint pain and degradation, torn rotor cuffs, repetitive stress injury, and carpal tunnel syndrome; which causes secondary injury or further disability.

1.4 Wheelchair Production in Bangladesh:

It is found from field observation that most of the wheelchair or its parts are imported to Bangladesh. This should be mentioned that Chinese products are mostly available. Many non govt. organizations like CRP (Centre for the Rehabilitation of the Paralyzed), Hope For Life are making wheelchairs. They are making mainly folding wheelchair and most of them are manual wheelchair. Some places are found from where we can make wheelchair as per our desired design. They can make even electric wheelchair also. There is a big market of wheelchair at Shiamoli near National Institute of Traumatology Orthopedics and Rehabilitation (NITOR) which is commonly known as Pongu Hospital in Dhaka from where we can find different types of wheelchair as well as other instruments for the physically challenged people and here most of the shops are retailer.

Fig 1.7: Wheelchair manufacturing in Bangladesh

CHAPTER 2

OVERVIEW OF THE WHOLE SYSTEM

2.1 Introduction:

The electric wheelchair under research and development has been manufactured by Beevatech Limited. This company, established in 2001, has the experience of making electric bicycle, electric scooter, pedicab rickshaws, electric three wheeler and other electric vehicles[6]. The available wheelchair is not fit for longer distance to run where our electric wheelchair has the proficiency to cover longer distance of 42 kilometer approximately. The electric wheelchair is made with light weighed modern steel body and different architecture from the existing three wheeled wheelchair. The massive modernization of such electric wheelchair will improve the lifestyle of huge number of disabled people. One of our main target is to find a solution to conserve power with the use of torque sensor pedal and solar battery charging kit. The electric wheelchair has a hub motor, three 12V 12Ah lead acid batteries connected in series, a controller unit, a throttle, a power key, an LVD charge controller, a front wheel break system and other components. Various views of customized electric wheelchair used in our experiment are shown below.

Fig 2.1: Side View of the Wheelchair

Fig 2.2: Front View of the Wheelchair

Fig 2.3: Rear View of Wheelchair

Fig 2.4: Top View of Wheelchair

2.2 Hub Motor:

The basic idea of turning stored electricity into motive power: feed an electric current through tightly coiled wire that sits between the poles of a magnet and the coil spins around making a force that can turn a wheel and drive a machine.

Most electric-powered vehicles (electric cars, electric bicycles, and wheelchairs) use onboard batteries and a single, fairly ordinary electric motor to power either two or four wheels. But some of the latest electric cars and electric bicycles work a different way. Instead of having one motor powering all the wheels using gears or chains, they build a motor directly into the hub of each wheel—so the motors and wheels are one and the same thing. That is why, it is called hub motor. A hub motor is electrified in the front wheel. Power of this motor is 250W. A rim is connected just beside the hub motor for the pedal chain. The basic mechanism of hub motor is almost same as with normal dc motor. The main difference is that it stays inside of the wheel and the weight is less. Another main advantage is that it does not take any extra space to keep it inside the wheelchair. We could not the show the inside structure of our hub motor due to lack of available resources.

Fig 2.5: Hub Motor & Adjusted Rim

Comparison with Conventional EV Design in Automobiles:

1. **Drive by wire**

- ✓ Cars with electronic control of brakes and acceleration provide more opportunities for computerized vehicle dynamics such as:

  - ➢ Active cruise control, where the vehicle can maintain a given distance from a vehicle ahead
  - ➢ Collision avoidance, where the vehicle can automatically brake to avoid a collision
  - ➢ Emergency brake assist, where the vehicle senses an emergency stop and applies maximum braking
  - ➢ Active software differentials, where individual wheel speed is adjusted in response to other inputs
  - ➢ Active brake bias, where individual wheel brake effort is adjusted in real time to maintain vehicle stability
  - ➢ Brake steer, where individual wheel brake bias is adjusted to assist steering (similar to a tracked vehicle like a bulldozer)

- ✓ As wheel motors brake and accelerate a vehicle with a single solid state electric/electronic system many of the above features can be added as software upgrades rather than requiring additional systems/hardware be installed like with ABS etc. This should lead to cheaper active dynamic safety systems for wheel motor equipped road vehicles.

2. **Weight savings**

Eliminating mechanical transmission including gearboxes, differentials, drive shafts and axles provide a significant weight and manufacturing cost saving, while also decreasing the environmental impact of the product.

3. **Unsparing weight concerns**

The major disadvantage of wheel hub motors are that the weight of the electric motors would increase the unsparing weight, which adversely affects handling and ride (the wheels are more sluggish in responding to road conditions, especially fast motions over bumps, and transmit the bumps to the chassis instead of absorbing them). Most conventional electric motors include ferrous material composed of laminated electrical steel. This ferrous material contributes most of the weight of electric motors. To minimize this weight several recent wheel motor designs have minimized the electrical steel content of the motor by utilizing a coreless design with Litz wire coil windings to reduce eddy current losses. This significantly reduces wheel motor weight and therefore unsparing weight. [5]

2.3 Batteries:

Three rechargeable batteries have been used and these are 12V,12Ah each. Batteries have been connected in series which supply 36V,12Ah to the hub motor. These are lead-acid batteries. Each battery is 6x4x3.56 inch in dimension. Two sets of batteries have been used. One is for wheelchair and another is for solar battery charger kit. The batteries will be swapped while it is necessary. The weight of one set of batteries is 13.75 kg. The batteries are placed under the seat as shown in fig. batteries are attached with the underneath sheet of the wheelchair such as it couldn’t be able to move during the driving of wheelchair and also such as that batteries can be changed whenever it is necessary. Each fully charged battery 12.7V or above across their terminals and 38.1 volts after connecting those in a series combination.

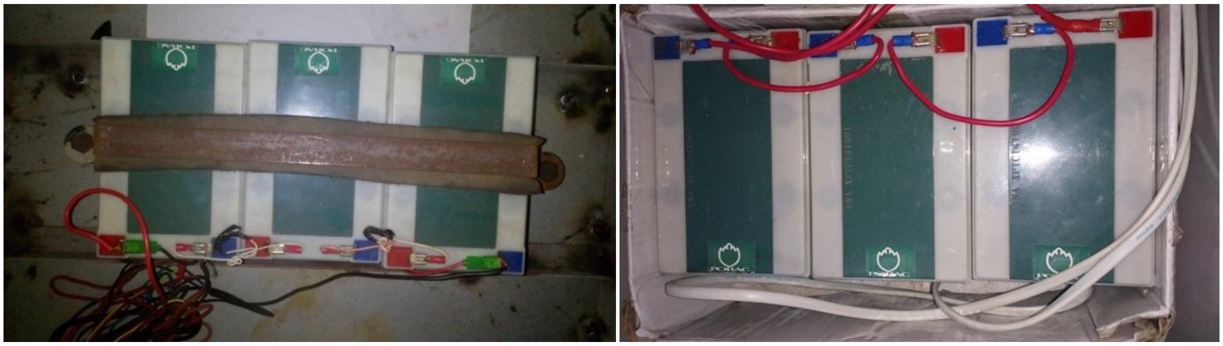


Fig 2.6: Two Sets of Batteries

2.4 The Torque Sensor:

The torque sensor is a device which is used to measure and record the torque of a rotating system.[7] It needs a biasing voltage of 5 volt from the DC source to operate. If the torque increases output voltage will increase. The speed of the motor is directly proportional to the output voltage. Fig 2.7 shows the torque sensor pedal that has been installed in the wheelchair.

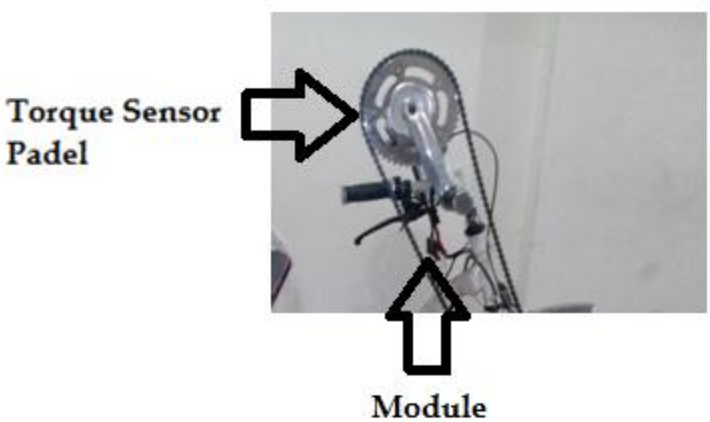


Fig 2.7: Torque Sensor Paddle & Module

2.5 The Solar Panel:

We have used total 3 solar panels of 225 for solar charger kit where each one is 75 watt. We have also made frame for solar panels which will be used during charging the battery and it has made in this way that it can keep the solar panel 23 degree angle.

Fig 2.8: Solar Panels

2.6 Charge Controller:

We have used total two charge controller in our whole system. One for wheelchair and another is for solar charger kit. Ratings of the charge controller for solar charger kit is 36V,20A.
Characteristics of the charge controller for the wheelchair is as below:

- Type : LVD (Low Voltage Disconnection)
- Ratings: 36V,25A
- Usefulness : For longevity of the batteries
- Disconnect the system on 36.3V (50% from SOC) battery charge
- Reconnect the system (LVR) on 37.4V (75% from SOC) battery charge

This charge controller is kept under the seat of the wheelchair.

(1) **(2)**

Fig 2.9: Charge Controllers for Wheelchair (1) & Solar Panel (2)

2.7 Motor Controller:

Motor controller is used to control all electrical part along with motor in parallel. General specification like low voltage protection is 31.5V and maximum current it can carry is 17A. it is kept under the seat of the wheelchair. Motor controller along with wiring diagram has been shown in Fig 2.10 and Fig 2.11.

Fig 2.10: Motor Controller

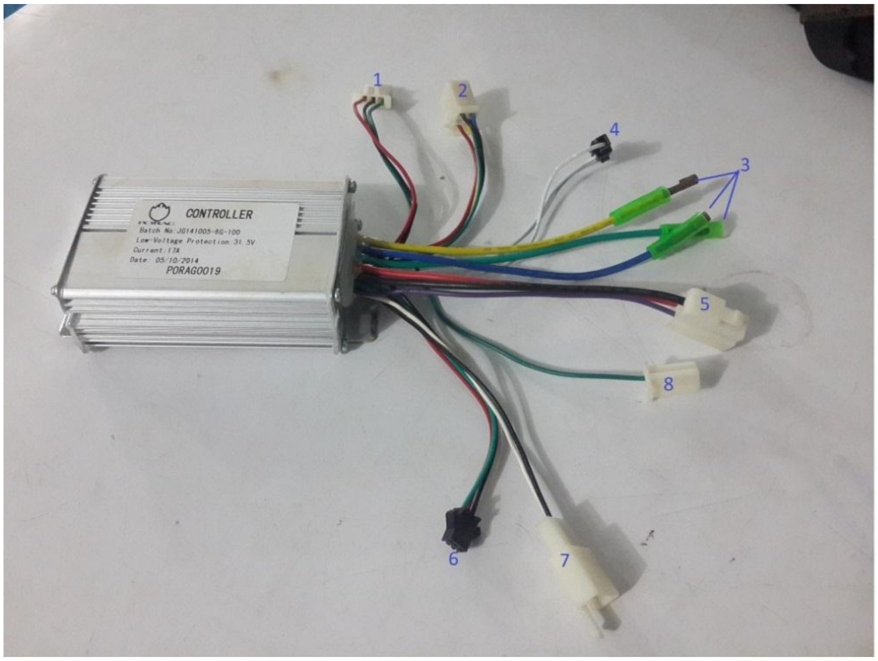


Fig 2.11 Wiring Diagram of Wheelchair

2.8 Throttle:

Throttle is used to control the speed of the motor. A throttle shown in Fig 2.10 is a specially designed potentiometer. It has a biasing voltage of 5V which is provided by the motor controller unit where its output voltage depends on the angle of the throttle. The output voltage is supplied to the controller. It should be noted that the speed of the motor depends on its output voltage. Along with that, the motor speed increases as the output voltage increases. It has been found from the field test that the motor starts when the output voltage is 1.4 volts and when the output voltage is 3.5 volt the motor rotate at its maximum speed.

Fig 2.12: Throttle

2.9 The Horn System:

We implemented horn system for our wheelchair which is uncommon in respect to other wheelchair. Existence of this horn system will help to rum wheelchair properly on the main. It is near to throttle as you can see in the figure. Horn system is also connected through motor controller and if you press the button it will take 5 Volts from the battery to horn.

Fig 2.13: Horn System

2.10 The Brake System:

Hand brake is used in our wheelchair. Brake system is constructed on the front wheel. Traditional hand clutch is used to stop the front wheel which is usually used in rickshaw or cycle. This hand-clutch is used to stop the wheel as well as the motor at once. When the hand-clutch is released, it returns to its original position and it allows the motor to start again when needed.

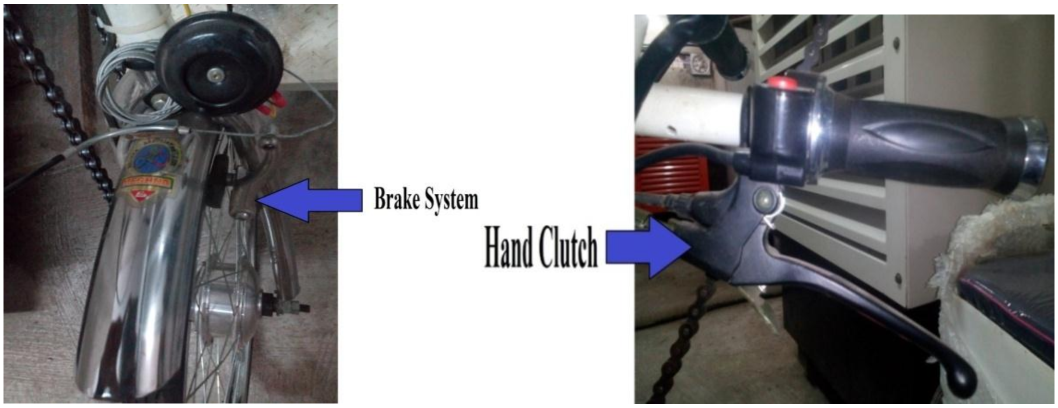


Fig 2.14: Hand Clutch

2.11 The Charging Material:

There are two charging system in our wheelchair. One is from the solar charger kit where we have to replace the battery as there is a suitable way to change the battery. Another way is from the national grid. For that we need a charger which can carry at least 36V,12A. The charging point is just corner of the footrest which can be easily accessed whenever it is necessary.

Fig 2.15: Charger

2.12 Wheels:

Three wheels have been used. One is on the front and two are on the back. Hub motor is connected in the front wheel. There is no motor connection in the back wheels. Back wheels will get power to run from front wheel motor. Normal rickshaw wheels have been used in our wheelchair. Diameter of the wheels is 26 inches which is enough to run properly with carrying a person.

(1)

(2) (3)

Fig 2.16: (1)Front Wheel (2) & (3) Back wheels

2.13The Footrest:

There is a footrest which is enough spacious to keep leg. We kept in our mind during designing our wheelchair that paralyzed people especially who have no feeling in their leg may also use our wheelchair. For that reason we kept it little bit more widely in respect the foot. The length of the foot rest is 12 inches.

Fig 2.17: Footrest

2.14 Chair & Seat:

A comfortable chair is used in our wheelchair because. It is enough spacious to sit properly for a disabled person. Length of the chair is 18 inches. We used comfortable cushions for the seat. We also used cushion in the back side for more comfort. Cushions are covered with polyethylene as our wheelchair will be used mainly for the outdoor activities where polyethylene will give the protection from the dust and rain.

Fig 2.18: Chair & Seat

Chapter 3

Designing & Construction of the Wheelchair

3.1 Introduction:

Designing of the wheelchair has two major parts. At first, designing the wheelchair and it's components from mechanical point of view and secondly, incorporate necessary electrical system to enhance the overall power mechanism. Drawbacks of the available manual three-wheelers as well as needs and requirements from the physically challenged are sincerely considered during the designing our wheelchair. In this chapter, mainly the design of the wheelchair's physical appearance is described.

3.2 Design Stages:

The overall designing of the wheelchair is done through different stages as: recognition of the needs, analysis and evaluation. First of all, the demand or requirements from the physically challenged people are identified. Then technical requirements found from the observation include all the specifications or characteristics for the wheelchair to be designed. After that the wheelchair under design has been analyzed whether it fulfills specifications. Once fulfilled, then it was optimized. Sometime, the analysis might reveal that the design is not the appropriate one. In evaluation stage, we changed the design according to the needs.

3.3 Design Consideration:

Some characteristics for design consideration control the design of the element or may be the whole system. Generally, the strength of each element, its dimension and geometry are important design considerations from the mechanical aspects. We had to take those considerations in our mind during the design. As it is a transport for the physically challenged people, the overall safety, stability, reliability, control, comforts were taken in to the consideration while designing the wheelchair. Total cost was one of the main considerations during the design. We tried to make the design as like the production of the wheelchair would be cost effective.

3.4 Mechanical Design:

The three wheeler used in present day is heavy and its design is not so standard. During designing our wheelchair, unnecessary weight is reduced by using light weight modern steel. Comparatively small wheels are used and we kept in our mind the weight of wheelchair should be less as much as possible. It has comfortable seat and under the seat there is enough space for keeping battery, charge controller, torque sensor circuit (PCB), motor controller and necessary wire to connect the system. Motor and break system are implemented on the front wheel. Seat is cushioned and water proof.

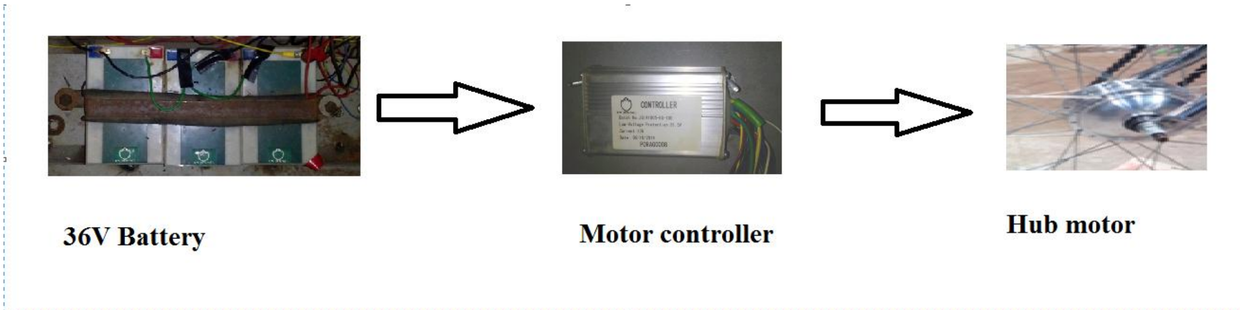


Fig 3.1: Power Management System of the Wheelchair

3.5 Proposed Design:

Design of our wheelchair from all point of views is shown below. This should be mentioned that we did these designs on p-spice schematic design manager.

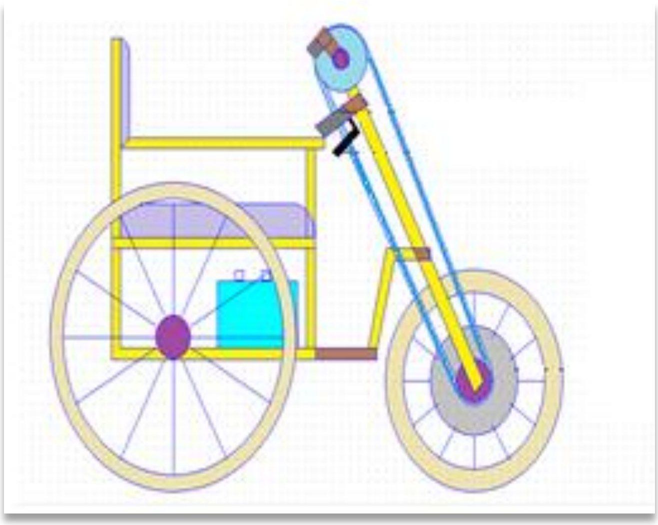


Fig 3.2: Side View

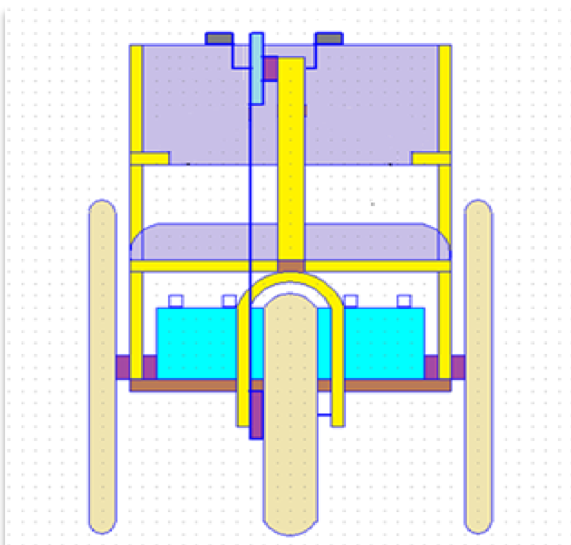


Fig 3.3: Front View

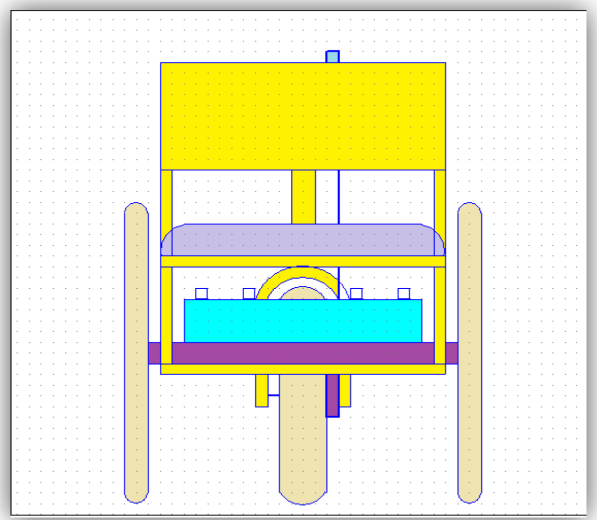


Fig 3.4: Back View

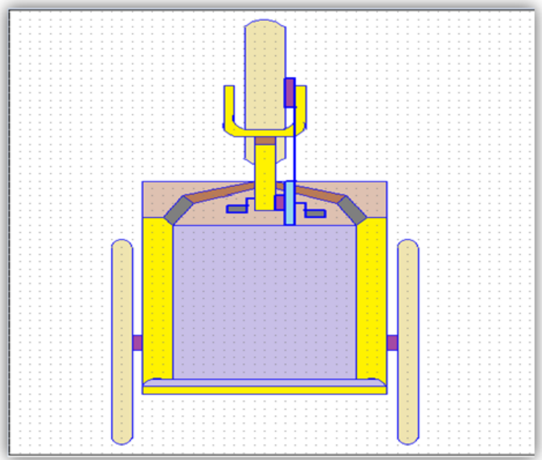


Fig 3.5: Top View

3.6 Dimensions of Physical Parts:

The dimension from different parts of the wheelchair are shown in the below table.

Parameter	Length
Length of the vehicle (from end to end)	62 inches
Length of the chair only	18 inches
Width of the vehicle (from side to side)	30 inches
Width of the chair only	24 inches
Height of the wheelchair	41 inches
Height of the seat from ground	28 inches
Height of the lower part(compartment for batteries and motor controller) from ground	12 inches
Height of the seat from the lower compartment	16 inches
Length of the footrest	12 inches
Diameter of wheels	28 inches

Table 3.1:Dimensions of Physical Parts

3.8 Construction:

After drawing the design we have sent Beevatech Company to construct it. They have made physical part as well as some of the electrical parts also like they have connected battery, motor and motor controller. We have implemented torque sensor paddle, charge controller (LVD) and solar charger kit. During the construction we have visited company many times. The figure is showing different stages of our wheelchair making.

Fig 3.6: Wheelchair on Making

3.6 Major Change after Design:

During making the wheelchair we have changed the design for better quality as we had to deal with the practical situation. Initially, in our design, two back wheels were larger than the front wheel. For better running mechanism we have made all the wheels same in size. In figure red mark is showing that change. Another change, two rods for have been introduced for back wheels. The green mark is showing that change.

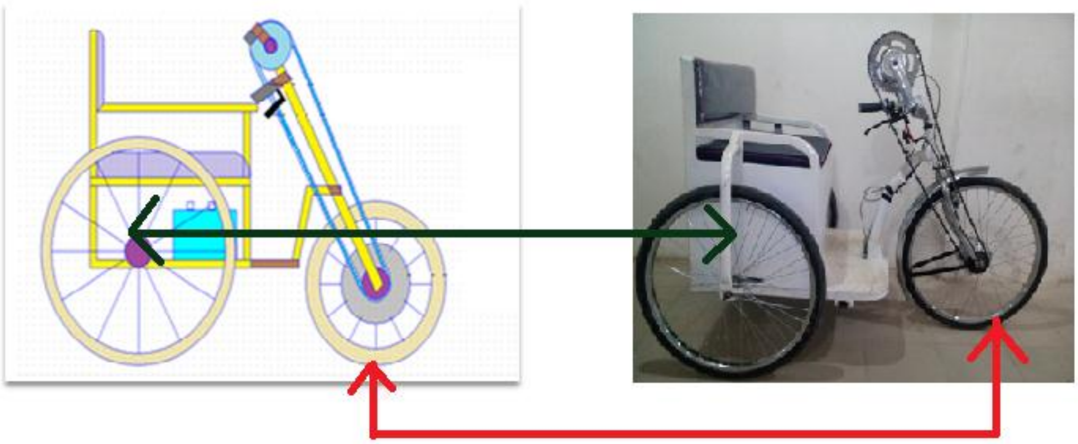


Fig 3.6: Major Changes

CHAPTER 4
Integrating Torque Sensor

4.1 Introduction:

The general features of torque sensor, its working theory and all portions of integrating it into the system are discussed in this chapter. Along with its mechanical fitting, the electrical connection system as well as power source management for the operation of the torque sensor circuit are also described in this chapter. These will explain the overall operation of the whole system of torque sensor.

4.2 Introduction to the Torque Sensor:

A torque sensor or torque transducer or torque meter is a device that measures and records the torque on a rotating system, such as an engine, crankshaft, gearbox, transmission, rotor, a bicycle crank or cap torque tester.[7] Commonly, torque sensors or torque transducers use strain gauges applied to a rotating shaft or axle. Actually, it converts torque based mechanical input into an electrical output signal. There are two types of torque sensors, the first one is reaction that measures static torque and the other one is rotary that measures dynamic torque.[8] Torque sensor takes input from a DC voltage source to be turned ON and generates output voltage corresponding to torque applied on the specific crank or shaft. The voltage output is linear with the applied torque within its operating region.

Fig 4.1: Torque sensor with module

4.3 Types of Torque Transducers and Torque Sensors:

• 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 [9]

4.4 Technical Parameter Data:

• V_{cc} = 5.15 V (+/- 0.15V)

• Output torque >15N-m

• Output, linear, zero-start, 0.5~4.5V

• Delay time < 50ms [10]

4.5 Features of Torque Sensor:

- Applicable to brush/brushless and hub motor controller
- Sensor/sensor-less motor-electrical system
- The hardware can be installed in the way of installing a normal chain wheel crank
- Responses instantly when the pressure on the paddle is changed that is pressure is applied or stopped or reduced
- Aluminum is used for the main crank shaft [10]

4.6 Applications:

- 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 [9]

The torque sensor for our wheelchair was purchased from Suzhou Victory Sincerity Technology Company Ltd which is located in Suzhou, China (http://www.jc-ebike.com). They have a group of experienced experts who develop, design and produce the components of e-bikes, mainly torque intelligent sensor system and relevant parts.

4.7 Mechanical Setup:

The torque sensor is made in such a way that it can be installed in any vehicle which has a structure for installing paddle system. In our wheelchair, it is installed in the upper part of the head tube over the handlebar (throttle and clutch) as it is a comfortable place to operate the paddle for the disabled persons.

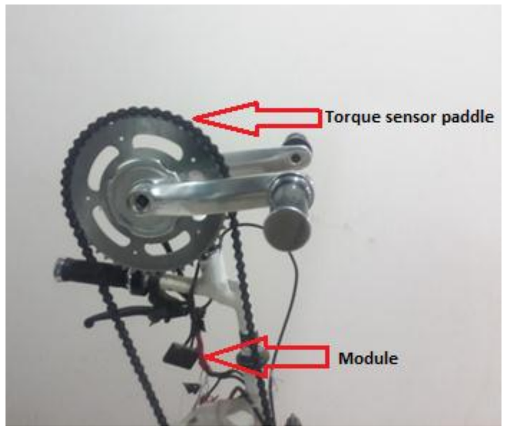


Fig 4.2: Torque Sensor paddle implemented on the wheelchair

There is a lock pin attached at the back of the sensor to keep the measuring circuitry stationary while rotating the chain-wheel crank so that the torque can be measured.

Fig 4.3: Lock pin at the back of the sensor

4.8 Electrical Connections:

The manufacturing company provided us the electrical connection diagram for the entire setup that includes brushless-controller, torque adjustor, chain-wheels, module etc. But for our project we used only the torque sensor and the corresponding signal-producing module from those. For getting input voltages from the controller connections, there were separate mechanisms. That was shown in the diagram provided by them. But in our system, a different circuit was incorporated with the sensor. That independent operation connection diagram is extracted from the main diagram.

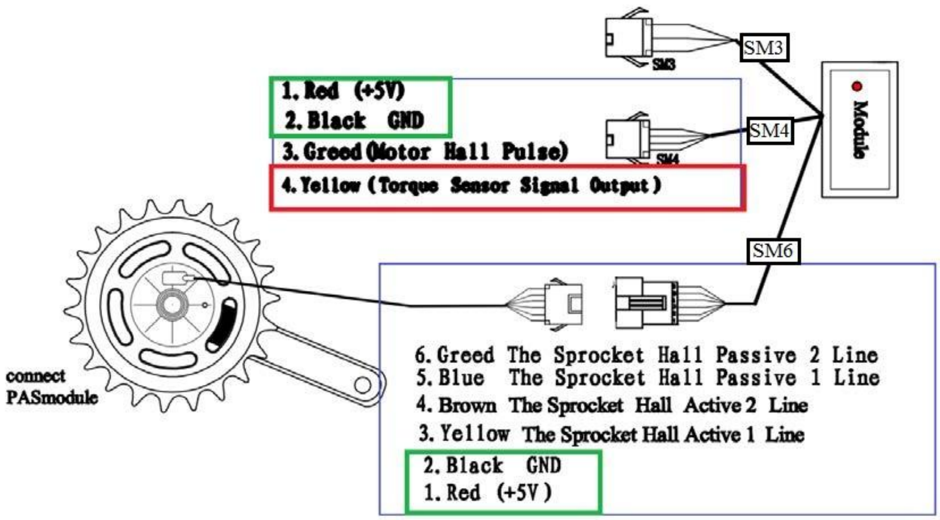


Fig 4.4: Electrical Connection diagram for independent operation of the sensor and module

The Fig 4.4 shows that the input biasing terminals for the sensor are the Red and Black wires from SM6 (marked as +5V and GND). This biasing voltage turns the module ON to come into the operation. The yellow wire from SM4 is the input voltage for the module which is the processed output from the torque sensor. This wire gives the output voltage with respect to GND according to applied torque in the pedal-crank of the sensor. So, this is the output which is supposed to be fed to the external control circuit.

4.9 Power Source Management:

We had to implement all the electrical system of our wheelchair using a single power source which is our batteries. Three 12V batteries connected in series have been used in the wheelchair. The external circuit design of the torque sensor specification setup requires a +5V source to power all these devices. To serve the purpose, an LM7805 was used to get a fixed output of +5V. This voltage regulator takes +12V as input which is provided by one of the three batteries as shown in figure. The power-source management used in the system is illustrated in the following figure.

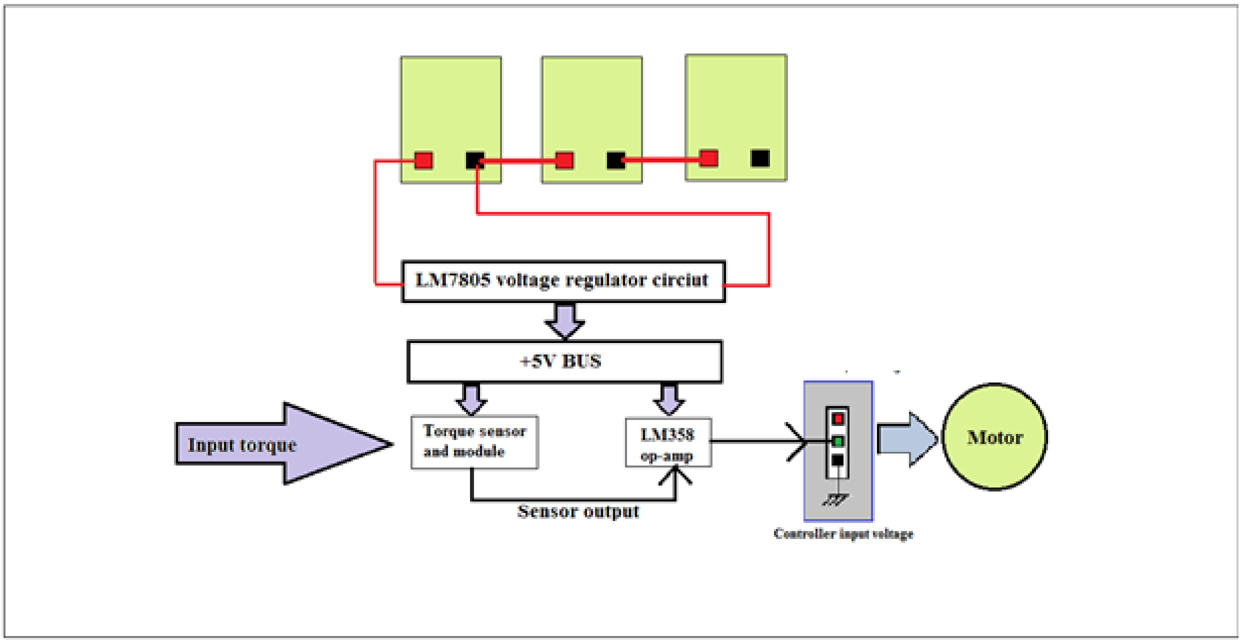


Fig 4.5: A complete overview of the power management and signal flow

The above Fig 4.5 illustrates the complete power management and signal flow of the system. Our system has three 12V batteries connected in series providing 36V. Only 12V is required as input to the voltage regulator circuit. This circuit will give +5V which will be fed to the amplifier circuit as biasing besides powering up the torque signal producing module. When pressure is applied on the pedal, there will be a certain torque for which the torque sensor will sense and will convert it to a certain voltage. This power will be then supplied to the amplifier circuit through the module.

4.10 The Voltage Divider & Amplifier Circuit:

A notable part of the amplifier circuit is the use of a voltage divider circuit in it. Instead of directly feeding the voltage coming from the torque sensor and module to op-amp, the input signal for the amplifier circuit passes through a voltage divider to reduce the incoming voltage to 0.6 times of the input voltage. This reduced voltage is then fed to the op-amp. If the incoming voltage is somehow very much high, it will be reduced to a certain value in this way and eventually limit the use of motor. While running the wheelchair practically, sometimes the voltage generated by the torque sensor can be reached to much higher value around 3-4 V. To minimize this voltage the voltage divider is used in such a way that the output voltage becomes 0.6 times less than the input voltage. That is, $V_{OUT} = 0.6*V_{IN}$.

The circuit diagram is shown in figure. Here a voltage divider circuit has been used in order to limit the torque sensor input voltage.

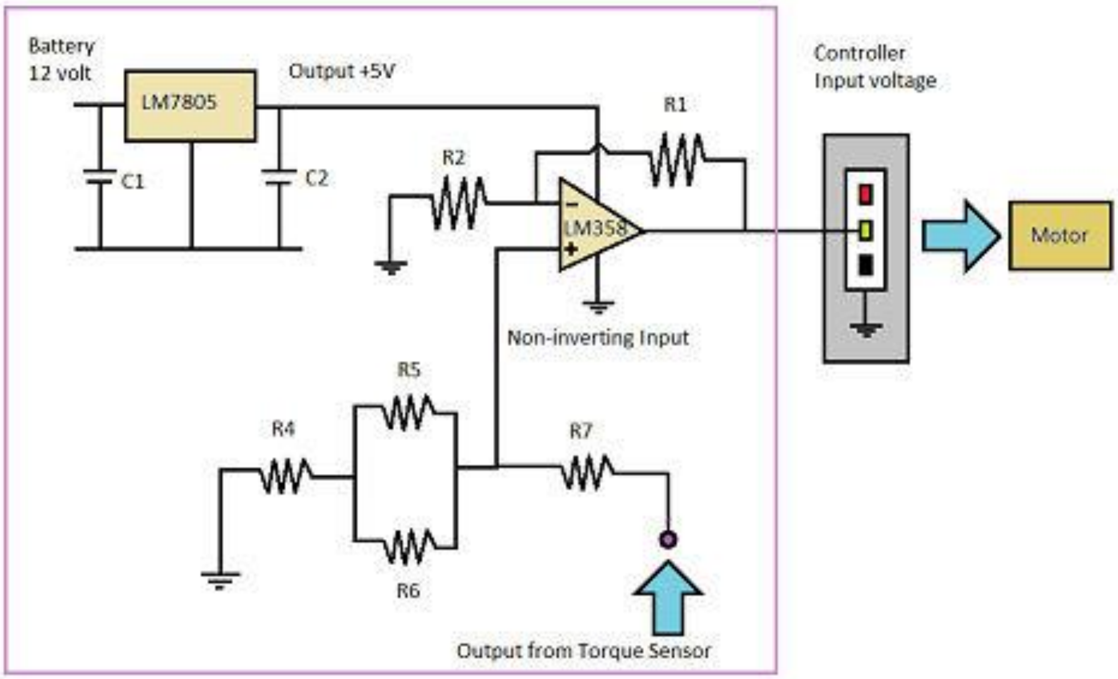


Fig 4.6: Circuit diagram of the amplifier circuit

The circuit will eventually output a voltage corresponding to the voltage provided by the sensor and module maintaining the ease while pedaling. This voltage is fed to the motor CU and eventually to the motor. Gain of the amplifier can also be adjusted by a potentiometer.

4.11 Hardware Implementation:

To eradicate the problem of appearing a lot of wires which occurs a mess of wires when circuit is implemented using breadboard and also to avoid the risk of getting the wires disconnected, the torque adjuster circuit was implemented in hardware. While going for the field test, the roads were not smooth, so hardware implementation will resolve the problem as each of the components are soldered on the PCB board and there is no chance of any component to fall apart or disconnected due to shakiness of the road.

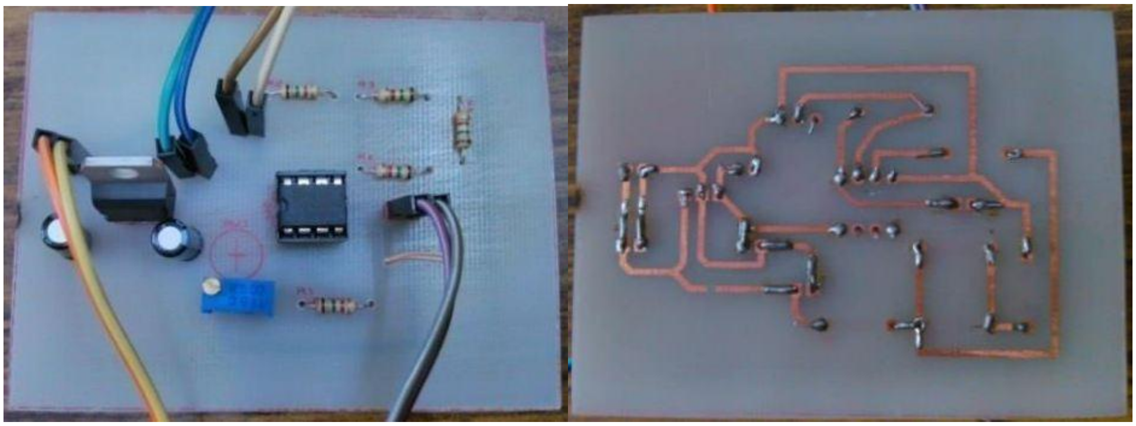


Fig 4.7: The hardware implementation of the complete system in PCB is illustrated

Fig 4.8: Torque adjustor circuit inside the wheelchair

4.12 Conclusion:

No unexpected performance took place during integrating the all parts of the torque sensor system and installing it. Other than the +12V from one of the three batteries, no external power supply was needed for the whole torque sensor system. After installing the torque sensor and the circuit in the way described above, the wheelchair was ready for the field test.

CHAPTER 5
Field Test

5.1 Introduction:

The objective of field test was to determine how far wheelchair runs up to 50% SOC voltage discharge with the help of torque sensor as well as without torque sensor and to determine maximum current it gains for both kind of running mechanism. The multi-meters were used to determine voltage across the battery. Clamp meter was used to measure current supplied by the battery. The test was carried out near the National Institute of Diseases of the Chest and Hospital area which had free road for running the wheelchair. The voltage and current readings for the battery were recorded. A GPS tracking system was used to estimate the distance travelled.

The field test was carried out in three steps:

1. By using throttle – the objective of the field test was to determine the distance that the wheelchair can travel with the battery discharged down to 50% SOC and the power consumed from the battery.
2. With torque sensor pedal – to determine the distance that the wheelchair can travel with torque sensor pedal support with the battery discharged down to 50% SOC .
3. With extra weight – to determine the distance that the weight can travel with torque sensor pedal with the battery discharged down to 50% SOC and power consumed from the battery

5.2 Data Acquisition Method:

The multi-meters were used to measure the voltage across the battery. One multi-meter was connected in parallel with 36V battery, another one was connected to torque sensor to find output torque voltage. Clamp meter was clamped on to a wire connected in series with the battery. A GPS tracking software was used in order to determine the distance travelled by the vehicle. At full load conditions, all the data were taken. All these readings were recorded by a video camera throughout the field tests. It should be mentioned that the data were retrieved from the video camera at 20 seconds time interval. All data are attached in the appendix part.

5.3 SOC of the Battery

State of charge (**SOC**) which is the equivalent of a fuel gauge for the battery pack in a battery electric vehicle (BEV), hybrid vehicle (HV), or plug-in hybrid electric vehicle (PHEV). The units of SOC are percentage points (0% = empty; 100% = full). An alternate form of the same measure is the **depth of discharge** (**DOD**), the inverse of SOC (100% = empty; 0% = full). SOC is normally used when discussing the current state of a battery in use, while DOD is most often seen when discussing the lifetime of the battery after repeated use [11]. The SOC of the battery has been determined from online source. Measuring SOC is not accurate for all the time and so SOC chart obtained from online source was used as a guideline. We have noted the battery voltage when the current has become approximately zero while battery charging. A fully charged battery 12V battery has 12.73V across its terminal and 50% discharged battery showed 12.1V across its terminal. The SOC chart is given in the table below in

Charge (SOC)	12V Battery	36V Battery
100%	**12.73**	**38.9**
90%	**12.62**	**37.86**
80%	**12.5**	**37.5**
70%	**12.37**	**37.11**
60%	**12.24**	**36.72**
50%	**12.10**	**36.3**
40%	**11.96**	**35.88**
30%	**11.81**	**35.43**
20%	**11.66**	**34.98**
10%	**11.51**	**34.53**

Table 5.1 SOC chart of lead acid battery [11]

5.4 Field Test Data without Torque Sensor:

Field test was carried out without torque sensor pedal (using throttle)to determine the distance travelled by the wheelchair up to battery discharged down to 50% SOC and the power consumed from the battery as well as to determine the maximum current it goes. Voltage across the battery and current drawn by the battery were recorded. All the data were recorded with the help of a video camera and then later we retrieved data at 20 second interval and used to compile the following graphs. Fig 5.1 represents the battery supply current and voltage. Fig 5.2 represents battery power [voltage* current].

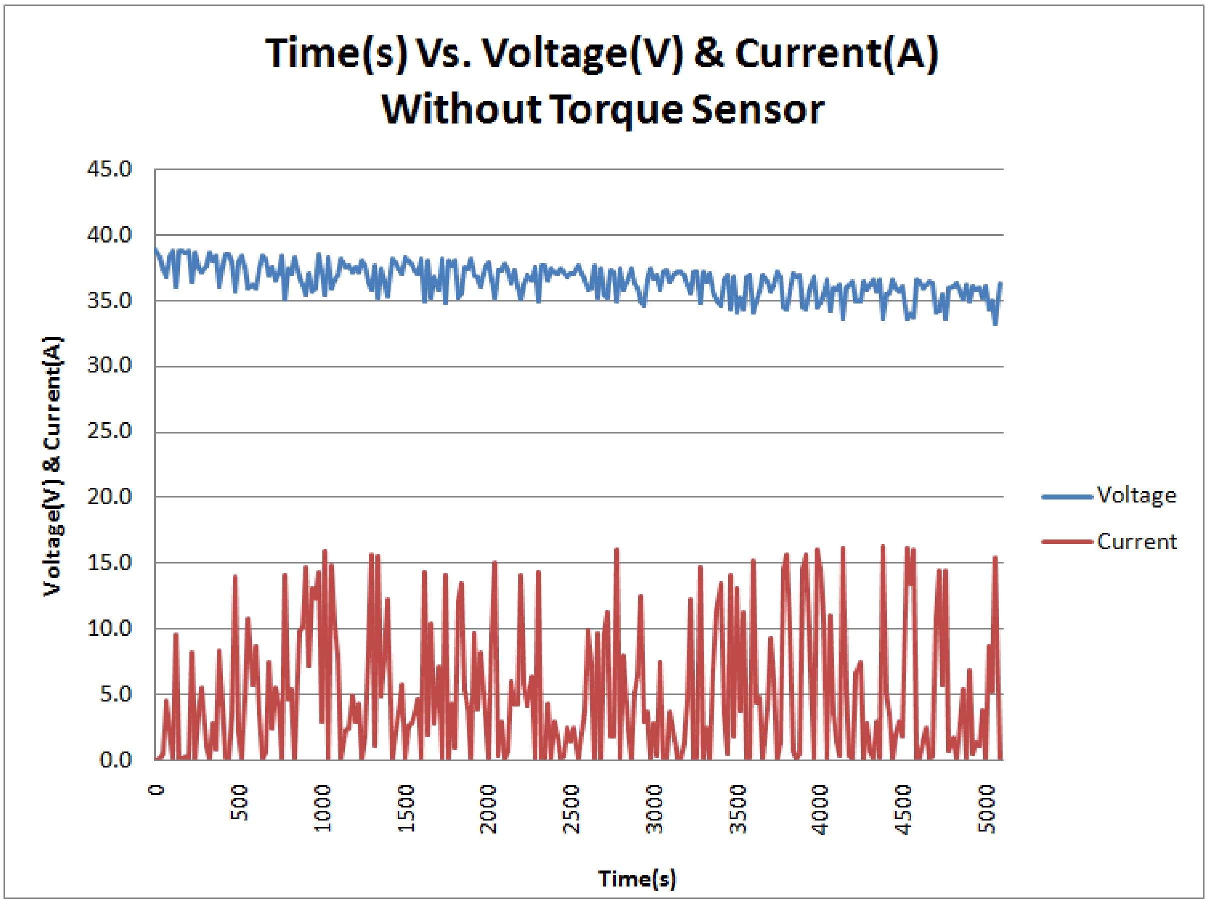


Fig 5.1: Voltage& Current Profile (Without Torque Sensor)

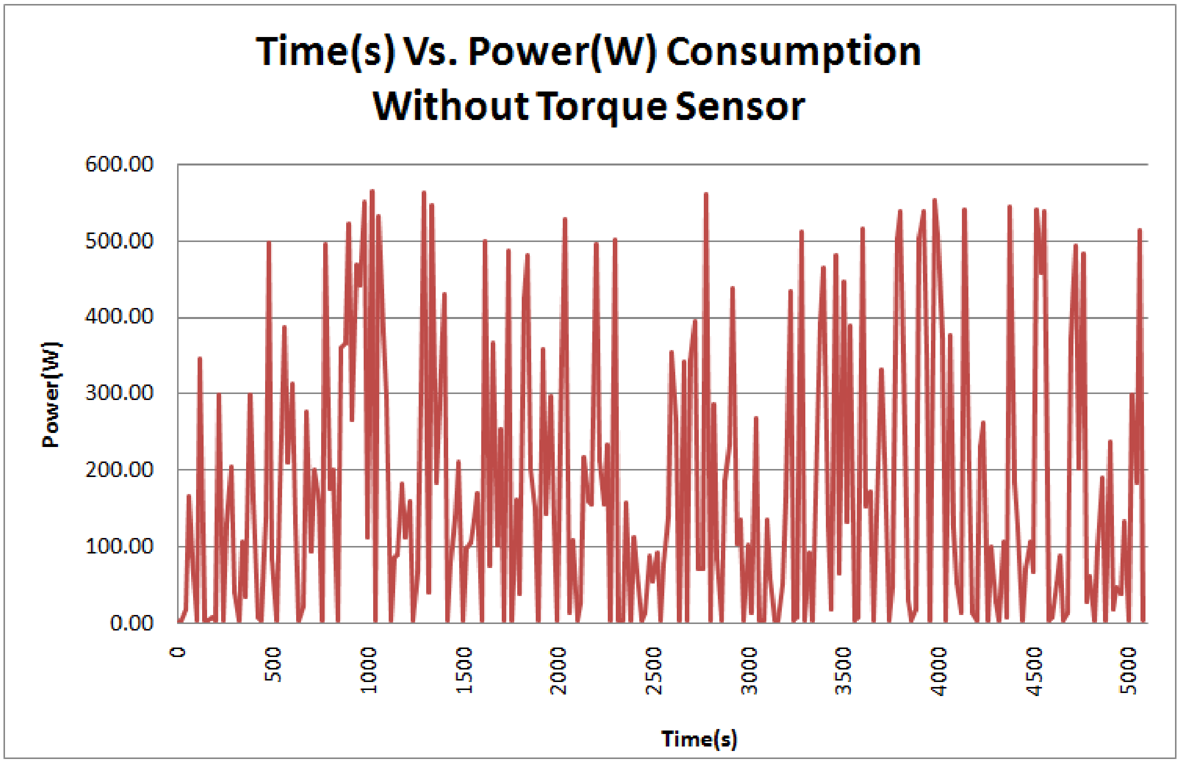


Fig 5.2: Power Consumption Profile (Without Torque Sensor)

The graph of battery power (W) vs. time (s) is used to calculate the energy consumed from the battery bank. In this case, the energy supplied by the battery is equal to the energy consumed by the load. Therefore, battery power supplied is equal to load power consumed. The area under the graph in Fig load power (W) vs. time (s) is used to calculate the energy consumed by the load from the battery. The energy consumed by the load from battery is 904931.7Joules.

5.5 Field Test Data with Torque Sensor:

Field test was carried out with torque sensor pedal to determine the distance travelled by the wheelchair up to battery discharged down to 50% SOC and the power consumed from the battery as well as to determine the maximum current it goes. Voltage across the battery and current drawn by the battery were recorded. The torque sensor input voltage to the controller unit and output voltage from the torque sensor pedal to the torque adjuster were recorded. All the data were recorded with the help of a video camera and then later we retrieved data at 20 second interval and used to compile the following graphs. Fig represents the battery supply current and voltage. Fig represents battery power [voltage* current].

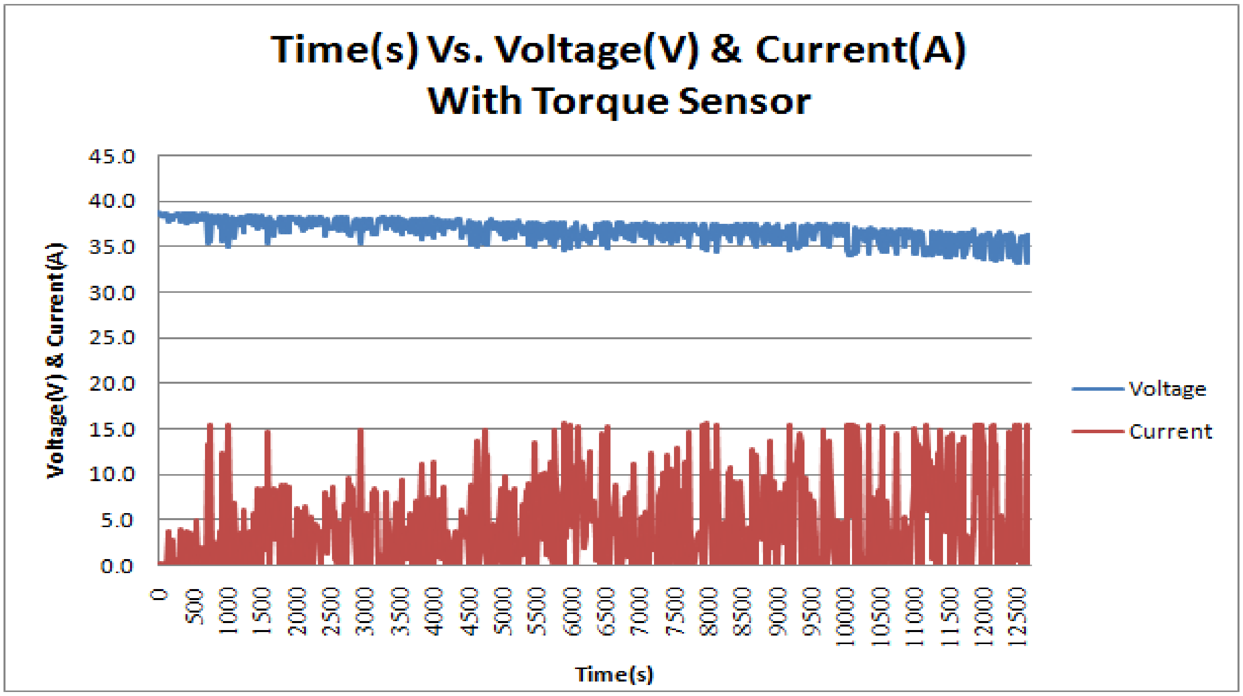


Fig 5.3: Voltage & Current Profile (With Torque Sensor)

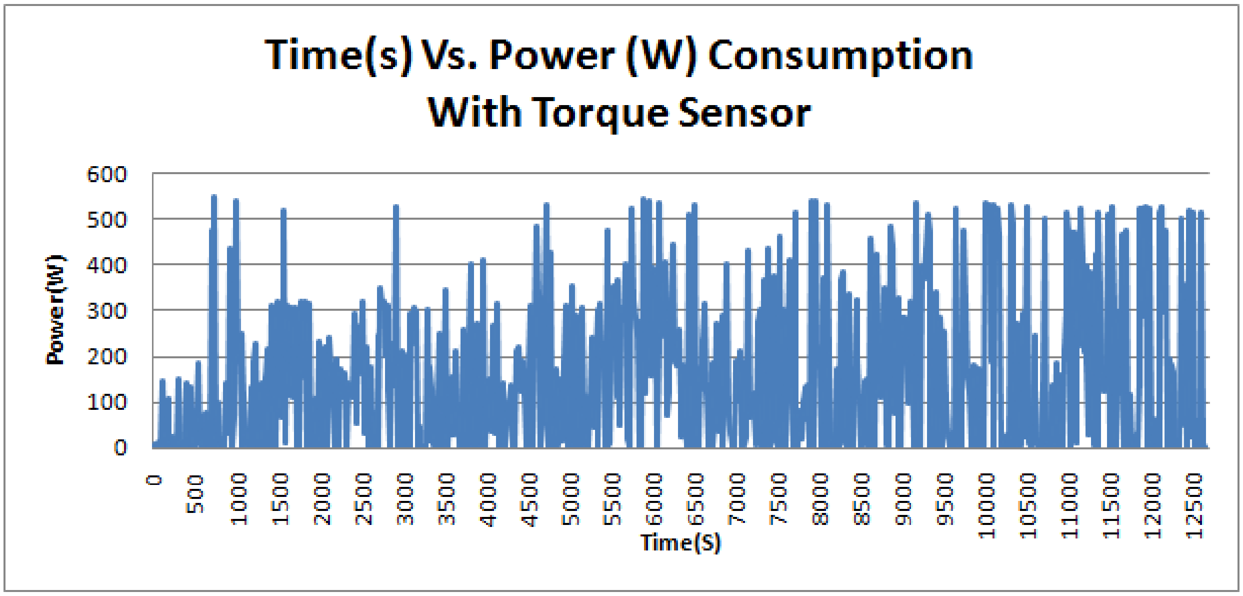


Fig 5.4: Power Consumption Profile (With Torque Sensor)

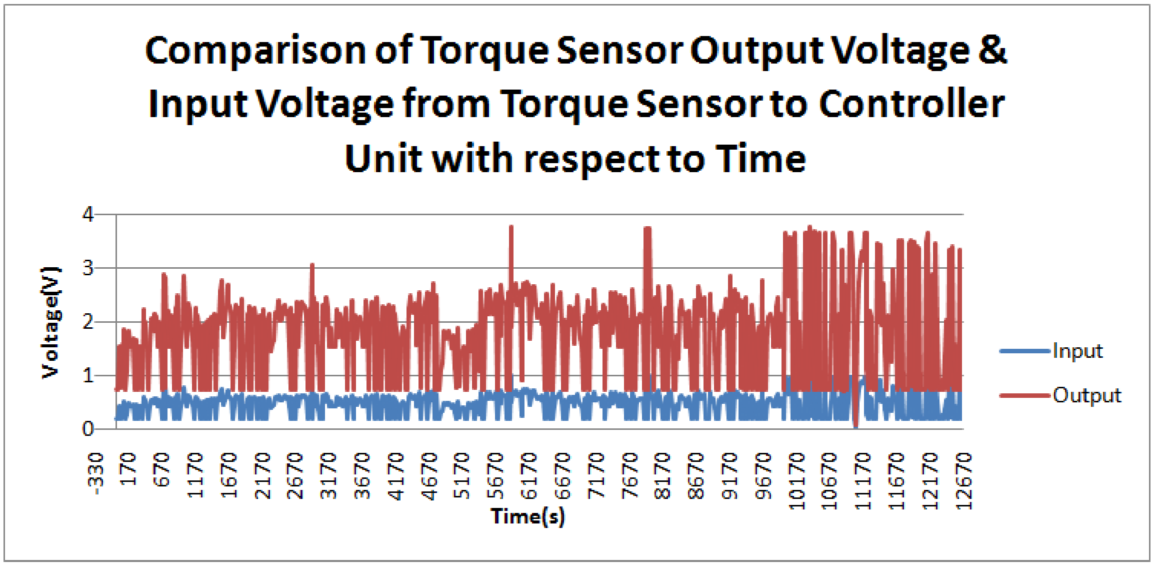


Fig 5.5: Comparison of torque sensor output voltage (volts) from the pedal to the torque adjuster circuit and input voltage(volts) from torque adjuster circuit to controller unit with respect to time (seconds)

The graph of battery power (W) vs. time (s) is used to calculate the energy consumed from the battery bank and from the body force. In this case, the energy supplied by the battery& renewable energy supplied by the body force are equal to the energy consumed by the load. The area under the graph in Fig load power (W) vs. time (s) is used to calculate the energy consumed by the load from the battery. The energy consumed by the load from battery is 2004674.3 Joules.

5.6 Field Test Data with Torque Sensor & Extra weight:

Field test was carried out with torque sensor pedal with extra 20 kg weight than the previous field test to determine the distance travelled by the wheelchair up to battery discharged down to 70% SOC and the power consumed from the battery as well as to determine the maximum current it goes. Voltage across the battery and current drawn by the battery were recorded. All the data were recorded with the help of a video camera and then later we retrieved data at 20 second interval and used to compile the following graphs. Fig represents the battery supply current and voltage. Fig represents battery power [voltage* current].

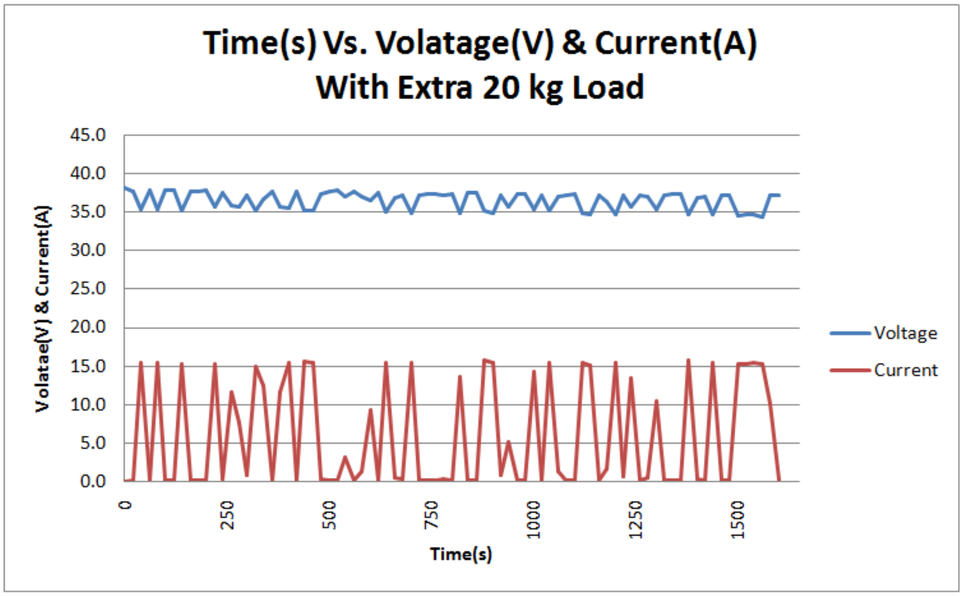


Fig 5.6: Voltage & Current Profile (Extra 20 kg weight)

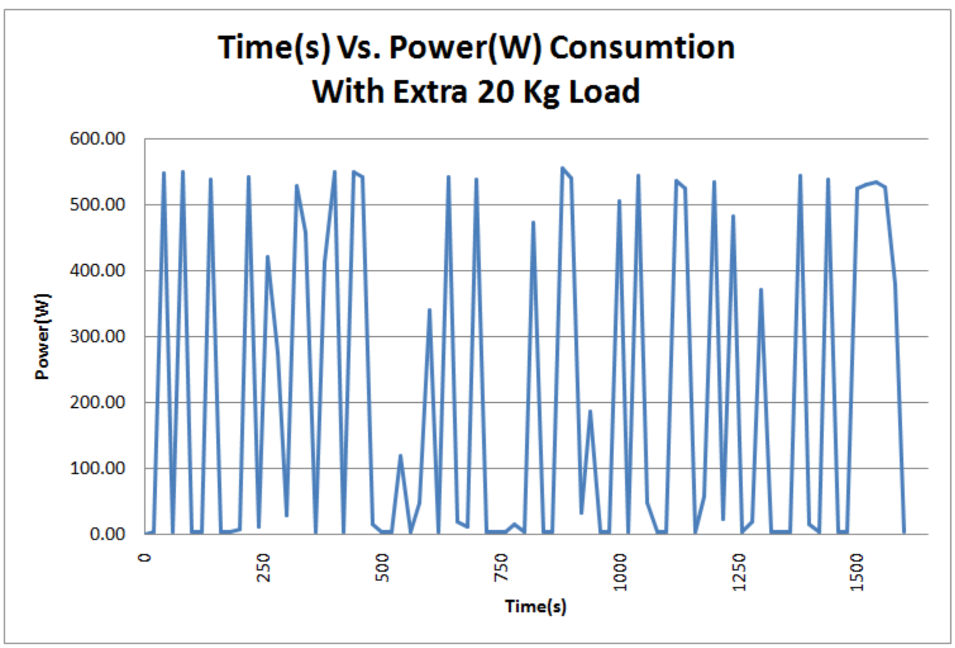


Fig 5.7: Power Consumption Profile (Extra 20 kg weight)

The graph of battery power (W) vs. time (s) is used to calculate the energy consumed from the battery bank and from the body force with extra 20 kg than the previous test. In this case, the energy supplied by the battery & renewable energy supplied by the body force are equal to the energy consumed by the load. The area under the graph in Fig load power (W) vs. time (s) is used to calculate the energy consumed by the load from the battery. The energy consumed by the load from battery is 334942.3 Joules.

5.7 Comparative Study:

Field test different running mechanism has been done. This part is all about the comparison of the result obtained from different running mechanism.

5.7.1 With & Without Torque Sensor:

The field tests were carried out until the battery discharged to 50% SOC. The results obtained from the two field tests reveal that the wheelchair can travel 42.1 km in 3.52 hrs (12660 seconds) with torque sensor and the wheelchair can travel 18.5 km in 1.41 hrs (5080 seconds) without torque sensor. The test reveals that with the help of torque sensor it consumes total 2004674.3 Joules and without torque sensor it consumes total 904931.7Joules of energy. From these energy calculations we can find out the total renewable energy supplied by the body force which is 1099742.6 Joules that is 45% of the total energy while using torque sensor where 55% energy is electric energy comes from battery bank.

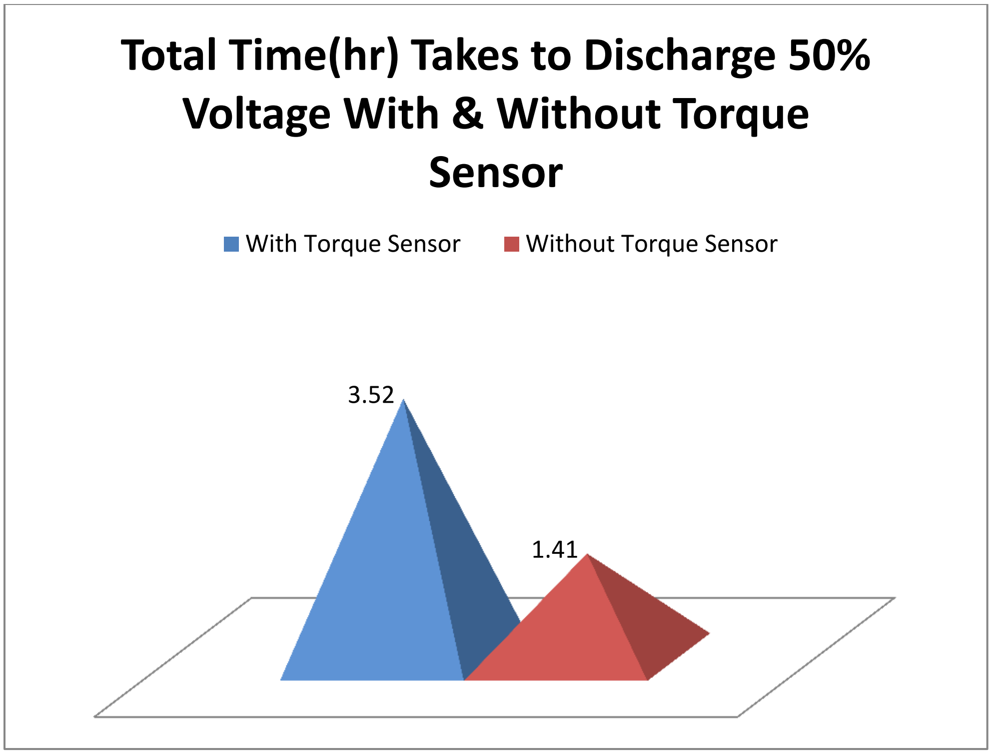


Fig 5.8: Time Calculation (With & Without Torque Sensor)

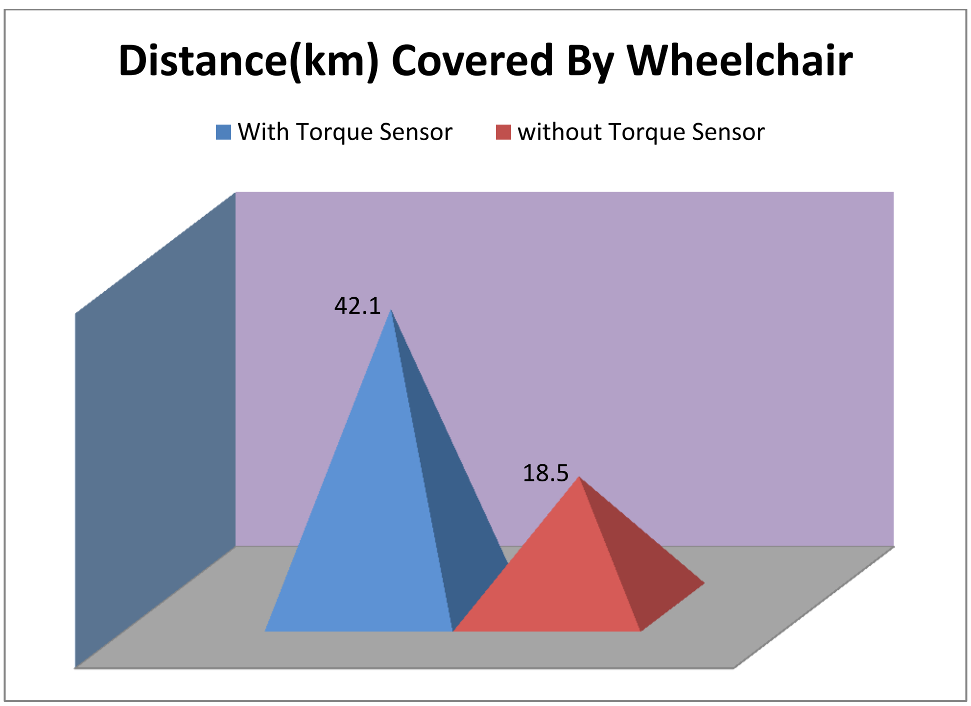


Fig 5.9: Distance Travelled (With & Without Torque Sensor)

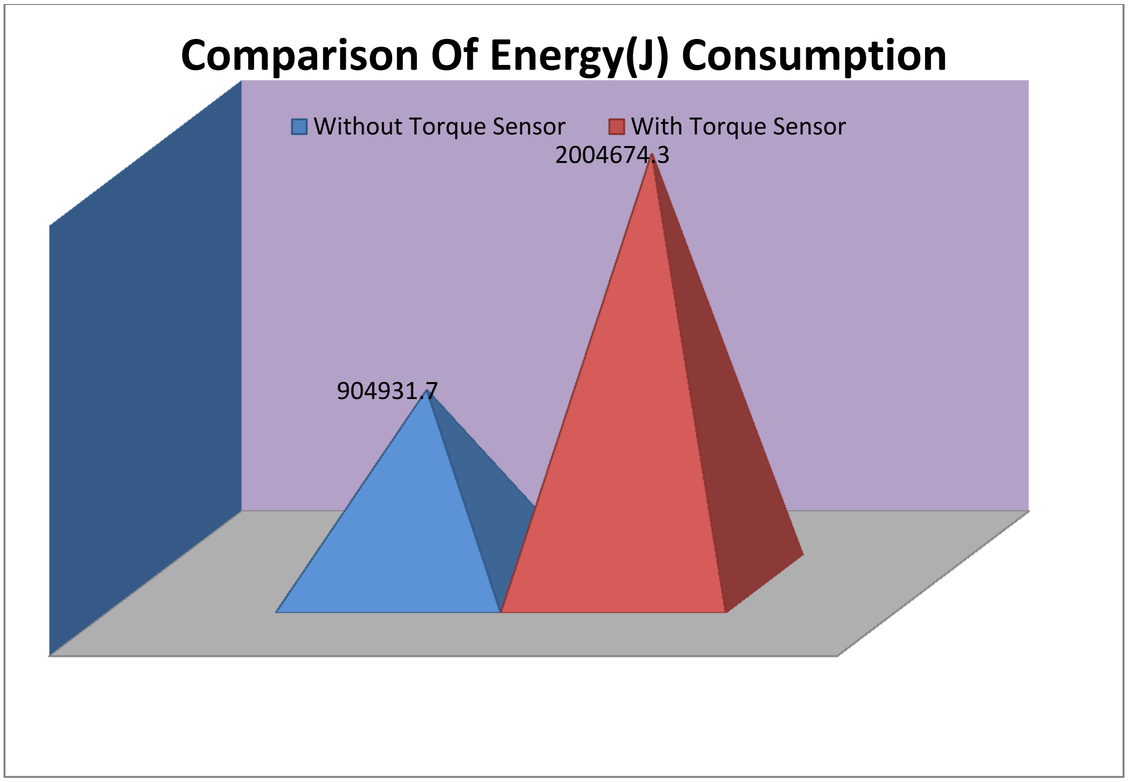


Fig 5.10: Energy Consumption Calculation (With & Without Torque Sensor)

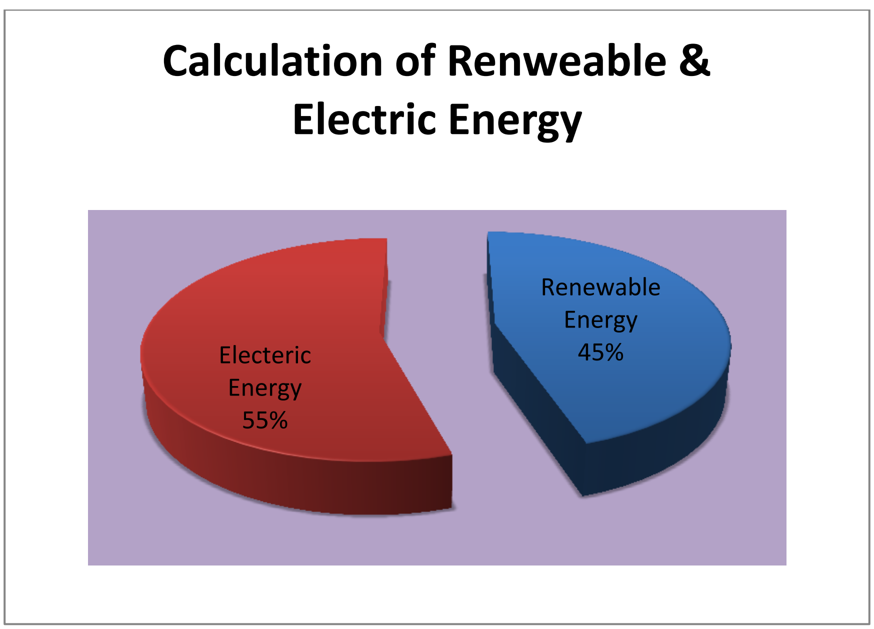


Fig 5.11: Electric & Renewable Energy Calculation

5.7.2 Comparison between 60 kg & 80 kg Weight:

With 60 kg load wheelchair goes 1.1 hr and with 80 kg load it goes .44 hr. From that experiment we can say if weight is higher, voltage will discharge quickly.

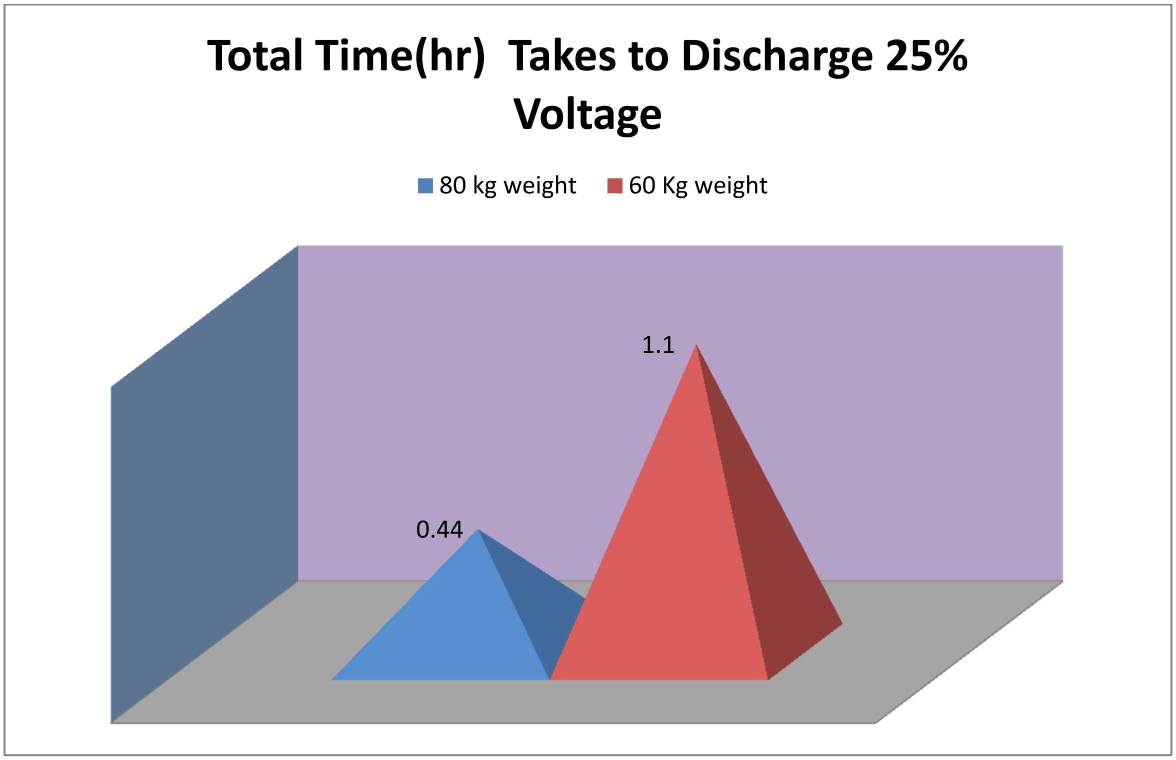


Fig 5.12: Time Calculation (60 kg & 80 kg weight)

5.8 Conclusion:

The chapter quantitatively proves that wheelchair driven by torque sensor paddle will be more appreciable. For with torque sensor running mechanism, 45% electric energy will be saved. So, it's better to use torque sensor paddle.

Chapter 6

Overview of the Dedicated Solar Charger Kit

6.1 Introduction:

The dedicated solar charger kit is mainly designed in order to provide the wheelchair to the people which is independent of national grid. The reason behind implementing the dedicated solar charger kit is to charge the batteries from sunlight through solar panel instead of charging from the national grid. Although torque sensor contributes to saving energy, at the end of the day, the battery still needs to get charged from the national grid. So in order to make it completely independent of the national grid, dedicated solar charger kit is implemented.

Fig 6.1: Solar Charger Kit

6.2 Function of Solar Charger Kit:

The idea of dedicated solar charger kit was to make it portable and user friendly so that the user can easily carry it from place to place without having much hassle. The portable solar charger kit and panels can be placed in an open place or rooftop in order to avail sunlight. All the other components along with batteries and charge controller comes in a compact box. In time of charging the batteries, the batteries must be fed from the panels through the solar charge controller. After the full charge completion, the batteries can be swiped with the batteries of wheelchair whenever needed. The people from rural area or living in such areas where national grid is unavailable can have the opportunity to use the electrically assisted wheelchair without any obstacles.

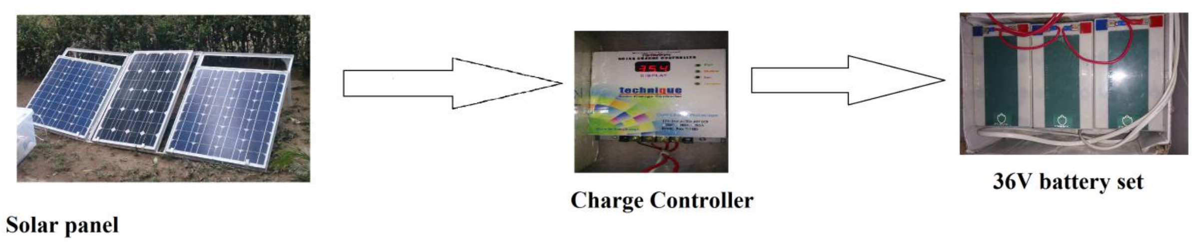


Fig 6.2: Power Management Process of Solar Charger Kit

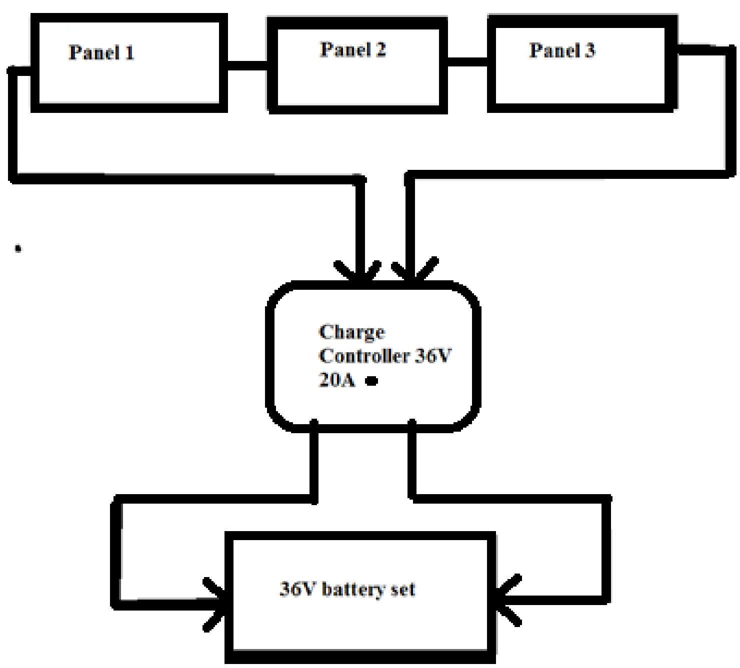


Fig6.3: Functional block diagram of dedicated solar charger kit

6.3 Components:

Our wheelchair contains a 36V battery set(3 units of 12V battery).So our dedicated solar charger kit contains another similar set of 36V battery set, a 36V 20A charge controller, A 225W solar panel set(3 units of 75W solar panel), a portable iron frame to carry the panels, a box to preserve the batteries and charge controller.

6.3.1 Solar Panels:

The three solar panels (225 Watts) are connected in series. Two types of solar panels we have used. The panels fed the batteries using the charge controller. The specification of the panel 2 (Fig 6.4)are mentioned below:

- Maximum Power: 75W
- Nominal voltage: 34.92V
- Nominal current: 5.70A
- Open circuit voltage: 22.54V
- Short circuit current: 4.35A
- Number of cells: 72
- Weight: 6.3 kg
- Dimensions: 937*545*35(MM)
- Max system voltage: 600V DC
- Power tolerance: +-5%

The specification of the panel 1 & 3 (Fig 6.4)are mentioned below:

- Model: GTS-36M-075-A
- Peak Power (Pmax): 75W
- Open Circuit Voltage (Voc): 22.52V
- Short Circuit Current (Isc): 4.40A

• Maximum Power Voltage (Vmp): 18.37V

• Maximum Power Current (Imp): 4.09A

• Maximum System Voltage (Vdc): 750V

• No. of Cells: 36

• Dimension (mm): 768*664*35

• Weight: 7kg

Fig 6.4: Solar Panels

6.3.2 Batteries:

Three rechargeable batteries have been used and these are 12V,12Ah each. Batteries have been connected in series which supply 36V,12Ah to the hub motor. These are lead-acid batteries. Each battery is 6x4x3.56 inch in dimension. Two sets of batteries have been used. One is for wheelchair and another is for solar battery charger kit. Batteries for solar panel will be kept into a box. The batteries will be swapped while it is necessary. The weight of one set of batteries is 13.75 kg. The batteries are placed under the seat as shown in fig. batteries are attached with the underneath sheet of the wheelchair such as it couldn't be able to move during the driving of wheelchair and also such as that batteries can be changed whenever it is necessary. Each fully charged battery 12.7V or above across their terminals and 38.1 volts after connecting those in a series combination.

Fig 6.5: Batteries & Box

6.3.3 Charge Controller:

Ratings of the charge controller for solar charger kit is 36V,20A. There is no load connection in this controller. It will be also kept into the box during charging.

Fig 6.6: Charge Controller for Solar Charger Kit

6.4 Conclusion:

As Bangladesh is an under developed country, grid connection is not available in every corner of the country. Solar charger kit is for those areas. For this charging mechanism, people will love to use our wheelchair.

Chapter 7

Conclusion

7.1 Future Work:

Since the time span allocated for our substantial thesis project was shortly one year, there are still some modifications we were unable to do according to the feedback given by CRP authorities. The valuable feedback CRP authorities given to us can be developed in the future and those feedbacks are:

- Width as well as height of the seat will be lower and backrest of the seat need to be round shaped.
- Footrest needs to be inner wards.
- Space of the battery place need to be smaller.
- Hub motor need to be in the back wheel.

There are some other modifications that can also be developed in future according to our own opinion. We believe those further modifications will provide user a more comfort and secured package along with our electric powered vehicle. Those modifications are:

- Seat belt need to be introduced.
- Indicator light needs to be introduced.

7.2 Summary:

Development of electrically assisted wheelchair is an enormous blessing for the physically disabled individuals and it brings significant change in their mobility as well as lifestyle. The overall designing of the electrically assisted wheelchair is done with an ambition to provide maximum possible facilities to its user - the disabled people. Installation of electric power, biomechanics, comforts and safety get maximum priority in designing. Other attraction of this wheelchair is flexible and modular designing. Because of flexibility and modularity in design, desired modification (change of wheels, seat, height of backrest etc.) if needed, can be done easily to meet up any individual requirement. Though it offers a dedicated solar charger kit, it can also be charged with grid electricity if desired. This electrically assisted wheelchair has been designed and developed in consideration of the disabled individuals of Bangladesh but disabled individuals at any corner of the world can use it provided there is sufficient amount of solar radiation. Finally it is important to mention that electrically assisted wheelchair is not merely environment friendly vehicle for disabled people but also prevent the secondary disability as auto power vehicle. So, it is a total solution for mobility of the disabled people of the society.

7.3 Specification of the Whole System:

General Specification	
Size: 62x30x41 inches	Steering/Drive System: Handle Bar& Torque Sensor Paddle
Batteries: 36V, 12A (3 units)	Speed Control: Continuous (Voltage Regulation)
Braking System: Hand Clutch (Front Wheel)	Seat: Cushioned and water proof
Tire Size: 26 inches	
Power Specifications	
Solar Panel : 225 Watts(3 units)	Batteries: 36V, 12A (6 units)
Motor: Hub Motor, 250 Watts	Charge Controller: 2 Units (36V, 25A & 36 V,20A)

Table 7.1: Specification of the whole system

Reference:

[1] World Health Organization Homepage: www.who.int/about/en

[2]] Centre for Disability in Development Homepage: www.cdd.org.bd

[3] Centre for Disability in Development Homepage: www.acwf-bd.org

[4]P. Norek, M. Ahmed, et al, Livelihood Challenges for Extremely Poor Disabled People in the Southwest Costal Region of Bangladesh, Shiree working paper 12, January 2013

[5] Wikipedia.Wikimedia Foundation https://en.wikipedia.org/wiki/Wheel_hub_moto.Retrived 10/12/2015

[6] Beevatech Limited Homepage: HUhttp://www.beevatech.com/index.phpU

[7]Wikipedia.WikimediaFoundation.Web.15Nov.2015.<https://en.wikipedia.org/wiki/Torque_sensor>.

[8]"RotaryTorqueSensor."TorqueSensor.Web.15Nov.2015.<https://www.transducertechniques.com/torque-sensor.aspx>

[9] http://www.appmeas.co.uk/torque-transducers-and-torque-sensors.html Retrieved November15, 2015

[10] Torque sensor operation manual v4.0; Suzhou Victory Sincerity Technology Company Ltd Retrieved<https://en.wikipedia.org/wiki/State_of_charge>.

[11] http://www.homepower.com/articles/solar-electricity/equipment-products/managingyour-batteries/page/0/2 Retrieved 10/06/2015

Appendix

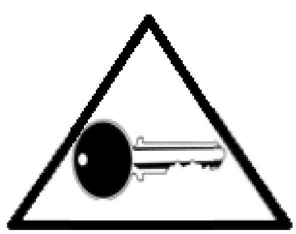
Appendix A

Caution for the Wheelchair

Whenever a vehicle has to depart from its garage, safety is always a concern. For this wheelchair, you need to take some caution as same way you do for other vehicle before riding.

Avoid dirty place to park. Tires, body part, motor and many other parts can be damaged.

Avoid wet floor to park, the wheelchair contains Iron, which can cause rust.



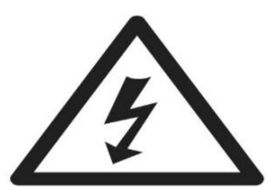
Always carry the wheelchair’s key with you; nobody knows when you need to move or ride.

Caution for the Charge Controller

The controller contains both electrical and electronic components. Improper handling can easily electrocute the user. The components are connected through various wire joints and PCB paths and thus require precise trouble-shooting when a problem occurs

The controller is an electrical device. Making it wet or washing it with water can cause severe damage to the controller, even can result in fire.

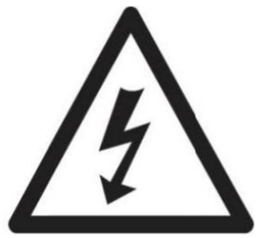
The controller contains both electrical and electronic components. Improper connections or short circuit can cause severe damage to the components or catch fire.



Always keep the PV panel neat and tidy. Tidiness will increase the efficiency significantly.

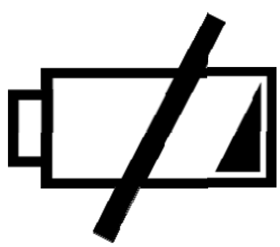
Do not put any heavy object on top of the controller, which can cause severe malfunction and unexpected results.

Caution for the Battery

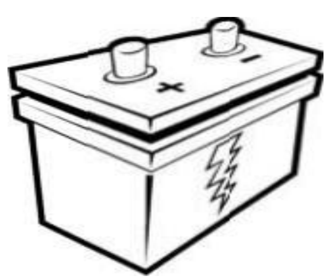


Do not over-charge the batteries.

Keep the batteries in cool/dry place.



Do not use the wheelchair when the battery signal is low or below 30%.

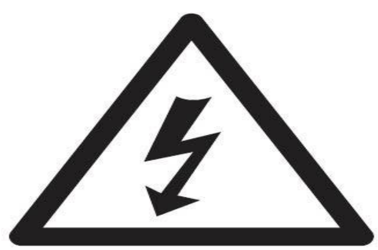


To keep the wheelchair healthy, change the whole sets of battery in every 2 years.

Maintenance

Repair or change the tube of the tire if tube is leaked

Lubricate the chain regularly



Discharged battery should be charged as early as possible.

Keep PV panel neat and clean

Appendix B

Table 1: Data of field test without torque sensor pedal

Time (seconds)	Battery voltage (V)	Battery current (A)
0	38.9	0.0
20	38.3	0.1
40	37.4	0.5
60	36.8	4.5
80	38.2	2.3
100	38.8	0.1
120	36.1	9.6
140	38.7	0.1
160	38.8	0.1
180	38.6	0.2
200	38.7	0.1
220	36.4	8.2
240	38.6	0.1
260	37.5	3.5
280	37.2	5.5
300	37.7	1.1
320	38.6	0.1
340	38.0	2.8
360	38.4	0.9
380	36.1	8.3
400	37.5	4.3
420	38.5	0.2
440	38.5	0.1
460	37.9	3.6
480	35.7	13.9
500	37.9	2.2
520	38.4	0.1
540	37.5	4.7
560	35.9	10.8
580	36.2	5.8
600	35.9	8.7
620	37.4	3.5
640	38.4	0.1
660	38.1	0.6
680	36.9	7.5
700	37.5	2.5
720	36.6	5.5
740	37.0	4.3
760	38.4	0.1
780	35.1	14.1
800	37.4	4.7
820	37.0	5.4
840	38.3	0.1
860	36.8	9.8
880	36.2	10.1
900	35.5	14.7
920	37.0	7.2
940	35.7	13.1
960	35.9	12.3
980	38.5	14.3
1000	37.2	3.0
1020	35.5	15.9
1040	38.2	0.1
1060	35.9	14.8
1080	36.5	10.4
1100	36.9	8.0
1120	38.1	0.1
1140	37.5	2.3
1160	37.6	2.4
1180	37.1	4.9
1200	37.5	3.0
1220	37.1	4.3
1240	38.0	0.1
1260	37.7	1.8
1280	36.4	8.2
1300	35.8	15.7
1320	37.6	1.1
1340	35.2	15.5
1360	37.4	4.9
1380	36.4	7.8
1400	35.3	12.2
1420	38.1	0.1
1440	37.9	2.1
1460	37.4	3.7
1480	37.0	5.7
1500	38.2	0.1
1520	38.0	2.6
1540	37.8	2.8
1560	37.3	3.6
1580	37.0	4.6
1600	38.1	0.1
1620	34.9	14.3
1640	38.0	2.0
1660	35.2	10.4
1680	36.8	2.8
1700	35.8	7.1
1720	38.1	0.1
1740	34.8	14.0
1760	38.0	0.1
1780	37.6	4.3
1800	38.0	1.0
1820	35.2	12.1
1840	35.6	13.5
1860	37.5	5.4

Time (seconds)	Battery voltage (V)	Battery current (A)
1880	37.4	4.0
1900	38.1	0.1
1920	36.9	9.7
1940	36.8	3.9
1960	36.1	8.2
1980	37.5	3.5
2000	37.9	0.1
2020	36.5	9.6
2040	35.2	15.0
2060	37.3	0.4
2080	37.3	2.9
2100	37.8	0.1
2120	37.3	0.7
2140	36.3	6.0
2160	37.3	4.3
2180	36.1	4.3
2200	35.1	14.1
2220	36.2	5.9
2240	36.9	4.2
2260	36.5	6.4
2280	37.5	0.1
2300	35.0	14.3
2320	37.6	0.1
2340	37.7	0.1
2360	36.6	4.3
2380	37.4	0.1
2400	37.2	3.0
2420	37.0	1.8
2440	37.4	0.1
2460	37.2	0.4
2480	36.8	2.4
2500	37.0	1.5
2520	37.0	2.5
2540	37.7	0.1
2560	37.0	2.1
2580	36.6	3.8
2600	35.8	9.9
2620	35.9	7.4
2640	37.6	0.1
2660	35.2	9.7
2680	37.4	0.1
2700	35.4	9.7
2720	35.2	11.2
2740	37.3	1.9
2760	37.2	1.9
2780	35.0	16.0
2800	37.4	0.1
2820	35.8	8.0
2840	36.7	2.3
2860	37.4	0.1
2880	36.3	5.1
2900	35.9	6.5
2920	35.0	12.5
2940	34.6	3.0
2960	36.5	3.7
2980	37.4	0.1
3000	36.7	2.8
3020	36.9	0.4
3040	35.8	7.5
3060	37.2	0.1
3080	37.3	0.1
3100	36.4	3.7
3120	37.0	1.6
3140	37.2	0.1
3160	37.2	0.1
3180	36.9	1.4
3200	36.2	4.5
3220	35.6	12.2
3240	37.1	0.1
3260	37.2	0.2
3280	34.8	14.7
3300	37.1	0.1
3320	36.4	2.5
3340	37.0	0.1
3360	35.7	6.8
3380	35.1	11.2
3400	34.6	13.4
3420	36.5	3.5
3440	36.9	0.5
3460	34.4	14.0
3480	36.8	1.8
3500	34.1	13.1
3520	35.2	3.8
3540	34.4	11.3
3560	36.8	0.1
3580	36.9	0.2
3600	34.1	15.1
3620	35.0	4.4
3640	35.7	4.8
3660	36.9	0.1
3680	36.4	3.9
3700	35.7	9.3
3720	36.2	6.0
3740	37.1	0.1
3760	36.8	1.3
3780	34.5	14.6
3800	34.3	15.7
3820	35.7	9.9
3840	37.0	0.8
3860	36.8	0.1

Time (seconds)	Battery voltage (V)	Battery current (A)
3880	36.9	0.5
3900	34.5	14.6
3920	34.3	15.7
3940	35.7	9.9
3960	36.8	0.1
3980	34.5	16.0
4000	34.8	14.6
4020	35.4	10.6
4040	36.5	0.1
4060	34.2	11.0
4080	35.9	3.5
4100	35.8	1.5
4120	36.2	0.4
4140	33.6	16.1
4160	35.9	5.5
4180	36.2	0.4
4200	36.4	0.1
4220	35.0	6.6
4240	35.0	7.5
4260	36.4	0.1
4280	35.8	2.8
4300	36.2	0.8
4320	36.5	0.1
4340	35.7	3.0
4360	36.5	0.2
4380	33.6	16.2
4400	35.4	5.2
4420	35.6	3.5
4440	36.6	0.1
4460	35.9	2.0
4480	35.7	3.0
4500	36.0	1.9
4520	33.6	16.1
4540	34.0	13.5
4560	33.7	16.0
4580	36.5	0.1
4600	36.4	0.2
4620	35.9	1.5
4640	36.2	2.4
4660	36.4	0.1
4680	36.3	0.4
4700	34.1	10.9
4720	34.2	14.4
4740	35.4	5.7
4760	33.6	14.4
4780	35.9	0.8
4800	36.0	1.7
4820	36.3	0.1
4840	35.7	2.8
4860	35.1	5.4

Time (seconds)	Battery voltage (V)	Battery current (A)
4880	36.2	0.1
4900	34.9	6.8
4920	36.1	0.5
4940	35.8	1.3
4960	35.9	1.1
4980	35.2	3.8
5000	36.1	0.1
5020	34.4	8.7
5040	34.9	5.3
5060	33.3	15.4
5080	36.3	0.1

Appendix C

Table 2: Data of field test with torque sensor pedal

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
0	0.74	38.7	0.0
20	0.74	38.5	0.2
40	1.55	38.4	0.1
60	0.76	38.5	0.0
80	1.58	38.4	0.3
100	0.79	38.5	0.1
120	1.86	37.8	3.8
140	0.74	38.4	0.0
160	1.08	38.4	0.2
180	1.83	37.9	2.8
200	1.55	38.4	0.1
220	1.55	38.4	0.2
240	1.69	38.3	0.6
260	1.55	38.5	0.0
280	0.74	38.6	0.0
300	1.66	37.8	3.9
320	0.74	38.6	0.0
340	1.55	38.3	0.3
360	1.55	38.5	0.0
380	0.75	38.5	0.0
400	2.22	37.5	3.8
420	1.55	38.5	0.2
440	1.99	37.8	3.5
460	1.55	38.5	0.0
480	0.74	38.6	0.0
500	1.55	38.5	0.0
520	2.06	37.8	2.2
540	2.03	38.0	4.9
560	1.83	38.3	0.2
580	2.14	38.0	1.9
600	2.09	38.3	0.3
620	1.55	38.5	0.0
640	1.99	37.9	2.0
660	1.55	38.4	0.0
680	0.73	38.5	0.0
700	2.87	35.5	13.3
720	0.77	38.3	0.1
740	2.82	35.6	15.4
760	1.55	38.3	0.1
780	2.19	37.5	2.6
800	1.55	38.2	0.0
820	2.10	38.1	0.5
840	1.55	38.3	0.0
860	0.73	38.4	0.0
880	2.26	37.2	3.8
900	1.87	37.8	0.9
920	2.47	35.7	12.2
940	0.75	38.4	0.0
960	1.55	38.4	0.1
980	1.89	37.6	1.8
1000	2.86	35.1	15.4
1020	2.12	36.8	5.4
1040	2.30	37.3	4.9
1060	1.55	38.1	0.1
1080	2.34	36.0	6.9
1100	2.22	37.6	2.8
1120	1.86	37.9	1.0
1140	1.65	38.0	0.1
1160	0.74	38.2	0.0
1180	2.26	37.3	3.5
1200	1.55	38.1	0.1
1220	2.12	36.6	5.1
1240	1.95	37.4	6.1
1260	0.73	38.2	0.0
1280	0.74	38.3	0.0
1300	1.95	37.6	3.8
1320	0.74	38.3	0.0
1340	0.74	38.4	0.0
1360	1.99	37.8	4.1
1380	2.02	37.3	5.7
1400	0.74	38.3	0.0
1420	2.07	37.0	8.4
1440	1.55	38.2	0.3
1460	2.14	38.0	2.8
1480	0.74	38.3	0.0
1500	1.99	37.2	8.5
1520	2.10	37.6	2.4
1540	1.97	37.9	1.8
1560	2.57	36.4	6.2
1580	2.78	35.5	14.6
1600	1.71	38.2	0.3
1620	2.02	37.4	8.3
1640	2.29	37.7	3.0
1660	2.68	36.3	8.4
1680	2.34	37.5	2.9
1700	2.28	37.6	7.5
1720	2.17	37.4	8.2
1740	0.74	38.2	0.0
1760	1.55	38.2	0.0
1780	2.32	36.6	8.7
1800	2.20	37.5	4.5
1820	2.14	37.5	4.1
1840	2.24	36.7	8.7

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
1860	0.74	38.2	0.0
1880	2.43	36.7	8.6
1900	0.74	38.2	0.0
1920	1.55	38.2	0.1
1940	1.55	38.2	0.0
1960	2.14	38.0	2.8
1980	0.74	38.0	0.0
2000	2.28	37.5	6.2
2020	0.73	38.2	0.0
2040	2.10	37.6	2.5
2060	2.24	37.4	5.8
2080	2.09	36.8	5.9
2100	0.74	38.0	0.1
2120	2.07	37.1	6.5
2140	2.12	37.5	4.8
2160	2.02	37.8	2.3
2180	0.74	38.2	0.0
2200	2.22	37.2	5.2
2220	0.74	38.1	0.0
2240	0.74	38.0	0.0
2260	2.04	37.3	4.6
2280	2.13	37.4	3.0
2300	2.15	37.3	4.3
2320	1.45	38.1	2.8
2340	1.60	38.1	0.1
2360	1.66	37.7	3.7
2380	2.18	37.3	3.5
2400	2.09	37.8	2.9
2420	2.39	36.3	8.1
2440	2.02	37.9	1.4
2460	2.05	37.1	7.2
2480	2.05	37.1	4.4
2500	2.27	37.1	4.8
2520	2.31	37.0	8.6
2540	2.15	37.9	0.9
2560	2.19	37.7	5.8
2580	1.55	38.1	0.4
2600	0.74	38.0	0.0
2620	2.24	36.9	4.7
2640	0.74	38.1	0.0
2660	2.12	37.8	2.0
2680	0.74	38.1	0.0
2700	2.36	36.8	6.7
2720	1.55	38.1	0.0
2740	2.18	36.4	9.6
2760	2.25	36.6	8.6
2780	2.38	36.3	8.8
2800	2.32	37.0	5.5
2820	2.29	37.0	8.4
2840	2.07	37.8	3.3

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
2860	0.74	38.0	0.0
2880	2.23	37.1	6.1
2900	2.06	37.4	3.6
2920	3.04	35.4	14.9
2940	0.74	38.0	0.1
2960	2.44	36.8	4.8
2980	1.61	37.9	0.1
3000	2.33	37.1	5.7
3020	1.41	37.0	5.5
3040	0.74	37.9	0.0
3060	1.55	38.0	0.1
3080	0.74	37.9	0.1
3100	2.30	36.5	8.0
3120	1.95	37.1	6.1
3140	2.44	36.4	8.4
3160	2.26	36.5	8.1
3180	1.55	37.9	0.1
3200	1.89	37.8	1.2
3220	1.55	38.0	0.1
3240	1.55	38.1	0.1
3260	1.55	38.1	0.1
3280	1.55	38.1	0.1
3300	2.23	37.0	8.1
3320	1.71	38.0	0.4
3340	2.14	37.5	4.7
3360	2.06	37.4	3.4
3380	1.55	38.1	0.2
3400	1.55	38.1	0.1
3420	1.96	37.0	3.0
3440	2.24	36.8	6.8
3460	0.73	38.1	0.1
3480	1.97	37.9	2.2
3500	1.85	37.8	2.1
3520	2.39	36.5	9.4
3540	0.73	38.0	0.1
3560	2.04	37.5	2.8
3580	2.10	37.0	4.2
3600	1.69	37.7	0.8
3620	1.93	37.5	0.8
3640	2.09	36.6	5.7
3660	1.98	37.6	2.2
3680	1.55	37.9	0.1
3700	1.91	37.7	0.3
3720	1.54	38.0	0.1
3740	2.39	36.5	7.1
3760	2.11	37.0	5.4
3780	0.74	38.0	0.1
3800	2.08	37.3	6.7
3820	2.37	35.9	11.2
3840	2.17	37.3	3.7

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
3860	1.54	38.0	0.1
3880	0.75	38.0	0.1
3900	2.44	36.4	7.4
3920	1.94	37.0	4.0
3940	0.74	38.0	0.1
3960	0.74	38.1	0.1
3980	2.29	36.1	11.3
4000	1.55	37.8	0.1
4020	2.24	37.4	3.8
4040	2.04	38.0	3.9
4060	0.74	37.8	1.0
4080	2.31	36.9	7.2
4100	0.74	37.7	1.1
4120	1.76	37.8	0.9
4140	2.27	36.5	8.6
4160	0.74	37.7	0.1
4180	2.13	37.4	3.3
4200	1.86	37.2	3.8
4220	1.67	37.7	0.1
4240	0.74	37.6	0.1
4260	1.65	37.2	1.5
4280	1.91	37.0	2.8
4300	1.83	37.3	3.7
4320	0.74	37.8	0.1
4340	0.75	37.9	0.1
4360	0.74	37.9	0.1
4380	2.25	36.7	5.7
4400	2.47	36.1	6.0
4420	2.20	37.0	3.3
4440	2.16	36.6	5.2
4460	2.35	36.8	3.2
4480	2.28	37.1	3.1
4500	1.57	37.7	0.1
4520	2.27	36.8	4.6
4540	2.54	35.2	8.8
4560	0.77	37.6	0.1
4580	2.13	36.8	6.2
4600	2.25	36.1	7.3
4620	2.37	35.1	13.7
4640	2.55	35.7	9.2
4660	0.74	37.5	0.1
4680	1.87	37.1	1.5
4700	2.51	35.8	8.2
4720	1.99	35.4	9.3
4740	2.70	35.5	14.9
4760	0.74	37.6	0.1
4780	2.48	35.2	12.1
4800	0.73	37.5	0.1
4820	0.73	37.5	0.1
4840	0.75	37.9	0.2

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
4860	1.11	37.1	4.6
4880	1.22	37.6	0.2
4900	1.83	37.0	4.0
4920	1.67	37.6	0.4
4940	1.75	36.8	5.1
4960	1.71	36.5	8.5
4980	1.82	36.4	7.7
5000	1.68	37.6	0.1
5020	1.52	37.4	0.9
5040	1.73	35.9	9.8
5060	1.13	37.6	0.1
5080	0.78	37.6	0.5
5100	1.88	36.1	8.0
5120	1.12	36.3	7.8
5140	0.79	37.5	0.1
5160	1.42	36.1	8.5
5180	1.44	37.2	1.7
5200	1.53	37.5	3.0
5220	0.75	37.7	0.1
5240	0.75	37.7	0.1
5260	1.64	36.9	2.8
5280	1.82	36.5	6.6
5300	1.45	37.2	1.2
5320	1.46	36.6	5.4
5340	1.85	36.4	8.3
5360	0.76	37.6	0.1
5380	1.93	35.3	8.9
5400	1.65	36.2	6.2
5420	1.75	36.8	4.6
5440	1.09	37.5	0.1
5460	2.57	35.1	13.5
5480	0.74	37.6	0.1
5500	0.74	37.5	0.3
5520	2.22	36.1	6.0
5540	2.55	35.8	9.9
5560	2.15	37.4	5.7
5580	2.35	37.1	3.0
5600	2.59	36.4	10.1
5620	2.21	37.3	1.3
5640	2.15	36.1	8.4
5660	2.36	36.7	7.6
5680	2.51	35.5	11.3
5700	0.75	37.5	1.1
5720	2.08	37.4	0.5
5740	1.75	37.5	0.1
5760	2.69	35.0	14.9
5780	2.43	36.0	9.0
5800	2.36	36.1	7.9
5820	2.34	36.5	6.7
5840	0.73	37.5	0.1

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
5860	2.54	36.4	7.5
5880	0.73	37.5	0.1
5900	3.76	34.7	15.6
5920	1.91	36.9	3.2
5940	2.52	35.5	10.9
5960	2.41	36.5	10.1
5980	2.71	34.9	15.5
6000	2.31	37.0	4.3
6020	2.44	35.9	10.9
6040	2.56	35.9	10.4
6060	0.90	37.5	0.1
6080	2.37	36.3	6.4
6100	2.72	35.0	15.3
6120	2.51	36.2	6.7
6140	2.75	35.8	8.9
6160	2.68	35.8	11.3
6180	1.69	37.2	1.9
6200	2.25	36.7	3.4
6220	2.55	35.9	7.5
6240	2.65	35.6	9.2
6260	2.65	35.4	12.5
6280	2.30	36.5	5.2
6300	2.08	36.5	4.9
6320	2.22	36.0	7.1
6340	2.17	36.8	2.6
6360	1.97	37.3	0.6
6380	2.35	36.7	4.9
6400	1.98	37.1	1.1
6420	0.74	37.4	0.1
6440	2.50	35.2	14.4
6460	2.11	36.0	7.2
6480	0.74	37.5	0.1
6500	0.77	37.4	0.1
6520	2.69	34.8	15.3
6540	0.74	37.5	0.1
6560	1.60	37.4	0.1
6580	2.23	36.3	4.8
6600	2.25	36.8	3.5
6620	2.44	36.1	6.5
6640	2.53	35.8	8.8
6660	1.95	36.8	3.2
6680	0.74	37.5	0.1
6700	0.74	37.5	0.1
6720	2.03	36.4	5.1
6740	0.74	37.5	0.1
6760	1.64	37.2	1.6
6780	2.27	36.1	7.5
6800	1.95	37.2	1.0
6820	2.18	36.6	4.3
6840	2.24	35.9	8.0

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
6860	1.59	37.4	0.1
6880	2.08	36.9	2.5
6900	2.49	35.7	11.2
6920	1.96	37.1	1.9
6940	1.69	37.4	0.9
6960	1.55	37.4	0.1
6980	0.74	37.4	0.1
7000	0.74	37.4	0.1
7020	2.10	36.2	5.2
7040	1.98	37.0	2.8
7060	2.40	36.1	5.8
7080	0.74	37.5	0.1
7100	2.24	36.5	5.2
7120	1.97	37.3	0.2
7140	2.03	37.1	0.7
7160	2.59	35.4	12.2
7180	2.01	37.3	1.8
7200	2.07	36.7	3.0
7220	2.12	36.9	3.2
7240	2.16	37.1	2.1
7260	1.54	37.2	0.2
7280	2.31	36.0	7.6
7300	2.25	35.8	8.4
7320	0.74	37.4	0.1
7340	2.17	35.7	10.2
7360	1.71	37.1	1.8
7380	1.56	37.2	0.2
7400	2.55	35.9	12.1
7420	1.80	37.3	0.1
7440	1.99	37.3	0.4
7460	2.48	35.4	10.6
7480	2.55	37.3	1.3
7500	1.96	37.0	0.7
7520	1.55	37.3	0.1
7540	2.49	35.6	12.9
7560	1.55	37.3	0.1
7580	2.19	36.8	4.5
7600	2.44	36.5	8.3
7620	0.74	37.3	0.1
7640	2.28	36.6	6.0
7660	1.65	36.0	11.4
7680	2.03	36.8	2.7
7700	0.74	37.4	0.1
7720	2.59	35.0	14.7
7740	2.18	36.7	2.4
7760	0.74	37.4	0.1
7780	2.06	36.9	2.2
7800	1.96	37.3	0.5
7820	2.01	36.9	2.8
7840	2.15	36.8	3.6

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
7860	2.08	36.5	1.7
7880	2.11	36.7	3.7
7900	0.74	37.4	0.1
7920	3.75	34.8	15.5
7940	0.75	37.4	0.1
7960	3.75	34.6	15.6
7980	3.75	34.7	15.5
8000	2.24	36.5	4.9
8020	2.10	36.7	4.8
8040	0.74	37.3	0.1
8060	2.45	35.8	10.3
8080	2.12	36.8	3.8
8100	1.55	37.3	0.1
8120	2.65	34.5	15.4
8140	2.25	36.2	5.6
8160	1.69	37.1	0.3
8180	0.74	37.2	0.1
8200	0.74	37.2	0.1
8220	2.24	36.5	4.7
8240	1.55	37.2	0.1
8260	0.74	37.2	0.1
8280	2.65	36.0	10.2
8300	2.55	35.7	10.7
8320	1.55	37.2	0.3
8340	0.74	37.2	0.1
8360	0.74	37.2	0.1
8380	1.73	36.5	9.2
8400	1.33	37.3	0.1
8420	1.32	37.4	0.1
8440	2.22	36.7	4.8
8460	2.39	35.4	9.1
8480	2.13	36.3	5.3
8500	2.16	36.7	2.9
8520	1.55	37.3	0.1
8540	1.55	37.3	0.2
8560	2.19	36.4	4.0
8580	2.19	36.5	4.1
8600	1.43	37.3	0.3
8620	0.73	37.4	0.1
8640	1.84	36.1	12.6
8660	2.40	35.4	10.5
8680	0.74	37.3	0.1
8700	2.65	35.0	12.1
8720	2.49	36.4	6.9
8740	2.16	36.5	3.4
8760	2.12	37.1	3.0
8780	2.19	36.3	5.8
8800	2.45	35.4	9.8
8820	0.74	37.3	0.2
8840	0.74	37.3	0.2
8860	0.74	37.3	0.1
8880	2.51	35.6	13.6
8900	2.35	35.6	12.3
8920	1.87	37.1	2.0
8940	2.14	36.3	5.6
8960	1.46	35.3	9.2
8980	0.74	37.2	0.1
9000	0.74	37.3	0.1
9020	2.04	35.2	8.0
9040	2.20	35.2	8.1
9060	1.87	36.7	5.0
9080	1.92	36.7	2.6
9100	2.19	35.9	6.7
9120	2.42	35.8	8.9
9140	1.93	36.9	4.4
9160	0.74	37.2	0.1
9180	2.86	34.7	15.4
9200	0.74	37.2	0.1
9220	1.21	37.3	4.1
9240	0.74	37.2	0.1
9260	2.61	35.3	11.2
9280	2.21	35.2	10.5
9300	2.50	34.8	12.5
9320	2.29	35.0	14.5
9340	2.39	35.2	13.4
9360	0.76	37.2	0.1
9380	2.25	36.2	4.9
9400	0.75	37.2	0.1
9420	2.46	35.3	9.6
9440	0.75	37.3	0.1
9460	2.09	36.4	7.8
9480	2.09	36.2	5.7
9500	0.74	37.2	0.1
9520	2.31	35.9	7.1
9540	1.98	36.8	2.8
9560	1.77	37.1	0.6
9580	0.74	37.3	0.1
9600	0.74	37.3	0.1
9620	1.90	37.1	0.9
9640	0.75	37.3	0.1
9660	2.76	35.2	14.8
9680	2.22	36.8	5.8
9700	0.74	37.3	0.1
9720	0.75	37.2	0.1
9740	1.87	36.8	2.2
9760	2.08	35.0	13.6
9780	2.13	36.8	8.7
9800	2.06	36.7	4.2
9820	1.63	37.2	3.2
9840	1.54	37.3	0.1

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
9860	1.54	37.3	0.1
9880	2.27	36.2	5.0
9900	2.45	36.5	4.8
9920	1.54	37.3	0.1
9940	2.13	36.3	4.7
9960	2.09	36.3	1.6
9980	1.99	36.8	2.1
10000	0.74	37.3	0.1
10020	3.65	34.6	15.5
10040	3.51	34.1	15.4
10060	2.48	34.1	15.5
10080	3.57	34.2	5.5
10100	3.47	34.3	15.4
10120	0.73	37.0	0.1
10140	3.57	34.3	13.7
10160	3.66	34.4	15.2
10180	1.96	36.6	12.7
10200	0.74	36.9	0.1
10220	1.99	36.8	0.6
10240	1.42	35.9	0.2
10260	0.74	36.7	0.1
10280	0.76	35.6	0.8
10300	0.73	36.8	0.1
10320	3.66	34.3	15.4
10340	3.66	34.2	14.2
10360	0.74	37.0	0.1
10380	3.77	36.3	2.7
10400	0.93	36.1	7.5
10420	1.90	36.8	0.1
10440	0.74	36.7	0.2
10460	3.67	35.5	8.2
10480	0.75	36.5	0.6
10500	1.93	34.9	5.1
10520	3.66	34.4	15.3
10540	0.73	36.8	0.3
10560	0.74	36.9	0.1
10580	0.73	34.5	2.6
10600	3.65	35.1	7.0
10620	1.99	35.5	3.5
10640	0.74	36.8	0.2
10660	0.75	36.6	0.3
10680	0.74	36.7	0.1
10700	1.95	35.2	4.0
10720	3.66	34.5	14.5
10740	3.47	34.2	14.3
10760	0.74	36.9	0.1
10780	0.74	36.9	0.1
10800	0.80	36.4	1.3
10820	2.15	36.5	3.7
10840	0.74	36.9	0.1

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
10860	3.34	35.0	5.2
10880	0.72	36.8	0.1
10900	2.67	36.1	1.0
10920	1.94	36.7	4.3
10940	0.74	36.8	0.1
10960	1.96	36.6	5.8
10980	3.66	34.8	8.9
11000	3.66	34.2	15.0
11020	3.20	34.2	13.7
11040	0.75	36.7	0.1
11060	0.07	35.5	13.2
11080	1.84	36.7	12.8
11100	1.95	36.5	0.3
11120	2.74	36.4	7.6
11140	3.15	34.1	6.5
11160	3.32	34.0	15.4
11180	3.15	34.2	12.2
11200	3.65	34.8	6.0
11220	3.65	34.3	11.6
11240	1.10	34.1	5.4
11260	0.74	36.7	0.8
11280	2.20	35.3	10.8
11300	2.09	36.1	6.3
11320	0.74	36.5	0.2
11340	1.18	34.2	12.3
11360	0.74	36.6	0.1
11380	3.44	34.3	14.9
11400	3.23	34.8	9.9
11420	1.99	35.2	4.5
11440	3.43	33.9	3.7
11460	1.94	36.4	4.1
11480	2.71	36.2	14.0
11500	1.41	33.8	12.1
11520	0.73	36.5	0.1
11540	1.43	36.2	14.5
11560	2.11	36.0	8.5
11580	1.97	36.3	0.1
11600	1.24	34.0	3.8
11620	2.98	36.3	8.2
11640	2.28	36.5	5.6
11660	1.89	35.0	13.3
11680	0.73	36.4	0.1
11700	3.52	33.8	14.0
11720	0.79	36.4	0.1
11740	1.88	34.2	3.3
11760	3.52	35.3	3.2
11780	0.74	36.4	0.1
11800	0.74	36.4	0.1
11820	0.73	35.7	0.8
11840	0.73	36.3	0.1

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
11860	3.16	36.8	4.1
11880	3.44	34.0	15.4
11900	3.50	33.8	15.4
11920	0.80	35.9	8.0
11940	3.49	33.9	15.5
11960	0.74	36.3	0.1
11980	3.40	34.0	15.4
12000	3.38	33.6	13.2
12020	0.73	36.2	0.1
12040	0.76	35.8	1.8
12060	0.74	36.4	0.1
12080	0.73	36.4	0.1
12100	0.73	36.2	0.1
12120	3.47	33.6	15.3
12140	3.66	34.0	15.5
12160	0.76	33.5	8.8
12180	2.04	35.9	13.2
12200	0.74	36.3	0.1
12220	2.87	36.0	5.3
12240	0.74	36.6	0.1
12260	3.46	33.6	5.4
12280	1.89	35.9	4.5
12300	0.73	36.1	0.1
12320	0.73	36.2	0.1
12340	0.74	36.2	0.1
12360	0.92	33.9	14.7
12380	0.73	36.2	1.4
12400	1.37	36.4	9.8
12420	2.03	36.1	6.0
12440	0.73	36.1	0.1
12460	3.35	33.5	15.4
12480	3.35	33.4	15.3
12500	0.81	35.0	0.7
12520	3.41	33.4	15.4
12540	0.73	36.0	0.1
12560	1.58	36.0	0.1
12580	0.74	36.1	0.1
12600	0.74	36.1	0.1
12620	3.35	33.4	15.4
12640	0.73	36.2	0.1
12660	0.74	36.3	0.1

Appendix D

Table 3: Data of field test with torque sensor pedal and 20kg extra load upto 75% SOC

Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
0	0.73	38.2	0.0
20	0.73	37.7	0.1
40	3.15	35.3	15.5
60	0.74	37.9	0.1
80	3.12	35.4	15.5
100	0.74	37.9	0.1
120	0.74	37.8	0.1
140	3.14	35.2	15.3
160	0.76	37.7	0.1
180	0.73	37.7	0.1
200	0.73	37.8	0.2
220	2.77	35.6	15.2
240	0.76	37.5	0.3
260	2.55	35.9	11.7
280	2.12	35.7	7.7
300	1.35	37.2	0.8
320	3.15	35.2	15.0
340	2.55	36.6	12.5
360	0.74	37.6	0.1
380	2.78	35.6	11.6
400	3.15	35.5	15.5
420	0.73	37.6	0.1
440	3.50	35.2	15.6
460	3.37	35.2	15.4
480	1.20	37.4	0.4
500	0.74	37.7	0.1
520	0.74	37.8	0.1
540	1.57	37.0	3.2
560	0.74	37.6	0.1
580	0.74	37.0	1.3
600	2.70	36.5	9.3
620	0.74	37.5	0.1
640	3.39	35.0	15.5
660	0.83	36.9	0.5
680	0.80	37.1	0.3
700	3.18	34.9	15.4
720	0.74	37.2	0.1
740	0.74	37.4	0.1
760	0.73	37.4	0.1
780	2.22	37.2	0.4
800	0.74	37.4	0.1
820	3.31	34.8	13.6
Time (seconds)	Torque sensor output (V)	Battery voltage (V)	Battery current (A)
840	0.74	37.5	0.1
860	0.73	37.5	0.1
880	3.30	35.2	15.8
900	3.33	34.8	15.5
920	2.45	37.1	0.9
940	2.65	35.7	5.2
960	0.74	37.4	0.1
980	0.81	37.3	0.1
1000	2.20	35.4	14.3
1020	0.74	37.2	0.1
1040	3.31	35.1	15.5
1060	0.83	37.0	1.3
1080	0.73	37.2	0.1
1100	0.73	37.3	0.1
1120	3.37	34.8	15.4
1140	3.32	34.7	15.1
1160	0.74	37.2	0.1
1180	0.90	36.4	1.6
1200	3.18	34.7	15.4
1220	1.55	37.1	0.6
1240	2.70	35.7	13.5
1260	0.74	37.1	0.1
1280	0.82	37.0	0.5
1300	2.78	35.3	10.5
1320	0.74	37.2	0.1
1340	0.73	37.3	0.1
1360	0.74	37.4	0.1
1380	3.50	34.7	15.7
1400	0.81	36.8	0.4
1420	0.73	37.0	0.1
1440	3.08	34.7	15.5
1460	0.73	37.1	0.1
1480	0.73	37.2	0.1
1500	2.09	34.5	15.2
1520	3.35	34.7	15.3
1540	3.55	34.7	15.4
1560	3.60	34.4	15.3
1580	2.80	37.2	10.2
1600	0.73	37.1	0.1

Appendix E

Questionnaire for CRP Engineers

The purpose of this study is to obtain the technical point of view of the rehabilitation engineers/ technicians about the assessment on the performance of the "*Electrically Assisted wheelchair for Physically Disabled People with Torque Sensor & Dedicated Solar Charger Kit",* while using it by the people with disabilities. The research team of CARC (Control & Application Research Centre) of BRAC University is conducting the survey to understand the technical feasibility of the developed electric wheelchair.

The survey is designed to explore all the possible technical areas involved to manufacture the wheelchair. Please give your technical feedbacks by answering the following survey questions.

1. The torque sensor pedal technology used on the electric wheelchair is user-friendly.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Disagree
   - ☐ Strongly Disagree

   Please comment:

2. The speed of the electric wheelchair can be controlled and sufficient for outdoor mobility.
   - ☐ Strongly Agree
   - ☐ Agree
   - ☐ Disagree
   - ☐ Strongly Disagree

3. To what extent, are you satisfied with the performance of the Dedicated Solar Charger Kit provided to charge the batteries?
   - ☐ Very much satisfied
   - ☐ Somewhat satisfied
   - ☐ Not satisfied at all

4. How long does it take to fully charge the batteries (from 50% State of Charge to 100%) using the provided photovoltaic panel only when the sun irradiation is at its peak value?
   - ☐ Less than 30 minutes
   - ☐ 31-60 minutes
   - ☐ 1-3 hours
   - ☐ More than 3 hours

Please specify:

5. How much total distance the wheelchair can cover till the battery charge drops upto 50% state of charge (SOC)?

Please specify:

6. How long does the electric wheelchair take to discharge the batteries upto 50% SOC by continuously driving the electric wheelchair?

Please specify:

7. To what extent, do you think the charging process of the electric batteries by using the renewable energy technology is environmentally sustainable?
   - ☐ Very sustainable
   - ☐ Somewhat sustainable
   - ☐ Not sustainable at all

8. The current battery swapping technique for the electric wheelchair is convenient and less complex for the technicians
   - ☐ Agree
   - ☐ Disagree

Please comment:

9. How often do you need to continue any maintenance works on the electric wheelchair?

Please specify:

10. The electric wheelchair has got an efficient braking system
    - ☐ Strongly Agree
    - ☐ Agree
    - ☐ Disagree
    - ☐ Strongly Disagree

11. Does the type of the wheels are able to drive the electric wheelchair at any types of surfaces (rough surface, plain surface etc)?

- ☐ Yes
- ☐ No

12. The space for the wheelchair is sufficient to ensure the disabled people can maneuver the wheelchair with comfort and convenience.

- ☐ Strongly Agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly Disagree

13. The current design of the electric wheelchair is user-friendly.

- ☐ Strongly Agree
- ☐ Agree
- ☐ Disagree
- ☐ Strongly Disagree

14. To what extent does the current design of the wheelchair meet the needs of the disabled people.

- ☐ Very much
- ☐ A little
- ☐ Not at all

15. Have you liked the current feature(s) of the electric wheelchair?

- ☐ Yes
- ☐ No

Please mention some features:

16. Do you think some more features may be needed to ensure safety of the patients and convenience of the patients in terms of their mobility?

- ☐ Yes
- ☐ No

If yes, please mention feature(s) and how feature(s) may be included

on the electric wheelchair?

17. Overall, are you satisfied with the current design of the electric wheelchair?

- ☐ Yes
- ☐ No

18. If the answer is No, please suggest some modifications and improvements on the design of that might be required.

19. Overall, to what extent are you satisfied on the performance of the electric wheelchair?

- ☐ Very satisfied
- ☐ Somewhat satisfied
- ☐ A little satisfied
- ☐ Not satisfied at all