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Eco-friendly Hybrid Tricycle for Handicapped

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Abstract - *In today's world, transportation has become one of the prime requirements of people for moving self or goods from one place to another. Mobility has thus become an essential part of our lives with many development and improvements happening in this field. It becomes more difficult for physically challenged people to commute and to perform their day to day activities like working, education, shopping etc. as they have to constantly depend on others for getting assistance to reverse the vehicle, park the vehicle, travel during night, travel during rains, etc. They may not be able to afford the daily fuel expenses. Through this project we introduce a feasible and flawless design solution - Hybrid Electric Tricycle, an environment friendly tricycle for the physically handicapped. This tricycle has multiple sources of inputs – a. c. power, solar power & regenerative braking. Mechanical hand pedaling is also provided as a backup. Apart from conventional hand pedaled tricycles and three-wheeler scooters, the option for Reverse driving is provided as assistance for handicapped. An electronic lock is also provided for protection from theft. It also provides features like headlight, horn & protection from rain. The tricycle would be a perfect companion for the future as it serves as a powerful solution for existing problems of pollution, exhausting petroleum fuels, etc. With its electric drive, reverse option and provision to carry light loads, all at a lower cost than a conventional scooter with assisting wheels, it makes a handicapped person self-sufficient. A full scale prototype of the same was also developed.*

Key Words: **tricycle, reverse, handicapped, controller**

1. INTRODUCTION

For easy mobility, which is a vital part of social life of a human being, vehicles have been developed but mostly all for normal people. Developments of devices that address the unique needs of people are fundamental to their quality of life. Vehicles for handicapped are either conventional hand operated or custom made. Present vehicles for handicapped fail to consider the factors like weight, cost, simplicity, emission and operational cost. If we have a look on the conventional tricycles, first, the current users of the hand-powered tricycles do not have the physical strength or coordination to propel themselves on the tricycle with their arms and hands. Next, motorize tricycle that used fuel as it prime mover. The tricycle use fuel that is costly. Besides that, motorized tricycle with fuel engine will make pollution that can adversely affect our environment especially in this period of global warming and ozone layer depletion.

Through this project we aim at mitigating the above issues by designing and fabricating a Hybrid Electric Tricycle which is driven by an electric motor. Tricycles are relatively new in the field of Hybrid Electric Vehicles. This project will develop a better tricycle. Here the hybrid sources are electric energy stored from common power supply and the other is solar energy. The relevance of solar is very important as India is located in the topic of Capricorn area where we are abundantly provided with sunlight but only a very few amount of it is being used wisely. Compared to other available tricycle the cost of operation and maintenance is very less. Also this tricycle can be available for users at affordable price. Reverse driving option, a feature that is which may not be relevant for light weight vehicles like two-wheelers and three wheelers, but is a cause of concern for physically challenged drivers. All the light weight vehicles are to be reversed manually. This may not be possible for physically challenged and for that they would have to obtain help from another person. Such a difficulty is avoided in this tricycle as motorized reverse feature is being introduced in this vehicle. The goal of the project is to make a handicapped person self-sustained for traveling from one place to another, relatively a longer distance than a vehicle for physically challenged person and also by taking into consideration environment friendly methods.


Fig -1: Conventional vehicles for handicapped

2. DESIGN

2.1 Mechanical Design

Mechanical design, the total weight was estimated to be 150kg. Running parameters, various forces acting on the tricycle were calculated based on [1], [2] and [3]. Drivetrain was determined to be chain & sprocket mechanism and gear ratio was fixed. The maximum braking torque was determined. A 3D model was designed using Blender software. Centre of gravity was determined by considering design aspects and stability of the tricycle was analyzed on slopes as well as horizontal positions.

2.2 Electrical Design

For the electrical aspects, we designed and corrected on the basis of various references and recommendations from engineers at Tesla Electric Cycle Manufacturing and Research, Maker Village, Kerala Startup Mission – Kochi. BLDC Motor was chosen as the power plant because of the following reasons: - high power to weight ratio, high speed, easily implementable electronic control, low maintenance and higher efficiency. The power rating requirement based on [4], [5] &, [6] was found out from the running parameters and load requirement, to be 850 W and bus voltage, 48V. Lithium ion battery was chosen as the energy storage unit because of its light weight compared to lead acid batteries. Also the lithium ion batteries have an inbuilt battery management unit that helps to provide constant voltage and constant current from charging. Battery management unit is provided for the protection of the battery. Solar energy was used in the tricycle to assist the battery charging. Thus a monocrystalline solar panel of 100W was chosen, due to space constraints.

2.3 Electronic Design

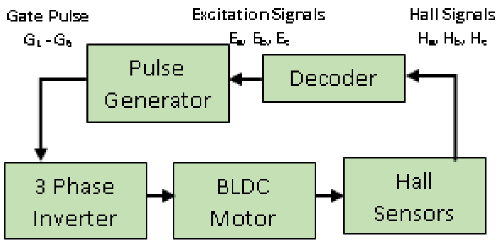

Fig -2: Prototype 3D Model

The main design part is the electronic design, which includes solar charger design, ac charger, motor controller, driver & inverter circuit. For the controller part, we used TMS320F28025 DSP from Texas Instruments. First we decoded the hall signal sensor signals into gate pulse using K-Map and then modelled the control logic in Simulink. Each controller part was tested and implemented into the DSP, directly from Simulink using ControlSuite & Code Composer Studio. So, DSP programming knowledge was not necessary.

In this project, the circuit designed to charge the battery from ac supply uses a fly back converter [7]. It is used as it is having a lot of advantages compared to other converters. The primary is isolated from the output. The advantages are that it is capable of supplying multiple output voltages, all isolated from the primary. It has the ability to regulate the multiple output voltages with a single control. It can operate on a wide range of input voltages. The Fly back [7] converters use very few components compared to the other types of SMPSs. The fly back converter is a power supply topology that uses mutually coupled inductor, to store energy when current passes through and releasing the energy when the power is removed. The fly back converters have architecture and performance similar to the booster converters. The primary winding of the transformer replaces inductor while the secondary provides the output. When the current flowing through an inductor is cut off, the energy stored in the magnetic field is released by a sudden reversal of the terminal voltage. If a diode is in place to conduct the stored energy somewhere useful, the diode is called a fly back diode. This only requires one winding on the inductor, so the inductor would be called a fly back transformer. This arrangement has the property of transferring energy to the secondary side of the power supply only when the primary switch is off.

2.4 3D Model

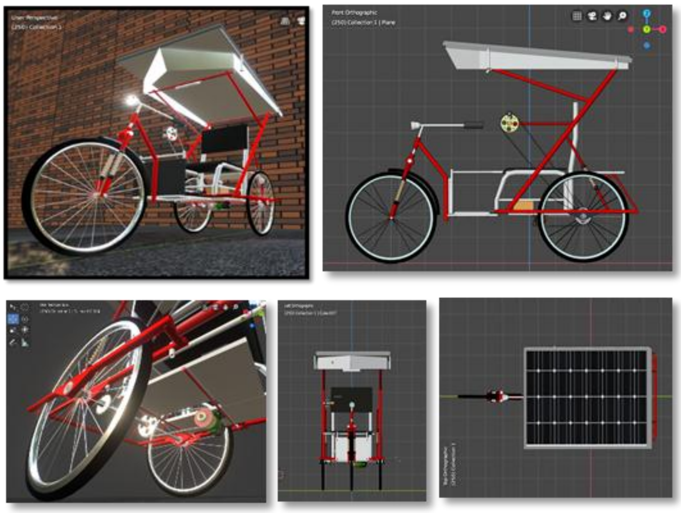

Fig -3: Prototype 3D Model

3. SIMULATION STUDY

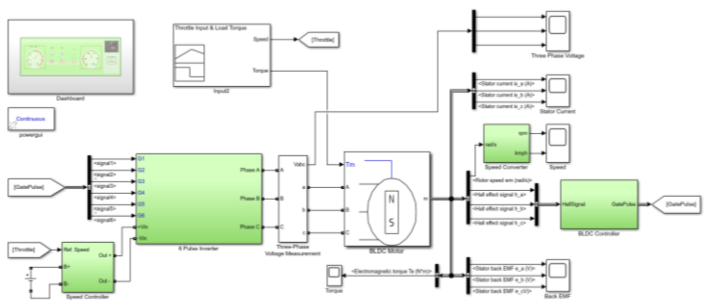

Fig -4: Simulation Schematic

The main simulation study was done with the above Simulink diagram. The BLDC controller [8], [9] has the decoder logic to develop the gate pulse required for the inverter. Separate logic is used for forward & reverse rotation, which can be mechanically selected by a switch. The speed controller implements a voltage control strategy by varying the input

DC voltage to the inverter based on the throttle input signal.

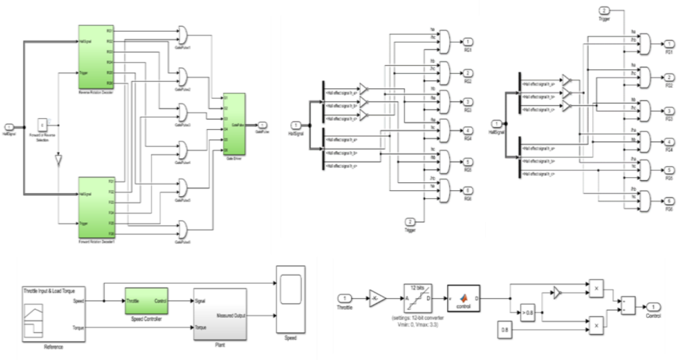

Fig -5: Simulation Block Expansions

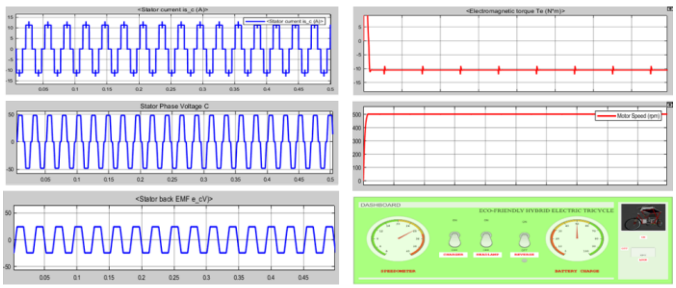

Fig -6: Simulation Results – Motor Controller

Simulation results for Fig.3 is shown above. Complete design & results are not included here. Fig.5 shows stator current, stator voltage & back emf for one phase out of 3, rated torque and rated speed, when rated voltage was applied. Speed control was also simulated to analyse proper response to throttle.

The AC Charger circuit employs a Fly Back Converter Type AC to DC Regulated Power Supply Design which converts the 230 V 50 Hz alternating supply to a constant 52 V DC output needed for battery charging. Protection devices including overcurrent and overvoltage protection are to be implemented, as the power supply is not completely reliable. We used a 48V 20Ah Lithium Ferrous Phosphate Battery for powering the vehicle.

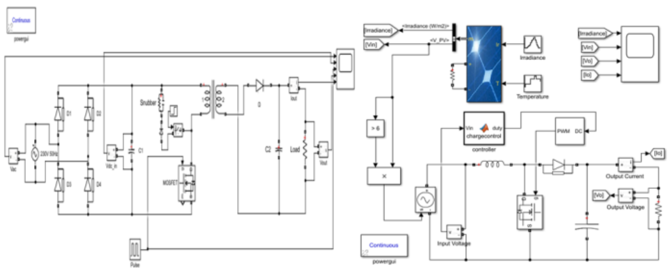

Fig -7: Simulation Schematic – AC & Solar Charger

The solar charger circuit was designed to convert the voltage developed across the 100W solar panel used in the tricycle into the required battery charging voltage. As the battery requires a constant voltage constant current input for getting recharged, the dynamic output voltage varying from 0V during night to 22V (maximum open circuit voltage possible) during daylight need not only step up, but kept constant at an optimum level. The output current was kept at 2A, so that battery can be fully charged in 10 hours without external supply. Principle used is same as that of a step-up chopper with an open loop control. Duty cycle was varied based on voltage input from solar panel. The circuits were drawn and PCB designing was done using Proteus and hardware was implemented [13]

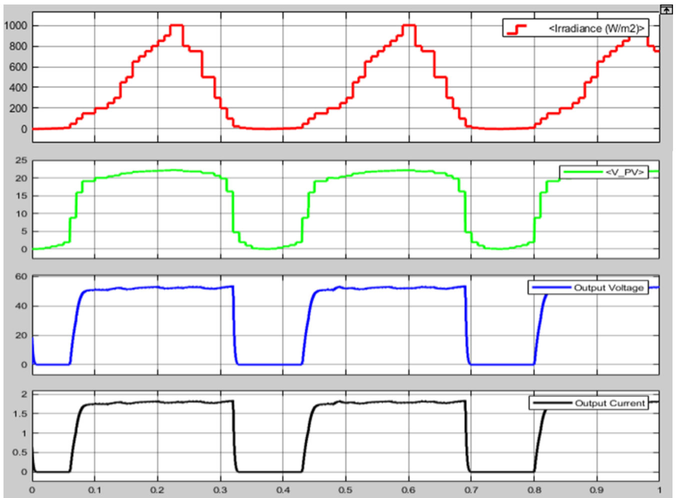

Fig -8: Simulation Results – Solar Charger

4. IMPLEMENTATION

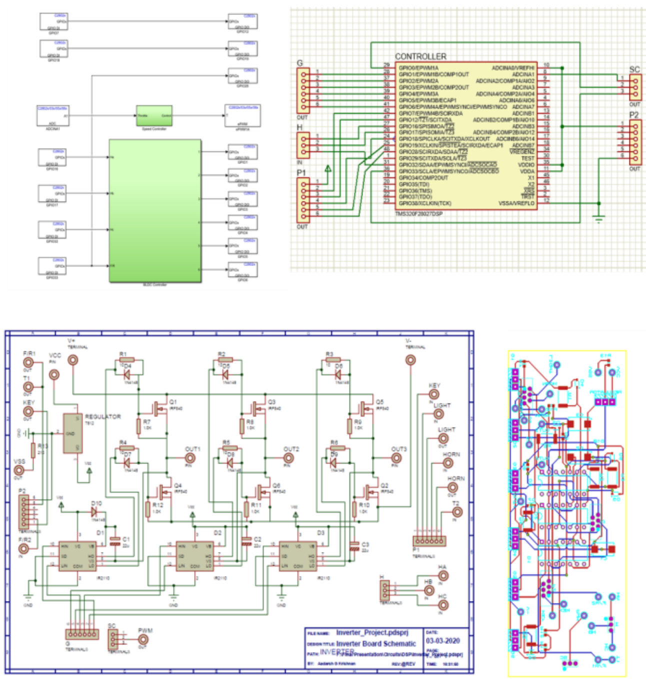

Fig -8: DSP Program & PCB Layouts

The Matlab graphic tool - Simulink should contain the following library/toolbox:
Embedded Coder Support Package for Texas Instruments

(TI), which could be downloaded and installed directly from the Add-on tab in the Matlab window. During installation, the toolbox for only required specific device was installed. This enabled us to generate a real-time executable and download it to the TI development board. Embedded Coder automatically generates C code and inserts the I/O device drivers in the block diagram. These device drivers are inserted in the generated C code.

Fig -9: Implementation Works

5. WORKING

During standstill mode the motor will be in its off position and the battery can be charged from the AC supply or from the solar power. When the sunlight is available the battery can be charged from the solar power. During daytime energy from sun is available in plenty so it can be utilized efficiently for charging tricycle. In the primary circuit of the developed model the solar charging circuit is connected along with the driver circuit so that the solar battery charging can also be done even when the vehicle is in motion. AC charging can be adopted when the sunlight is not available. The secondary circuit of the tricycle consists of the ac charging circuit. The user can choose the mode of charging according to their preference. By default, solar charging is selected, which can be shifted to AC charging by using the mechanical switch. The battery has an inbuilt battery management system to cutoff charging when the battery is full.

During full acceleration or constant speed mode the brushless DC motor will be in its motoring mode. Solar charging is also available during this time. The energy stored in the battery is used by the motor to produce mechanical energy to drive the wheels. During this mode the brushless DC motor is having positive speed and positive torque that is the torque is propelling the tricycle in forward (motor-clockwise) direction. Also the supplied voltage is greater than the back emf. The primary circuit of the developed model consists of the solar charging circuit along with the motor driver circuit. Thus during constant speed or full acceleration mode that is when a person is riding the tricycle, the solar energy can be utilized to charge the battery.

During the constant speed mode, the controller provides pulses of current to the motor windings which control the speed and torque of the motor. The BLDC motor works on the principle of internal shaft position feedback and it is achieved using multiple feedback sensors. In BLDC motor hall-effect sensor is being used. When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Rotor is a permanent magnet. Though the source of supply is DC switching makes to generate an AC voltage waveform with trapezoidal shape. Due to force of interaction between the electromagnet stator and permanent magnet rotor, the rotor continues to rotate. Whenever rotor magnetic poles pass near the hall sensor, they generate high or low level signal which can be used to determine the position of shaft. Based on the signal from the sensor the controller decides particular coils to energize. This energizing of the windings is done with the help of electronic switching using an inverter circuit. For example, in case a BLDC motor has three pairs of stator windings, a pair of switches must be turned on sequentially in the correct order to energize a pair of windings. The sequence of switching of the inverter circuit is developed by analyzing each and every position of the Hall Effect sensors.

During reverse mode of operation, the BLDC motor will be in its motoring mode but it rotates in the anticlockwise direction. Here the motor has reverse speed and reverse torque with reference to the forward motion. Solar energy can be utilized to charge the battery during this mode of operation.

The BLDC motor is initially made to rotate in the clockwise direction, but when the speed reversal command is obtained, the control goes into clockwise regeneration mode, which brings the rotor to standstill position. Instead of waiting for the absolute standstill position, continuous energization of the main phase is attempted. This rapidly slows down the rotor to a standstill position. Therefore, there is the necessity for determining the instant when the rotor of the machine is ideally positioned for reversal. Hall effect sensors are used to ascertain the rotor position and from the hall sensor outputs, it is determined that the machine has reversed its direction. This is the ideal moment for energizing the stator phase so that the machine can start motoring in the counter clockwise direction.

BLDC motor requires a DC voltage source to be applied to its stator windings in a sequence so as to sustain rotation. It is done by electronic switching using an inverter circuit. The circuit employs a half n- bridge for each stator winding. Controller is used to read the rotor position information from the Hall Effect sensor so as to sense the reversal of rotation during the reverse operation.

As a whole we can generalize the working of the proposed tricycle as follows: In the proposed tricycle BLDC motor is used to drive the wheels. The rotation of the motor is controlled by a BLDC driver circuit that is by an inverter circuit. The switching pulses for the inverter circuit are given with the help of a DSP controller. DSP controller provides the necessary speed control and rotation. The hall sensor signals from the motor are given as input to controller which the controller processes to give the six gate pulses for the inverter. Also throttle input is given to an ADC pin of the controller, which processes the same to generate the PWM pulses for the speed control action. Lithium ion batteries are used as storage units to provide necessary power to drive the motor. These lithium batteries can be charged by using AC supply or from solar power. AC charging is used when there is no sunlight available. Solar energy can charge lithium ion batteries even when the tricycle is moving. The mode of charging can be selected by the physically challenged person by means of a mechanical switch which is being provided. The direction of motion (forward/ reverse) can be selected by the user by means of a switch. The controller is programmed to move in forward or reverse direction according to the choice of the user. This advantage eliminates the need of depending on second person for reversing the tricycle by a physically challenged person. Mechanical braking systems are employed in the proposed tricycle to halt the tricycle when and where needed.

6. OUTCOMES

The tricycle was successfully developed based on our design and was tested completely for its performance, efficiency & braking mechanisms. It was tested under warm weather condition to ensure the safety of the user and stable operation of the tricycle. The testing was carried out in normal roads with normal traffic to ensure smooth working. It was also tested in heavy traffic area so as to ensure the proper working of the brakes. Test conditions:

Road condition	Flat roads with small slopes
Weather condition	Warm weather
Weight of test person seated	72 kg
Distance covered in one full run	10 km
Maximum speed obtained	25 km/h
Brakes	Properly working
Seating	Comfortable throughout
Hand pedaling	Not possible

Table -1: Test Details

The shaft speed was limited to 25 km/h by clamping the speed controller PWM signal duty ratio to the interval 0 to 0.8 inside the controller itself and hence applying voltage less than the rated value. This was done because there exists a legal limitation to limit the maximum cruising speed of vehicles for the physically challenged to 25 km/h. The selected motor had a rated speed of 500 rpm but was limited to 400 rpm for the above reason. Images of first test run is shown below.

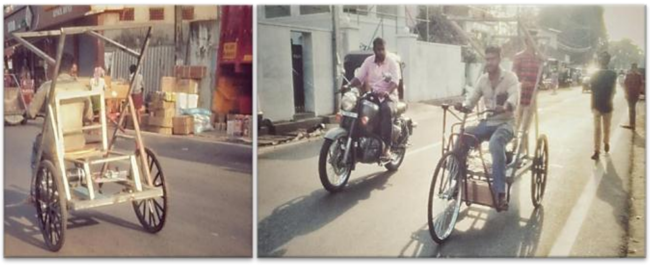

Fig -10: Test Drive

There were some problems with our first run and we had to troubleshoot each problem and final run was almost successful. A clutch mechanism was needed for proper shifting between hand pedaling and motor drive, which we will include in our future development. Without it, both hand pedal and motor will be engaged with the shaft and will rotate together, which was a wastage of energy. We found that we cannot apply regenerative braking in this tricycle. This is because of many reasons. Regenerative braking [10], [11], [12] is not by itself sufficient as the sole means of safely bringing a vehicle to a standstill, or slowing it as required, so it must be used in conjunction with another braking system such as friction-based braking. The regenerative braking effect drops off at lower speeds, and cannot bring a vehicle to a complete halt reasonably quickly with current technology. Current regenerative brakes do not immobilize a stationary vehicle; physical locking is required, for example to prevent vehicles from rolling down hills. The regenerative braking effect available is limited, and mechanical braking is still necessary for substantial speed reductions, to bring a vehicle to a stop, or to hold a vehicle at a standstill. Moreover, regenerative braking only works on driven wheels. If an electric vehicle isn't all wheel drive, with a motor for each wheel, then the wheels that lack rotors aren't able to benefit from regenerative braking. Regenerative brakes typically don't provide enough braking force under panic stop conditions. That's one area where traditional brakes still work much better. The efficiency of a regenerative system is limited by factors like the capacity of the energy storage system and the output of the electric motor. Also regenerative braking implementing is costly. Some regenerative systems are forced to use supplemental "dynamic braking" that doesn't store the reclaimed kinetic energy.

For achieving the reverse motion, the sprocket had to be welded from rotating freely in one direction. There was a problem while using single handle because it was difficult to control both direction and brakes simultaneously, so we replaced it by normal handle. Brakes were placed on both handles, so that any of them can toggle the front brake.

Rear brakes are not possible because of the shaft connection between the wheels. Some cost reduction methods are:

Mass production.
Use of lead acid battery instead of lithium ion battery.
Use of polycrystalline solar panels instead of monocrystalline panels.
Use of DC Motors instead of BLDC.
Acquiring Government subsidies and incentives.
Weight reduction using Aluminum frame & subsequent less power rating requirements.

However, initial cost reduction will compromise the efficiency and distance covered by the tricycle. Lead Acid batteries are way cheaper than Lithium batteries of same size. But the former has high specific power, i.e., supports a high power load for a short time period, consequently reducing the total distance covered in one charge. It can be used for short run vehicles. The latter has high energy density, i.e., supports a low power load for a long period and can be used for long run vehicles.

The solar charger circuit was designed, but was not able to be implemented due to limitations posed by COVID 19 lockdown. All other electronic hardware including the controller and AC charger was implemented. A speedometer was also designed to measure the real time speed of the Arduino.

3. CONCLUSIONS

This project demonstrates the use of an efficient and lower cost controller based on DSP programming to control the speed of BLDC motor. The advantages of digital hardware are very high speed and easily adjusted to comply with software. The use of DSP in digital control can be easily adapted to analog control. The effectiveness of PWM technique for speed control in both forward and reverse directions for a BLDC motor and its practical application in an EV has been demonstrated using a prototype. Using DSP platform drives are easily controlled, least time consuming, real time control action, parallel processing and transient response is fast compared to microcontroller based approach. The speed control of BLDC Motor was simulated on Matlab, the results were validated and was implemented on hardware, using a TMS320F28027 DSP controller. The speed of the motor was controlled based on the input signals from the throttle. Implemented a control strategy for forward and reverse driving of the motor using a throttle. Designed from the basic parameters and requirements, a prototype of the proposed hybrid electric tricycle was developed and tested successfully.

Embedded Hardware Components used:
C2000 Piccolo Launchpad with TMS320F28027 DSP Microcontroller [14], [15]
Arduino Uno R3 Development Board with ATMega328 Microcontroller
High Power PWM Mosfet Drive Regulator
LM7812 Voltage Regulator
IR2110 Mosfet Driver [16]
IRF540 Power Mosfets [17]

We found that we cannot apply regenerative braking in this tricycle. This is because of many reasons.

Regenerative braking is not by itself sufficient as the sole means of safely bringing a vehicle to a standstill, or slowing it as required, so it must be used in conjunction with another braking system such as friction-based braking. The regenerative braking effect drops off at lower speeds, and cannot bring a vehicle to a complete halt reasonably quickly with current technology. Current regenerative brakes do not immobilize a stationary vehicle; physical locking is required, for example to prevent vehicles from rolling down hills. The regenerative braking effect available is limited, and mechanical braking is still necessary for substantial speed reductions, to bring a vehicle to a stop, or to hold a vehicle at a standstill.

It can be concluded that a new type of tricycle can be developed for the handicapped, which gives a cost effective solution to their problems of mobility, without compromising utilization of renewable sources of energy and at zero pollutant emission level, by using cutting edge technologies of digital signal processing, solar photovoltaics and lithium ion energy storage.

Scope for Future Work: Electric & Hybrid Vehicles are the future of transportation, so there will be many modifications possible on our basic design. There could be some modifications possible for improving the efficiency, safety and performance.

In order to increase the range of the distance covered by the tricycle, the proposed tricycle can be used with a lithium ion battery of higher ampere hour ratings. Thus by increasing the ampere hour rating of battery, more energy can be stored in the battery as a result distance covered by a single charging increased.

The charging current of the solar charging circuit should be increased thus solar energy utilization becomes more efficient. The proposed model has a charging current of 2A, thus by increasing the charging current to 5A, we can implement fast charging using solar energy.

Optimization of several energy sources into single source to drive all the IC's, controller, Arduino etc. is required in order to reduce the complexity of the electronic circuits used. This also have an advantage of making the tricycle cheaper.

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