Converting Gas-Powered Go-Kart to Electric Power with a Brushed DC Motor

Sponsored by: General Motors

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School of Electrical and Computer Engineering
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Agenda

- Motivation/Objective
- Project Description and Goals
- Group Member Roles
- Design Approach and Technical Specifications
- Codes and Standards
- Marketing and Cost Analysis
- **Demonstration**
- Problems/Issues
- References

Motivation/Objective

- Today's vehicles are getting larger and larger meaning that more needing non-renewable fuel is required to travel the same distance as smaller vehicles.

- This project looks to remedy this by creating a lightweight alternative that anyone could easily adopt.

- The solution is to create a small vehicle that runs solely off electricity for short daily commutes around town.

Project Description

- The team designed an electric powertrain system to replace an existing internal combustion engine on a two-seater go-kart.

- The replacement powertrain consists of:
  - Lithium-ion Battery Module
  - Lithium-ion Battery Management System
  - Lithium-ion Battery Charger
  - Brushed DC Electric Motor
  - Brushed DC Motor Controller

- The motor will also be configured to function as a generator, able to regain energy to the battery when the vehicle needs to slow down.

Group Member Roles

Team Leadership	Christopher Hooper
Expo Coordinator	Christopher Hooper
Documentation Coordinator	Daniel Bruce
Analog Design	Daniel Bruce
Webmaster	Hong Yee Cheah
Real-Time Coding	Hong Yee Cheah
Project Management Expo	Moongyu Kang
Mechanical Design and Assembly	Moongyu Kang

Goals

General

- Able to seat at least two people

Motor

- Able to achieve a cruising speed of 25 miles per hour
- Able to return power to the battery through regenerative braking
- 2-3 horsepower output
- 2-3 kilowatts output

Battery

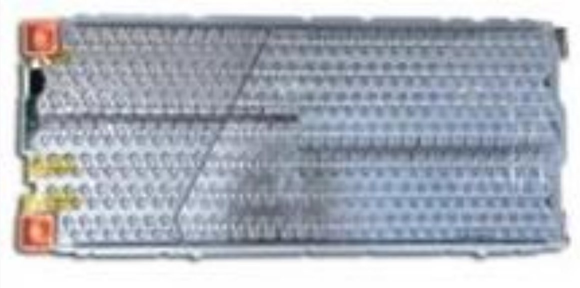
- Output enough power to drive a 24 V, 2 horsepower electric motor
- Enough capacity to drive for at least 1 kilometer
- Able to be safely charged and discharged

Design Approach - Lithium-ion Battery Module

- For the Lithium-ion Battery, a Tesla Model S Battery Module was used as it was available to be loaned from the Georgia Tech Senior Design Lab.

- A Lithium-ion battery was chosen due to their lightweight and large charge capacity, making it essential to keep the range of the Kart to the desired specification.

- The battery was the most important component to decide as the rest of the powertrain depended on it’s specification.



[1]

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Technical Specifications - Tesla Model S Battery

Features	Specification
Capacity	250 Ah, 5.3 kWh
Height	3.1 in
Width	11.9 in
Length	26.2 in
Weight	55 lbs.
Bolt Size	M8
Nominal Voltage	3.8V/Cell, 22.8V/Module
Charge Voltage Cut-Off	4.2V/Cell, 25.2V/Module
Discharging Voltage Cut-Off	3.3V/Cell, 19.8V/Module
Lithium-Ion Cell Arrangement	74p6s
Maximum Discharging Current (10 sec.)	750 A

[1]

Design Approach - Lithium-ion Battery Management System

- The Orion BMS 2 was used for this project as it was already attached to the loaned Tesla Model S Battery Module.

- The previous group that used the battery module wired the BMS to code and we were required to keep it ‘as-is’ to use the battery in this project.

[2]

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Technical Specifications - Orion BMS 2

Features	Specification
Input Supply Voltage	30 V_{DC} Max
Supply Current - Active (at 25ºC)	<2 Watts
Supply Current - Sleep (at 25ºC)	450 µA
Operating Temperature	-40 - 80 ºC
Cell Voltage Measurement Range	0.5 - 5 V
Cell Voltage Measurement Error	0.25 %

[3]

Design Approach - Lithium-ion Battery Charger

- This project required a safe way to recharge the Lithium-ion battery in a reasonable amount of time.

- Thusly, a Challenger Accessories EMC-180 was chosen due to the cost and power output.

- The charger is a 24V 5AH Lithium-ion Charger, being able to charge the Tesla battery from flat to full in 50 hours, but ideally the battery will never be fully discharged.

[4]

Technical Specifications - Challenger Accessories EMC-180

Features	Specification
Input Voltage	110 V_{AC}
Output Voltage	29.4 V +/- 0.2 V_{dct}
Constant Charging Current	5 A +/- 0.5 A
Shut-off Point Current	0.25 A
Charging Method	3-Stage
Weight	0.9 kg
Working Temperature	<40°C

[4], [5]

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Design Approach - Brushed DC Motor

- For the Brushed DC Motor, a Jinle ZD2973A was chosen due to its low-cost and high output power.
- A 24 V DC Motor was necessary as it matched the nominal voltage of the Tesla Model S Battery Module, so no DC/DC converters were required.
- A DC motor was essential for this project as an AC motor would have required an additional DC/AC Inverter that would have added to cost, complexity and weight.

[6]

Technical Specifications - Jinle ZD2973A

Features	Specifications
Size (Height*Width*Length)	35*15*15 cm
Weight	17 kg
Type	Brushed DC Motor
Input Voltage	24 V
Output Power	4 kW
Torque	10 N*M
Speed	3100 RPM

[6]

Design Approach - DC Motor Controller

- For the DC Motor Controller, a Roboteq HDC2460S was chosen as it supports 1 motor channel operation, at the voltage and current levels our motor requires.
- The motor controller also has native support for regenerate breaking.
- This controller is also able to be controlled and control other devices with it's built-in microcontroller.

[7]

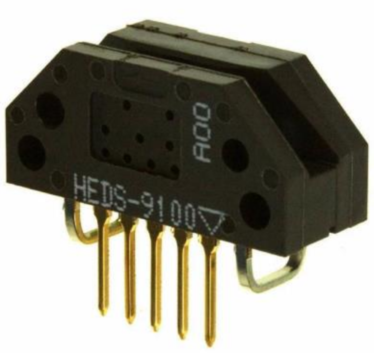
Technical Specifications - Roboteq HDC2460S

Features	Specification
Number of Channels	1
Amps/Channel	300 A Max
Voltage	60 V Max
Analog and Digital Inputs Voltage	30 V Max
RS232 I/O Pins Voltage	15 V Max
Case Temperature	85 ºC Max
Humidity	100% Max
Built-In Microcontroller	32-Bit
Scripting Language	Micro Basic

[7], [8]

Design Approach - DC Motor Encoder

- To know the speed of the DC Motor, we require an optical encoder.
- The group chose an optical rotary encoder due to their low cost and decent accuracy required by the motor controller.
- The encoder chosen was a Broadcom Limited HEDS-9100#A00, and the matching HEDS-5120#A06 rotary wheel.



[9]


[10]

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Technical Specifications - Broadcom Limited HEDS-9100#A00 and HEDS-5120#A06

Features	Specification
Encoder Type	Optical
Pulses per Revolution	500
Supply Voltage	5 V
Codewheel Channels	2 CH
Codewheel Cycles per Revolution	500
Codewheel Shaft Diameter	¼ in

[9], [10], [11], [12]

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Design Approach - Go-Kart Body

- To demonstrate our electric drivetrain we needed a base for the vehicle.
- As this is an electrical based project, a gas-powered Go-Kart was chosen as it provides all required mechanical components. Ex: Wheels, Frame, Steering, Brakes, and Seats.
- Our advisor provided his Go-Kart for this project, a Kenbar Model SK-956.

[13]

Technical Specifications - Kenbar Model SK-956

Features	Specification
Size (Length*Width*Height)	81*51.5*61 in
Curb Weight (with original gas-powered engine)	402 lbs.
Ground Clearance	4.5 in
Front Tires	16 in diameter
Rear Tires (Driving)	18 in diameter
Seat Belt	3 Point Seat Belt

[13]

Codes and Standards - State

- According to the Georgia Department of Public Safety, all Low Speed Vehicles must conform to the following standards [14]:
    - A four-wheel electric vehicle
    - Top speed obtainable in one mile is greater than 20 MPH, but no greater than 25 MPH
    - Manufactured in compliance of Federal Motor Vehicle Safety Standards for Low-Speed Vehicles

Code and Standards - Federal

- According to the Federal Motor Vehicle Safety Standards for Low-Speed Vehicles, Low-Speed Vehicles must include [15]:
  - Headlamps
  - Front and rear turn signal lamps
  - Taillamps
  - Stop lamps
  - Reflex reflectors: one red on each side as far to the rear as practicable, and one red on the rear
  - An exterior mirror mounted on the driver's side of the vehicle and either an exterior mirror mounted on the passenger's side of the vehicle or an interior mirror
  - A parking brake

Code and Standards - Federal Cont.

- According to the Federal Motor Vehicle Safety Standards for Low-Speed Vehicles, Low-Speed Vehicles must include [15]:
  - A windshield that conforms to the Federal motor vehicle safety standard on glazing materials
  - A Vehicle Identification Number
  - A Type 1 or Type 2 seat belt assembly conforming to standards
  - Low-speed vehicles shall comply with the rear visibility requirements
  - An alert sound

Marketing and Cost Analysis

- Target market: individuals traveling short distances (with minimal cargo) and favor renewable energy
- The total cost for the parts is $4,293. (cost breakdown in next few slides)
- Estimations were made for the cables, and packaging

Marketing and Cost Analysis: Prototype

Part	Cost ($)
Kenbar Model SK-956 Go-Kart [13]	1,529
Tesla Model S Battery Module [1]	1,580
Jinle ZD2973A DC Motor [6]	135
Roboteq HDC2460S Motor Controller [7]	595
Challenger Accessories EMC-180 Li-ion Charger [4]	58
Cables/Miscellaneous	150
Packaging/Shipping	246
Total Part Cost	4,293

Marketing and Cost Analysis: Development Hours

Labor	Number of Hours
Weekly Meetings	50
Report Preparation	45
Research	5
Software Design	25
Hardware Design	40
Assembly	10
Testing	10
Total	185
Cost at $34/hr	6,290

- Labor costs were determined by using the average hourly pay for an Entry-Level Electrical Engineer of $34/hr. Multiplying the labor cost for four engineers comes out to be $25,160

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Marketing and Cost Analysis: Total Development Cost

Development Component	Cost ($)
Parts	4,293
Labor	25,160
Fringe Benefits, 30% of Labor	7,548
Subtotal	37,001
Overhead, 120% of Material, Labor, & Fringe Benefits	43,105
Total Development Cost	80,106

- This table shows the total development cost of $80,106 for the project assuming 30% fringe benefits of labor and 120% overhead on materials/labor/fringe benefits.

Marketing and Cost Analysis - Cont.

- Assumptions:
  - The production run will run five years, in which 5000 units will be sold
  - The parts cost is estimated at a 10% bulk discount
  - The labor cost is based on a technician getting paid $20/hr to assemble and test the unit.
  - The marketing and advertising for the Solaire Rider will be roughly 10% of the total input cost.
  - The amortized development cost is the total development cost of $80,106 divided by 5,000 units to result in $16.

Marketing and Cost Analysis: Price Per Unit

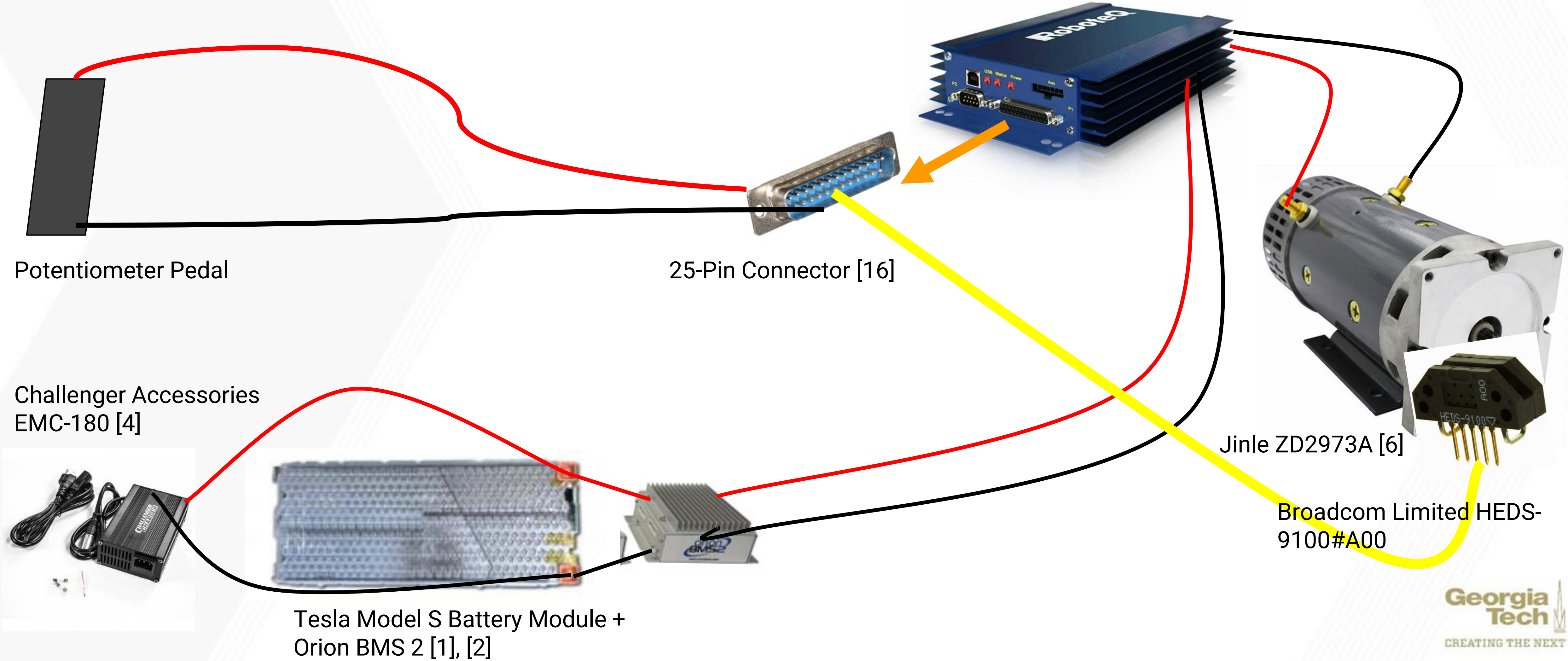
Aspect of Development	Cost ($)
Parts of Cost	3,864
Assembly Labor	40
Testing Labor	20
Total Labor	60
Fringe Benefits, % of Labor	18
Subtotal	3,942
Overhead, % of Material, Labor & Fringe Benefits	4,730
Subtotal, Input Costs	8,672
Sales Expense	867
Amortized Development Costs	16
Subtotal, All Costs	9,555
Profit	2,445
Selling Price	12,000

Converting Gas-Powered Go-Kart to Electric Power with a Brushed DC Motor: Demonstration

Demonstration Agenda

- Circuit Diagrams
- Gear Ratio Result
- Go-Kart Top Speed
- Go-Kart Acceleration
- Motor Controller Programming (Microbasic)
- Go-Kart Travel Range at Full Speed (Electrically)

Top-Level Electrical Overview



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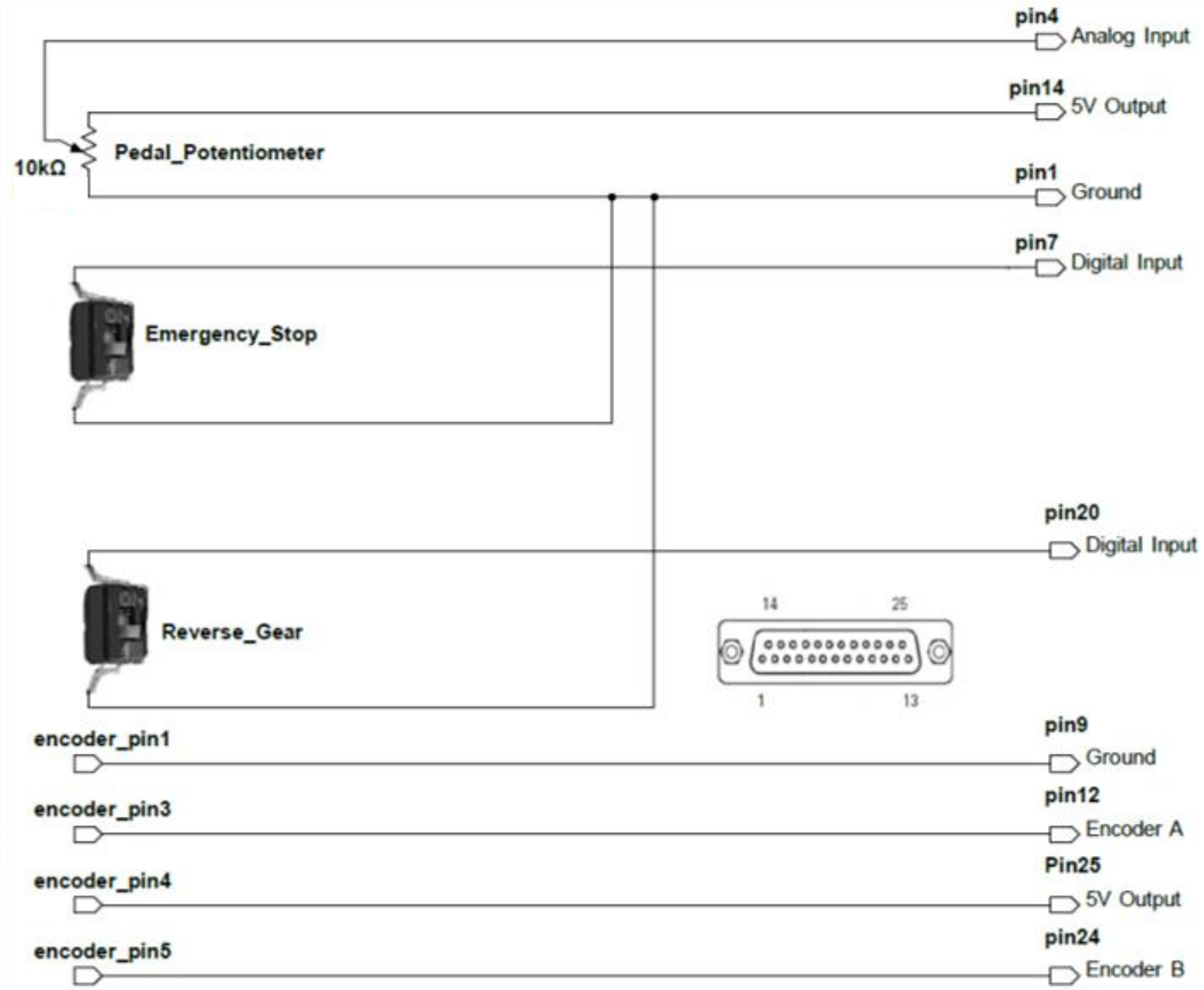
25-Pin Main Connector Schematic



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Circuit Diagram for DC Motor Controller

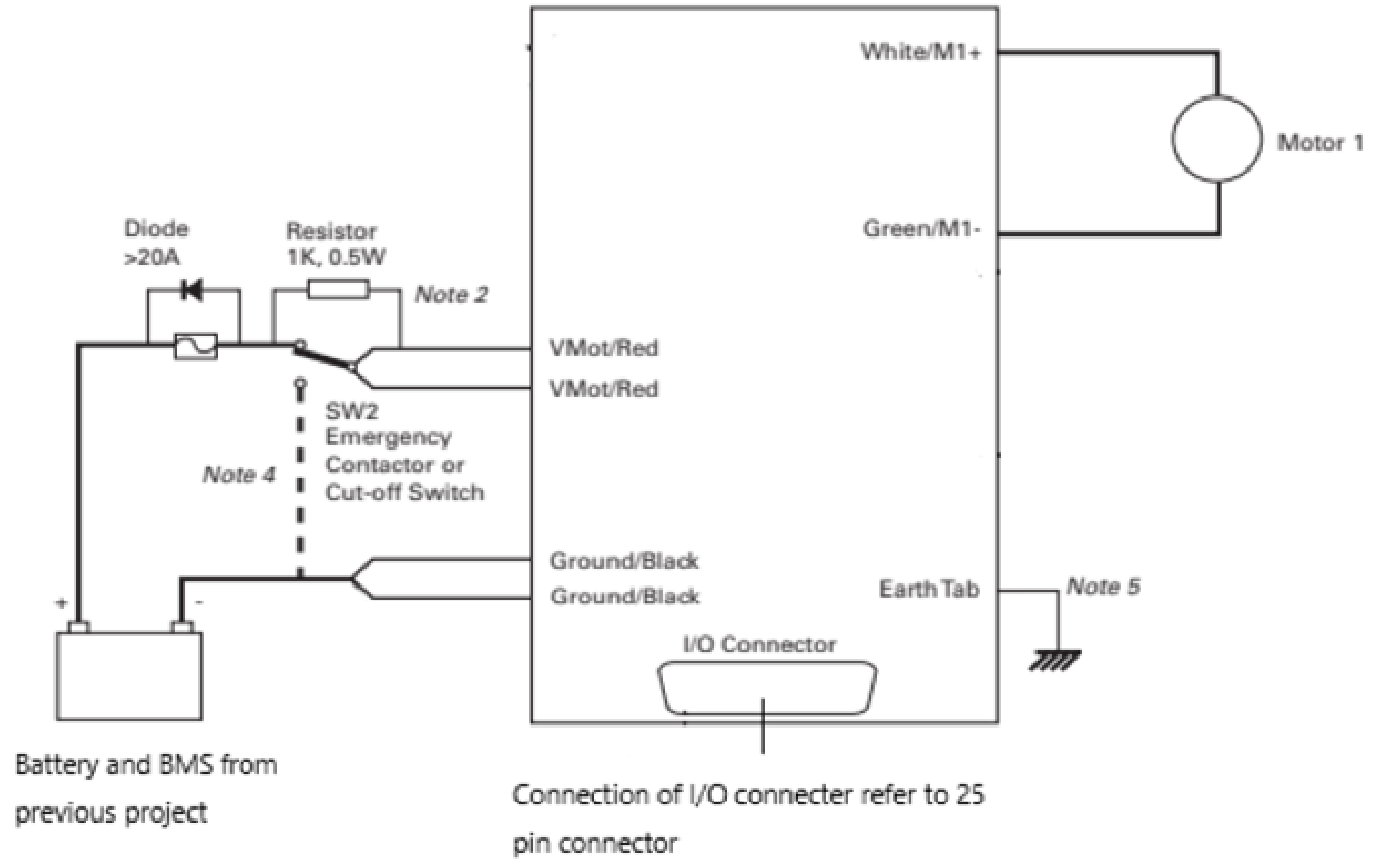

Diagram is an Edited Version of the Diagram from the HDC24xx Datasheet [8]

Gear Ratio

- A Gear Ratio has to be designed to step down the DC Motor’s RPM to provide a reasonable top speed.
- We decided on a top speed of 25 MPH.
- The Kart already features a Gear Ratio of 7.2:1 from the Original Powertrain.
- We need to design an additional gear ratio if 7.2:1 does not align with the desired top speed.

MATLAB Code to Calculate Gear Ratio

RAW CODE	EXPLANATION FOR EACH LINE
`WheelDiameter = 18;`	Wheel Diameter Input in Inches
`TopSpeed = 25;`	The Desired Top Speed of the Kart in MPH
`MotorRPM = 3100;`	The Rated RPM of the DC Motor
`CurrentRatio = 7.2;`	The Gear Ratio Currently on the Kart
`Circumference = WheelDiameter*pi`	Calculating Wheel Circumference
`TopSpeedRPM = TopSpeed*63360/60`	Converting the Top Speed to Inches per Minute
`AxelRPM = TopSpeedRPM/Circumference`	Calculating needed Wheel RPM for Desired MPH
`GearRatio = AxelRPM/MotorRPM`	Calculating needed Gear Ratio for Desired MPH
`GearRatioTo1 = 1/GearRatio`	Putting Gear Ratio in Traditional Format
`NeededRatio = GearTo1/CurrentRatio`	Determining an additional ratio to be added to the Kart's current ratio to get the desired ratio.

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MATLAB Code to Calculate Gear Ratio - Results

- Circumference = 56.5487 in
- TopSpeedRPM = 26,400 in/min
- AxelRPM = 466.8545 RPM
- GearRatio = 0.1506
- GearRatioTo1 = 6.6402:1
- NeededRatio = 0.9222:1

- From the calculation, the needed gear ratio is close to original (7.2).
- Therefore, we decided to keep the original.

Go-Kart Speed

- The rated speed of the motor is 3100 RPM.
- Kart already features a step-down gear ratio of **7.2:1.**
- Therefore, the wheel rotates at ω = 3100/7.2 = **430.556 RPM.**
- The rear wheel diameter of the Kart is, d = 18 in.
- Every rotation, the wheel travels a distance of, x = π*d = 18π in/rev.
- The speed of the kart, s = ω*x = 24347.34 in/min.
- Converting to MPH, s = **23.056 MPH.**

Acceleration

- We set our kart acceleration to **4 MPH/s.**
- The time required to accelerate to 23.056 MPH, t = 23.056/4

  = **5.762s**.
- Thus, the motor acceleration should be, a = 3100/5.762

  = **538 RPM/s.**

How far does the Kart travel during acceleration?

- From previous slide, we know the karts acceleration is 4 mph/s, and it takes 5.762 s to reach our top speed of 23.056 mph

- Using the kinematic equation: $x_f = x_o + v_o t + \frac{1}{2}at^2$

- Assuming initial position and velocity = 0, and converting a = 4 mph/s to a = 1.788 m/s^2 and plugging in t = 5.762 s, you get x = 29.68 m

- Therefore, my final position is 29.68 meters = 0.01844 miles, this conforms to the state requirements for low speed vehicles.

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MicroBasic Code for Motor Controller

```
'microbasic code
'input enable
'initialize variable

dim speed as integer
dim urgent_stop as integer
dim currentspeed as integer
dim reverse as integer
'initialize the initial condition
setcommand(_GIQ,1,1500)'maximum current is 150A output to motor pg 185
setconfig(_EPPR, 1, 500)'set the encoder PPR value
 setcommand(_C, 1, 0)'reset encoder counter

top:
currentspeed= getvalue(_S,1)'report current speed RPM
urgent_stop=getvalue(_DIN, 15)'pin7 for stop emergency stop button
pedal=getvalue(_AI,3)'reading of pedal in MV for pedal analog input connected at pin4
speed=pedal/5; 'convert the pedal mV to a fraction with 1000 as the maximum of 25 mph
reverse=getvalue(_DIN,16)'pin20 for reverse gear

if (reverse = 1) ' if reverse  is command
    speed=-speed;
end if
```

MicroBasic Code for Motor Controller - Cont.

```
if (currentspeed*1000/3100<pedal) 'if current speed is slower than the command speed increase speed
    setcommand(_AC, 1, 5380) 'Acceleration value in 0.1 * RPM/s
elseif (currentspeed*1000/3100>pedal)'if current speed is higher than the command speed decrease speed
    setcommand(_AC, 1, -5380) ' Acceleration value in 0.1 * RPM/s
else
    setcommand(_AC, 1, 0)


if (urgent_stop = 1) ' if urgent_brake  is pressed
    setcommand(_EX,1)'emergency stop
else
    setcommand(_MG, 1)'emergency stop release
end if

goto top 'repeat infinitely every 10ms
```

Range

- The battery has a capacity of, c = 5.3 kWh.
- At rated speed, our motor draws, d = 4 kW.
- If we assume we operate the motor at rated speed continuously, in ideal circumstances, we can run it for, t = c/d = 1.325 hours.
- At a speed of, s = 23.06 mph, we can travel a distance of:
  d = s*t = **30.55 miles = 49.16 km.**

Range - Cont.

- The power draw of other components was omitted because they are negligible in comparison to the motor.

- Note: This calculation is **only** electrical and does not account for physical losses such as friction, drag, weight, etc. Additionally the calculation did not account for saved power due to regenerative braking.

Problems/Issues

- **COVID - 19**
  - The Institution has closed in response to this pandemic. This left the group unable order the parts necessary for the Go-Kart. This resulted in us being unable to take actual data of the prototype to verify desired technical specifications.
- **Budgetary Constraints**
  - We planned to borrow a DC Motor Controller from Georgia Tech but had to purchase a new DC motor controller for $535. We originally had a solar panel aspect of the project that had to be removed because solar charge controller was $200, and would have put us over budget.
- **24 V Li-ion Battery Module Severely Limited Motor Choices**
  - Most heavy-duty, high speed motors require 48V or more input.

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Conclusion

	Desired Goals	End Result
Top Speed (MPH)	25	23.056
Regenerative Braking	Yes	Yes
Motor Output (kW)	2-3	4
Theoretical Range (km)	1	49.16

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