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

Final Project Report

<u>ECE 4012 Senior Design Project</u>

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Executive Summary

The Solaire Rider is a small, light, two-person electric powered vehicle that is able to be recharged through household wall power. The vehicle runs by having an electric motor connected to the driving axle through a step down gear ratio. The team used a high performance DC motor controller to accommodate regenerative braking when coasting or stopping. Lastly, switches were hooked up to the controller in order to control the direction of the motor and have an emergency power cut-off.

The motivation was to develop a more environmentally friendly alternative to gasoline powered vehicles that anyone, from a daily commuter to car enthusiasts, can enjoy driving. Today's vehicles are heavier and require more non-renewable fuel for a person's daily commute. With the world's supply of oil dwindling rapidly, the need for a lighter vehicle powered from an alternative source of energy is needed.

The Solaire Rider prototype was a conversion from a gas powered, two-seater, go-kart into an electric powered vehicle. The team took an existing go-kart, removed its internal combustion engine and gearbox, and replaced it with an electric power-train. The power-train consists of an electric DC motor and controller, Tesla Model S Battery Module, battery management system and battery charger. The expected outcome was to build a fully functioning prototype that can be easily scaled up through the use of a larger motor and additional battery modules, however, due to an unforeseen pandemic and school closure, the team was only able to simulate the prototype and derive theoretical results for range and speed. The team's cost to create the prototype is approximately $950.

1 Introduction

The Solaire Rider project team designed and simulated a small two-seater commuter car, powered by a Tesla Model S Battery Module that could be recharged with regenerative braking and standard household power. The team is requesting $950 of funding to develop a physical prototype of the electric commuter car.

1.1 Objective

The objective of the electric commuter car was to create a small vehicle that runs solely off electricity for short daily commutes around town. The vehicle is small and light, but still able to seat up to two people, with the standard pedal layout of a typical internal combustion vehicle. The car is driven using an electric motor and matching motor controller, which regulates the power output depending on the user’s desired speed. The motor draws energy from a large battery pack that is able to be recharged while driving through the use of regenerative braking. Additionally, the vehicle features a standard 120 V (Volts) wall plug for overnight charging.

1.2 Motivation

The motivation behind this vehicle was to reduce the carbon footprint and use of gasoline in the average person’s daily driving. Today’s vehicles are getting larger and heavier, needing more fuel to travel the same distance as smaller lighter vehicles. There is no reason that one person should be commuting to work, or school, every day in a vehicle that is nearly twenty times their mass. This project remedies this with an alternative that anyone from the average person to a car enthusiast can easily adopt. The alternative is a small, lightweight, full electric vehicle suitable for relatively short daily commutes, hopefully replacing the large gas-guzzling cars on today's roads.

1.3 Background

1.3.1 Battery

An electric vehicle requires a lot of power, and it is highly impractical to tether the vehicle to a household outlet in order to supply the required power. Therefore, a lightweight high-capacity battery with high output power is needed to propel the vehicle. The best and most commercially used battery type for this application is Lithium-ion for their lightweight capacity, and ability to be re-charged when depleted. A single Lithium-ion cell is insufficient to power the vehicle, for example the EM3 LIR18650 Lithium-Ion cell has a nominal capacity of 3,000 mAh and a nominal voltage of 3.78 V [1]. One must connect multiple cells of the same voltage and capacity into a mixture of parallel and series configurations to achieve their desired output. The connected cells are enclosed in a case and referred to as a battery module. The battery is needed to be chosen first and foremost, because all of the components of the powertrain depend on the choice of battery. Luckily, the Tesla Model S battery Module meets all the necessary requirements, and was able to be loaned from the Georgia Tech Senior Design Lab.

1.3.2 Motor

The type of motor used depends on the input current and voltage source waveforms. DC motors are typically 30% more efficient than AC motors [2]. The disadvantage of having a DC motor is that it creates a lot of heat and requires more maintenance due to having to replace the commutator as it wears down due to friction. However, AC motors do not require this level of maintenance as they do not require a commutator. Adversely, AC motors are more complicated to control, due to multivariable coupling, and a time-varying nonlinear system. In turn, DC motors are much simpler to control due to their linear behavior.

2 Project Description, Customer Requirements, and Goals

The team will design and install a new electric powertrain system for an existing internal combustion powered two-seater Go-Kart. The new powertrain will consist of a Lithium-ion battery module, battery management system, battery charger, brushed DC motor and DC motor controller with built-in microcontroller. The motor will be connected to the driving axle with a step-down gear ratio to have a reasonable speed output. The DC motor will also be configured to function as a generator that is able to return energy to the battery when the vehicle needs to slow down. The Lithium-ion battery is a single Tesla Model S Battery Module that was obtained already connected to an Orion Battery Management System II. An external Challenger Accessories EMC-180 Lithium-ion battery charger will be included to recharge the battery. Lastly, the entire powertrain will be controlled by a Roboteq HDC2460 DC Motor Controller through the use of it’s built-in 32-bit microcontroller. This microcontroller will be used to control the direction, speed and acceleration of the motor through the use of inputs such as switches, an optical encoder and a potentiometer pedal. The project goals of this vehicle are as followed:

General

- Able to seat at least two people

Motor

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

Battery

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

3 Technical Specifications

There are seven major components which affect the overall performance of the vehicle. **Table 1** shows the Lithium-ion battery module specification. **Table 2** and **Table 3** specify the battery management system and Lithium-ion battery charger respectively. **Table 4**, **Table 5**, and **Table 6** specify the DC motor, DC motor controller and encoder respectively. Lastly, **Table 7** shows the go-kart specification. A 4 kW, 24 V, 3100 RPM DC motor will be used to reach a cruising speed of roughly 23.056 MPH as discussed later in this report.

Table 1. TESLA MODEL S BATTERY MODULE SPECIFICATIONS [3]

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

Table 2. ORION BMS II SPECIFICATIONS [4]

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 %

Table 3. EMC-180 LITHIUM-ION BATTERY CHARGER SPECIFICATIONS [5], [6]

Features	Specification
Input Voltage	110 V_{AC}
Output Voltage	29.4 V +/- 0.2 V_{dct}
Charing Output	5 Ah
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	<40ºC

Table 4. Jinle ZD2973A DC MOTOR SPECIFICATIONS [7]

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

Table 5. ROBOTEQ HDC2460S DC MOTOR CONTROLLER [8],[9]

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

Table 6. BROADCOM LIMITED DC MOTOR ENCODER [10], [11], [12], [13]

Features	Specification
Encoder Model Number	HEDS-9100#A0
Encoder Type	Optical
Pulses per Revolution	500
Supply Voltage	5 V
Codewheel Model Number	HEDS-5120#A06
Codewheel Channels	2 CH
Codewheel Cycles per Revolution	500
Codewheel Shaft Diameter	¼ in

Table 7. KENBAR MODEL SK-956 GO-KART SPECIFICATIONS [14]

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

4 Design Approach and Details

4.1 Design Concept Ideation, Constraints, Alternatives, and Tradeoffs

The electric drivetrain is composed of three main parts. First, the main fuel source, the battery. The battery needs to have enough capacity to supply the motor with the power required to move the go-kart at least one kilometer. Secondly, the DC motor has to have a large enough output power to move the entire weight of the go-kart and all components at the chosen top speed. The last main component is the DC motor controller which is required for the motor to function. The DC motor controller regulates the average output voltage to the motor through PWM at an extremely high current. A controller like this is necessary due to the high current, which would fry any typical microprocessor. The DC motor controller here also has a built in microcontroller allowing use for additional user input devices such as a potentiometer gas pedal, switches, and encoder. These additional input devices have to be connected to a custom made 25-pin connector to interact with the motor controller. The designed 25-pin connector is shown in **Figure 1**. To understand the interaction between battery, motor and motor controller, a diagram showing powertrain circuit works is shown below in **Figure 2**.

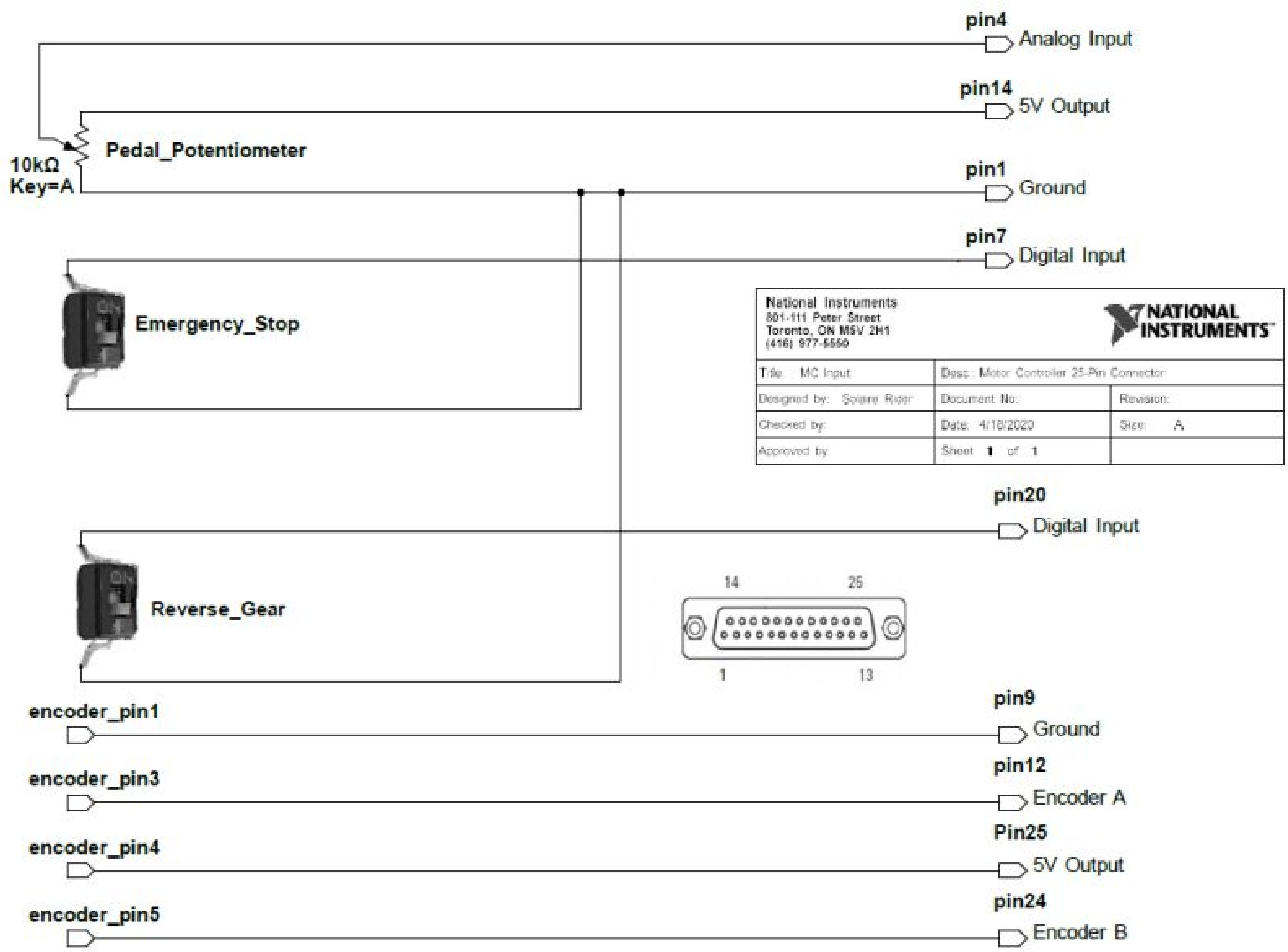

Figure 1. Diagram showing how the 25-pin connector is wired up to attach the additional input devices to the motor controller.

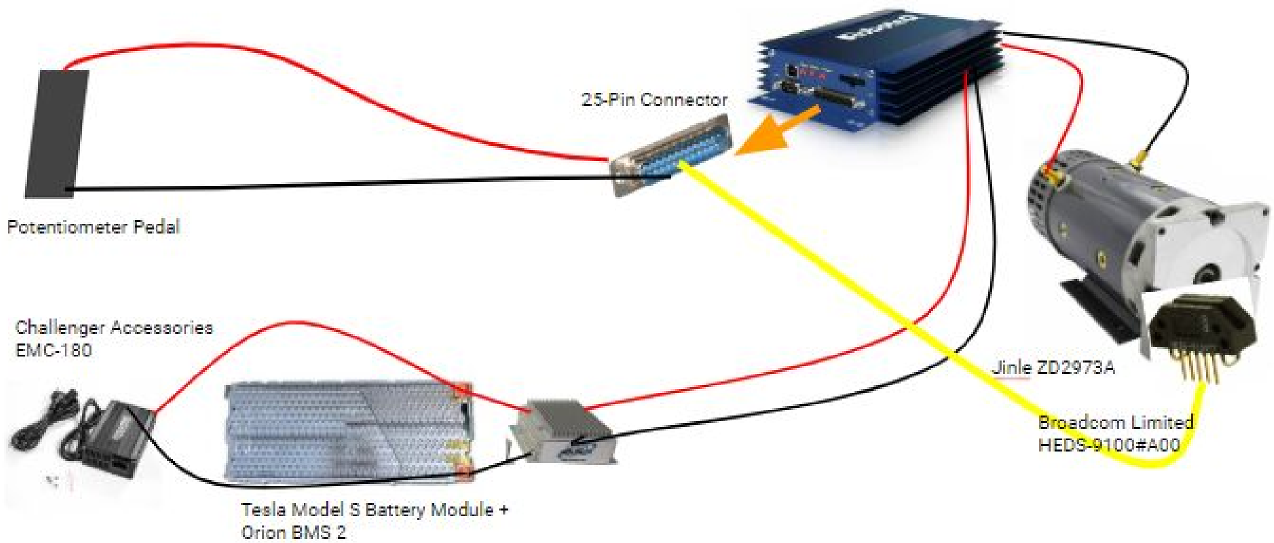

Figure 2. Diagram showing the interconnection between each part [3], [7], [15], [16], [17].

According to **Table 1** and **Table 3**, the battery capacity is specified as 5.3 kWh and the given charger is 5 Ah. When charging the Tesla Battery from flat, the charger should be able to fully recharge the battery in approximately 44.17 hours, according to **Equation 1**. While this is a large amount of time, the battery should ideally never be fully discharged.

$$Charge\ Time(hr) = Battery\ Capacity(Wh)/(Charger\ Voltage\ Output\ (V) * Charging\ Output(Ah))$$

(Eq. 1)

The DC motor is rated to run at 3100 RPM and the Go-Kart features 18-inch diameter rear driving wheels. According to Equations 2 and 3, if there was no gear ratio between the wheels and motor, the kart would travel at around 166 MPH. Not only is this unreasonable, this is not a safe speed for such a small vehicle. A gear ratio is required, and the go-kart already features a 7.2:1 ratio from the original engine. The group used **Equation 3**, substituting Motor Speed for Axel Speed, and solved for the Axel Speed required for the go-kart to move at 25 MPH (466.855 RPM). Next **Equation 4** was used to determine what gear ratio was needed between the motor to the wheel axle. The result was the go-kart would need a gear ratio of 6.64:1, comparing the two ratios resulted in an additional 0.922:1 gear ratio to obtain the desired ratio. As this is a mostly electrical based project and the additional ratio is almost unity, the original gear ratio of 7.2:1 on the go-kart was kept.

$$Circumference(miles) = 2\pi * Radius \quad \textbf{(Eq. 2)}$$

$$Go\ Kart\ Speed(mph) = Motor\ Speed(RPM) * Circumference(miles) \quad \textbf{(Eq. 3)}$$

$$GearRatio = Axle\ Speed(RPM)/Motor\ Speed\ (RPM) \quad \textbf{(Eq. 4)}$$

A major part of the project was the team's choice of using a DC motor over an AC motor. While an AC motor typically features a higher output power and does not require as much maintenance as a DC motor, it would require a DC/AC inverter to function with the DC battery. Adding an inverter would add to the cost of the prototype, increase the overall weight, and create an additional point of failure.

The original design of this project featured one or more solar panels to recharge the battery while the go-kart was in use or parked outdoors. The use of solar panels would require a solar panel charging controller to be added. Lithium-ion solar panel charging controllers are quite expensive and would bring the prototype over budget. Consideration had been given to custom building a solar panel charging controller instead of using a pre-built one, but Lithium-ion charging circuits are very complex and the team did not want to risk the safety of the Tesla Model S Battery Module. Additionally, fabricating a controller would take additional time and resources which were outside the scope of this prototype. Given these downsides, the team decided to forfeit the solar panel aspect of the project to ensure the group could afford all parts required to have a functioning prototype drivetrain.

The initial plan was to design a custom frame for the vehicle but due to time, budget, and the team member's skillset this was unfeasible. A prebuilt two-seater go-kart frame donated by Dr. Habetler provides all required safety equipment while still allowing for customizations. Emission standards that affect most vehicles currently on the road today are not a consideration in the design for the proposed vehicle as the vehicle will have no emissions due to running purely off electricity.

4.2 Codes and Standards

For the codes and standards, the team assumed that for the potential use of the go-kart on public roadways it will be classified as a Low Speed Vehicle. According to the Georgia Department of Public Safety, all Low Speed Vehicles must conform to the following standards [18]:

- A four-wheel electric vehicle
- Top speed obtainable in one mile is greater than 20 MPH, but no greater than 25 MPH
- The vehicle was manufactured in compliance of Federal Motor Vehicle Safety Standards for Low-Speed Vehicles

While the State of Georgia only has three standards to conform to, the federal standards are more rigorous. According to the Federal Motor Vehicle Safety Standards for Low-Speed Vehicles, Low-Speed Vehicles must include [19]:

- 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
- 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
- The vehicle complies with rear visibility requirements
- An alert sound

While this vehicle is only a prototype to demonstrate the electric drivetrain used on the go-kart, attempts were made to conform to as many of these standards as possible. Being fully in compliance is unobtainable given the resources and scope of this project, however the drivetrain could be adapted to a vehicle that meets the standards listed above.

5 Schedule, Tasks, and Milestones

The Gantt chart in Appendix A shows the team's plan for the project. The tasks highlighted in red are major milestones such as assignment deadlines, presentations, and Senior Design Expo. However, the Senior Design Expo was cancelled due to the COVID-19 campus closure. The team was not able to assemble and test the prototype, so Dr. Habetler suggested a switch to a completely theoretical design.

The team did it's best to split the project responsibilities evenly throughout this semester. Christopher Hooper was in charge of scheduling team meetings and ordering parts. Daniel Bruce was responsible for the teams weekly reports and determining the gear ratio needed for the go-kart. HongYee Cheah is the team webmaster and determined how to configure the 25 pin connector on the motor controller. Moongyu Kang was responsible for developing the DC motor controller micro basic code along with HongYee's assistance. Anytime a project deliverable/presentation was due all four members would get together and divide the work evenly.

The biggest difficulty the team faced was the occurrence of COVID-19. Georgia Tech closed in response to this pandemic, which left the group unable to order the DC motor controller or battery charger. Without the motor controller the kart had no chance of running safely, therefore, the team was unable to obtain actual field data of the prototype to verify the desired technical specifications. The project advisor suggested the team write the code as if they had the controller, determine the needed gear ratio, and maximum theoretical range.

Another difficulty the team faced was a lack of budget. The original DC motor controller the team borrowed from Georgia Tech could not output enough current for the chosen DC motor. This issue was resolved by purchasing a new Roboteq DC motor controller for $535. This unanticipated expense pushed the solar panel aspect of the project beyond budget, because the Genasun GVB-8 (Boost) solar charge controller was $205 [20]. Consequently, the team decided to remove the solar panel aspect as it was not required for the prototype to function.

6 Final Project Demonstration

Unfortunately, due to the school closure, the team was unable to order necessary parts required to build a fully functioning prototype. Therefore, the team had to perform theoretical calculations and simulations of the project. A complete list of the project goals/specifications, as well as, the result from the theoretical calculations is shown below in **Table 8**.

Table 8. PROJECT SPECIFICATIONS AND RESULTS

	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

To determine the go-kart's top speed, the team first determined how fast the rear wheel rotates when the motor spins at rated speed. The rated speed of the motor is 3100 RPM, and the go-kart already features a step-down gear ratio of 7.2:1 between the motor and rear axle. Therefore, the wheel rotates at 430.556 RPM from **Equation 5** below. If the rear wheel diameter of the Kart is 18 inches, then for every rotation, the wheel travels a distance of 18π in/rev as shown in **Equation 6**. Then from **Equation 7** top speed of the go-kart is 24,347.34 in/min. Converting that into the standard miles per hours, the speed is 23.056 MPH.

$$\omega = 3100/7.2 = 430.556\ RPM \quad \textbf{(Eq. 5)}$$

$$x = \pi * d = 18\pi\ in/rev \quad \textbf{(Eq. 6)}$$

$$s = \omega x = 24347.34\ in/min \quad \textbf{(Eq. 7)}$$

The accomodation for regenerative braking was fairly easy to implement with the Roboteq HDC2460s Brushed DC Motor Controller. A member of the team just had to write one line of code enabling the contoller's built in regenerative braking functionality.

At the start of the project the team determined a 2-3 kW electric motor would be needed to effectively move the kart. After many hours of searching, the team was able to find the Jinle ZD2973A motor from Alibaba Express. This 24 V motor features a 4 kW output at the rated speed of 3100 RPM, and a max torque of 10 Nm. The team was not able to build a physical prototype and test the exact motor output, however, the project advisor is confident that this motor is powerful enough to meet the specifications.

To calculate range the team first needed to determine how long the motor can spin continuously. The battery has a capacity of 5.3 kWh, and, at rated speed, the motor's consumption is 4 kW. The project advisor suggested the power draw of other components should be omitted because they are negligible in comparison to the motor. According to **Equation 8**, If the motor is operated at rated speed continuously, in ideal circumstances, it can spin for 1.325 hours. At a speed of 23.06 MPH, the kart can travel a distance of 30.55 miles (49.16 km) as shown in **Equation 9**. It is important to note that 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.

$$t = c/d = 1.325\ h \quad \textbf{(Eq. 8)}$$

$$x = st = 30.55\ miles \quad \textbf{(Eq. 9)}$$

In order for the Solarie Rider to qualify as a low speed vehicle in Georgia it must include a plethora of safety equipment, some of which came with the go-kart. However, one requirement is that the top speed obtainable in one mile is greater than 20 MPH, but no greater than 25 MPH. The top speed of the kart was already determined to be 23.056 MPH, so it already meets the second half of that requirement. The team determined it would take 5.762 seconds to reach a top speed of 23.056 MPH with an acceleration set in the motor controller of 4 MPH/s (1.788 m/s^2). Assuming initial position and velocity to both be zero, one can find the distance traveled using **Equation 10.** Converting that into miles, the team discovered the kart travels 0.01844 miles during acceleration, which is well within the requirement for low speed vehicles.

$$x_f = x_0 + v_0 t + 0.5at^2 = 0.5at^2 = 29.68\ m \quad \textbf{(Eq. 10)}$$

The team's final project presentation and demonstration and be found on the team website; http://ece4012y202002.ece.gatech.edu/sd20p26/

7 Marketing and Cost Analysis

7.1 Marketing Analysis

The target market is primarily individuals who usually travel short distances with minimal cargo, and favor a more environmentally friendly option to a gasoline vehicle. According to CarMax, the number one EV on the market is the Nissan Leaf with an estimated range of 150-226 miles per charge and 24 cubic feet of cargo space [21]. A brand new 2020 Nissan leaf starts at $31,000. The Solaire Rider is much smaller in size, weight, range, and price as the Nissan Leaf.

7.2 Cost Analysis

The total cost for the parts to develop a prototype is broken down in **Table 9.** The total cost for the parts is $4,293, however, the biggest ticket items, such as the go-kart and Tesla battery module were donated free of charge or loaned to the project. Additionally, estimations were made for the cables, shipping and packaging.

Table 9. PROTOTYPE COST

Part	Cost ($)
Kenbar Model SK-956 Go-Kart [14]	1,529
Tesla Model S Battery Module	1,580 [3]
Jinle ZD2973A DC Motor	135 [10] bulk=130
Roboteq HDC2460S Motor Controller [8]	595
Challenger Accessories EMC-180 Li-ion Charger [5]	58
Cables/Miscellaneous	150
Packaging/Shipping	246
Total Part Cost	4,293

Table 10 contains an estimation for the number of hours invested in different categories of the project per engineer. Labor costs were determined by using the average hourly pay for an entry level Electrical Engineer of $34/hr [22]. Multiplying the labor cost for the four engineers comes out to be $25,160 for development labor.

Table 10. DEVELOPMENT HOURS PER ENGINEER

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 [22]	6,290

Table 11 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.

Table 11. TOTAL DEVELOPMENT COST

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

The production run will last for five years, in which an assumed 5,000 units will be sold, at a price of $12,000 per unit. The parts cost is estimated at a 10% bulk discount, and the labor cost was based on a technician getting paid $20/hr to assemble and test the unit. It was also estimated that marketing and advertising for the Solaire Rider will be roughly 10% of the total input cost. To calculate the amortized development cost the total development cost of $80,106 was divided by 5,000 units to result in $16. Adding up all the costs is a grand total of $9,555, and at $12,000 per unit expected profit is $2,445 which is roughly 20% profit per unit sold. The production cost, profit, and sale price are shown below in **Table 12**.

Table 12. DECISION OF PRICE PER UNIT (based on 5,000 unit production)

Aspect of Development	Cost ($)
Parts 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

8 Status Pre-COVID-19

Before the start of this semester the team already secured a Tesla Model S Battery Module and an Orion Battery Management System II from the ECE Senior Design Lab at Georgia Tech. The team had also obtained a gas powered, two-seater go-kart to use as the body of our vehicle from the project advisor Dr. Habetler.

Throughout the current semester the team had discussed, researched, and decided on a final parts list for the project based on price, performance, and compatibility with other parts, shown in **Table 13**. Most of these parts were ordered and delivered before Georgia Tech's campus closure. However, some parts did not arrive in time.

The Roboteq AX2850 DC Motor Controller the team originally borrowed from ECE Senior Design Lab was not the model for which the team hoped. The AX2850 is not capable of combining the two output channels into our one motor, so the team ordered the HDC2460s Brushed DC Motor Controller from Roboteq. Due to budget constraints the team chose to not buy solar panels and accompanying solar panel charging controller. This meant that the Tesla Battery did not have any means to charge. To solve this problem, the team ordered a Lithium-ion battery charger from Top Mobility.

Unfortunately, Georgia Tech's Atlanta campus had to close due to the 2020 COVID-19 outbreak. The DC Motor Controller and Lithium-Ion Battery Charger were in the process of being ordered when campus closed, which left the team without access to these essential parts needed to have a working project. Due to this setback the project was adjusted and the steps moving forward are addressed and detailed in Section X COVID-19 Adjustments/Next Steps.

Table 13. PART LIST

Part	Model Number	Status	Price
Brushed DC Motor	ZD2973A: DC Motor 24V 4kW	Delivered	$235.00
DC Motor Controller	Roboteq XDC2460 Brushed DC Motor Controller	Shipped, Not Arrived before COVID-19	$535.00 + $16.32 Shipping + Taxes
Battery Management System	Orion BMS 2	Borrowed from Georgia Tech	Borrowed
Lithium-Ion Charger	Challenger Charger EMC-180 24V 5AH LI-ION Battery Charger	Shipped, Not Arrived before COVID-19	$58.00 + Free Shipping + Taxes
Lithium-Ion Battery	Tesla Model S Battery Module	Borrowed from Georgia Tech	Borrowed
Go-Kart Frame and Parts	Unknown	Borrowed from Dr. Habetler	Borrowed
Misc. Parts	Resistors, Diodes, Switches, Encoder, Etc.	Borrowed from Georgia Tech	Borrowed

9 COVID-19 Adjustments/Next Steps

Without access to the DC Motor Controller and Lithium-ion Battery Charger the team was unable to assemble the vehicle off-campus as these are essential parts. To account for this and still complete this project on time, the team has decided to instead change the approach to a more simulation based plan instead of physical prototyping. The parts we used for the simulations are the parts we already had or decided to get to keep within the budget and spirit of the original idea. The team created a block diagram for the top-level view of the project, determined a potential range for the kart, and gear ratio needed. The team rushed to construct figures to show how the various components would connect, and created code for the motor controller that would be used if given the opportunity to bring the project to completion.

10 Conclusion

The team set out to develop a lightweight, electric powered vehicle that could satisfy short commutes and has the ability recharged at home with wall power or roof mounted solar panels. The team desired the kart to reach a top speed of 25 MPH, drive a range of 1 km, incorporate regenerative braking, and a manual feeling digital gearbox. Unfortunately, due to a lack of budget and school closure, the team decided to forgo the solar panels, and digital gearbox portion of the project. Even with a lack of resources the team was able to determine the karts theoretical range, top speed, and gear ratio. The team also wrote code to set up the DC motor controller and created a 25-pin connector diagram and high level wiring diagram describing this project.

Moving forward, a lead acid battery source might be used to reduce the cost of the prototype, but add additional weight. Lead acid batteries require less complicated charging circuits and do not require the use of a battery management system. Furthermore, it is much easier and cheaper to put lead acid batteries in series to achieve a higher voltage than placing Tesla battery modules in series. Another alternative to explore would be using a synchronous AC motor with matching motor controller instead of their DC counterparts. With today's current technology AC motors are more reliable, require a lower power demand on start and feature a typically higher output power for input voltage.

11 Leadership Roles

Table 14. TEAM LEADERSHIP 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

References

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Appendix A - Project Gantt Chart