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EECE 404: Senior Design II

The E.V. 2.0

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Summary

Given the environmental impacts of the emissions from combustion engine vehicles, there is a growing demand for electric vehicles. The long term goal of the EV 2.0 project is to create an autonomous electric vehicle while the academic year goal is to create a detailed implementation plan to convert the vehicle from a series hybrid to a fully electric vehicle. To achieve the academic year goal, we set up design requirements such as a battery life of at least 2 years, a range of about 75 miles, a gross vehicle weight of 1600 kg, and a budget of $10,000. There were certain constraints we encountered such as the National Highway Traffic Safety Administration and the Society of Automotive Engineers standards for electric vehicles. There was also a lack of access to the vehicle for half the academic year, and a large learning gap for the team at the beginning of the project. We also examined current electric vehicles in the market like Tesla Model S3, BMW i3 and Ford Focus to get an idea of the current state of art in the industry. Based on this, we were able to come up with our solution design that replaces the Genset (generator and alternator) and Ultracapacitors with lithium ion batteries and a charger. This was used to develop a detailed implementation plan that provided information on converting the series hybrid vehicle to a fully electric vehicle. The implementation plan was then accompanied by a prototype 3D Model and CAD Drawings that provide a visualization of the proposed propulsion system and also serve as deliverables for the first year of the project.

Problem Statement

The hybrid vehicle has an inefficient internal combustion engine (ICE) that emits greenhouse. The emission of greenhouse gases by combustion engines is one of the major causes of global warming. Replacing the combustion engine with an electric propulsion system will reduce the emission of greenhouse gases.

Long Term Goal

The long term goal for the project is to turn the series hybrid General Motors EV 1 into an autonomous electric car.

Academic Year Goal

The academic year goal for the project is to create a detailed implementation plan to replace the current propulsion system of the hybrid vehicle with a fully electric drivetrain

Design Requirement

It is important to clearly state the design requirements that would meet the needs addressed in the problem statement before designing the solution to the problem. Highlighted below are our requirements the electric vehicle must meet after the conversion is done:

1. A battery pack with a lifespan of at least 2 years.
2. Range per full charge of at least 75 miles.
3. Accelerate from 0-50 mph in 6.5 seconds.

4. A motor power of 103 kW.
5. Battery module weight of 470 to 520 kg.
6. Gross vehicle weight of 1600 kg
7. The cost of the propulsion system to be about $10,000.

The design requirements is based on our desire for the EV 2.0 to be comparable in performance to the current electric vehicles in the market while not deviating too much from the specifications of the EV1. A battery pack lifespan of two years ensures that the vehicle would only need battery maintenance biannually. Although a range of 75 miles is low compared to most of the conventional (internal combustion engine (ICE)) vehicles, it is well within the range of most of the electric vehicle in the market presently. The motor specification is modeled to match the motor that was in the EV1. Lastly, the battery module weight of 470 to 520 kg is needed to avoid interfering with the vehicle's motion dynamics because the EV 1 had a battery module weight of 489 kg.

Constraints

As part of our design requirements, we ensured that our design aligned with some of the regulations and standard that have been set for electric vehicle industry. The electric vehicle must adhere to all National Highway Traffic Safety Administration (NHTSA) standards. These standard relate to safety on the road such as having functioning brake lights, windshield wiper, airbags and keeping the intensity of the sound generated by the car under a specific limit. Electrical requirement standards are set by the Society of Automotive Engineers (SAE). There are several standards like SAE Standard J2293, "Energy Transfer System for Electrical Vehicles," stated by SAE to ensure that the electrical system of the vehicle is innocuous to the drivers, passengers and the environment.

The electric vehicle industry is plagued with several socio-cultural and political constraints. There are over 150,000 gas stations in the United States compared to about 50,000 electric car charging stations. This lack of charging stations is one of the reasons the electric vehicle industry is lagging behind the conventional vehicle industry. Another factor affecting the electric vehicle industry is the low range per full charge. Owing to the large weight and sizes of battery modules, there number of battery modules that can be placed in a vehicle is limited. Consequently, the range of the car on a full charge is also limited.

Over the course of working on this project, we also faced some project specific constraints. The major constraint was the inaccessibility of the vehicle for half of the academic year. We had to base our initial design off an arbitrary hybrid car until we eventually had access to the car. The amount of information available to us with regards to understanding the propulsion system of the vehicles was also limited. General Motors did not provide us with the blueprints of the car and the changes made to the vehicle when it was converted to a series hybrid vehicle were not well documented.

Current Status of Art

Electric vehicles are undoubtedly the future of personal transportation as car manufactures like Ford, Nissan, BMW and Tesla are committing a lot of resources to the research and development of electric vehicles in anticipation of an increased market for electric vehicles in the future. The demand for electric vehicles is expected to increase due to the fact that electric vehicles are more efficient and greener than gasoline-powered cars and the electricity needed to power them can be obtained from various energy sources such as wind, solar and biofuel.

The Tesla Model 3 has a 259 horsepower motor and can move from rest to 60 mph in less than 6 seconds and reach a top speed of 130 mph. It can go up to 220 miles on a single charge which is about twice the range of one of its competitors. The Model 3 can be charged to half its battery capacity in about 20 minutes at a Tesla supercharger station. It has one battery pack - 50 KWh or 70 KWh and with new advancement in battery technology, it is 400 lbs lighter than older models. This is one of the design changes made by Tesla to make Model 3 their fastest model. Unlike gasoline-powered cars, electric vehicles have low cooling needs since they do not have internal combustion engines that generate a considerable amount of heat.

The performance of the latest Ford Focus Electric model (another EV in the market) is quite different from the Tesla Model 3 as its electric propulsion system has different design specifications. It has a 143 horsepower permanent magnet electric motor and a range of about 115 miles which is better than its predecessor. The batteries have become denser and thus can hold more energy per volume which shows rapid advancement in electric vehicle technology. The size of the car curtailed the size of the battery which is why they increased the power density of the battery. A lot of research is being conducted on how further increase the power density of the electric car batteries. The advancement in battery technology is crucial to the success of the electric vehicle industry. The Ford Focus uses a 23 KWh Lithium-ion battery that can be fully charged in 3.6 hours at 240 volts. It can reach 60 mph from rest in 9.9 seconds and a top speed of 84 mph. In general, the specifications of the Tesla Model 3 are better than the Ford Focus Electric as the Tesla Model 3 has a higher top speed, range and acceleration among other things. However, this does not prove that the performance or efficiency of the Tesla Model 3 is better than that of the Ford Focus Electric. The Focus is $29000, which is $6000 less than the cost of the Model 3. One could infer that the price difference is the reason the specifications of the Model 3 are better.

Electric Vehicle	**Tesla Model 3**	**Ford Focus Electric**
Price ($)	35,000	29,000
Range (mi)	220	115
Lithium Ion Battery (kWh)	70	23
0-60 mph (seconds)	6	9.9
Top speed (mph)	130	84
Charge Time @ 240V (Hours)	2.5	3.6
Horsepower	259	143

Table 1 - Specifications of Popular Electric Vehicles

The various electric vehicles that exist are dependent on the components in their electric propulsion systems. As a manufacturer, you have to choose the best components to use in the vehicle design that would meet your design requirement keeping the budget in mind. So, the main issue most manufacturers face today is how to increase the performance of their vehicles without significantly increasing the market price of the vehicles. Table 1.0 below shows the specifications of electric cars and their prices.

Solution Design

Converting a series hybrid vehicle to an EV is a complex process that requires a good understanding of the operation of a vehicle. The main source of power for the hybrid vehicle is a combination of a Genset and ultracapacitors. For a purely electric vehicle, the only source of power is a battery system or fuel cells. In this conversion, we plan to replace the ultracapacitors which are located under the car and the Genset which is in the trunk with 32 12V 50Ah lithium-ion batteries which will be fitted into the tray that currently holds the ultracapacitors. Installing the batteries is one of the steps involved in converting the series hybrid vehicle to an electric vehicle.

Conversion Steps

The following steps highlight the major steps involved in the conversion:

- Get the auxiliary system to work

An auxiliary system is used to describe a collection of related automotive electrical components that interact with the main car systems and components to support the functionality. Electrical Auxiliary Systems are components related with Security Systems, Comfort Systems, Lighting Systems and Information Systems which are very important to help the main system to perform properly. The first step is to test the existing auxiliary battery in the vehicle to see if it still works. If it doesn't work then you replace the auxiliary battery with the new battery with same specifications. Test the different components that are connected to the auxiliary system. These include, but are not limited to, the central locking door system, seat adjustment system, windows control, windshield wiper & cleaning system, front lighting, rear lighting, compartment lighting, signalization lighting, side mirror controls, air-conditioning, radio, cd readers, sensors. If any of these components are defective then they should be replaced.

- Install battery system

Professor Ganley modeled the power system of the series hybrid vehicle to meet the ratings of the powers system that was in the EV1. The EV1 had 26 modules of 12V, 53Ah lead acid batteries connected in series to yield a nominal system voltage of 312 V and a nominal capacity of 53Ah. This configuration produces 16.2 kilowatt-hours of energy. The Genset in the hybrid vehicle consisted of a gasoline-driven generator with a peak energy output of 16.5 kilowatt-hours which matches that of the EV1 and an alternator that converts the mechanical energy produced by the generator to electrical energy. The General Motors power electronic controller that came with the EV1 when it was donated to Howard

University can take between 200-400 volts and the ultracapacitors in the series hybrid vehicle had a nominal voltage of 388 volts. Therefore, the ultracapacitors will be replaced with a battery system with a nominal voltage of 380 V. The high voltage is needed because we the total energy capacity determines the mileage of the vehicle.

The efficiency of the original EV 1 for a driving cycle range of 78.2 miles based on Society of Automotive Engineers (SAE) standard, SAE J1634, is 164 Wh/mile. We used this as our benchmark efficiency for the EV 2.0. From our design requirements, we set a target range per full charge of 75 miles. Since this nominal value cannot be guaranteed after the -components are assembled and the vehicle is tested, we decided to base our calculation using 90 miles which is twenty percent more than the desired range. The total energy for a 90 mile range was then calculated to be 15 kWh for a driving cycle range. The driving cycle range takes into account different driving speeds in estimating the total energy needed. A constant speed range at 60 mph requires more energy than that of a driving cycle range. Although most drivers that use personal vehicles for domestic purposes do not drive at a constant speed of 60 mph, we decided to account for such an extreme case by increasing the estimated total energy by 25% which brings it to about 19 kWh from 15 kWh.

Since we know the voltage and the energy required, we calculated the charge rating of the battery to be 50 amp-hour using the formula shown below.

$$Total\ Energy\ = Voltage\ *\ Electric\ Charge\ in\ Amp-Hour$$

So a 380V 50 Ah battery pack is needed to supply a total energy of 19 kWh. The 380V battery pack would consist of 32 12V lithium-ion batteries. Each battery module weighs 16kg and the 32 modules weigh 512 kg all together. It is important to keep the battery system weight close to the weight of the lead acid batteries that were initially in the EV1 (490 kg), because the vehicle was designed to carry a specific amount of load. Any irregularity in the weight distribution might affect the motion dynamics of the car and the efficiency of the electric motor.

The power system of the series hybrid vehicle must be removed before the batteries can be installed. This includes the generator, ultracapacitor models, three-phase diode bridge modules and other related components. They should be replaced with the lead acid batteries and other electrical components that are needed to integrate the battery pack with the vehicle’s drivetrain. Electrical devices such as fuses, circuit breakers or main contractors, must be installed to protect the vehicle from thermal overload which might be induced if the battery system becomes overheated by overcurrent. A system similar to the EVC 250 high-voltage contactor for hybrid and electric vehicles can be used as a safety element at the interface between the energy storage system and the vehicle electrical system. Together with the fuse, this component has the task of protecting the battery from thermal overloading. The system can carry overcurrents of up to 6 kA for 20 ms without any key properties being affected.

- Replace other defective components

After replacing the battery system, any other defective or irrelevant component should be removed from the vehicle. These defective components can be determine by running test targeted at determining whether or not they are still operational. There will be a need to dissemble certain components so that they can be thoroughly examined. One of such components is the power electronic controller shown in *Figure 4*. The various components that exist in the controller must be examined individually.

- Determine the performance of the electric vehicle

The last step involved in the conversion is to determine the mileage, top speed, and battery longevity of the vehicle and to compare the data with the initial design requirements of the vehicle. The cause of any observed discrepancies should be determined and the necessary modifications should be made. All modifications should be documented so that the information is available whenever it is needed.

Based on the conversion steps, we were able to create this diagram that highlights the components needed in the EV 2.0 propulsion system:

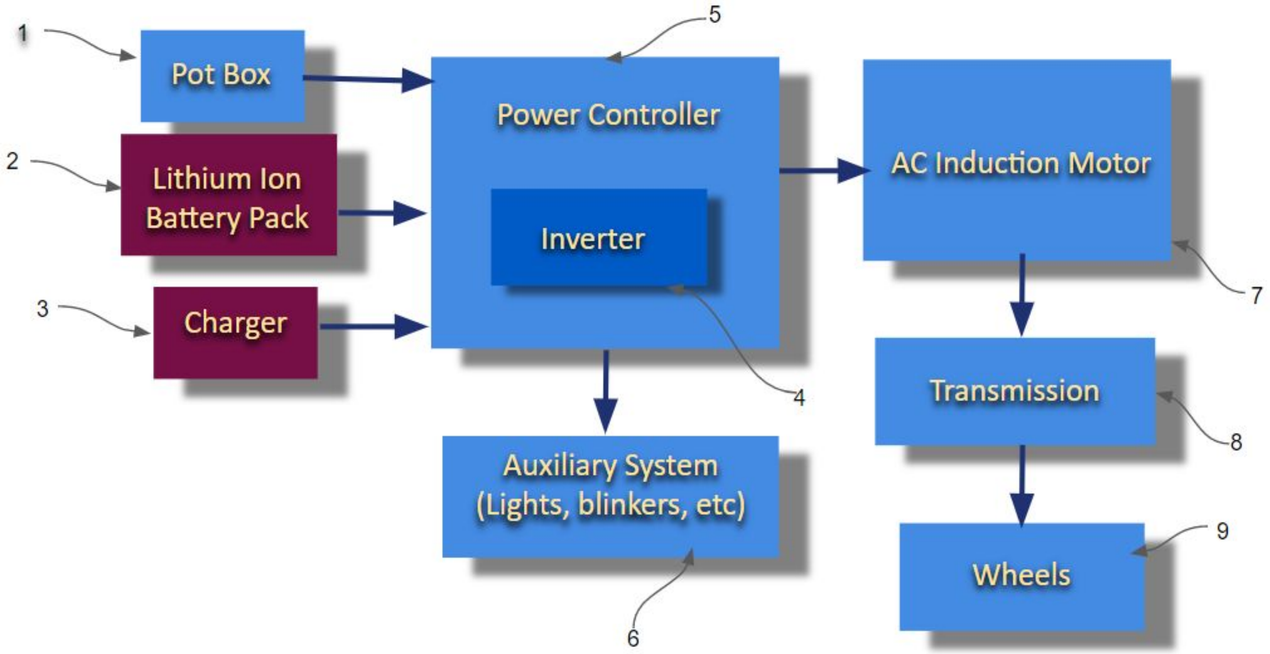

Figure 1 - Proposed Propulsion System

The initial items in the Series Hybrid vehicle are labelled **1,4,5,6,7,8**, and **9**. The Pot Box **1** is hooked to the accelerator pedal via the accelerator pedal cable. It tells the power controller **5** how much power to deliver to the AC induction motor **7**. varies power delivered to the motor. Since the propulsion system is being changed to a fully electric drivetrain, we included a Lithium Ion battery **2** pack as the main power supply of the electric vehicle. It is arranged in series to produce a maximum voltage of 380V. The charger **3** charges the battery pack by connecting it to an external power source. The type of charger used influences the charging time of the battery pack. The Inverter **4** converts the direct current from the battery pack to alternating current needed by the motor. The power controller **5** is used to distribute the power supplied by the battery to the motor and other necessary components like blinkers that need power. The auxiliary system **6** includes components of the vehicle that are not powered by the main power supply. The AC Induction Motor **7** is the main component that turns the wheels which in turn moves the car. The speed of the rotor depends on the ac supply from the battery. The motor gives power to the transmission **8** which transfers engine power to the driveshaft and rear wheels. Gears inside the transmission change the vehicle's drive-wheel speed and torque in relation to engine speed and torque. The wheels **9** move the car.

Project Implementation Plan

Month	Week No	Tasks	Member in Charge	Monthly Deliverables
Jan	1 - 3			EV 1 Assessment Report
	4	1. Assess the EV 1 and list all the available components of the car.	Ikenna & Olaniyi	
		2. Reach out to GM to get the blueprint of the EV 1	Arinze	
		3. Research and understand the simulations Dr. Ganley did for his propulsion systems	Goodness	
		4. Determine and order necessary tools to examine the car	Ikenna & Olaniyi	
Feb	1	1. Determine the useful components in the car	Ikenna & Olaniyi	Simulation Report and CAD drawings
		2. Determine the component to be added	Goodness & Arinze	
		3. Calculate required motor, controller and power rating	All	
	2	1. Find software needed to run simulations	Goodness	
		2. Learn and use software to run simulations	All	
		3. Compare simulation results to theoretical analysis of EV 2.0 and revise.	Goodness & Ikenna & Arinze	
	3	1. Commence CAD Drawings	Arinze	
	4	4. Continue CAD drawings	Ikenna	
Mar	1	1. 3D printing	Goodness	3D model and Complete implementation plan
	2	1. Create implementation plan	Ikenna	
	3	1. Finalize implementation plan	Olaniyi	
	4	1. Finalize final Presentation	Goodness	
Apr	1	1. Practice final presentation	Arinze	Complete electric propulsion system design
	2	Project Demo + Presentation Event	All	
	3 - 4			

Table 2 - Implementation Plan

Project Implementation Process

To achieve our academic year goal of creating a detailed implementation plan to convert the current EV propulsion system to an electric propulsion system, we set key milestones for each month between January and April and took steps towards achieving those milestones.

January: EV1 Assessment Report

The key task for January was to fully assess the EV, given we finally got access to the vehicle. After creating the project plan for the semester, Olaniyi and Ikenna took responsibility of physically going to the car to determine if it was in working condition and doing an initial assessment of the vehicle. They also took charge of finding a space to work on the vehicle as winter had arrived and working in the parking lot would provide a great deal of discomfort and health challenges. Arinze was tasked with reaching out to General Motors for the original blueprints of the EV1 to enable us accurately dimension our proposed drivetrain. Goodness was tasked with researching the possible simulation tools to be used in verifying our proposed design and researching how to carry out the simulations.

Requests were made by the team to the civil engineering department through Dr Glakpe and Dr Amooh to use the civil engineering lab as our workshop to protect us from the elements. Various GM employees and customer service helplines were reached out to to obtain the blueprints and Siemens Customer Service was reached out to to discuss the properties of their simulation software.

By the end of January, the EV was not fully assessed due to the poor working conditions and lack of confirmation from the civil engineering department head to use the civil laboratory. We were also awaiting responses from GM and Siemens and had to carryover some of the work into the following month.

February: Simulation Report and CAD Drawings

The key task for February was to complete the assessment of the EV and begin the process of simulations and CAD drawings. Ikenna and Olaniyi were tasked with assessing the EV, Goodness and Arinze were tasked with determining the components to be added to the EV and the entire team was tasked with performing calculations to determine battery requirements and arrangement as well as motor and controller ratings.

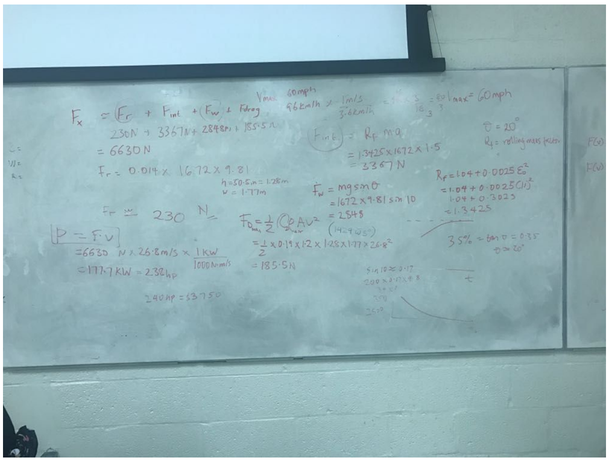

Figure 2 - Some EV pictures

The end of February proved more fruitful than January. We were able to do some assessment of the EV and take the pictures of the components of the EV and read up their specifications from various sources online. We also got in contact with Professor Ganley, the last person to work on the vehicle and convert it to a series hybrid vehicle. We obtained his calculations as well as a detailed report of his work, giving us an accurate assessment of the state of the EV.

March: CAD Drawings and Implementation Plan

The key deliverable for this month was the CAD drawings and the implementation plan. Goodness and Ikenna were tasked with learning how to use the CAD software (NX) and creating the CAD drawings for the drivetrain parts (i.e. the battery modules, wheels, battery tray/chassis, ac induction motor, controller, gears for single speed transmission). Goodness was also tasked with securing the 3D printer for use when the CAD drawings were completed. Olaniyi and Arinze were tasked with creating the outline for the implementation plan and we were all tasked with with completing the implementation plan.

Goodness and Ikenna worked with the mechanical engineering students on the VIP team and with the senior mechanical engineering students to learn how to use NX and validate the CAD drawings. Olaniyi and Arinze created the sections of the implementation plan and assigned sections to each member.

Implementation Plan Outline

1. Background on EV
2. Advantages of electric vehicles
3. Disadvantages of electrical vehicles
4. Principle of Operation of an Electric Vehicle
5. General Motors E.V. 1
6. EV 1 discontinuation
7. Professor Ganley's Changes
8. EV 2.0 project
    a. Conversion of the Series Hybrid Vehicle to an Electric Vehicle
    b. Conversion Steps

c. Computer Aided Design Drawings
d. Cost Analysis
e. Sensor Requirements
f. Conclusion

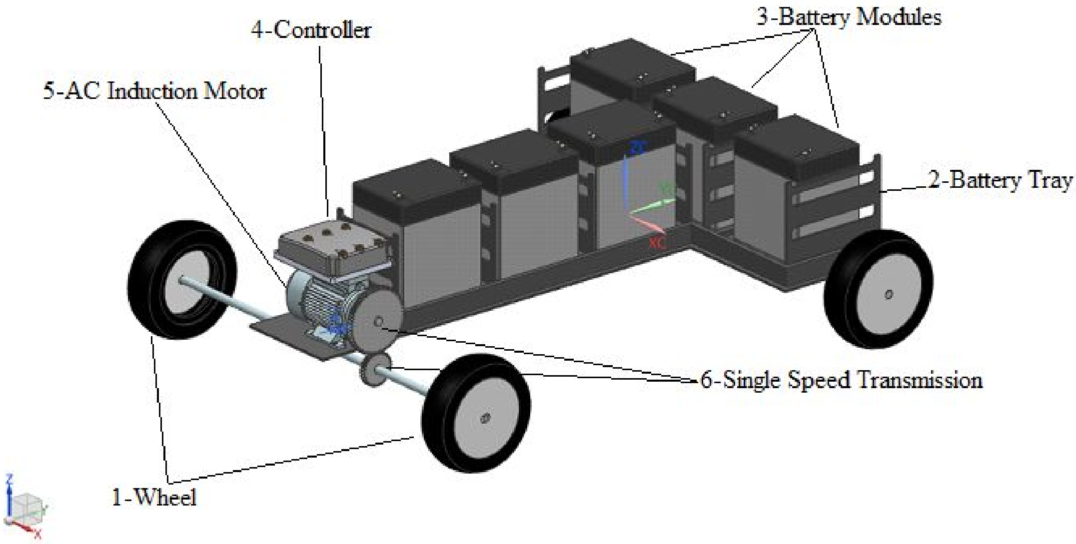

Figure 3: Assembled EV 2.0 Drivetrain

By the end of March, we had completed the CAD Drawings and had also started the detailed implementation plan, with sections assigned to various team members. The spring break slowed the pace of the team during this month but decent progress was still made.

April: Assemble 3D Model and Complete Implementation Plan

The key deliverable for April was the assembled 3D printed model with the completed implementation plan. Goodness was tasked with 3D printing and assembling the 3D model while the entire team was responsible for completing the detailed implementation plan.

The 3D model was printed and assembled using ABS plastic for majority of the parts and a steel bearing for the motor and a steel shaft for the front wheel tires to bear most of the weight of the system. It was the assembled based on the assembled model of the CAD drawings of the drivetrain. To demo the scaled down prototype electric propulsion system, the electric motor was fixed in the steel bearing and connected in series to a resistor which was connected to a power source. As the power source increased, the speed of the rotating tires increased, confirming that the single speed, front wheel drivetrain we proposed would work.

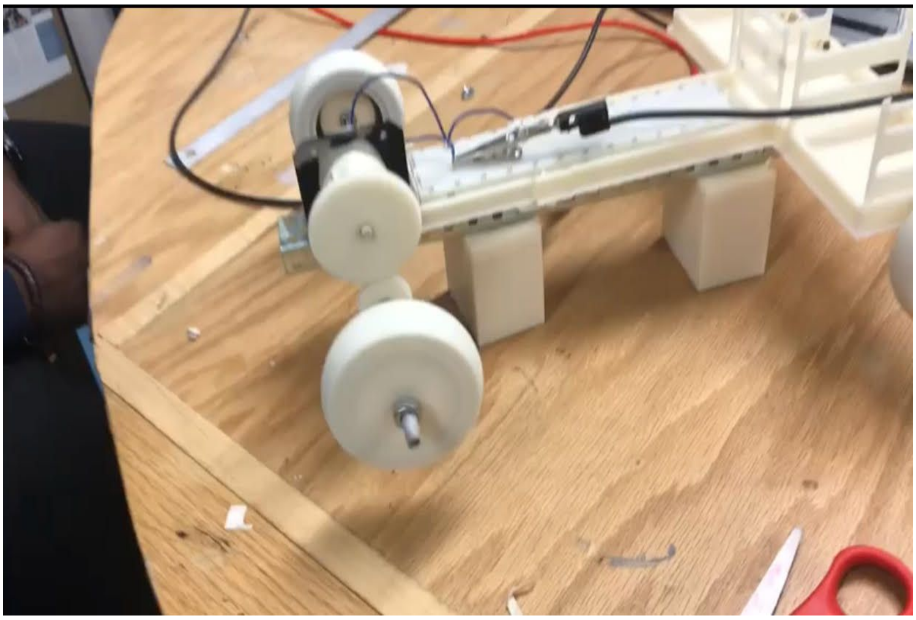

Figure 4: Assembled 3D Printed Model with motor connected to power supply

The implementation plan was completed, with a cost analysis, implementation steps and required materials also included with background information and a section of Professor Ganley's changes to the EV1. Reviews of the implementation plan followed its completion to ensure the document was detailed enough and all sources were cited. The final presentation of the academic year work followed the review process.

Conclusions

A significant percentage of the world is gaining confidence in electric vehicles and this is due to the growing innovative strides being made in the industry. The more innovation in the industry, the more projects like EV 2.0 will be carried out at the university level. Due to the emission of greenhouse gases that ultimately causes global warming, many automotive companies are shifting production from internal combustion engine vehicles to electric vehicles. During the time of this research, we learned a great deal about electric vehicles that we would not be able to learn in any classroom. We also learnt about series hybrid cars while assessing the vehicle and to understand how the conversion is done. The full scope of the project which would be to turn the car to a fully autonomous vehicle would have students introduce sensors into the car. These sensors would communicate with each other and other relevant devices to acquire and analyse the information needed for autonomy and to provide a great experience for the driver. With great advancement in internet of things (IoT) technology, the EV 2.0 team should complete the project in the specified timeline of four years.

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