ALAMO COLLEGES

SAN ANTONIO COLLEGE
Physics/Engineering/Architecture

NSF

SAC Undergraduate Research Program (SURP)

Solar Electric Cart Performance

Final Research Project Report

By

Spring 2016 SURP team

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Abstract

SAC Solar Electric Cart Performance Undergraduate Research Project

Since 2010 the San Antonio College Physics, Engineering and Architecture Department has managed a very successful undergraduate student research program funded by both corporate donations and government grants. A number of the early research projects under this program studied different ways to improve the efficiency of solar photovoltaic (PV) panels in order to maximize energy produced. These projects demonstrated the benefits and potential applications of solar energy and led to the summer, 2015 research project where 8 SAC undergraduate students converted an old 1980's gas-powered utility cart into a solar-powered electric cart. This difficult and complex project produced a functional vehicle with two roof-mounted solar panels. However, due to time constraints vehicle performance was not tested, and certain desired capabilities were not incorporated. During spring semester, 2016 a team of 4 students worked to complete research on the solar electric cart. Performance testing determined solar panel output, battery charge time in sunny conditions, and the cart's top speed and range with fully charged batteries. In addition, the team upgraded the vehicle by installing a DC to DC converter for electrical accessories, and adding storage compartments to hold flyers and educational materials. The Mathematics Engineering and Science Achievement (MESA) Center will use the vehicle to promote STEM programs at various events at SAC and other campuses. This NSF-funded project will showcase the SAC undergraduate research program while also promoting sustainability and the practical use of renewable energy.

Introduction

It is common knowledge that the ability to harness solar energy is of growing importance in today's world. With a sweepingly vast amount of economic and environmental opportunities it is vital to study solar energy's potential applications and discover ways of integrating them into our daily lives. Starting in the summer of 2010, San Antonio College built a student undergraduate research program that focused primarily on increasing the capability of a solar panel to maximize the net energy it collects and harnessing it for potential applications. Using data collected from previous undergraduate research teams, two 4-person student teams from San Antonio College in 2015 successfully converted a surplus gas-powered utility cart into a solar-powered electric cart, called the SolGo ARV (Solar Go Alternative Research Vehicle). The importance of the research done as part of this project was to demonstrate that a vehicle such as the SolGo ARV, when fueled by the natural energy of the sun, can be capable of performing in terms of speed and range as well as a cart powered by fossil fuel, but doing so in a more environmentally-friendly and sustainable manner. With this in mind, we hope that the success of this undergraduate research project will inspire students of all ages to pursue engineering education as well as foster a deeper appreciation for the importance of renewable energy to our future.

Overall Goal and Objectives

The overall goal of this research project is to design, research, and procure materials to repair, upgrade and test the performance of the existing solar electric cart with the specific objectives below:

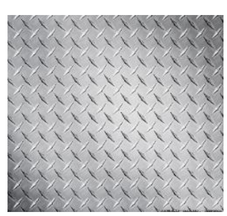
- Repair inoperative headlights, and parking brake
- Add clear plastic cover over the electrical subsystem
- Replace ignition on/off key switch with toggle switch
- Install available DC-DC Converter for powering accessories (lights, horn)
- Develop a User/Maintenance manual
- Install storage compartments on sides
- Construct and install adjustable motor mount
- Measure solar panel output in various weather conditions
- Measure battery charge time in sunny and cloudy weather conditions
- Determine top speed and range with fully charged batteries

Parts

With the project goals and objectives in mind it was important to acquire the necessary parts for the SolGo ARV. All the following parts below were purchased with the vehicle's design, style, and compatibility in mind with the exception of the brake parts which were incompatible with the vehicle's current mechanical design.

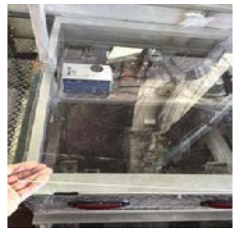
Diamond Metal Sheet

- 4 ft. x 8 ft. by 1/16 inch thick
- Place: WESTBROOK METALS
- Cost: $125.00
- Number: (800) 400-2024



Steel angle (L-shaped)

- Quantity: 3
- 12 ft. length
- -1 inch by 1 inch
- 16 gauge
- Cost: $17.63
- Place: Ashley Recycling Center
- Number: (210) 922-7631



Plexiglas

- Quantity: 1
- length 33in, width 28in (33” x 28”)
- ¼ inch thick
- Cost: $60.50
- Place: Plastic Supply of San Antonio
- Number: (210) 222-8091

Brake Parts

- Hill brake latch kit. For Club Car G&E 1981-97.
- OEM# 1011877
- Cost: $17.56
- Place: Mission Golf Cars
- Number: (210) 545-7868

Belt

- Drive Belt
- MPN# EPGC122
- Cost: $ 26.13
- Place: Mission Golf Cart
- Number: (210) 545-7868

- TOTAL COST FOR ALL PARTS = $246.82

Methods of Testing and Equipment

To successfully complete the project we required special equipment, and methods of testing, to complete our project objectives. The equipment and testing methods below were used for the completion of our project.

1) Vernier Hardware and Software- An educational tool using sensors that connects to the Vernier interface which connects to a laptop and then produces live information and graphs. In our project this tool is used to measure voltage, power, current, illumination, and resistance.

2) Voltmeter- A tool used for measuring voltage between two different points in a circuit. In our project it is used to directly measure individual battery voltage, circuit voltage, and to find loose or faulty connections.

3) Cycle Analyst - Turns on automatically with the vehicle. The default screen shows five pieces of information, voltage of batteries, power output in watts, speed of the vehicle, trip distance, and net amp-hours alternating on the screen. Used in our project to easily gauge battery life.

4) Charge Controller- Used to regulate power from the solar panels into the vehicle's batteries. It also provides another means for reading vehicle solar charging voltage and current.

5) Stanley GBCPRO Golf Cart Battery Charger

Used to charge batteries from 120 volt outlet.

Motor Top Speed with Fully Charged Batteries (52v)

To determine the vehicle's top speed with fully charged batteries we marked a distance of 100 ft. and used a stopwatch to time how long it took the cart to travel 100 feet once it had reached its top speed. We then converted this speed data to mph using the following formula:

$$\text{speed (mph)} = \frac{100\text{ ft}}{\text{time(s)}} \times \frac{1\text{ mi.}}{5280\text{ ft}} \times \frac{3600\text{ s}}{1\text{ hr}}$$

Battery Charge Time in Sunny Weather

To measure this data, we exposed both solar panels to direct sunlight outside the Facilities building on San Antonio College from 10am to 5pm, and measured the time it took to fully charge the batteries to 52 volts starting with "dead" batteries.

Battery Run Time on Full Throttle and Half Throttle

To determine battery life of the solar cart on a full 52 volt charge with maximum throttle and half throttle, we drove the cart around San Antonio College campus with appropriate throttle on April 9th and April 15th, waiting until the vehicle's battery pack reached 20 volts (batteries discharged) and was undriveable. We used the Road Bike app on our phones to track time and distance of our movement.

Battery Run Time Simulating an Event

We also determined the solar cart's performance in an event such as STEM appreciation week, where the MESA center of San Antonio College would use the solar electric cart to drive people around and entice the scientifically curious. We drove the vehicle around campus for intervals of 2-3 minutes and rested the vehicle for 5-7 minute intervals until the vehicle ran out of power.

Solar Panel Output in Various Weather Conditions

To determine the solar panel voltage and current outputs in different weather conditions and timeframes, we recorded our data outside the Chance Academic Center at San Antonio College on May 18th (cloudy day), and May 27th (sunny day), using the Vernier equipment. We taped an illumination (lux) sensor to the top of the vehicle so that it would sit next to the solar panel and collect data. We also connected current and voltage sensors at the solar charge controller located in the electrical subsystem of the vehicle to measure charging voltage and current.

Results and Repairs

Motor Top Speed with Fully Charged Batteries (52v)

We ran 3 sets of 5 trials. In the first set of trials we had two people in the cart weighing 378 lbs. total. For the five trials the speed averaged 10.94ft/sec which equals 7.5mph. In the second set of trials one person was in the vehicle weighing 178 lbs. The average was 11.31ft/sec which equals 7.68mph. In the final set we recharged the batteries and had one person in the vehicle weighing 190 lbs. This resulted in an average speed of 11.31ft/sec or 7.73mph. The raw data is below.

Set 1	***Time taken to cross 100ft***	***Speed (ft/sec)***
Trial 1	8.89s	11.25
Trial 2	9.09s	11.0
Trial 3	9.07s	11.03
Trial 4	9.32s	10.73
Trial 5	9.37s	10.67

(Table 1. Set 1)

Average = 10.94 ft/sec or 7.5mph

Set 2	***Time taken to cross 100ft***	***Speed (ft/sec)***
Trial 1	8.87s	11.27
Trial 2	8.66s	11.55
Trial 3	8.99s	11.12
Trial 4	8.54s	11.71
Trial 5	9.01	11.10
Trial 6	8.81s	11.35
Trial 7	9.03s	11.07

(Table 2. Set 2)

Average = 11.31 ft/sec or 7.68mph

Set 3	***Time taken to cross 100ft***	***Speed (ft/sec)***
Trial 1	8.61s	11.61
Trial 2	8.91s	11.22
Trial 3	9.30s	10.75
Trial 4	8.82s	11.34
Trial 5	8.60s	11.63

(Table 3. Set 3)

Average=11.31 ft/sec and 7.73mph

Battery Runtime on Full Throttle and Half Throttle

To determine battery life of the solar cart with a full 52 volt charge at maximum throttle, we drove the cart around San Antonio College campus for two trials, averaging 52.9 minutes per trial and an average distance of 5.54 miles. We drove the cart until the battery dropped to 20 - 21 volts at which time the cart would not move anymore. The raw data follows:

Trial 1

Time Driven (min:sec)	*Distance Traveled*	*Trial End Voltage*
50:01	5.56 miles	21 volts

(Table 4. Trial 1)

Trial 2

Time Driven (min:sec)	*Distance Traveled*	*Trial End Voltage*
55:04	5.52 miles	20 volts

(Table 5. Trial 2)

Battery Runtime on Half Throttle

Time Driven (min:sec)	*Distance Traveled*	*Trial End Voltage*
1 hr, 13 min	5.2 miles	22 volts

(Table 6. Half Throttle)

Battery Runtime Simulating an Event

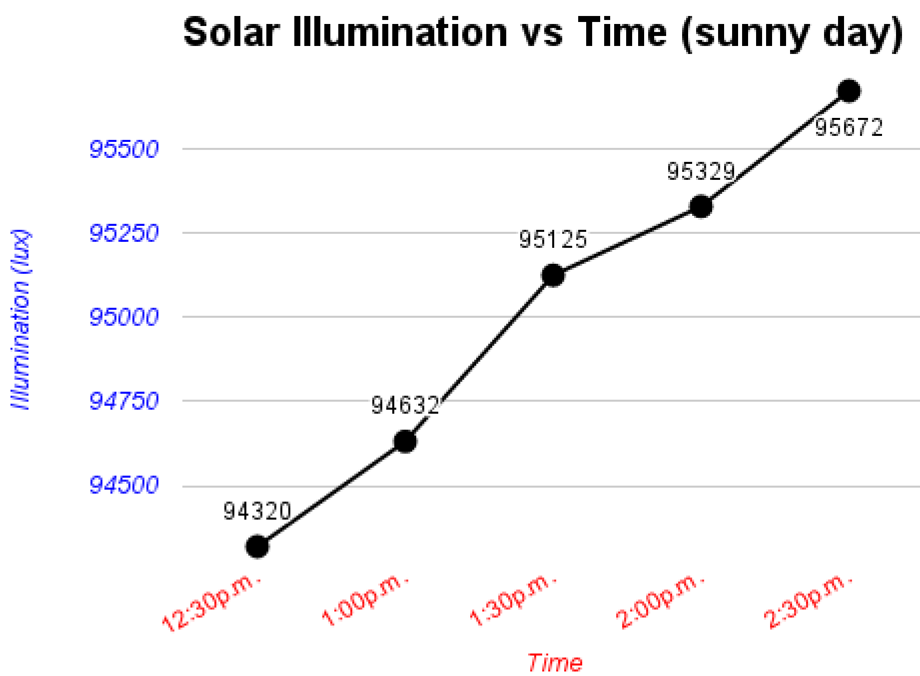
Time Driven (min:sec)	*Distance Traveled*	*Trial End Voltage*
2hr, 7 min	5.7 miles	24 volts

(Table 7. Event Simulation)

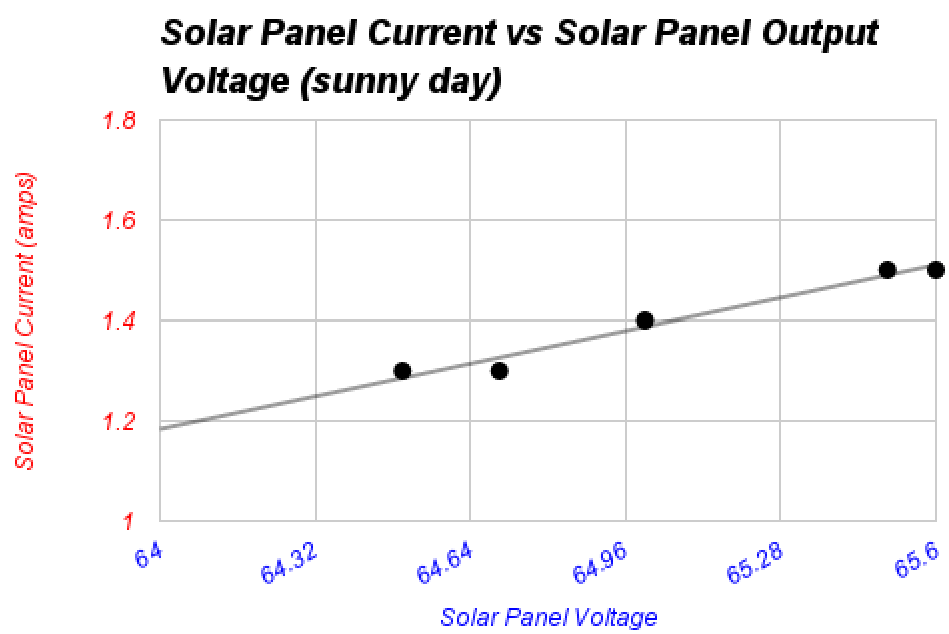
Solar Panel Output in Sunny Weather (May 27th)

Time Recorded	*Illumination (lux)*	*Voltage*	*Current (amps)*
12:30p.m.	94320	64.5	1.3
1:00p.m.	94632	64.7	1.3
1:30p.m.	95125	65.0	1.4
2:00p.m.	95329	65.5	1.5
2:30p.m.	95672	65.6	1.5

(Table 8. Sunny Weather)



(Graph 1. Lux vs Time)

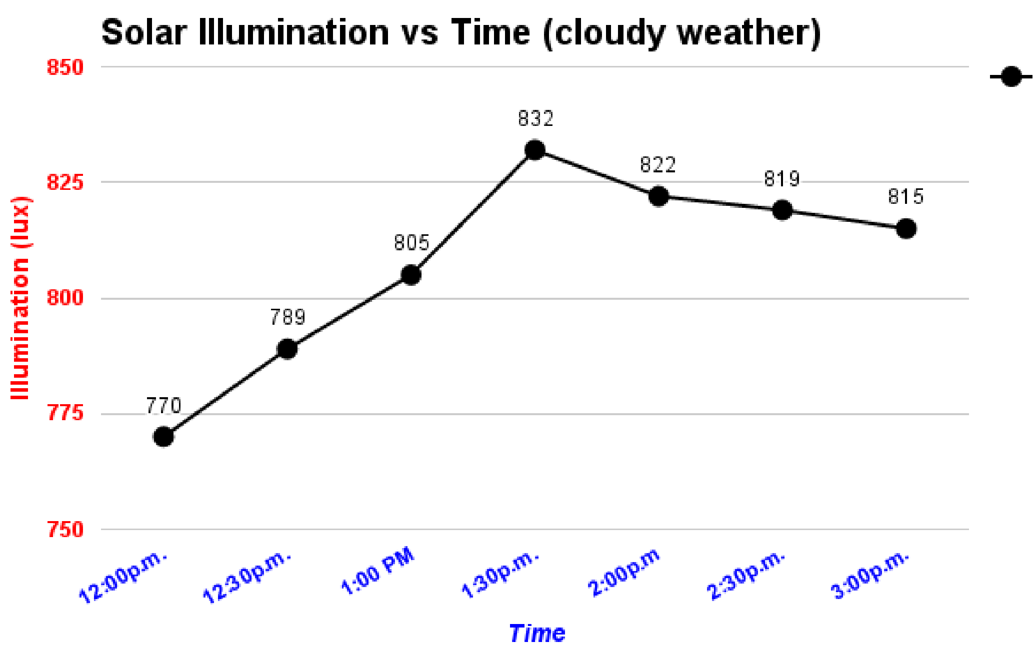


(Graph 2. Current vs Solar Panel Voltage)

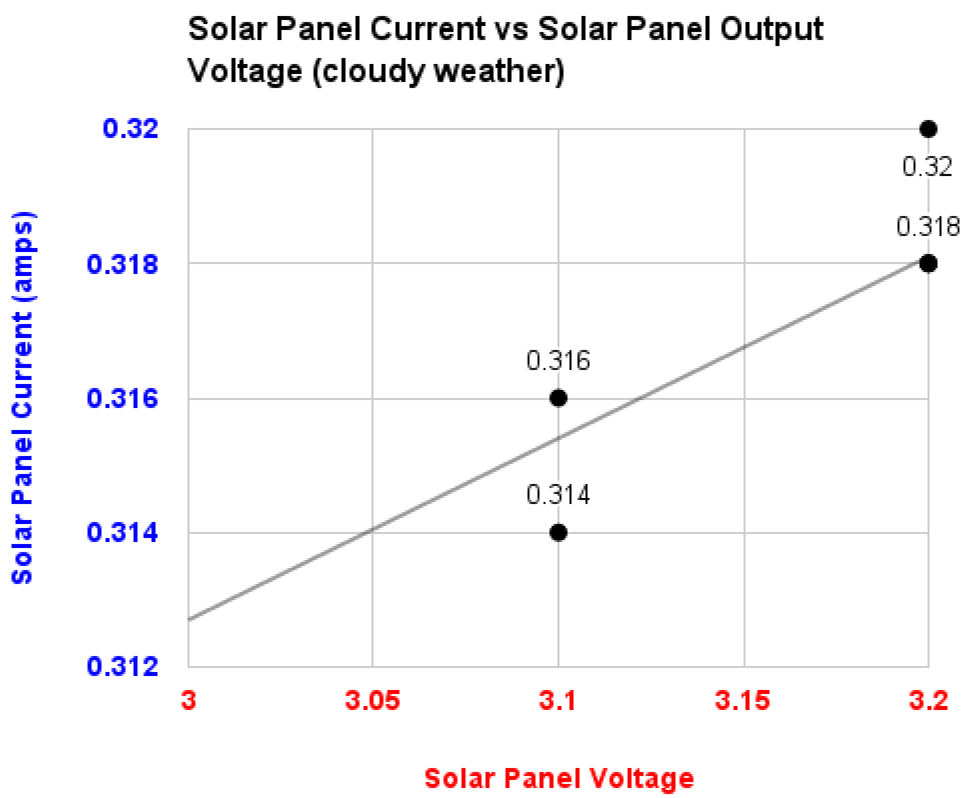
Solar Panel Output in Cloudy Weather (May 18th)

Time Recorded	*Illumination (Lux)*	*Voltage*	*Current (amps)*
12:00p.m.	770	3.1	.314
12:30p.m.	789	3.1	.316
1:00pm	805	3.2	.318
1:30p.m.	832	3.3	.320
2:00p.m	822	3.2	.320
2:30p.m.	819	3.2	.318
3:00p.m.	815	3.2	.318

(Table 9. Cloudy Weather)



(Graph 3. Illumination vs Time, Cloudy Weather)



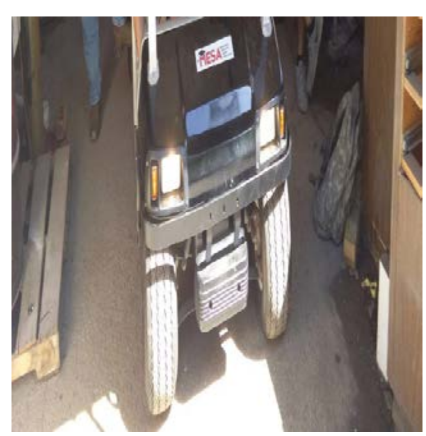
(Graph 4. Solar Panel Output vs Voltage, Cloudy Weather)

Battery Charge Time in Sunny Weather

With dead batteries (20 volts) it took the cart 6.2 hours to return to a 52 volts full charge in totally sunny weather. Due to the low solar panel output current and voltage in totally cloudy weather, the solar cart batteries would not charge.

Headlights

The headlights were the only lights not working upon initial inspection. The MadJax Ultimate Light Kit was installed by the electrical team of 2015, but due to limited time they were unable to resolve this issue. Using a 12-volt test light, the team discovered the



problem was due to the headlight switch being miss-wired. After rewiring the headlight switch another issue was found near the left side headlight connector which needed adjustment and was resolved. Now all lights and switches are operating and powered by a 48 volt to 12-volt DC-DC converter rather than a single 12-volt battery from the battery pack.

New Compartments and Plexiglas Cover

With the solar electric cart’s main purpose as a STEM marketing tool, it is essential that the cart has side compartments installed for backpacks, flyers, and other handouts. Also, a clear protective cover over the motor and electrical subsystem was needed, not only for these objects to be protected from the elements, but also to be clearly visible for bystanders to see the electrical components, and be able to ask questions about the vehicle. We placed a piece of clear Plexiglas (33”x28”) that is ¼ of an inch thick over these components. Being transparent, the Plexiglas serves as an educational tool for people to see the vehicle components. As for the side compartments, we used 3 pieces of 1x1, 16-gauge steel to frame the compartments and diamond sheet metal to finish them. The compartments cover both sides of the vehicle behind the driver and passenger seats.

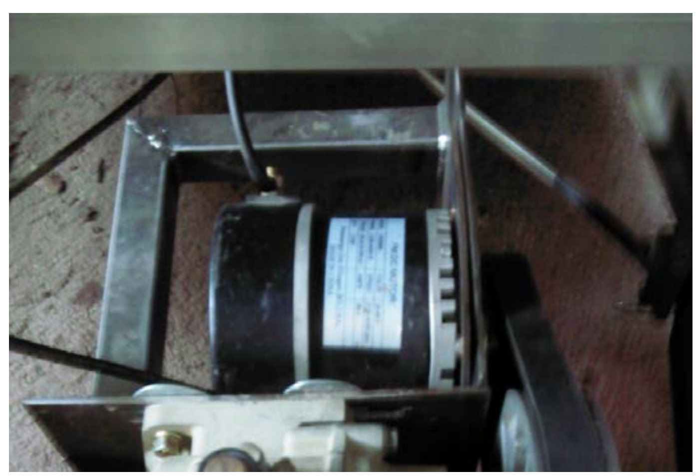
DC-to-DC Converter

A DC-to-DC converter is an electrical device used to convert a source of direct current from one voltage to another, in essence a power converter. The converter prevents draining too much power from a single battery. We installed this device in the solar-powered cart in order to safely and effectively send out power to different electrical accessories; headlights, taillights, blinker signals, hazard lights, and the horn. This allowed us to turn on the cart without worry that there would be an excess amount of power being drained from a single battery and avoiding possible damage. We bolted the converter between the 4 batteries in order to facilitate connection between all parts. After bolting the converter down, we connected the wiring.

Installation, troubleshooting and connection did not take longer than an hour and increased the reliability and performance of the cart overall.

Motor Mount

In designing the new motor mount the first order of business was developing a way to increase tension of the drive belt. The idea of adding a separate tensioner pulley was entertained while keeping the motor in a fixed position on the mount. In the interest of keeping the configuration simple and reliable it was decided instead to allow tension to be applied to the belt by allowing lateral adjustment of the motor on the mount. To accomplish this, the mounting surface of the mount is designed with channels for the pulley and mounting hardware to slide forwards and backwards in relation to the differential, thus allowing adequate belt tension to be applied . As a result, the motor, as is, would not mount flush to the mounting surface of the mount because of a small flange on the face of the motor casing. To remedy this issue a sandwich plate was developed to provide clearance between the motor face and the mounting surface of the motor mount. The second task at hand was achieving structural rigidity of the mount and alleviating the unwanted flexing in the mount and

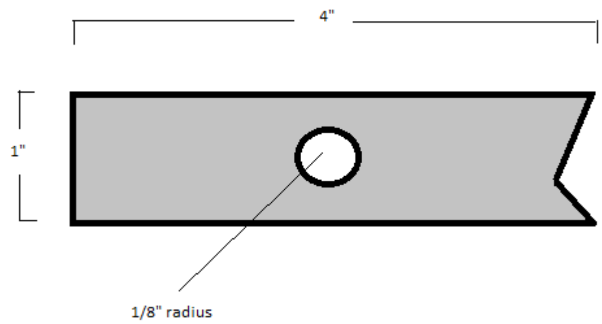


torqueing of the motor. To do this a number of changes were made to the original motor mount design. First and most important is the use of strong, high quality materials as follows. The main structure and sandwich plate is constructed using heavy ¼” steel plate. This alone is a vast upgrade over the thinner perforated steel plate used before, mainly because it allowed for a really strong weld to be generated where the two plates make their 90-degree transition. Next, instead of leaving the mount open in a 90-degree fashion the motor is boxed in with 14 gauge, 2-inch square tubing for more strength and rigidity. As a result, the motor no longer experiences any torqueing or flexing under load. Finally, the mounting hardware was upgraded to eight heavy duty bolts, nuts and washers. Addressing the aesthetics of the motor mount was the final task in the motor mount redesign. This was achieved in a few simple ways that in the end, were also inherent in making the design stronger to begin with. First, clean strong welds made the final product look clean and professional. Second, the utilization of new matching hardware not only strengthened the design but also made the final product look uniform and professional. Lastly, all the metal surfaces were brought to a polish and then clear-coated to prevent rust.

Parking Brake

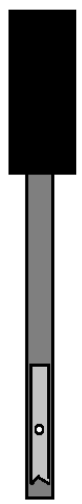
The parking brake issue was not resolved with the hill brake latch kit ordered from Mission Golf Carts due to other missing parts. The original throttle pedal was designed to disengage the brake latch when pressed in and this was caused by a cylindrical bar connecting the two petals. This bar was removed in order to mount the new electric petal by the 2015 SURP teams. In order to solve this issue the 2016 Spring SURP team designed a latch to hold the brake pedal in. The latch consists of a metal plate which swivels on the pedal so one can reach down and set the latch in place. The first attempt failed due to the swivel point being too high on the pedal causing the pedal to rise. Lowering the swivel point solved this problem.

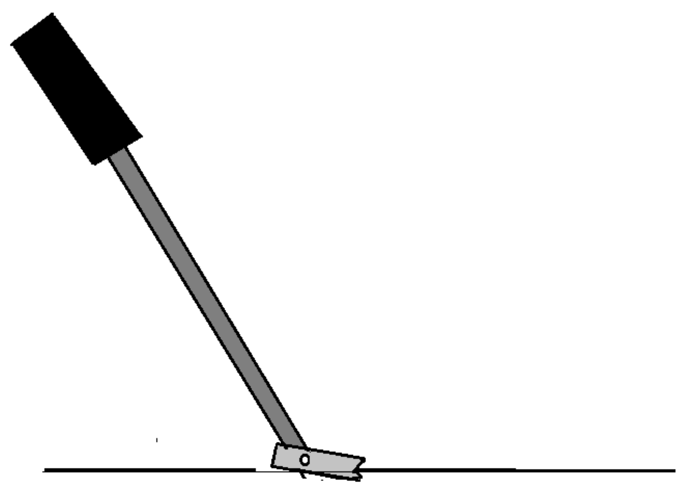
New parking brake design



(Diagram 1. Parking Brake Latch)

Brake pedal with new parking brake **Brake pedal with parking brake in use**





(Diagram 2. Parking Brake Not In Use) (Diagram 3. Parking Brake In Use)

(The Finished Vehicle)

Discussion and Conclusions

Recommended Changes for Future Projects

The project team has noted key things that could be changed in the future to further enhance the usefulness of the SolGo ARV. As noted from the data and charts gathered from above it is clear the battery life on the vehicle meets the bare minimum to be useful for an event, which is the vehicle's sole purpose. To improve this, our team recommends replacing the cart's 12 volt universal batteries with higher energy capacity golf cart batteries to increase the runtime of the vehicle. In addition, our team encountered many issues with the wiring of the vehicle, which included multiple faulty connections and tangled wires. This made diagnosing issues tougher. In order to make future repairs much simpler our team recommends neatly rewiring the cart and using appropriate wire color coding.

Data Interpretation and Suggestions

As seen from the data and graphs it is clear that the vehicle's quickest charge time and maximum potential occurs in sunny weather. The vehicle will charge in partly sunny and cloudy conditions but at a much slower rate. Also, the most optimal time for charging is between 12pm and 4pm. That's when the sun's illumination is at its highest allowing more power to charge the vehicle's batteries.

Final Word

In conclusion, the SURP team of 2016 successfully met all the objectives to repair, upgrade, and performance test the solar electric cart. The cart is now fully operational and can be used by the MESA center and other SAC entities to promote STEM programs and SURP, as well as to showcase sustainability and renewable energy.

Participants

Kevin Espinosa – Team Leader

Oscar Omenson – Team Member

Aldo Hernandez – Team Member

Matthew Lowe – Team Member

Klaus Bartels – Faculty Advisor

Acknowledgments

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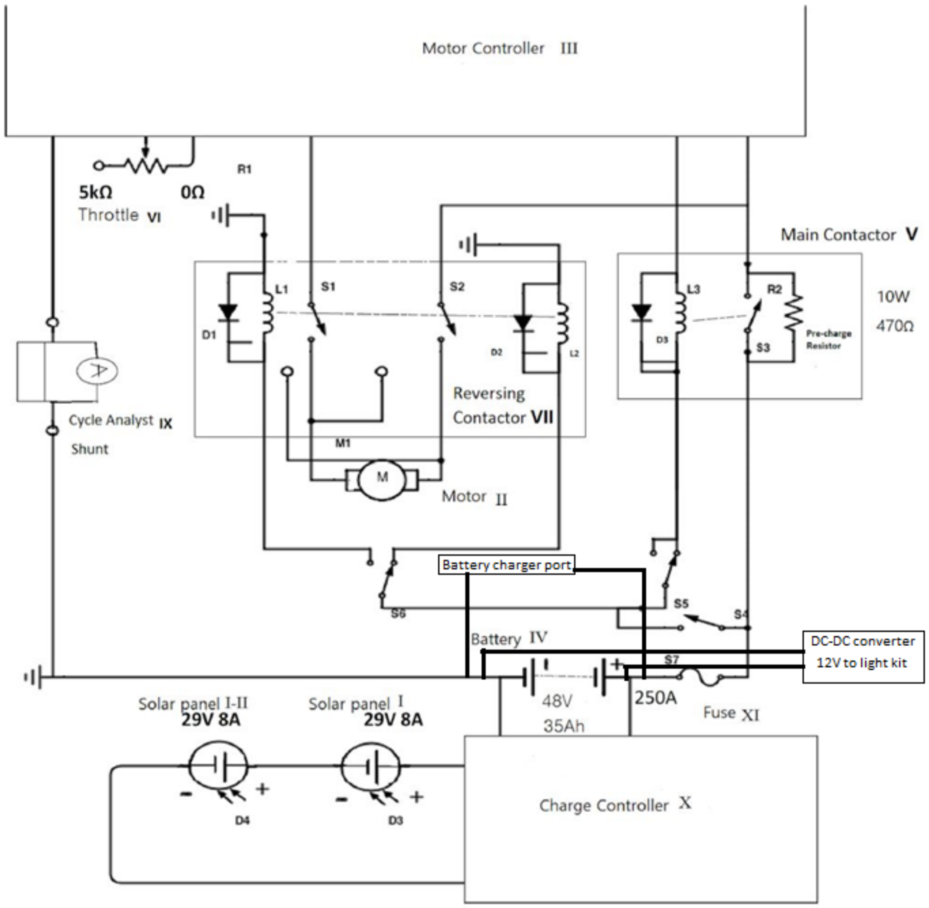
Appendix



(Electrical Diagram of SolGo ARV)