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Semi-Autonomous Golf Cart

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COLLEGE OF ENGINEERING

DEPARTMENT OF
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BIOMEDICAL ENGINEERING

Semi-Autonomous Golf Cart

UT Capstone Design Project (ME 450 & 460)
Fall 2016 – Spring 2017

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Introduction
Objectives

The main goals as specified at the onset of the project are as follows. The project will seek to retrofit a used golf cart with an upgraded or new electrified propulsion system with energy storage and design for recharge from a commercial solar charger or standard 110 AC input. The cart will also have some semi-autonomous features designed into the cart, such as the ability to stop when obstructed, and steer around moderate obstructions toward a selected GPS target location, with manual oversight and override capabilities for safety. If successful, the cart will be used by MABE for VIPs so that Students on the team will be involved in the electrification of the propulsion system with energy storage, retrofitting and design of a proper suspension, steering, and transmission system, as well as design and testing of the semi-autonomous sensing and operational transportation vehicle. Expertise required will include electrical power storage, conversion, transmission and safety, mechanical design of suspension and supporting system structure, and sensing and control for semi-autonomous operation.

Background and Summary

The goals of this project were initially broken down into two main subsystems: the physical system, which included the changes to the power train and the physical alterations, and the control system, which included the code and electrical components to interface with the golf cart. The laser scanner that was to be used for this project is a Hokuyo UTM-30LX-EW Scanning Laser Rangefinder.

In order to manage our objectives, each member initially chose a group in which the majority of their focus would be centered. Due to time limitations caused largely by the arrival date of the golf cart, delays in ordering key components of the cart, and losing our only workspace for the golf cart, the progress during the first semester was very slow. During this semester, we waited over a month from the start of the class for the used golf cart to arrive. After initial research on what we would need to know for the project, there was not a large amount of work to be done. There was also a long time before the batteries and motor were replaced or refurbished as models had to be created and testing had to be done before justification could be made regarding purchases. During this time, effort was focused on creating these models in order to speed this process along and thus the control systems side of the project fell behind. In the second semester, progress was much quicker and many of the objectives were completed by the end of the semester. It was decided that creating systems to both brake and maneuver the cart would not be feasible and thus the primary focus was turned toward braking. The base code for braking the cart was completed fairly quickly; however, delays in purchasing an actuator hindered progress. Overall, the project was considered a success with completion of the physical features of the golf cart and foundational work completed for any future efforts desired with respect to the autonomous features.

Design Process
Physical System

The received club car is an Electric 1995 DS Golf Car model; the condition at time of arrival can be seen in Figure (1) below.

Figure 1: Original Golf Cart

As can be seen in the above figure, the cart at this time could only hold two passengers and most of the physical features were worn or damaged in some way. It was desired that the cart be completely refurbished and that the cart could carry four passengers. Because essentially the entire golf cart needed to be replaced, the first step when working on the cart was to completely strip the golf cart down to the metal chassis, Figure (2).

Figure 2: Chassis of Golf Cart

This also helped in seeing the electrical system. We were able to find an online wiring diagram for the golf cart, which can be seen in Figure (3).

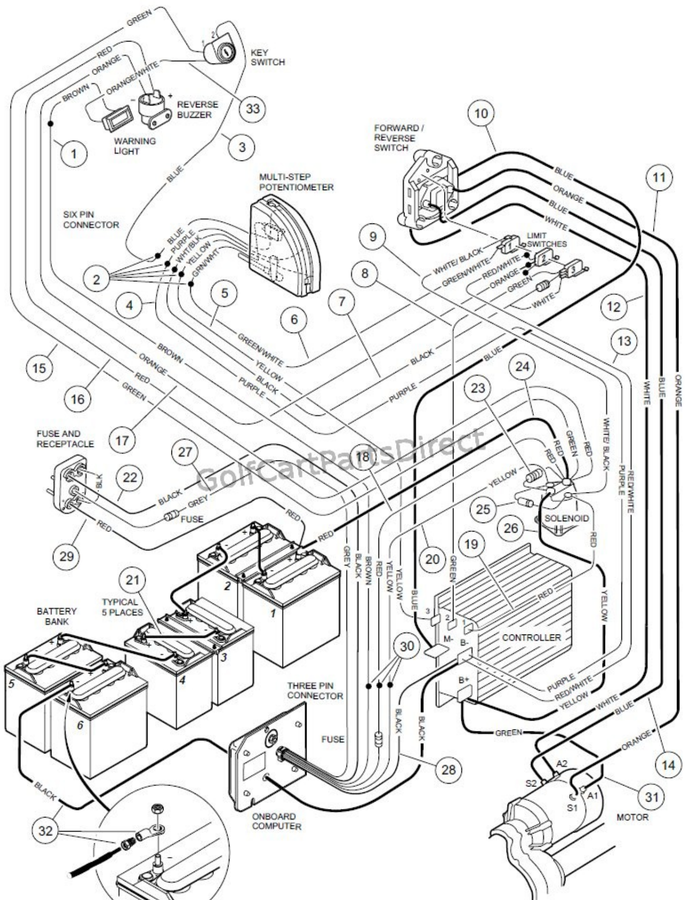


Figure 3: Golf Cart Wiring Diagram

After budget discussions, we purchased a new body, wheels, and tires, Figure (4).

Figure 4: New Body of Golf Cart

During this time, Matthew had been in contact with Efficient Energy of Tennessee and was able to obtain a donated Suniva 325 W solar panel , Figure (5), from them that could be used in order to power an auxiliary battery that would power the additional features of the cart. After discussing where the cart would be located when not in use and whether or not the additional weight of the solar panel would negatively affect the drivability of the golf cart, it was decided that the solar panel would work well as the roof of the golf cart. Testing near the end of the project determined that the solar panel was able to keep the auxiliary battery near full charge for normal conditions.

Figure 5: Suniva Solar Panel

Due to the cart now needing to carry four people instead of two as well as having a higher desired speed, several of the mechanical components as well as the power train needed to be replaced. For the mechanical component side, the original leaf spring suspension in the front and rear of the cart was replaced with stiffer springs in order to account for the additional weight. The braking system of the golf cart consists of a cable connected to two rear drum brakes in the wheels; the brake pads in these were replaced with new ones to shorten braking distance. The battery pack was replaced with a battery pack with a larger group size and high quality batteries. The battery cables were also changed from 8 gauge to 4 gauge thickness in order to reduce the internal resistance and thus increase the efficiency and decrease the heat generation. In the powertrain, the electric motor was replaced with a refurbished motor that has more dense field coils in order to increase the horsepower of the motor.

An additional 12 V battery was also purchased that was used to run additional electronic features. Wiring was ran throughout the golf cart to connect all the accessories to the front dash, Figure (6), as well as to a fuse box connected to the battery.

Figure 6: Front Dash of Golf Cart

The final version of the golf cart can be seen in Figure (7); additional physical features added onto the cart include the following: additional rear seats, custom UT front seats, diamond plate on side, large brush guard in front to protect cart and laser scanner, carbon fiber dash, windshield, side steps, handles, side mirrors, power T lights, underglow, led headlights and taillights, MABE and sponsor decals, heated seats, and speakers. Additionally, since the top of the cart had to be reconfigured, the metal supports were grinded down to smooth them out and remove any sharp metallic corners and all exposed metal was painted black. All of the accessories can be controlled via switches on the front dash. In the future, rain protection could be added to the side along with a humidity sensor located on the cart to automatically drop down a rain cover if it begins to rain.

Figure 7: Final Golf Cart

Engine and Battery

The batteries and engine were two of the most important things that needed to be determined as they were expensive and an inaccurate calculation could mean trouble down the line when testing or approximating the capabilities of the golf cart. An initial model for approximating the necessary horsepower of the engine was created early on; however, there were errors in the code that caused the estimation to be drastically off and none of the team members were able to find the errors. At one of the meetings with Dr. Mench he told us to make approximations for several of the forces in order to get a more reasonable answer and to simplify the problem down. From here, an excel sheet was generated that made approximations for the necessary power and a more reasonable estimate was made. In order to fit the cost more easily into our budget we decided to send in our old motor and receive a refurbished motor which was much more cost effective then buying a brand new motor. The refurbished motor had a higher density of the field coils in order to provide a higher horsepower output. The horsepower increased significantly from 3.1 HP to 4.3 HP, and the cart achieved a new max speed of 22 mph.

Upon receiving the new batteries, their performance was tested in a lab setting. Although many of the characteristics between the old and new batteries were similar, the new batteries had a much longer run time on a single charge because the battery quality had not been degraded due to age. The polarization curve for a single battery can be seen in Figure (8)

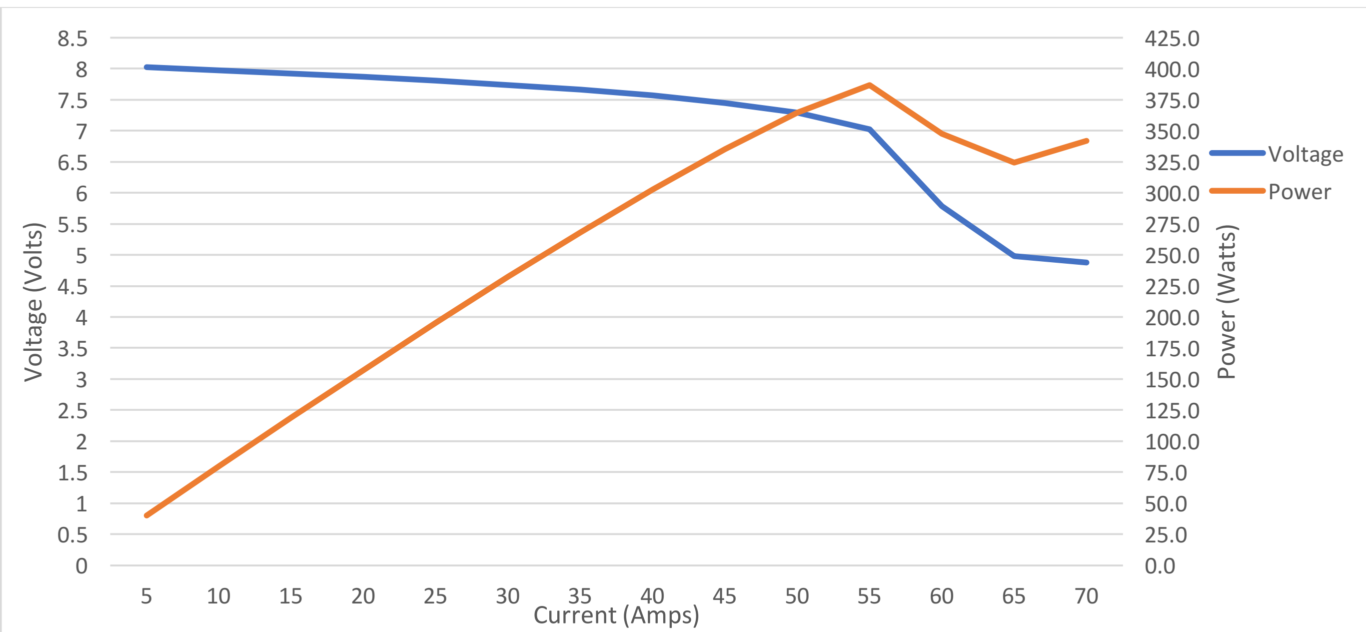


Figure 8: Polarization Curve for Trojan T-875

The graph shows that the voltage that the battery can supply slowly decreases with increasing current draw until approximately 55 amps at which point it drops much more significantly. The max power output of a single battery is around 390 watts at a current draw of approximately 55 amps. Generally, the system should not be designed where it draws more current than the current draw at the max power

Control System – Code and Electrical

In order to read the data into MATLAB from the UTM-30LX-EW Laser Scanner, which has a range of 30m and 270˚. The scanner has to be connected via an Ethernet connection to the computer running MATLAB and needs 12V input for power. The setup that the graduate students in Dr. Chakraborty's lab had previously used to communicate with the laser is a data viewing tool called URG Benri. Unfortunately, this software does not read in the data dynamically at was used by the graduate students for post processing of the data. For our project we needed a code that would continuously read in the data from the scanner and send out output signals based on the scanner inputs. In order to read the data in from the laser scanner an API created by Stathis Fotiadis was found on the MathWorks website that read the output into meaningful data. This base code consisted of three separate functions and a C++ file that needed to be compiled into a MEX file by MATLAB. The setup we used for testing can be seen in Figure (9) below.

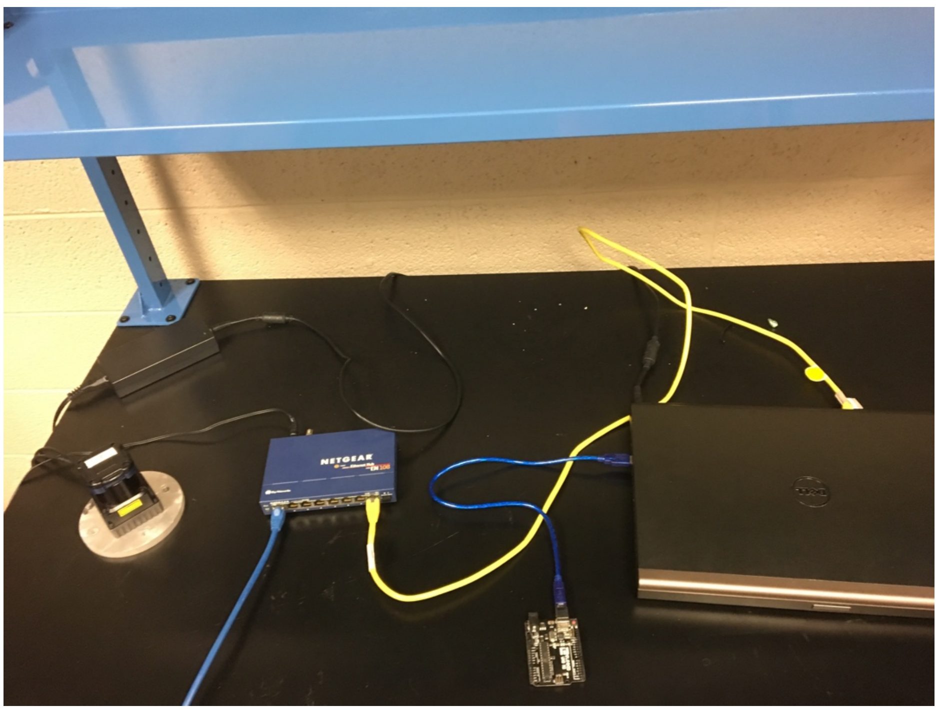


Figure 9: Testing Setup

After the code was compiled and functioning properly, the setup was tested to see how accurate the laser scanner was and to create a baseline for possible braking distances that could be tweaked at a later time. Although it was not necessary for the code to run, the data was also graphed to get a visual understanding of how the data was being imported. In Figures (10, 11, & 12) on the next page, two sample scans can be seen with an accompanying picture of the layout of the room.

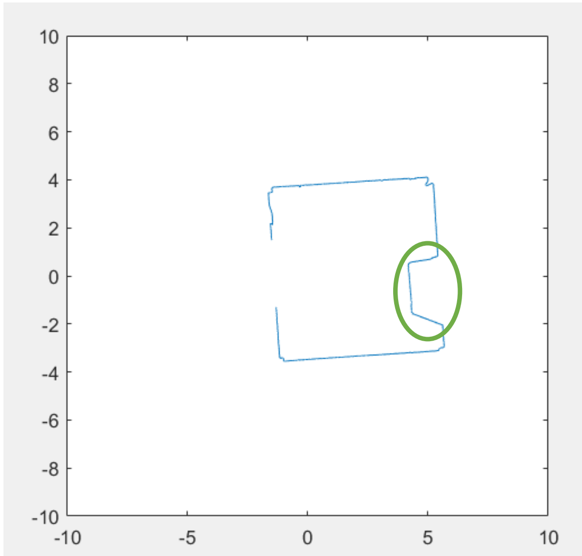


Figure 10: Scan of Room, High

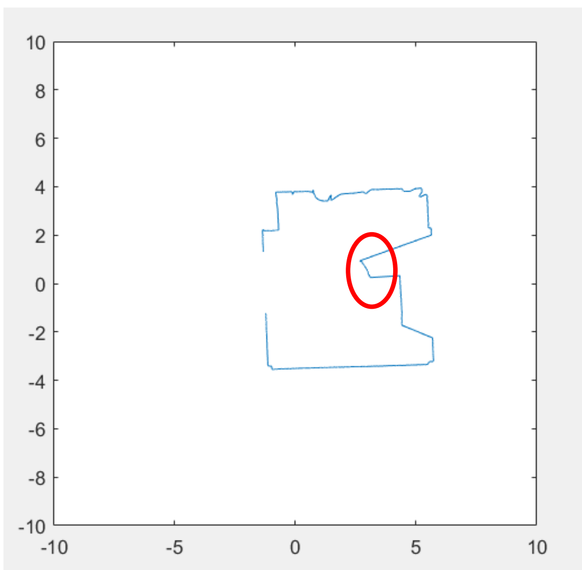


Figure 11: Scan of Room, Low

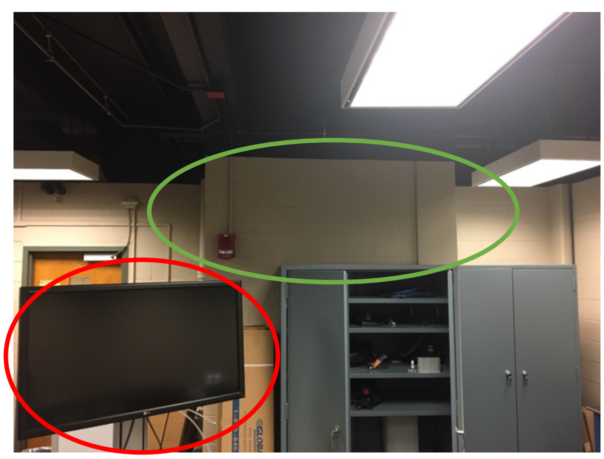


Figure 12: Room Layout

For the scanner data, the scanner is located at (0,0) on the graph. From this point an imaginary x-axis extends positively in the x-direction and an imaginary y-axis extends positively in the y-direction. Directly in front of the scanner corresponds to 0˚ from the x-axis on the graph and rotating to the left in the physical world corresponds to an increase in the angle from the x-axis (rotating counter-clockwise from 0˚).

Figure (10) shows a scan of the room at above head height; because of this, only the large outcropping outlined in green is visible along with some smaller obstacles around the room. It is also observable in Figure (10) that the right edge of the outcropping appears to be at an angle; this is because of the angle that the scanner makes with the outcropping and thus it is unable to fully see around the edge. In Figure (11), more obstacles are observable including the standing television screen outlined in red and a large drawer in the back left of the room (top left of graph) that is unobservable in the picture.

After getting the base code to work and read in the data, code was added to process the data. The output of the MATLAB code wrote a signal to a digital pin on an Arduino depending on whether the actuator needs to extend or retract. In Figure (9), the setup is only the testing setup and thus does not have the electrical connections after the Arduino that would be used to control the braking. In the actual setup, an H bridge connects the battery output to the linear actuator. The signal from the Arduino determines whether the H bridge will pass a positive or negative voltage and for how long this voltage is allowed to pass to the actuator. The time that the actuator is extended determines the position and thus how strong the braking will be. Currently the actuator is set up so that it directly applies force to the brake pedal. This is so that a system malfunctions at worst results in the brakes being applied and the cart coming to a stop; in the future this system could be improved. Although we did not get to the point where we could implement parking, our general idea for future work would be a servo motor with a clutch connected to the steering shaft. This would allow the driver to disengage the steering motor if necessary.

Challenges

One of the main challenges of this project was delays caused both by external and internal factors. Outside of the project group's control included factors such as getting the golf cart late after the start and getting kicked out of the lab space we had to work in with the golf cart. Because we were getting a used golf cart from an alumni, we had to wait for the cart to be ready for pick up. This took a little more than a month; although we had initial research that could be performed and brainstormed project ideas, the bulk of our project occurred after we received the golf cart. In retrospect, this is one area that could have been improved, because even though our project plan detailed us starting the physical and control modifications after we received the cart, the initial work on the controls system did not require the cart. Thus, we would have been more likely to get further into the project on the autonomous features of the golf cart. Another external factor that affected our team included getting kicked out of our workspace due to renovations that were occurring in the room. This delayed installing physical features onto the golf cart by around a week and created additional work that needed to be done moving and rearranging all of our equipment.

Internally we had a few instances where delays in purchasing of equipment created various challenges that had little time to be overcome. One instance of this was a delay in buying a linear actuator for the automatic braking mechanism. Although we knew our project would be using a linear actuator by late February, one was not purchased until mid April. Since we did not have the actuator until near the end of April, there was only one week to figure out how it would work since none of us had hands-on experience using actuators before. After figuring out how it worked we then needed to update code and electrical circuits to work with the actuator. Despite determining that the actuator extended and retracted based on the polarity of the voltage and updating the code, we realized we would need a high amperage H bridge to control the polarity of the voltage. This had to be ordered and would take one-two weeks to arrive meaning that the project would not be completed in time for the Engineering Expo.

Encountering these obstacles stressed the importance to all of the team members the importance of efficient time management and identification of parts of the project which are needed for completion of the project. In the future, properly deciding which portions of the project must be done in series and which must be done in parallel will help in the progress of projects.

Conclusions and Recommendations

Overall, the project was a success. Despite the autonomous features not being fully complete by the end of the semester, the physical features and aesthetics are done. The golf cart has already been used to transport VIPs and is expected to see much more use in the future. All of the controls for braking are in place, it is only necessary to finish wiring up the H bridge after delivery.

Figure 13: Group Picture at Engineering Expo

In the future, it will definitely be beneficial for the more of the students who sign up for the project to be comfortable with basic coding as well as control systems. One major limitation was that all the coding and controls aspects of the projects were written and implemented by a single student as no one else on the team was comfortable with the work necessary. This caused delays as the portion of the project no one on the team was completely familiar with was delegated to only one person. Since all of the current physical features for the golf cart are completed, the majority of the work on the cart will be implementing autonomous features.

Team Member Contributions

Valerie Cherry – In charge of purchasing orders for the golf cart. Maintained an updated budget for the team. Researched into legal and safety requirements of golf cart on campus. Put together final poster for presentation.

Brooke Davidson – Wrote weekly reports for meetings. Created Gantt Chart first semester as well as put together the first semester progress report.

Richard Emeott – Lead student working on installing all of the physical features of the golf cart. Wired all of the accessories to run through auxiliary battery and be controlled through the dash. Created model that was used to approximate run distance and run time of golf cart as well as the final model that was used to approximate the necessary horsepower of the motor. Found a service that refurbished used motor to increase horsepower. Worked with a graduate student in Dr. Mench's lab to determine old versus new battery output.

Daniel Garza – Lead student working on all autonomous features of the golf cart. First semester created preliminary model for determining horsepower requirements of golf cart. During the second semester found a base code that would read in data from laser scanner into MATLAB and wrote all additional code for braking system. Worked with a graduate student in Dr. Chakraborty's lab to determine how to interface MATLAB output into the physical braking interface.

Matthew May – Worked with Richard to install various features of the golf cart. Contacted multiple external organizations to attempt to acquire donations for the project. Successfully acquired the large solar panel that acts as the roof to the golf cart.

References

Club Car. (1994). 1995 DS Golf Car Gasoline/Electric: Owner's Manual. Augusta, GA: Author.

Fotiadis, Stathis. (2012) *API for Hokuyo UTM-30LX-EW* (Version 1.0) [Source Code]. http://www.mathworks.com/matlabcentral/fileexchange/37613-hokuyo-utm-30-lx-ew-for-matlab

Wiring – 48V. (2017). Retrieved from https://golfcartpartsdirect.com/Category/563

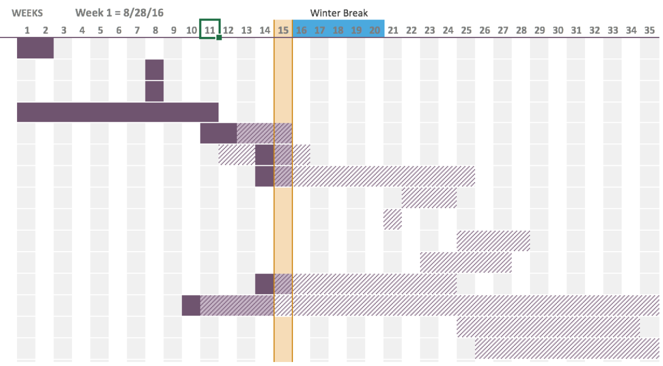
Appendices

Gantt Chart

Autonomous Golf Cart

Period Highlight # | Plan | Actual | % Complete | Actual (beyond plan) | % Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Brainstorm Project Ideas	1	2	1	2	100%
Examine Cart and Create Action Plan	8	1	8	1	100%
Disassemble and Clean Cart	8	1	8	1	100%
Research Ideas and Fit to Budget	1	11	1	11	100%
Test Old vs New Battery Performance	11	5	11	5	50%
Pair Motor with New Batteries	12	5	14	2	10%
Aethestic Upgrades	14	12	14	2	10%
3D Printed Wheels	22	3			0%
Body Installation	21	1			0%
Suspension	25	4			0%
Weather Protection	23	5			0%
Integrate Solar Power	14	11	14	2	20%
Sensor Programming	10	26	10	5	5%
Autonomous Integration	25	10			0%
Excess Budget Upgrades	26	10			0%



MATLAB Code Sample

```
%%  Hokyuo UTM30-LX-EW
%Daniel Garza
%UTK MABE 2017
parking = 0; %false / GUI to change to 1 (true) if auto-parking
range_old = []; range_comp = [];
bnew = 0; bold = 0;
if isempty(a) %checks if arduino connection has already been opened and saved
    a = arduino();
end
%% Start Continuous Loop
while true
%Fotiadis API found online
if ~exist('t','var')
    t=utmOpen;
end

start=0;
stop=1080;
skip=0;

res=0.25;        %URG-30LX-EW

angleVector=((res*start:res:stop*res)-135)'.*pi/180;

%clear data

tic
    rangeVector= utmGetScan(t,start,stop);
    plot(rangeVector.*cos(angleVector)/1000,rangeVector.*sin(angleVector)/1000)
    axis([-10 10 -10 10])
    axis square
%plot above not needed
toc
%end of online API
%% Computational Start
if isempty(range_old) %initial values for old data
    range_old = zeros(size(rangeVector));
end
changerange = rangeVector-range_old;
range_old = rangeVector;

%% Braking

i = 1;
for k = 1:size(angleVector,1)
    if angleVector(k) >= -pi()/4 && angleVector(k) <= pi()/4 %361 values
        range_comp(i) = rangeVector(k);
        i = i+1;
    end
end
%Step braking currently, possible to add more or make a continuous increase
%in braking
range_compfar = range_comp; range_compmid = range_comp; range_compnear = range_comp;
range_compfar(range_comp<600) = 0;
range_compmid(range_comp<400) = 0;
range_compnear(range_comp<200) = 0;
tol = 350; %values needed above threshold

%The pause is how long the actuator is active for depending on object
%distance; afterward rewrites signal to 0
if (nnz(range_compnear) < tol) && (parking == 0)
    disp('BRAKE HARD')
    writeDigitalPin(a,'D13',1)
    pause(1.5)
    writeDigitalPin(a,'D13',0)
    bnew = 1;
elseif (nnz(range_compmid) < tol) && (parking == 0)
    disp('BRAKE MEDIUM')
    writeDigitalPin(a,'D13',1)
    pause(1)
    writeDigitalPin(a,'D13',0)
    bnew = 1;
elseif (nnz(range_compfar) < tol) && (parking == 0)
    disp('BRAKE SOFT')
```

```
    writeDigitalPin(a,'D13',1)
    pause(0.5)
    writeDigitalPin(a,'D13',0)
    bnew = 1;
else
    bnew = 0;
end
%Retract Brakes if previously braking but not currently braking
if bnew == 0 && bold == 1
    writeDigitalPin(a,'D13',1)
    pause(5)
    writeDigitalPin(a,'D13',0)
end

bold = bnew;
%% Parking
if parking == 1
    disp('Auto-Parking Initiated') %placeholder for parking
end

pause(0.1) %delay time between scans
end
```