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Montañas del Sol: A Solar Charging Station

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Abstract

The workload that many students undertake can often be stressful and overwhelming. Students are constantly tethered to electrical outlets because technology is required to complete most work; this means studying outside is rare and short-lived. In 2014, the American Psychological Association reported an approximated one half of college students suffered from anxiety and roughly one third from depression[2]. These percentages have risen steadily since 2010, as have the number of college students who have considered suicide. Studies have shown that sunlight, an important source of Vitamin D, can help lessen the feeling of depression. Others suggest that sunlight can even increase cognitive thought[1]. Using this information, it was determined that a mobile solar-powered charging station is the most appropriate response to this problem. To create such a structure required overcoming a variety of challenges including multiple redesigns, limited funding, a lack of knowledge on solar energy, and a strict schedule. The purpose of the station is to create an avenue for students to be productive outside while receiving the benefits of sunlight and fresh air. Artistic form coupled with engineered functionality and sustainability provide a stress-reducing environment in which students can comfortably work.

1. Introduction

The motivation behind Montañas del Sol is to apply engineering to sustainability and mental health. It will have a profound impact on campus; therefore, many individuals in the university will have some level of investment. Stakeholders of this project include Neil Rosenberg and Susan Reiser, as well as faculty and students on campus. In order for the project to receive approval and sponsorship, it was necessary to excel in many aspects. These include sustainable energy, autonomous behavior, artistic form, safety, and mobility. The photovoltaic cells draw enough power to charge devices and simultaneously store energy for situations with non-favorable conditions. Autonomy is implemented through solar tracking to achieve maximum efficiency. The visual aesthetics serve to draw the attention of students, faculty, and visitors, thus increasing the project's impact in the community. User interaction is limited and other precautions have been taken to ensure the station meets safety regulations. The advantage of creating a mobile station is that the station has an increased lifespan and is protected from extreme weather conditions. The vision behind its fabrication is to allow the station to function for many years and become a mainstay on campus.

2. Background

A 2009 study about the "effect of sunlight exposure on cognitive function among depressed and non-depressed participants" [3] by Shia Kent from the University of Alabama at Birmingham, analyzed data from what is referenced as the "Stroke Belt" and compared it to "non-Stroke Belt" inhabitants. The data sets were chosen based on baseline data from another large study called "REGARDS". The study references other known ideas that serotonin and melatonin regulation depends on the climate and season[3]. The chemicals affect mood and cognition; this would reduce to the chemicals directly affecting cognitive function. Another study on the "benefits of Sunlight" states "Moderately high serotonin levels result in more positive moods and a calm yet focused mental outlook" [11]. In short, both studies concluded that there is a relationship between sunlight exposure and cognitive function based on sunlight exposure for a duration of two weeks[3].

Another study by Kara Zivin, researched the prevalence of mental health problems among college students in regards to longitudinal data[10]. Zivin used surveys to conduct the research across large public universities with a two-year follow up survey and found that over half of the students surveyed at the beginning had at least one mental health issue[10]. After the two year follow up, 60% of those students still had at least one mental health condition[10]. Serotonin and Melatonin levels would decrease with a difference in longitudinal location as there is less sunlight with an increase in longitude, thus causing mental health problems. The conclusion was that there is a prevalence of mental disorders amongst students, and that those students who do suffer from disorders do not seek treatment. If students across universities do not seek personal treatment, then the results from Zivin's and Kent's studies could lead to a possible solution for individuals who cannot seek treatment.

Based on these results, a possible solution is a solar charging station that does not inhibit an individual's ability to work while exposed to sunlight. If an individual is tethered to an outlet indoors for a long period of time, the individual may begin showing signs of depression. Therefore, if the only object(s) keeping the individual indoors is an outlet and wireless internet connection, then an outdoors charging station that provides internet and shade to work under should be a solution to depression. The extra benefit of the station is its ability to use clean energy while providing services to a consumer.

2.1 Literature Review

Studies have shown an increase in mental health disorders amongst college students and have shown that sunlight has a positive effect on cognitive thought while decreasing depression[3, 10]. Many universities, including the National University of Singapore, King Abdullah University of Science and Technology, and Hampshire College, have implemented solar powered charging stations on their campuses, similarly addressing the rise in mental health disorders[1, 4, 9]. Photovoltaic stations on college campuses are a supported effort with many benefits including recruiting potential students and raising environmental awareness[8]. Many devices, especially those in industrial and developing nations, take a mobile and transportable approach to provide affordable power to regions in need of renewable energy[5]. Batteries play an important role in the longevity of the device[2] as well as the peak output[7]. Ethics factor in greatly when selecting the appropriate solar panels, whose fabrication has been linked to chemical pollution[6].

2.2 Market Research

This device is relevant to students' need to decrease stress levels in addition to the provision of power. Compared to pre-existing solar charging stations, this structure is mobile and incorporates solar tracking in order to maximize power generation. Similar to Montañas del Sol, other stations incorporate a sense of environment and allow individuals to interact with the device and with one another[8]. Sol-up highlights the differences between common charging stations around established universities and this product. Currently, all of them are stationary and unable to track the sun causing a decrease in efficiency and an increase in time spent charging[8]. Stationary stations without solar tracking or visual aesthetics cost approximately $3,900. This price is slightly more than the Montañas del Sol budget. Another product for mobile charging is a micro solar panel. Each panel is capable of charging mobile devices such as cell phones in a matter of a few hours[5] . The downside to micro solar panels is their size and capacity. They do not provide shade to work from, they do not provide internet access, and they cannot store energy.

3. Development

3.1 Design Process

Professional help was sought as a starting point to maximize the efficiency of our station. Individuals from Sundance Power Systems supplied a general outline of how a solar power system functions, the electrical components required, and the recommended items necessary for the project. Bob Harris, a solar expert, suggested a Solar Pathfinder should be used to determine the maximum amount of sun exposure any location would experience (Figure 1).

Figure 1. Solar pathfinder on UNCA quadrangle

The Solar Pathfinder is placed due south and shows any structure that may block the sun. Each vertical line represents a time in a day. The horizontal lines represent the month of the year. For an example of a structure that will block the sun, the tree on the right side of the Pathfinder (Figure 1) close to the actual sun will create shade between the hours of 4:30 P.M. and sunset during late summer and early autumn. The Pathfinder was used to find several optimal locations on the campus of UNC Asheville.

The original design was a large stationary structure with seven slanted solar panels at various locations on top. The arrangement of panels would work in hand with the mountainous shape used to symbolize Asheville’s geographic region. It would charge four devices while also providing a bench for students to work in the shade provided by the structure. However, after campus policies were taken into consideration, it was necessary to increase mobility and to scale the structure down.

The intermediate design was comprised of five solar panels. The solar panel configuration consisted of one stationary panel and four panels that would move autonomously. Five solar panels at 350 watts each could power four laptops and two USB ports. The four moving panels started in a vertical position and raised through a 90° angle to end in a horizontal position parallel to the ground. When fully horizontal, the system’s height would be six feet tall. The panels would then pitch up or down to capture maximum sunlight. The motion of the solar panels was to be initiated by data collected from an array of photoresistors. However, this design had certain flaws such as weight, safety concerns, and a large budget. In order to address these flaws, a change in size of the project, the storage of the solar panels, their motion, the number of devices being powered, and the number of panels to complete the project.

The final design is a mobile charging station that can power two laptops and one USB device with two 200 watt solar panels. The solar panels will “bloom” from the top of the structure and find the most optimal position for power production from the sun, as seen in (Figure 2) and (Figure 3). Having the solar panels dispatch from the top of the structure is necessary to limit potentially hazardous user interaction. Once the panels are fully extended, values from an array of photoresistors are taken and processed to change the pitch of both panels. For example, if the resistors angled towards the horizon experienced higher values than the resistors looking directly up, then the panels would be realigned to draw the most intense light.

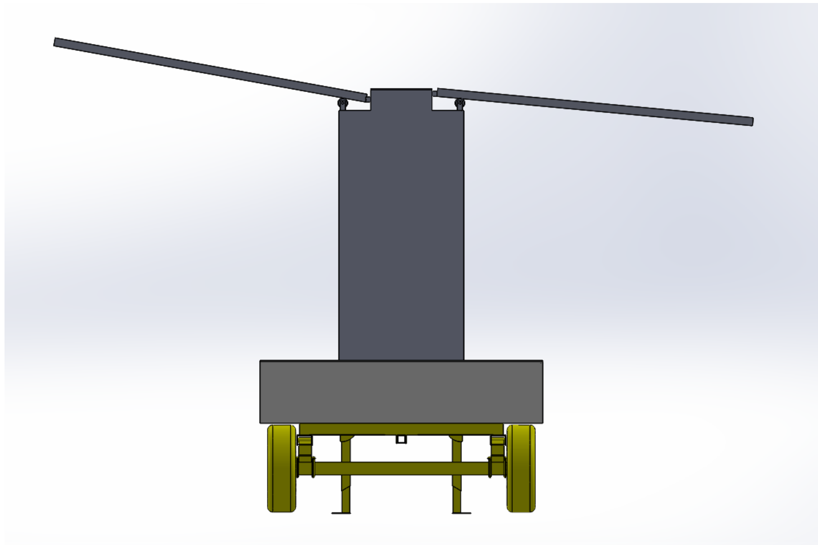

Figure 2. Final design in fully bloomed position

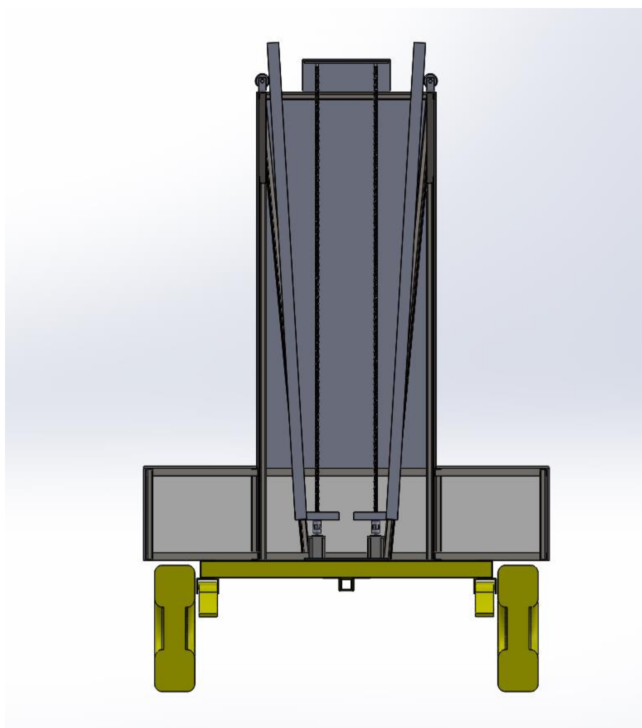

Figure 3. Final design in stored position

The transition from the state seen in (Figure 3) to the state seen in (Figure 2), is due to a system of acme lead screws driven by NEMA 23 motors. This system has a total of six rods that are vertically aligned in two sets of three, with the center pole being the driving lead screw. A poplar wood piece that is six inches by thirty-two inches will allow the solar panels to be raised and lowered to desired heights. Rollers are placed at the top of the structure, as seen in (Figure 3), to aid in a smooth transition described above.

In order to measure the angle of the sun, a housing unit was fabricated to snap fit photoresistors into place at 18° apart. The photoresistor housing was modeled using a cross-section of an extruded semi-circle as the main inspiration to track the angle of the sun. It was determined to be based on a semi-circle so that placement of the photoresistors are perpendicular to the incoming sun's rays, which would create the ability to follow the sun from sunrise to sunset.

Although this project is mobile, it is necessary to secure and ground the structure while in use. With an establishment of a desired location, ground anchors will be used to prevent theft, hinder tilt and potential instability, and to ground the cart for electrical safety purposes.

3.2 Design Justification

The size of the station has progressed throughout the design process. The original project was to be a permanent structure to support a seven solar panel construction. However, due to the legal implementation and delays that a permanent structure would create, the idea was discarded and resized to fit on a hitch trailer. The trailer is 81 inches long measuring from the hitch to the back, 52 inches wide measuring from wheel to wheel, and a maximum height of 16 inches. These dimensions became the system boundaries for future development.

Prior discussions with Bob Harris led to a minimum height of eight feet on the system otherwise all electrical wires would need to be completely concealed in conduit due to safety concerns regarding exposed electrical wiring and human interaction. Pedestrians cannot have the opportunity to reach and interact with a wire as this could cause a failure in the system and/or potentially cause harm to the pedestrian. Considering the potential for structural issues with an eight-foot frame and a strict height restriction of seven feet in the storage location of the cart, the maximum height of the station was set at 6.5 feet with all wires being concealed and housed inside of the structure.

It is necessary to limit the interaction between the moving panels and a passerby or potential user. Precautions were taken to make sure the solar panels at maximum deflection go no lower than six feet and two inches above ground level. Given that the total height would be six feet and ten inches, give or take an inch, it was discovered that the five foot and two inch long solar panels could be angled downward at approximately six and half degrees without interfering with an average height user.

Tran describes mobile charging stations as a more productive use of a station because it accommodates its functionality to different populations on campus and broadens the user population size, thus creating a higher demand for another similar system[8]. The function of mobility is used for an increase in the promotion of the school and the clean energy programs on campus. It is also used to allow for future designs to be based on this current system. Lastly, due to the issue with building a permanent structure on a public campus, a mobile system would avoid most legal issues with building and safety tests.

The benefit of tracking the position of the sun is that it increases the efficiency of the system by more than twenty percent. Using previous studies, such as Maroma's cell phone charging station, it was deduced that the panels needed to have mobility to provide an effective amount of power to charge devices and continuously track the sun[1]. Because Maroma concluded that the panels were not completely optimized to capture the sun unless they are manually changed, a system with automated mobility would eliminate this issue. Without mobility, the final product could have no benefit leaving the project with a similar result such as Maroma's.

3.3 Criteria for Success

In order for the system to be classified as a success, the structure must be able to move the solar panels into the "initial position" where they are parallel with the ground. The Arduino Mega microcontroller can then begin to read values from the photoresistor housing. It must be able to change both solar panel's angles to keep the solar light perpendicular to the panels using only the photoresistor values as the input variable to describe the angle. The panels cannot create shade on one-another, but are required to provide shade to users below the structure. The reflection of light from the panels must not interfere with the photoresistors as this may cause false measurements. The system must be able to charge multiple devices such as a laptop and a cellular device while turned on. Wi-Fi extension should be available from the cart for the devices in proximity to the station so they can connect to the internet. The solar panels need to be retracted back into the internal frame for storage if the intensity of light is not sufficient. Interaction between a user and the system must be limited; a user may only have access to plugging in their devices and "turning on" the device.

The system must serve an average of two to four people for eight hours continuously per day when placed out in high traffic areas to be considered a success. Usage of the device would include using the panels above as shade from the sun, charging a mobile device, and using the Wi-Fi extender built in to connect to the campus internet.

The system should diminish an individual's stress by allowing the person to work while being exposed to the outdoors. This is measured by asking for potential users to take a survey before and after the station is introduced.

3.4 Material and Budget

The electrical system is designed to run on 24 volts of direct current (DC). Two, 205 Watt solar panels generate DC power from the sun that is then stored in two 12-volt lead acid gel batteries and then distributed to the rest of the system. A voltage regulator is used to ensure the batteries do not overcharge, which can lead to a shortened lifespan. Six photoresistors provide inputs to an Arduino Mega 2560 which then outputs a signal to two stepper motors. A controller provides voltage to the voltage regulator from the solar panels and batteries. Any excess power to the voltage regulator goes back to the batteries. A pure sinusoidal wave inverter converts the DC power into AC power. A Wi-Fi extender was added to improve study conditions at the station by creating a stronger Wi-Fi network wherever the cart is placed. Other electrical components include 12 and 22 gauge wire and a GFCI outlet.

The mechanical system has one degree of freedom in the vertical direction, which is created by the combination of a stepper motor and a six-foot lead screw. Linear bearings and couplings are also used in conjunction with the motor and lead screw. The panels are lifted vertically through the frame with weight as the driving force that pulls the panels down. In order to ease the lowering of the panels, slow close hinges are used to dampen the motion and protect the panels. Once the panels are fully extended, the panels rotate according to the intensity of sunlight. To create a smooth rotation of the panels, a plastic roller is used.

The base of the station is a single axle trailer, with dimensions 81 inches in length, 52 inches in width, and 16 inches from ground to base. The frame is made of 0.125 inch thick angle iron. The electrical components are housed inside the frame and sit on a bed of plastic. The outer casing is made of plastic board with aluminum trimmings.

3.5 Funding

With the overall budget for the project at approximately $3500 USD, the items on the overall Bill of Materials, as seen in (Table 1) below, had to be separated into multiple budgets because funding was coming from multiple locations that were unaffiliated. From the overall Bill of Materials, multiple budgets, separated by the Undergraduate Research Grant, funding from the department, outside gifts, and team fundraising, were created to distribute the cost effectively.

Table 1. Overall Bill of Materials

Item Name	Description	Quantity	Unit Cost	Total Cost Per Item
Inverter	Pure sine wave power inverter rated 1000 - 2000 W DC 12V(A series)/24V(B series)/48 V (F series)	1	$150.00	$178.00
Solar Panels	205 Watt 24V solar panel 62.2x31.8	2	$229	$670.06
Lead Acid Gel Batteries	Maintenance-free back up power 97.6 amp hrs, 12 V	0	$138.88	$0.00
Voltage Regulator	12/24v auto switch PWM battery regulator charge controller, maximum 480W	1	$13.58	$13.58
Photoresistor	20 pcs sunkee photolight sensitive resistor phosoresistor optoresistor 5mm, max voltage- 150v DC, max wattage- 100mW	1	$6.99	$6.99
22 gauge wire	22 AWG stranded Type B electronic Hook up wire, 100 ft	3	$8.50	$27.41
12 gauge wire - Donation	100 ft gray 12 gauge wire with 3 wires rated for 600 v	0	$69.96	$0.00
GFCI- Donation	15 amp 125 v GFCI for Indoor/outdoor use	0	$19.98	$0.00

Stepper Motors		2	$39.99	$85.98
Couplers	Wrong Size	2	$10.50	$22.58
Acme Nuts		2	$31.77	$68.31
Lead Screws	6'	2	$69.71	$149.88
Arduino Mega 2560		1	$34.95	$37.57
Linear Bearings	Support runners	4	$27.78	$119.45
Guide poles 6 ft long	Will need to ask for discount to get this price	4	$6.98	$30.01
Bearings to cap lead screw		4	$5.57	$23.95
Hinges for mounting panels	Sugatsune NSDX-20LK, Left Hand Adjustable Soft-down Stay	4	$15.73	$27.00
Coupler	1/4" to 1/2" Flexible Coupling Set	2	$11.00	$40.51
Angle Iron	1/2" angle steel 20' pieces	10	$20.00	$193.67
Aluminum Trim	96 in. Decorative Aluminum Edging A813 in Anodized	4	$18.99	$81.66
Silicone Caulk	Silicone II 10.1 oz. White Kitchen and Bath Caulk	6	$5.98	$38.57
Rollers for top of case	Proto-Pasta High Temp Carbon Fiber PLA Filament 3.00mm (0.50 kg)- to print bearings	1	$43	$46.23
WI-Fi Extender	USB Wi-Fi Range Extender,TONGJI High Gain 2.4GHz 300Mbps Wireless Wi-Fi Signal Range Amplifier (White)	1	$32.99	$35.46
Plastic Lumber	4′ X 10′ X 1/16″ to 1/2″	3	$94.02	$552.83
Nomex Type 410	.003 x 24 000 x 36 000 ft. Heat resistance, strength, durability and dielectric properties	1	$20	$20.00
Rubber strip	X-Treme Tape TPE-X36ZLB Silicone Rubber Self Fusing Tape, 1" x 36', Triangular, Black	1	$11.61	$11.61
Handles	Cabinet lock	2	$8.57	$17.14
Ground Anchors	Auger-Style Anchors	2	$36.75	$88.45
Lifting Mechanism	Poplar wood board for lifting the solar panels	1	$23.6	$23.60
L BRKT 7/16H 1.88	Bracket for rollers	8	$5.70	$57.69
K40P10	Rollers	4	$12.82	$51.40
Rocker Switch	125 VAC 16 A illuminated	1	$2.92	$2.92
	Sub Total:	$3,206.77	Total:	**$3,431.25**

The two grants from Undergraduate Research each provided $500 USD; additionally, the Mechatronics program provided $500 USD. The grant from Undergraduate Research funded major electrical hardware such as a pure sine inverter and a voltage regulator along with small items like nuts and bolts. The Mechatronics program gives each senior design team a set budget of $500 USD for the entire year; therefore, all of it was saved for the final product's most expensive mechanical items such as the angle iron for $198.00 from Bonfire Barbeque in Asheville NC. It was cheaper to purchase through a local business due to delivery charges and the university's tax-exempt status.

A Go Fund Me page was created to finalize all funds necessary in a timely manner so that the product could be built and tested. The initial goal was $1500 USD to cover the minimum components that were remaining on the Bill of Materials at the current time. However, the goal was raised to $2000 USD to also cover any material that would be required for any rising issues during the build process. The more ambitious goal was met with enough surplus to cover the charge for the Go Fund Me account and all other deductions required to transfer the funds. In creating a Go Fund Me, the building and testing processes were expedited.

3.6 Testing (Methodology)

Testing the charging station requires testing the major components of the system such as all photoresistors being used and their reaction to different mediums, the two stepper motors, the control program, and the integrity of the structure.

3.6.1 photoresistors

The design to track the sun requires six photoresistors snap-fitted into a round, semi-circular housing (Figure 3.). Each photoresistor, (Figure 4), is placed at a different angle so that the theoretical value of light intensity generated by the resistor cannot be replicated by another resistor. The testing procedure can be done without the housing.

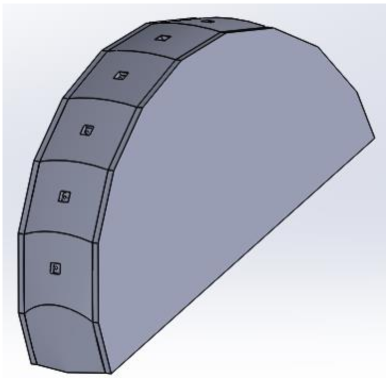

Figure 3. Photoresistor housing.

Figure 4. Photoresistor.

First, each resistor must be tested to ensure that they all have similar values when exposed to direct sunlight. A test bench is created using one resistor. The resistor is placed on a breadboard and taken outdoors with full sun exposure. The test bench is tilted either towards the direction of the sun, or away from the sun. This causes the values from the photoresistor to increase if tilted towards the sun, or decrease if angled away. A serial print of the values from a photoresistor can be seen in (Figure 5). The numbers shown below represent the light intensity when the photoresistor was held perpendicular to the sun.

```
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1008
Analog reading = 1008
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1007
Analog reading = 1006
Analog reading = 1006
Analog reading = 1006
```

Figure 5. Serial print for direct sunlight test of one photoresistor.

Next, the photoresistor was tested to see if a plexiglass cover causes the values to change. This question is asked because light can refract through a given medium, in this case, clear plexiglass. Plexiglass is being used to prevent any moisture from interfering with the terminals on the photoresistors and prevent corrosion on the housing. To test this, a photoresistor is placed on a flat surface so that the error created in the test is at its minimum. Then, the plexiglass sample covers the resistor, making a medium between the light source and the resistor, and values are taken and compared to the sample with no plexiglass.

3.6.2 stepper motors

Many methods were examined when deciding how to create the desired motion of the solar panels. Initially, linear actuators were chosen due to their light weight and ability to lift tremendous amounts of weight. The price of the actuators exceeded the budget and the strength was not necessary since the amount of solar panels was reduced to two panels. Neil Rosenberg, a faculty advisor, suggested using two stepper motors controlling lead screws as a cheap, reliable, and simple way to lift the two panels.

Integrating stepper motors with an Arduino Mega involves driving the motors with an A4988 driver which is powered by the Arduino. The driver takes the four inputs from the stepper motor then utilizes power from a 12-volt battery and a step and direction pin to turn the motor. The step pin and direction pin connect to the Arduino. The step pin alternates between a high output and a low output which sends a pulse, or step, to the motor; two hundred steps make one full revolution of the stepper motor. The direction pin controls which way the shaft of the motor rotates; when high, the shaft rotates counterclockwise and when low, the shaft rotates clockwise.

To ensure no damage occurs to the NEMA 23 motors due to excessive amounts of current, a current limit must be set. Embedded onto the driver is a potentiometer that has a small screw that adjusts the amount of current supplied by the driver to the motors. The potentiometer is set by twisting the screw with a small screwdriver while checking the voltage, or Vref, from the potentiometer to the ground. Using equation (1) and knowing that the NEMA 23 stepper motors have a current limit of 2.8 amps, it follows that the Vref can be no more than 1.4 volts.

$$\text{Current Limit} = 2 * V_{ref} \quad (1)$$

3.6.3 coding

Once the drivers and motors are wired correctly, code is created to control the motors. Initially, the motors have to drive the solar panels up the entire length of the acme lead screw. The lead screw is six feet and moves one inch per ten revolutions; knowing this, the code tells the motors to complete sixty revolutions so that the panels are out of their housing. Once the panels are completely extended and in the "initial" position, the panels are then rotated according to the data from six photoresistors. There are three cases in the code: rotate the panels approximately 6.5° below horizontal, keep the panels horizontal, or rotate the panels approximately 6.5° above horizontal. The six photoresistors are divided into three sections. For case one where the panels rotate below horizontal, the two photoresistors to the far left of the photoresistor mount have the highest values. Case two where the panels are horizontal corresponds with the middle two photoresistors on the mount having the highest values. Case three where the panels rotate above horizontal corresponds with the two far right photoresistors having the highest value. An example of the logic put into the code can be seen in (Figure 6).

```
FinalCode

//bring the solar panels to horizontal position
for(x=0; x<(init_posSolarPanel*200); x++)
{
  digitalWrite(stepPin1,HIGH);
  delayMicroseconds(Speed);
  digitalWrite(stepPin1,LOW);
  delayMicroseconds(Speed);
  digitalWrite(stepPin2,HIGH);
  delayMicroseconds(Speed);
  digitalWrite(stepPin2,LOW);
  delayMicroseconds(Speed);
} delay(5000);


photocellReading1 = analogRead(photocellPin1);
photocellReading2 = analogRead(photocellPin2);
photocellReading3 = analogRead(photocellPin3);
photocellReading4 = analogRead(photocellPin4);
photocellReading5 = analogRead(photocellPin5);
photocellReading6 = analogRead(photocellPin6);

//find the initial position of the sun
if ((photocellReading1 + photocellReading2) > (photocellReading3 + photocellReading4)) {
  digitalWrite(dirPin2,LOW);
  current_state = STATE_ONE;
  for(x=0; x<angle_switch; x++)  { //rotates panels to the left position 6 degrees
    digitalWrite(stepPin1,HIGH);
```

Figure 6. Arduino code for controlling the stepper motors.

3.6.4 structural integrity

The trailer was tested by putting 175 pounds of force along its outer beams, as well as the dividing beam running through the center. Once the sheet metal was attached to the trailer, 100 pound weights were added to test its integrity. These tests resulted in negligible deflection and showed that the structural integrity of the trailer was satisfactory to handle up to 2000 pounds.

With the trailer dimensions defined, a Solidworks model of a frame to go on top of the trailer was created. The frame was designed to be made out of 1.0"x 1.0"x 0.125" angle iron. Angle iron was chosen to be suitable for the structure because it has strong characteristics, is lightweight, and is easy to work with in regards to welding and attaching components. When first modeled, the frame was created with the intention of minimizing the use of material in order to cut down on cost and weight. However, when testing the Factors of Safety (Figure 7), a catastrophic failure occurred in which parts of the frame would oscillate given a downward test force. Factor of Safety is the load carrying capacity of the frame beyond what the frame is intended to handle.

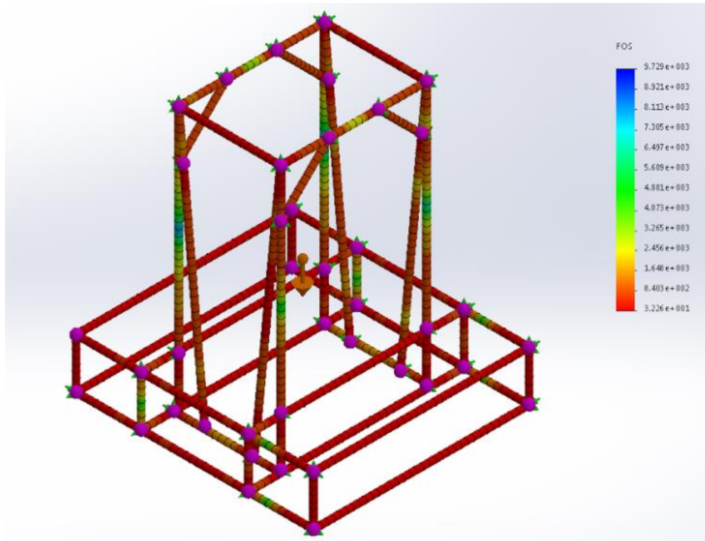

Figure 7. Factor of safety, Test 1.

(Figure 7) shows the color red, which is associated with the minimum potential strength of the frame. Strength refers to the maximum weight an object can handle before failing. Therefore, a high potential strength is desired which would be reflected by the color blue. In order to change the color from red to blue, support had to be added to the sides in a vertical position, and horizontally across the frame. Once these adjustments were made by adding in extra support on the bottom piece of the structure vertically and horizontally, a second test was performed. This test resulted in an increase of 200% success (Figure 8). This test solidified the frame dimensions for manufacturing before adding external attachments.

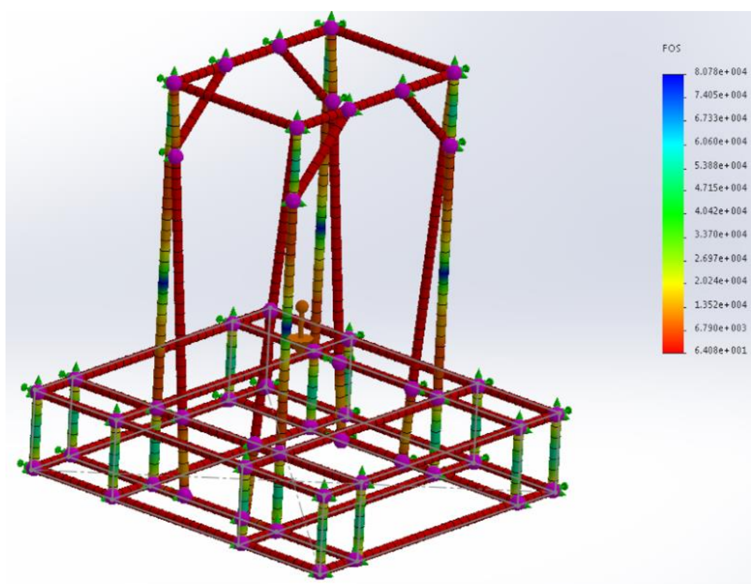

Figure 8. Factor of safety, Test 2.

(Figure 8) shows that with extra support on the bottom frame, where the failure from test one occurred, the maximum amount of force the frame can experience had an increase in strength by a factor of two. The red color is still occurring, but this does not mean that there needs to be additions or substitutions to the frame. It means that the minimum amount of strength the frame could handle at those locations is double the strength that test one handled at those same positions and that those areas are the weakest in comparison to the strongest locations.

The final test the frame model must undergo is a maximum displacement test. This determines the deflection that the frame will experience if given a point load at its weakest position. The closer the value is to zero, the closer the model is to be being robust. The frame designed in the Factor of Safety test two was tested for its maximum displacement (Figure 9). If the displacement is too high, then the frame must be redesigned and retested for its Factor of Safety again before moving on to testing its maximum displacement.

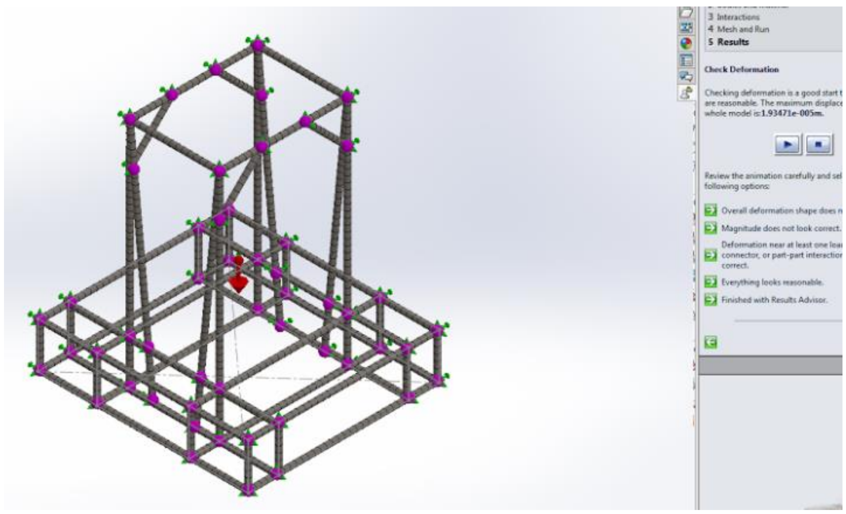

Figure 9. Maximum Displacement Test

(Figure 9) shows the maximum displacement test resulted in a maximum displacement of 1.9347*10^-5(0.000019347) m. This is as thick as a single human hair. In other words, the frame's weakest locations will not move significantly given a load.

3.7 Project Management

The work required to build a project on this scale requires a method of dividing tasks into short features that would allow for the completion of mechanical, electrical, and software development. The two forms of management to choose from were "Waterfall" and "Agile". Waterfall is compatible with mechanical and software development as it breaks tasks into sequences, however there are issues when some parts of the project are in a different phase than other parts. It also does not blend well with multiple team meetings. Agile on the other hand, allows for different areas of a project to be at different phases and promotes the use of team meetings called "scrums". Each scrum is used to keep all members of the team up to date on all events within another individual's tasks. From these two choices, Agile was better suited for the project as it allows tasks to be divvied up to members of a team at a rapid rate. It also fits into the demand to allow for scrum meetings at regular intervals.

Because the type of management chosen was Agile, Kanban is an added bonus to the project because it is a tool that gives a visual aid for recording all progressing, uncompleted, or completed tasks. This tool also asserts that if the task is completed, it may not need to be revisited again unless a major issue occurs with the project backlog.

The project backlog is a prioritized list of functions that are desired by a set date. It does not define all steps required to finish a task because the scrum meetings are meant for that. To build a working charging station, six items were on the backlog: completion of receiving a grant for sustainability, mechanical design by February 3rd, software development by April 1st, electrical implementation by March 21st, structure built by April 1st, and product tested by April 26th. Some of the items' due dates were either too early for practicality or predicted at too late. Due to a pressing deadline, a Go Fund Me fundraiser was created to test if it could take the place of the Sustainability Grant. Because of the fundraiser's early success, the scheduled backlog could change with the elimination of the completion of the grant. Timing was crucial for this project. For example, the mechanical design which required all power calculations, the location of the device, the orientation and motion of the solar panels among other tasks, was completed by February 3rd which led to the construction portion of the project to be on schedule.

4. Calculations

Because the charging station is off-grid, power is a limited necessity to both the control system and the user(s). To determine the number of panels, the power must be calculated as if it were fully loaded. P is power, measured in watts, V is the voltage, and I is the current. In other words, the maximum amount of power being drawn from the controller and the mobile devices must be calculated. The hardware's power usage is calculated using equation (2).

$$P = V*I. \tag{2}$$

Then each component's watt-hours are calculated based on an estimated amount of time being used. For example, the controller was estimated to run for 24 hours. Therefore, the power, in watts, of the controller is multiplied by 24 hours. Once each component's watt-hours are found, the sum is taken for the total amount of watt-hours required. Then the total is divided by the efficiency of the system because the power is converted from direct current to alternating current. Equation (3) represents this concept, where "t" is the estimated time of use and "e" is the efficiency.

$$Wh = \sum(P*t)/e \tag{3}$$

The next equation is based on the amount of sunlight exposure the planned location will experience. It was calculated that the most sunlight the station would experience would be approximately 5.4 hours because the panels are able to track the sun therefore increasing the efficiency of the system. For comparison, stationary panels receive 4.8 hours of sun exposure. Using 5.4 hours of peak sun hours, equation (4) multiplies the hours by a solar panel wattage to determine its watt-hours. "T" is the peak sun hours and the panel wattage is "W." Peak sun hours are the solar insolation a location receives measured in time.

$$\text{Panel Wh} = W*T \tag{4}$$

Dividing the watt-hours demanded by the watt-hours supplied by the panel, the number of panels required can be determined using equation (5) where "N" is the number of panels.

$$N = Wh/ \text{Panel Wh} \tag{5}$$

The battery voltage was determined to be 24 volts, but this does not affect above calculations as it is used to determine the average amount of amperes and ampere hours, which is important for grid tied systems. The complete calculation for the system (Table 2) includes all calculations.

Table 2. Power Calculation Of Off Grid System

#comp	2	90		180				eff	0.85
motor	2	124		248				discharge	0.8
cont	1	2.88		2.88				volt	24
USB Port	1	0.625		0.625					
			hrs	8	6	5	4		
			Wh	1912.61	3106.90	2602.64	2098.37		
			avg amp	79.6921	129.454	108.443	87.4323		
			amp hr	348.653	566.363	474.439	382.516		
panel W	hours	Wh							
205	5.4	1107		1.73	2.8	2.35	1.90		

From (Table 2) the panel wattage chosen was to be 205W as two panels would produce enough power to keep the system stable. The total watt-hours, as seen below the hour's row, is an overestimation as different device adapters may differ in power rating and the exact amount of watts for a Wi-Fi extender (USB port) is for a generic model of such a device.

5. Societal and Ethical Impacts

The solar charging station affects users in a multitude of ways: it creates a sense of community, promotes the flow of ideas between individuals, and helps to decrease depression. One of the main goals of the station is to allow multiple people to gather so that they may exchange ideas, make new friends, and assist each other on work. Furthermore, being tethered to an outlet indoors for a long period of time may cause an individual to show signs of depression due to the fact that the person is giving up their ability to attain necessary Vitamin D in exchange for obligatory work. Studies have shown that sunlight, an important source of Vitamin D, can help lessen the feeling of depression[3, 10, 11]. As this station is outdoors, scholars will be able to work outdoors without sacrifice in any way. They will be able to work as there is a wireless internet connection and access to power for their devices should they need it and they will be able to acquire sunlight without damage to their skin as the device provides shade.

This project is attempting to provide green energy via solar panels in order to prevent the use of fossil fuels. It is true that solar energy is environmentally cleaner than fossil fuels, but according to Dustin Mulvaney there are situations where the manufacturer has not kept the environmental impact to a minimum[6]. The panels being used in this project are made from polysilicon. The process to manufacture polysilicon requires refining quartz, which creates a byproduct called silicon tetrachloride and when exposed to a water supply, it can cause soft tissue inflammation and render crop growth[6]. To prevent this, silicon tetrachloride can be reused to manufacture polysilicon. Polysilicon is cut into wafers and processed with hydrofluoric acid which is more hazardous than silicon tetrachloride. If the acid is exposed to skin, it will "destroy tissue and decalcify bones"[6]. It may also contaminate a region's water supply which causes fish and all animals that rely on the water to die. A substitute to this process is sodium hydroxide, which is safer than hydrofluoric acid, but it can still cause chemical injuries as described above. Not only is the process toxic, but according to Mulvaney, the energy cost and water usage is extremely high. He describes that if the Chinese used the panels manufactured there, the "high carbon intensity of the energy used and that of the energy saved from using the panels would cancel each other out, with the time required to counterbalance greenhouse-gas emissions as the same as the energy-payback time"[6]. The process also requires roughly one and a half billion liters of water[6], but compared to fossil fuels, it is significantly lower.

Overall, the process has improved thanks to organizations, companies, and consumers demand for clean solar panels. The manufacturing companies that use Chinese factories have consistently monitored the process and tracked all emissions and chemicals used. Solar panels are truly a greener technology than burning fossil fuels and the energy-payback time is relatively short when installed.

All intentions in this project have focused on improving work conditions for the users while supporting the campus-wide green initiative. Students, faculty, staff, and visitors will have the opportunity to work outdoors comfortably all while knowing they are using clean, renewable energy.

6. Conclusion

Stress is unnecessary, but inevitable in college students. The Montañas Del Sol charging station will combat that stress and create an outdoor atmosphere of learning, as research suggests that studying outside is both more productive and more relaxing. This project is unique in the fact that it encourages students to attack the source of their mental anxiety instead of finding an alternative method to alleviate that stress. In order to facilitate this, the station is engineered to have minimal distractions such as moving parts, noise pollution, accessibility, and discomfort. Through the use of solar tracking, the solar panels will be utilized to their maximum, providing and storing enough power to ensure the extended use of the station is possible. Thorough precautions, including safety regulation, well-fabricated framework, steady electrical connection and standard sealants, will allow this project to work for many years with minimal maintenance and user interaction. It will be a staple of the University of North Carolina at Asheville and represent the institution's ideals, including creativity, environmental awareness, and productivity.

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