Practicality and Implementation of A Solar Tracking Panel

INTRODUCTION / PROBLEM STATEMENT

The lack of sustainable energy has become a crisis in the modern world, and any way to increase the generation of energy will ultimately become beneficial to the future of both the world's ecosystem and the livelihood of humanity as a whole. The problem we face today in solar energy is the amount of energy being wasted. By having a dual axes solar panel that follows the sun's movement, you are able to harvest the maximum energy that a solar panel is actually capable of producing in one day. The solar-tracking system implemented in this research takes use of Arduino electrical systems and hardware.

LITERATURE REVIEW

A report done by Dr. M.G.R at Chennai University studied relatively the same project basis as the one shown in 1a. Dr. M.G.R tested the energy efficiencies between single and dual axi panels. He also referenced the relationship between the Earth and Sun's geometrical reference position to find the optimum angle for setting the photovoltaic panel. Reference angles are important to the project because an algorithm can follow a set path instructions to keep the panel on track if there is a cloudy day. Avoiding an algorithm can cause the panel to miss valuable times that the panel could be facing the sun. The panels that Dr. M.G.R tested include: fixed panel, single axis panel, and dual axis panel. The results of his finding between a 10 hour time interval (8:00 a.m. -> 6:00 p.m.) include an efficiency rating of 32.17% from a static panel and 81.68% from a dual axis panel. In other words, the dual axis panel had a power generation increase of 49.51%, which is an immense improvement in photovoltaic amount.

A detailed technical report done by the Faculty of Electrical Engineering and Computer Science at the University of Maribor, Slovenia, defines the different types of solar-tracking panels by classifying them into 4 categories: Fixed PV systems, tracking PV systems, single-axis tracking systems, and dual-axis tracking systems. Single axis tracking systems can be further subdivided into horizontal, vertical, and neutral tilt panels, referred to as (HSAT), (VSAT), and (TSAT), respectively. The dual axis panel can also be subdivided into two more further categories: azimuth-altitude and tip/tilt tracking systems. These two systems are abbreviated to (AADAT) and (TTDAT), respectively. They define the different types of panel configurations because there are two ways a solar panel can receive a higher concentration of solar energy, increase the solar absorbency of the surface material or increase direct solar radiation by directing tilt perpendicular to the sun's UV rays.

HYPOTHESIS

I hypothesize that the photovoltaic tracking system (TTDAT) will return a voltage rating of >35% in comparison to a static PV panel. The results are highly dependent on the time interval's allowance for perfect solar absorption, so I will choose days that have very similar cloud percentages. I believe that the panel will return over 35% more energy compared to a static system because upon reviewing technical reports on the subject matter, TTDATs suggest that efficiencies can range between 30-55% compared to their static counterparts, so I chose an amount on the low-end to take into account lower quality components.

RESEARCH QUESTIONS

1. How much more energy can a solar-tracking panel harvest compared to a fixed panel?
    a. Solar-tracking panels require two dimensional rotations in order to properly track the sun's movement throughout the day. A non-moving panel is deprived of valuable time under direct sunlight in order to harvest as much viable energy from an approximate 14.5 hours of daylight. With a solar-tracking system, the total amount of solar energy gathered would exceed the total amount of solar energy gathered from a non-moving panel.
    b. If the system were to be scaled, the application for a 2-axes panel expands to anywhere that receives daylight between (x-y amt). Designing such a system would optimize non-moving planar panels and produce more solar energy. Panels now are only 15-18% effective at receiving the sun's energy. By finding out the difference in efficiency between a solar-tracking panel and a fixed one, one could determine the viability of the project by comparing the effort to build a tracking system versus the actual energy received.

2. What type of solar-tracking systems can you make on a budget?
    a. The simplest form of solar-tracking is a single degree PV system that rotates around the azimuth angle and has a set inclination angle focused towards the sun. Rather than buying sensors, one could write an algorithm that calculates a very basic movement of the sun. If an algorithm was avoided, the project wouldn't be very viable because it loses out on inclination capable of directing itself perpendicular to the sun. This project most likely could be done with an arduino, solar panel, servo, and some cables. The estimated cost would be around 40 dollars. However, an algorithm-based system would be extremely difficult to code because one would have to account for change of sunlight during solstices, and the loss of efficiency because the lack of a second degree of freedom

b. A flat, dual axis solar tracking system that rotates around the azimuth-altitude angle (AADAT) is an intriguing type of solar tracking system because of its low-profile design. The azimuth-altitude solar tracking system rivals the tip-tilt solar tracking system because it allows for two degrees of freedom and can be made with relative prices- around 61 dollars.
c. The best choice for the most efficient, low cost, and simple design is the tip-tilt system. Dual axes allows for 2 degrees of freedom, which surpasses the single axis panel because it does not require an algorithm to track the sun. By avoiding an algorithm based project, sensors can be used to allocate the panel to face directly perpendicular to the sun. The tip-tilt system costs an estimated 60 dollars, which is negligible compared to the azimuth-altitude system. The greatest advantage of the tip-tilt is its simplicity to build. An azimuth-angle panel requires a central shaft and bearings to operate, while a tip-tilt's driving mechanisms can be directly connected to their solar panel, hence the simplicity to build. This is most likely the reason why large-scale solar plants use tip-tilt designs.

OBJECTIVES

- Replicate a tip-tilt dual axis tracking panel.
- Harvest the maximum amount of solar energy possible with the components being used.
- Contrast solar yield between a tip-tilt system and static PV system.
- Begin to learn how to implement 3d-printed designs through cad files.
- Determine whether cost input is feasible in comparison to the energy output of a TTDAT system.
- Discuss scaling opportunities and how to achieve them.

METHODOLOGY

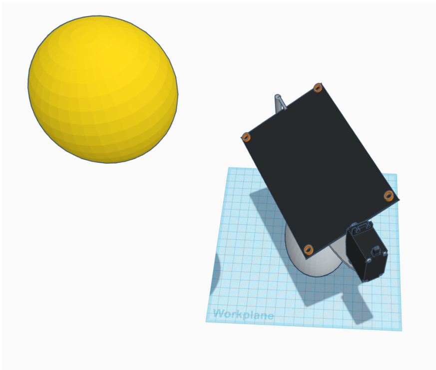
Materials used:

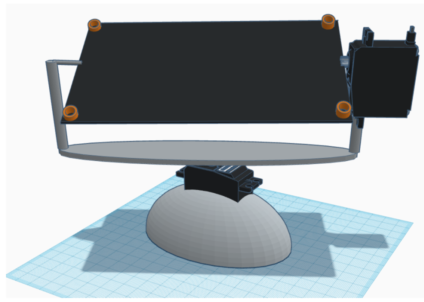
1x Arduino Uno
1x Mini BreadBoard
2x SG 90 Micro Servo
4x LDR Sensors
4x 10k-ohm Resistors
1x 5V Solar Panel
Assorted jumper wired

Mechanical Components Used:

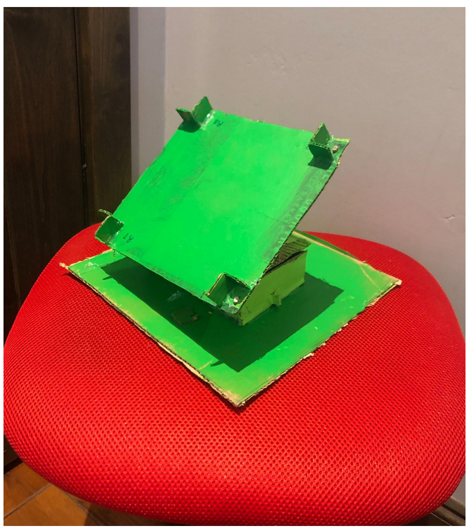
Basic Soldering Kit
Basic 3D Printer

Initial CAD Design:

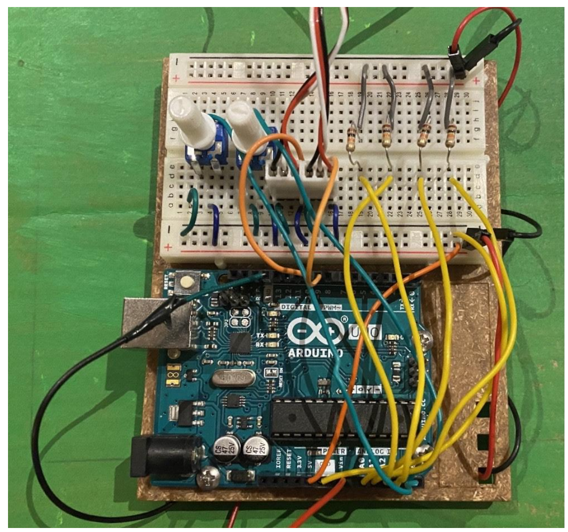




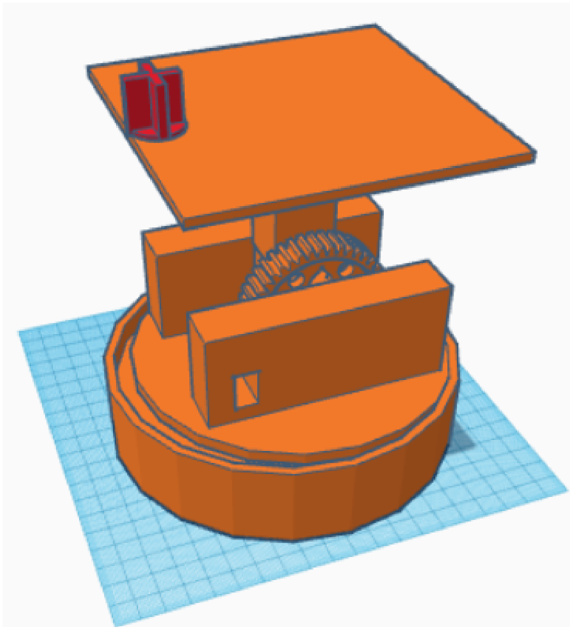
Temporary "Cardboard" Design:

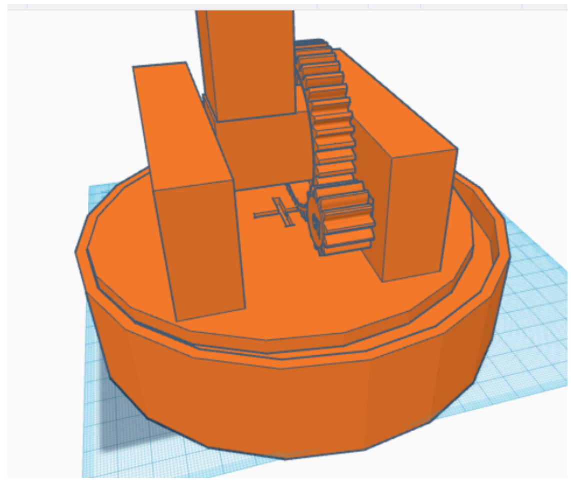


Arduino Wiring:



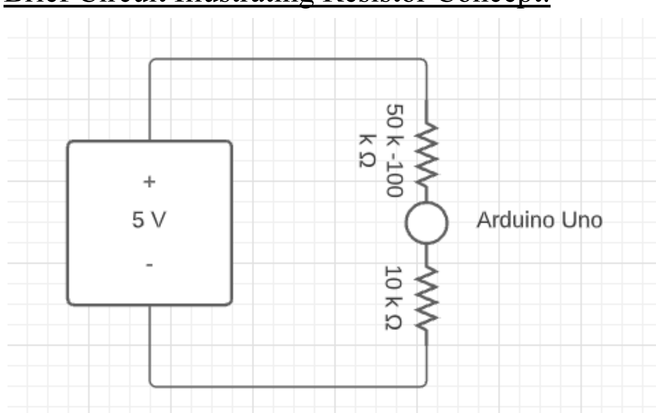
Final CAD design





The final CAD design (shown above) is what I decided would be the most resilient design. The larger base is to accommodate the imbalances when displacing the solar panel's weight over a smaller area, which I made the mistake of designing when the project first started. The vertical tilt mechanism struggled under the torque of the panel, so I implemented a 1:5 gear ratio to increase the stall torque of the servo. The sunlight isolator (red object on top of the panel) allows the LDRs to accurately read the proximity of the sun based on their locations. Locating the LDRs at the edge of the panel allowed for unwanted sunlight to reach a sensor, causing the panel to confuse its position in relation to the sun.

Brief Circuit Illustrating Resistor Concept:



Equations:

Ohm's Law V=IR where V is the voltage across some point, I is the current, and R is the resistance. The current remains constant throughout the system, so it will always force a voltage to zero across x amount of resistance.

$P = IV$

Torque On System $\Sigma \quad = 0 => {}_a + {}_p => (m_a g * \frac{r}{2})(1.3=>1.5)+$
$(m_p * g * r)(1.3 => 1.5)$

Normal Force $\quad \Sigma F_y = 0 => F_n - W_a - W_p = 0 => 1.5 F_n = W_a + W_p$

$\% \, difference = \frac{difference}{initial \ value}$

Scientific Steps:

In an attempt to prove my hypothesis, I determined two methods to measure my results and find the total power. Method one is to create another circuit system, and have that system store and manage the power being generated by the solar panel. After a specified time interval, I would check the total amount stored from both systems (TTDAT and static). Method two involves using a multimeter to measure the voltage and the current of the two solar panels at different points during the specified time interval. Ideally the time interval would be a span of 13 hours, and I would check the current every 1 hour. Once I would have all the measurements for each time interval, I would calculate the power using $P = IV$ for each specified time. Once calculated, I would find a formula to map the results of the power using regression. Next, I would integrate the equation with the same interval as the time I tested the panel. When I have both integrals solved, I can find the percentage difference between the panels by subtracting the statics value from the TTDATs value, then dividing that answer by the statics value.

Upon analyzing the two methods, I decided that method two would be the best course of action for the circumstances I faced. I begin testing at 6:00 am. I would check the voltage every 1 hour until 7:00 pm when I would take my last measurement and remove the panel from testing. I would test the static panel the next day, (I only have one solar panel, so I can't measure both at the same time) or a day following with the most similar weather conditions. I would face the panel south and have it angled 33^o greater than the latitude. I would begin and end my test in the same fashion as the first: 6:00 am to 7:00 pm with 1 hour intervals. Once I have gathered all of my data, I would calculate the power and find the total power for that time interval. Once calculated, I could finally find the percentage difference between the two to prove my hypothesis.

FINAL RESULTS

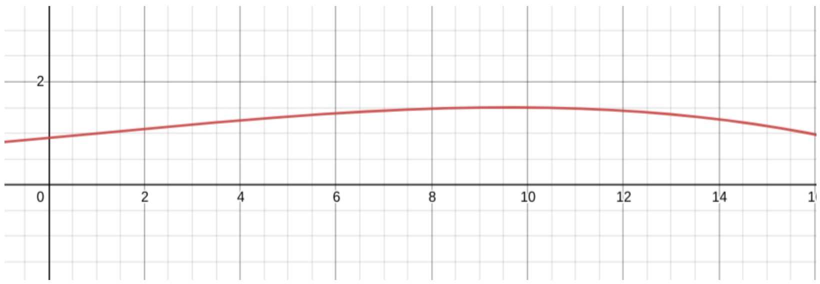
TIME	CURRENT (STATIC)	VOLTS (STATIC)	WATTS (STATIC)	CURRENT (TTDAT)	VOLTS (TTDAT)	WATTS (TTDAT)
6:00 A.M.	121 mA	3.9 V	**0.4719 W**	124 mA	4.9 V	**0.6076 W**
7:00 A.M.	180 mA	4.09 V	**0.7362 W**	193 mA	5.12 V	**0.9882 W**
8:00 A.M.	188 mA	4.12 V	**0.7746 W**	198 mA	5.22 V	**1.0336W**
9:00 A.M.	194mA	4.27V	**0.8284 W**	198.3 mA	5.25 V	**1.0411 W**
10:00 A.M.	194.7 mA	4.33V	**0.8431 W**	199.1 mA	5.25 V	**1.0453 W**
11:00 A.M.	191 mA	4.44V	**0.8480 W**	193.2 mA	5.3 V	**1.0240 W**
12:00 P.M.	191.2 mA	5.25V	**1.0038 W**	191.6 mA	5.65 V	**1.0825 W**
1:00 P.M.	191 mA	5.56V	**1.062 W**	193 mA	5.66 V	**1.0924 W**
2:00 P.M.	192.4mA	5.6V	**1.0774 W**	194.4 mA	5.7 V	**1.1081 W**
3:00 P.M.	191.5 mA	5.56V	**1.0647 W**	194.3 mA	5.7 V	**1.1075 W**
4:00 P.M.	187.9 mA	5.46V	**1.0259 W**	192.4 mA	5.61 V	**1.0794 W**
5:00 P.M.	187.36 mA	5.37V	**1.0061 W**	192 mA	5.7 V	**1.0944 W**
6:00 P.M.	183 mA	5.3V	**0.9699 W**	198 mA	5.7 V	**1.1286 W**
7:00 P.M.	162.6 mA	4.91V	**0.7984 W**	187.5 mA	5.45 V	**1.0219 W**
		AVERAGE POWER:	**0.8936 W**			**1.0325 W**

CUBIC REGRESSION LINE OF STATIC PANEL (91% ACCURATE)

Where F(t) = $(-\ 3.975 \cdot 10^{-4})t^3 + 0.0012t^2 + 0.0869t + 0.4660$

And $\int_{0}^{13}[(-3.975 \cdot 10^{-4})t^{3} + 0.0012t^{2} + 0.0869t + 0.4660]dt =$

$11.4416\ Wh\ or\ 0.011\ kWh$

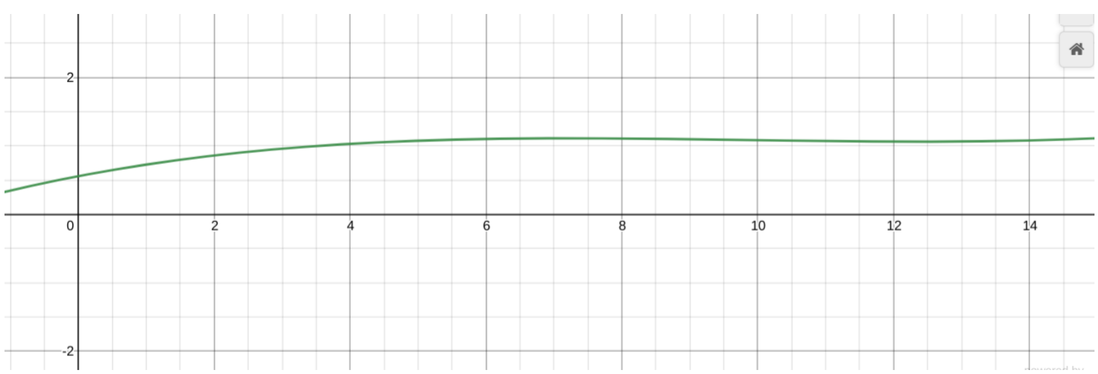


<u>CUBIC REGRESSION LINE OF TTDAT (77% ACCURATE)</u>

Where F(t)= $(7.0687 \cdot 10^{-4})t^{3} - 0.0208t^{2} + 0.1899t + 0.5569$

And $\int_{0}^{13}[(7.0687 \cdot 10^{-4})t^{3} - 0.0208t^{2} + 0.1899t + 0.5569]dt =$

$13.1009\ Wh\ or\ 0.013\ kWh$



-After calculations, I was finally able to determine that the TTDAT system had a **15% greater** power yield in comparison to the static PV system.**-**

<u>DISCUSSION</u>

The TTDAT system proved to output more energy in comparison to the static system; however, a thirty percent increase was not achieved. The most likely occurrence of this is because the static panel was faced at the optimum degree for receiving a steady amount of sunlight throughout the day. A system where the panel was perpendicular to the sky would be unrealistic, which rendered the tracking system less effective at receiving additional sunlight. That being said, the tracking system yielded 15% more wattage. The implementation of Calculus was used to roughly calculate the amount of kWh that the panel produced. A cubic regression line was used for both data sets to get an approximate function, modeling the curves produced by the two panels. By taking the integral of the power with respect to time, the amount would be the wattage produced in a time interval, also known as the Watt hours (converted to kWh). The research does not accurately support the results of my findings most likely due to inexpensive components. Scaling of the project would be simple because the design of the system was robust and relatively accurate. Scaling would include larger solar panels, metal gears and larger gear boxes, powerful motors instead of servos, and a monitoring system that would replace human involvement every hour.

The preliminary design couldn't handle the torque caused by the weight of the panel, so a gear ratio was used for the vertical tilt. A gear ratio can multiply the stall torque of the servo by using a smaller to larger tooth count. The number of teeth on a small gear in comparison to a larger gear can be expressed as a ratio between the teeth number e.g. 1:4, 1:5, etc. The smaller gear must rotate the amount of times expressed in the ratio, multiplying its own output by that amount. This project utilized a 1:5 gear ratio to increase the stall torque by 5 times, which proved to be valuable, saving the servo from destroying itself under the panel's weight.

CONCLUSIONS

The design and implementation of a TTDAT system was achieved and compared to a static PV system. CAD development to 3d print parts for the project proved to be valuable in terms of time management and relatively accurate models. It is likely that more energy can still be harvested with my components, so it is important that I continue to develop ways to improve my system in an attempt to make the increase greater than 15%. Once a design has been created that has a desirable power increase, increasing the scaling of the project would ultimately be the final goal.

FUTURE PLANS AND RECOMMENDATIONS

- Use method 1 rather than method 2
- Use a new and larger solar panel
- Use better, higher torque rated servos
- Implement a "return to position" function in the code to return to a specified position once the day is over
- Test over a larger span of time
- Make project larger scaled
- Determine a way to increase the power output
- Test a time based system instead of a sensor based tracker and compare the two

Bibliography

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