Overcoming LDR Saturation in a Sun Tracking Solar Panel System

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Introduction

Dwindling, non-renewable energy sources, including carbon, petroleum, natural gas, and nuclear power, will soon necessitate a viable alternative. Yet, it is argued that renewable energy sources, such as equipping solar energy, are inefficient and expensive. Using solar panels to harness solar energy may provide a promising alternative, eradicating the search for hydrocarbon deposits. However, for solar panels to be commonplace, the process of capturing solar energy must be refined and efficiency increased. Utilization of a sun-tracking solar panel system may provide part of the answer for increasing efficiency. A sun-tracking solar panel not only has the capability of harnessing energy from solar rays, it includes a system that automatically orients the solar panel to the most efficient angle, relative to the sun, throughout the course of the day. A study by Sidek, et al. showed that the average sun-tracking solar panel system can be 26.9% more efficient compared to a fixed, tilted panel system. Yet, complications, such as saturation and effectiveness during low-visibility conditions, remain problematic for traditional sun-tracking system. Saturation occurs when the charge capacity of the photocell, or Light Dependent Resistor (LDR), is reached, making the current constant (York). If the charge capacity is reached, the algorithm that governs movement of the panel will error, returning to the first point of saturation rather than facing the sun. Given that the initial saturation location is often close to the desired position, this problem is typically ignored. Additionally, research has provided means to overcome the issue by utilizing a manual sun-tracking solar panel system (Bhattacharya *et al.*). However, this requires an individual to manually change the orientation of the panel, which is ineffective and unattainable for large scale, solar panel facilities. The aim of this study is to explore a more efficient solution for saturation.

To combat the saturation problem, a filter was placed over the LDR, causing the flux through the LDR to be proportionally lower in all conditions. By preventing saturation, the filter allows the panel to maintain an efficient angle relative to the sun on clear days. However, Mie scattering effects make efficient angles on cloudy days more difficult to determine. Mie scattering, a solution to Maxwell's equations, occurs when light, in this case from the sun, reflects off a non-homogeneous media with particles that are approximately the size of the wavelength of the light (Xiaoyu *et al.*). This occurs as light passes through clouds, becomes more diffuse, and causes the most efficient angle to be more difficult to determine. Thus, a difference in the most efficient method of light detection on cloudy days versus sunny days was expected.

The flux values with and without the filter were compared in a variety of light intensities in order to determine whether the filter made a difference in the panel's efficiency, or if it would be more effective for the panel to remain parallel-to-the-ground during low-visibility days. Light intensity values (measured with a Luxmeter) and voltage at the LDR, with and without the filter, were recorded. A plot of lux and voltage were formed to directly compare the perceived light intensity by the LDR with and without a filter and a trendline was found for both sets of data using Excel, allowing the effect of the filter to be analyzed.

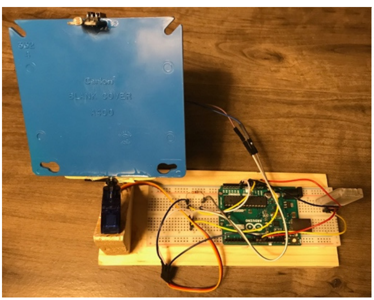
System Hardware

A servo motor with one degree of freedom controlled the position of the solar panel shown in Figure 1.a. The servo motor interfaced with an Arduino Uno microcontroller, that was instructed by a C++ code that modulated movement of the LDR. The LDR is a resistor of which resistance is inversely proportional to incident light intensity due to the photoelectric effect. LDRs are also referred to as photocells or photoresistors (see Figure 1.b).

The motor is able to move the panel from zero to one-hundred eighty degrees along its one degree of freedom every fifteen minutes, and voltage values were taken and stored in an array at each degree. The maximum voltage of the array, and the associated position, was found using a program in Arduino (using C++). Once found, the servo motor adjusted the solar panel to the maximum voltage position.

The motor was held at a fifty-one-degree angle, relative to the horizontal, with the panel facing south. The specificity of this position and angle was used because, at the equinox, the sun's altitude was fifty-one-degrees. This angle was obtained by subtracting Kansas City's latitude, which is approximately thirty-nine, from ninety degrees. Given that the ecliptic at equinox is the average altitude of the sun, this will result in the panel being at a more efficient angle throughout the year (Jenkins).

The filter used during the measurement was made of polyethylene, a polymer commonly found in grocery bags. Polyethylene was chosen for its accessibility and efficacy. The filter was created by cutting a portion of plastic bag that would cover the photocell and then secured with a rubber band.



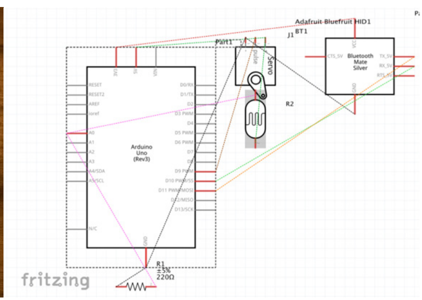


Figure 1.a (Left): Photograph of the sun-tracking solar panel.
Figure 1.b (Right): Circuit diagram of the sun-tracking solar panel. Made via Fritzing.

Application (STSP)

An application called STSP (Sun Tracking Solar Panel) was generated using Blynk to collect user-input data concerning the visibility (sunny versus cloudy) (see Figure 2.a.). The app displayed a graph of maximum light intensity (Lux) values throughout the day by interfacing with the Arduino and recording measurements in the form of virtual pins. The collected data was sent to one of two virtual pins, and the determination of which pin the data was recorded under depended on whether the user selected "SUNNY" or "CLOUDY" in the application. The collected and categorized data was then used to create a graph of light intensity, or flux per unit area, versus time as seen in Figure 2.b.

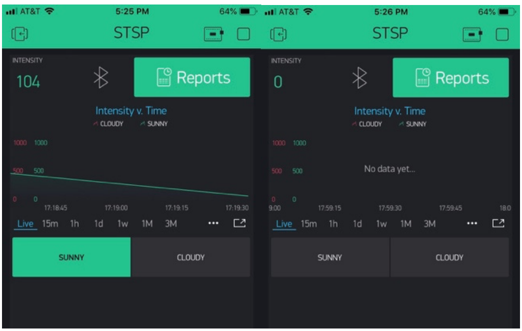


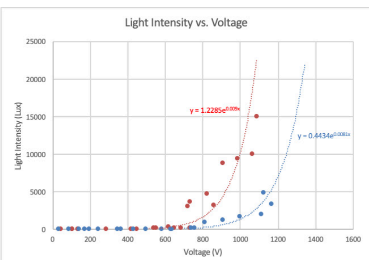
Figure 2.a (Left): A screenshot of the app prior to collecting data.
Figure 2.b (Right): A screenshot of the app while in use. Since "SUNNY" is selected, the data is stored in the corresponding virtual pin and used to create the graph shown.

The other widgets in the app were "Reports" and "Bluetooth." "Reports" created a description of the data stored in the virtual pins. "Bluetooth" provided communication between the Arduino and STSP. The panel would not be able to work unless connected via Bluetooth to STSP. To stop the panel from turning, a feature that is important in terms of efficiency during the night, the Bluetooth connection between the devices was disrupted. Additionally, STSP is capable of exporting data from the graph into Comma Separated Value (CSV) format via email.

Code

A code was written in C++ to instruct the Arduino to interface with the servo motor and record the voltage values detected at each degree in STSP. The code instructed the motor to move the solar panel from zero to one-hundred eighty degrees and store the voltage values, obtained with the attached photocell, in an array. The maximum value in the array, along with the corresponding location, was found using a loop. The servo motor then moved the panel to the location at which the detected voltage was at a maximum. Through use of a delay function, the code instructed the motor to carry out this function every fifteen minutes. At night, the user may disrupt the Bluetooth connection to prevent the panel from continuing the program. Shutting-down operation overnight assisted in maximizing the efficiency of the sun tracking solar panel system.

The data points in the array were sent to and displayed in the Arduino's serial monitor and plotter. The maximum voltage value was converted to a light intensity value and sent to STSP via Bluetooth. Depending on whether "SUNNY" or "CLOUDY" was selected in the application's "Segmented Switch" widget, the code instructed the data to be sent to one of the two virtual pins. The data was then displayed on the graph shown in STSP's user interface (Figure 3.a and 3.b).



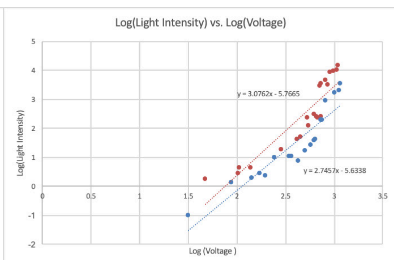


Figure 3.a (Left): The graph depicts light intensity versus voltage for an LDR with (red) and without a filter (blue).
Figure 3.b (Right): The graph depicts the log of light intensity versus the log voltage for an LDR with (red) and without (blue) a filter.

Equations

The values were converted from voltage to light intensity using one of two equations obtained by measuring intensity with a lux-meter that corresponds to a voltage value and then a line of best fit was found. Two equations were required in order to compare the effect of the filter on efficiency of the panel, specifically on cloudy days. These equations were included in the C++ code, and the converted value was sent to the app via Bluetooth. The equations obtained for converting Voltage (V) to Light Intensity (I) were as follows.

Without a filter:

$$I=0.4434*e^{\wedge 0.0081*V} \quad (1)$$

With a polyethylene filter:

$$I=1.2285*e^{\wedge 0.009*V} \quad (2)$$

A comparison of equation (1) and equation (2), reveals that the exponentially growing intensity corresponding to increasing voltage values are within a thousandth of each other. This discrepancy arises as the filter provides a larger horizontal shifting effect to the graph of light intensity versus time. It follows that different filters would have different coefficients and, therefore, would provide different horizontal shifting effects. Thus, equations (1) and (2) can be generalized with an approximate exponent as follows:

$$I=A*e^{0.00855*V} \quad (3)$$

where A is a constant dependent on the material of the filter. The constant A can be found by using multiple light sources that have known light intensity, and measuring the voltage produced by each light source. This process is akin to the steps taken to obtain equations (1) and (2).

Results and Discussion

The initial question asked how the filter affected the sun-tracking solar panel's light detection capabilities on cloudy days. This question was later extended to whether the filter would have a non-linear effect on the intensity of the incident light detected by the LDR. The equations show that the exponential relationship between intensity and voltage grows approximately the same amount, with and without a filter.

Additionally, Equation (3) provides a basis for what to expect with and without a filter on cloudy days. From analysis of the graph, it is apparent that the filter will have less effect on cloudy days than on sunny days. However, further investigation is required to determine if this prediction is consistent with experimental results. If the prediction is correct, then the most efficient method of collecting energy on cloudy days is to leave the solar panel in a parallel-to-the-ground position during low visibility days. This conclusion arises from the large uncertainty associated with the location of the light source due to the effects of Mie scattering.

Voltage (No Filter)	Intensity (No Filter)	Voltage (Filter)	Intensity (Filter)
808	924	825	4796
907	1240	861	3265
998	1709	910	8862
1113	2044	987	9365
1167	3377	1065	10,000
1125	4848	1087	15,000

Table 1: The table illustrates the top 6 values of light intensity versus voltage values used in Figure 3.a and 3.b.

Figure 3.a shows that the point of saturation is significantly higher when using the filter. The higher point of saturation is

because, with a given constant voltage value, the output of equation (3) is a greater intensity while the filter is utilized and, therefore, a higher intensity value is required to saturate the photocell. This effect can be seen in the larger voltage values in Figure 3.a. As seen in Table 1, comparable voltage values output greater intensity values when using equation (2) rather than equation (1). This demonstrates that the LDR will remain sensitive to a larger incident light intensity before reaching saturation with the use of a filter.

Conclusion

As shown in Figure 3.a and Table 1, use of a filter is superior on sunny days as it allows the LDR to remain sensitive to higher incident light intensity and subsequently locate the most efficient position. As expected, the filter did not significantly change efficiency on cloudy days. Possibilities of increasing the effectiveness of the sun-tracking solar panel system on cloudy days include: leaving the panel at a parallel-to-the-ground position throughout the day, allowing the panel to function the same as it does on sunny days, or changing the filter to a material that is more suitable to finding the most efficient angle during low-visibility days. With these possibilities in mind, the best option would depend on the amount of energy required to run the system. For example, on cloudy days with a high-energy requiring sun-tracking solar panel system, the system may use more energy than it collects. In such case, the most efficient solution would be to leave the panel in a parallel-to-the-ground position throughout the day.

From equation (3), one can consider how different filters affect light intensities perceived by the LDR. Therefore, while the method of maximum effectiveness may change based on the system's power requirements, the material of the filter, or visibility conditions, a prediction of what is most efficient can be made with equation (3). The data acquired using STSP, along with equation (3), may assist in the development of a more efficient procedure in harnessing energy on cloudy days.

Ultimately, this procedure may assist in making solar panels more efficient, and thus eradicating the search and need for hydrocarbon deposits.

Works Cited

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