Dual Axis Solar Panel Control System

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***Abstract*—This paper describes a control system to enhance the performance of a solar panel. A two-axis mechanism is developed that tilts and turns the solar panel to face the highest intensity of light. The system was designed in LabVIEW, and implemented on the Arduino Mega 2560. The physical model of the system was built using servo motors and photoresistors. The pilot plant was tested by applying a source of light from various directions and monitoring its response. The solar panel was able to face towards the highest intensity of light with high level of precision.**

I. INTRODUCTION

Modern day technology is progressively pushing for a more environmentally friendly source of power, for which solar energy is increasingly more popular. However, large solar panels are often not as optimal at gathering solar energy due to their stationary builds, which often causes them to be out of the most optimal line of sun light for long periods of the day. There are several approaches to optimize the performance of the solar panels, [1]. Self-cleaning solar panels can be efficient, [2], but have high cost. [3]. Solar tracking is currently one of the most intensively studied technologies for cost reduction and maximization of the solar energy production. Solar tracking is implemented using one-axis [4], and for higher accuracy, two-axis sun-tracking systems. Polar (equatorial) tracking and azimuth/elevation (altitude – azimuth) tracking are the main types of two-axis sun-tracking system, [5].

In this paper we propose an alternate, two separate axis control system that would benefit the solar panel and increase its rate of generating energy. The goal of the control system is to automatically position and tilt the solar panel towards the strongest line of light. The first axis is in charge of tilting the solar panel left and right towards the strongest side of light. The second axis enables rotation of the entire system so that the first axis can tilt in the direction of light with the highest intensity. This configuration allows the dual axis solar panel to consistently stay in the highest intensity of light in the area, and generates more energy than its stationary counterpart.

II. SYSTEM OVERVIEW

The dual axis solar panel consists of two separate control systems: the tilting axis, and the rotating axis. The tilting axis is housed in a wooden frame with a 180-degree servo motor attached to the end and the solar panel resting on top (Fig. 1). The second axis is attached to plate under the wooden structure with a 360-degree servo motor. On each of the four edges of the solar panel, a single photoresistor or light dependent resistor (LDR) is mounted. The LDRs and the servo motors are powered by the Arduino Mega 2560 microcontroller. The LDRs are also read by the microcontroller and their readings are processed through a LabVIEW Virtual Instrument (VI). The LabVIEW architecture for data acquisition, monitoring and control is given in the Appendix. The results of these readings are sent out through the microcontroller to the servo motors and allow the dual axis solar panel to dynamically adjust its positioning in accordance with the strongest line of light. The costs of materials for building this small size pilot plant are summarized in the Appendix.

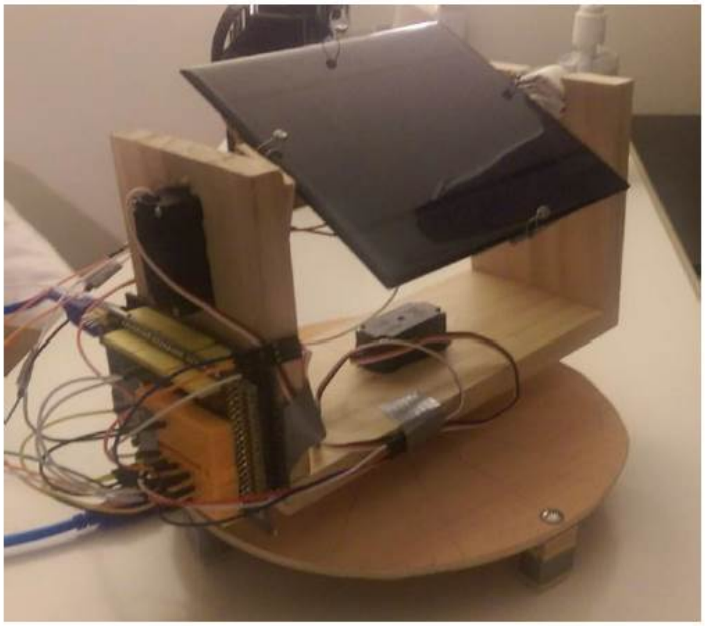

Fig. 1. Dual axis solar panel control system

The reference input to each closed loop system is zero voltage, which corresponds to an equal intensity of light measured by each two opposite LDRs (in voltage). The controller converts the voltage error into the necessary angle of displacement which is executed by the servo motor.

The current angle of the motor corresponds to a difference between the measurements of the two LDRs. This difference is fed back into the system after being normalized by the ambient LDR value. The ambient voltage helps the solar panel tilt even when there is an abundance of light present. When the difference is zero (equal to the desired reference input), the servo angle is held constant and the control system halts at its current state.

III. OPEN LOOP TESTS AND SYSTEM MODELING

We developed the control schemes for each axis separately. To properly design the controllers, we obtained a mathematical model (represented as a transfer function) of each open loop system dynamics (180- and 360-degree servo motor), and conducted tests with digitally generated inputs (light intensity) in LabVIEW. The recorded responses suggested that a first order transfer function is a suitable model of the open loop systems. The general form of a first order transfer function with time delay is:

$$G(s) = \frac{K_p e^{\theta s}}{\tau_p s + 1} \tag{1}$$

where K_p is the process constant, $e^{\theta s}$ is the time delay term and τ_p is the process time constant.

A. Model of the tilt motion system (with 180 degree servo motor)

We start with the tests for the 180-degree servo motor responsible for the tilting of the solar panel. The initial angle of the servo motor (and the solar panel) was fixed at 90 degrees with a reference angle of 140 degrees. We kept the rotational speed of the servo motor constant at its max operational value. Fig. 2 shows that the response is fairly quick, results in no overshoot, and achieves the reference angle without steady state error. The tilt motion of the solar panel has acceptable performance with respect to both transient and stationary regimes.

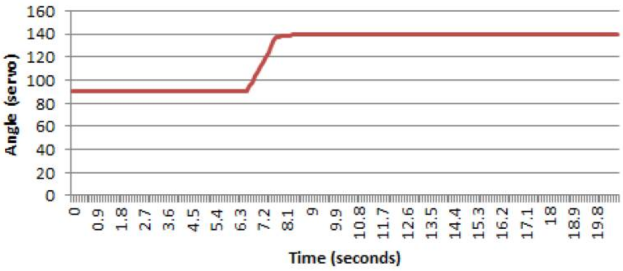

Fig. 2. Open loop response of tilt motion system

We note that the time delay θ of the open loop response is negligible, therefore the time delay term was set to one. We experimentally determined the process time constant from the curve in Fig. 2, and adjusted the process gain using MATLAB's SISOTOOL function until the settling time of the model matched that of the servo response. Based on these experiments we obtained the following transfer function

$$G(s)_{tilt} = \frac{0.8}{s + 1.38} \tag{2}$$

B. Model of the rotation motion system (with 360 degree servo motor)

For the rotation motion system, we used a 360-degree servo motor. This motor can rotate in either direction (±180 degree) at a varying speed defined by the difference between the reference angle and the initial 90 degrees motor position. The varying speed makes the motor move slightly faster than the 180-degree servo motor as seen in Fig. 3. The test was done with initial position of the servo motor fixed at 45 degrees with a reference angle of 90 degrees.

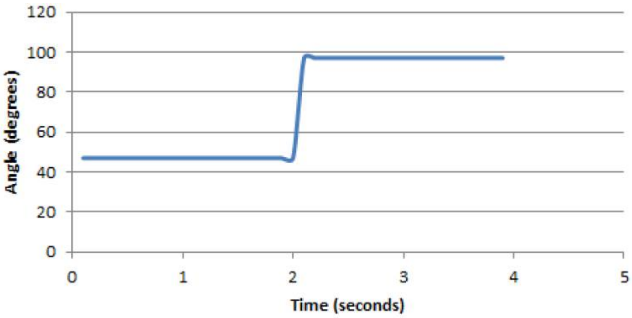

Fig. 3. Open loop response of rotation motion system

Similar to the tilt motion system, we experimentally adjusted the model of the rotation motion system as a first order transfer function without a delay.

$$G(s)_{rot} = \frac{27}{s + 16.6} \tag{3}$$

IV. CLOSED LOOP CONTROL

Following the modeling and confirmation of the tilt and rotation motion systems to be stable in open loop with test inputs digitally generated from LabVIEW, we designed the closed loop control for each subsystem. The solar panel will face the most intensive direction of light if each two opposite LDRs register the same amount of light. Therefore the desired position of the solar panel is to have zero difference between the opposite LDRs measurements. The feedback error comes from the subtraction of the light intensity between the two opposite LDRs. The error will be zero when the solar panel is turned such that the opposite LDRs register the same value. The error-based controller determines how much voltage to supply to the servo motor in order to turn in the desired direction and achieve zero LDR difference. To remove the effect of ambient light, we added an ambient LDR to the system and used to normalize the other four LDR sensors. We then used a moving average filter to remove the environmental light noise. We initally tested a Proportional-Derivative (PD) controller using both artificially generated light in LabVIEW and actually shining a light on the LDRs to observe the system performance. We excluded the integral action, due to the lack of steady state error (any desired angle position is reachable). We observed, however, that the PD controller caused the closed loop system to stutter. Consequently we switched it out for a proportional controller.

A. Closed loop tests of tilt motion system

We used a flashlight, shined on a single LDR and the 180 degree servo motor, driven by a proportional controller, turned to allow both of the LDRs to have an equal amount of light. When the difference between the two LDRs is 0, the servo motor stops its movement and stays at its current angle. The initial panel position was 45 degrees and in order to equalize the LDRs light intensity it had to move to 90 degrees angle. Fig. 4. illustrates the results for this experiment. The system achieves the desired steady state in less than 2s with practically no error; however, further tuning the controller gain can help attenuate the overshoot.

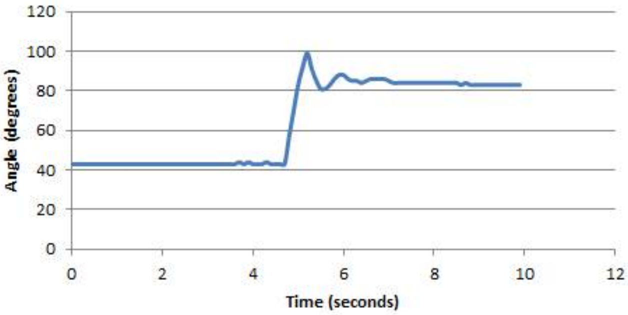

Fig. 4. Closed loop response of tilt motion system

B. Closed loop tests of rotation motion system

We performed similar tests with the rotation motion system: we used a flashlight shined on the right LDR, as a result of which its voltage increased and the motor turned to correct it. When the amount of light on both LDRs became equal, the servo motor settled back at its initial position of 90 degrees. Fig.5 shows the closed loop response with a high-gain proportional controller ($K_p = 25$), whereas Fig.6 illustrates the case when the gain was reduced to $K_p = 5$ such that the solar panel moves without osculations and overshoot.

Parameter tuning allowed us to isolate the best values for the proportional gain for each of the servos. More specifically, for the 180-degree servo motor, the proportional gain affected the volatility of the tilting of the solar panel. This means a larger gain would allow the servo to more aggressively turn as the difference between the LDRs are amplified with higher gains. In the final version of the system, we made these adjustments so that even at very large differences in light, the servo motor would not attempt to sharply rotate and hit the physical limitations due to the construction elements of the pilot solar panel. After careful fine tuning and testing, the following results were obtained.

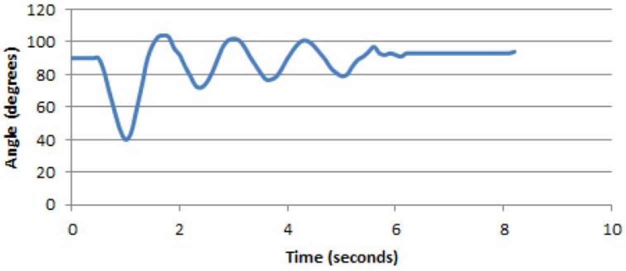

Fig. 5. High-gain ($K_p = 25$) closed loop response of rotation motion system

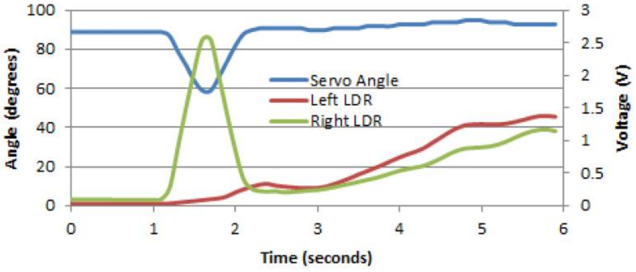

Fig. 6. Small gain ($K_p = 5$) closed loop response of rotation motion system. Left&Right LDR voltage

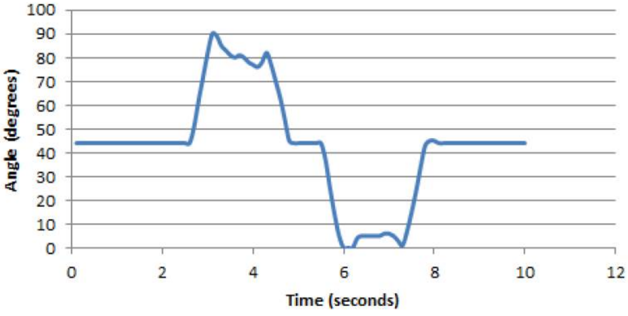

Fig. 7. Angle trajectory of tilt motion system for two impulse lights on Top and Bottom LDR.

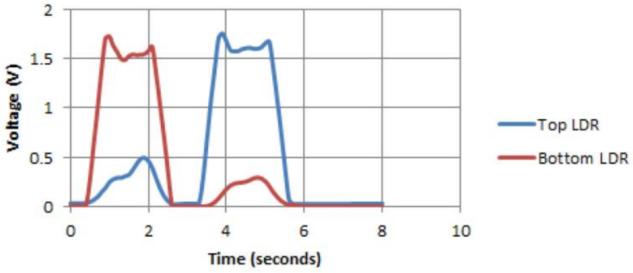

Fig. 8. LDR voltage response to changes in flashlight position

Fig. 7 shows that for the controller gain chosen for the 180-degree servo motor (in this case $K_p = 28$), the tilt motion system responds to direct impulses of light on Top or Bottom LDR by approaching rapidly the angle that would equalize the voltages (the intensity of light) of the two LDR. We note that we conducted our experiments with a controlled ambient light (the voltage of the ambient LDR was set at 1 V). For a lower ambient voltage, the servo motor will experience greater differences in voltage for the LDRs as the four LDRs are normalized by the ambient LDR reading. To combat this problem, we instituted an offset in order to maximize the rotational coverage of the solar panel. Consequently, the gain for the 180 degree servo is fairly flexible, and can be changed to adapt to certain environments depending on how often the ambient light may be changing. Tuning the 360-degree servo required a more traditional approach as the rotation motor overshot the reference when the gain was too high (see Fig.5 and Fig.6).

C. Ambient LDR smoothing filter

LDR voltage readings can vary highly due to variations in the ambient light (i.e., the environmental noise). In order to achieve a more stable reading that also improves the performance of the control system, we filter the ambient light sensor signals. To show the application of the smoothing filter, we tested the ambient LDR with a varying light source.

From the raw unfiltered voltage shown in Fig. 9. in blue, the jerky response of the system to such readings can be seen, as abrupt changes (from 0 to 3V in this case) cause a large reaction in the servo motor. With the inclusion of a moving average filter, the results shown in red are more consistent, and the servo motor smoothly moves to keep up with these changes.

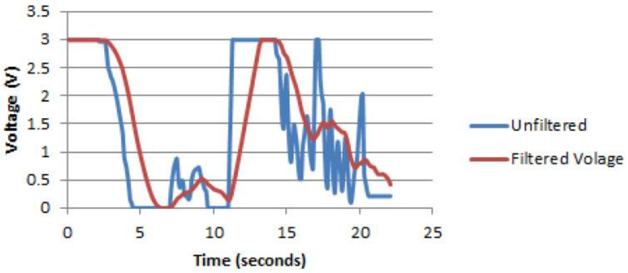

Fig. 9. Filtered vs. Non-filtered Ambient LDR

V. CONCLUSIONS

The final control scheme we chose for the dual axis solar panel system is the proportional controller with filtered inputs. This configuration allowed the system to move quickly to the position of most intensive light without any overshooting or steady state error. The overshoot was rectified by adjusting the gain on the proportional controller and the zero steady state error was due to the servo's integral action. This combination of filtering and proportional controller performed very well and was able to track and face light as desired. The system itself, however, is limited by the need to attach a USB cable to the laptop and the Arduino microcontroller. Therefore, when the solar panel rotates enough, the chord becomes tangled up in the system. This can be rectified by using an external battery pack and attaching it to the wooden frame. Another limitation is the use of this system in actual sunlight. Since sunlight is not nearly as concentrated as a flashlight, the area between the four LDRs is not nearly large enough. Therefore, all of the LDRs would be hit evenly and the solar panel would not move. For future improvements, the system can be implemented on a larger solar panel, thus spreading the LDRs out even further. The larger the distance between the LDRs, the more accurate the tracking will be when trying to track large light sources such as the sun.

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APPENDIX

The developed LabVIEW architecture for data acquisition, monitoring and control tests is depicted in Fig.10 and Fig.11.

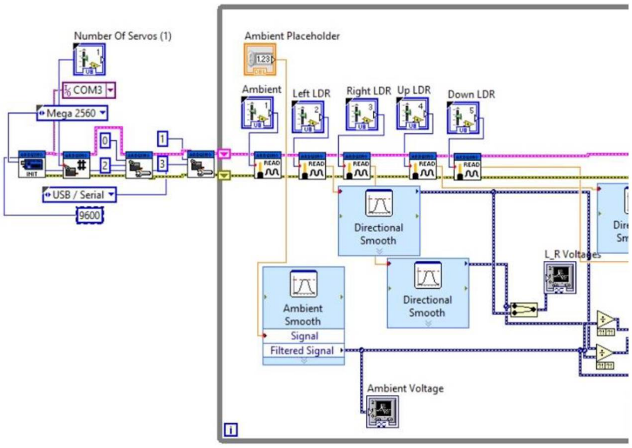

Fig. 10. LabView system (first half)

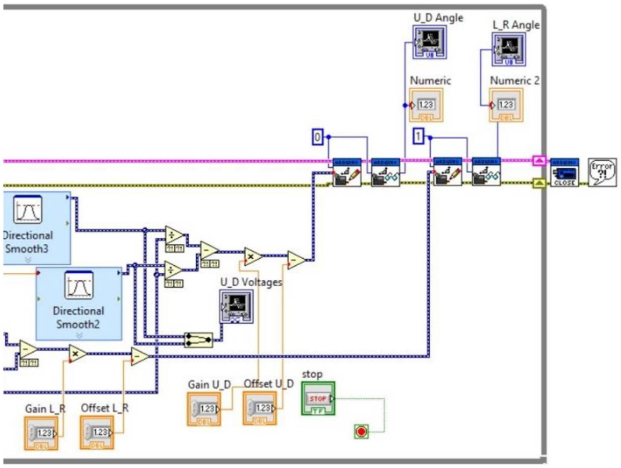

Fig. 11. LabView system (second half)

TABLE I
BILL OF MATERIALS

Arduino Mega 2650	$14.99 (Amazon)
180°Futaba S3003 Servo Motor	$10.65 (Amazon)
360° RioRand SM-S4303R Servo Motor	$17.19 (Amazon)
Sunkee Photoresistors (bought as pack of 20)	$6.99 (Amazon)
Wood	$5.99 (Home Depot)
ALLPOWERS 2.5W Solar Panel	$8.59 (Amazon)
LTK Creation Breadboard Jumper Wire (75 pcs)	$4.77 (Amazon)