Implementation of Two Axis Solar Control Systems

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Abstract—One of the most technological inefficacies of harnessing solar energy originates from the understanding that sunlight will produce many different angels of absorption throughout various time frames. To account for this, more robust control systems are needed to ensure that the maximum amount of sunlight is absorbed at any given time. This paper will convey a two axis Proportional Integral Derivative (PID) controller system solution, and cross reference the conclusions and research of other papers. This will best distinguish the feasibility of the system, as well as provide critical insight on how robust controllers can significantly impact the solar market.

Index Terms—

✦

1 INTRODUCTION

STATIC solar exposure onto photo- voltaic cells is a major fall-back to many industrial, and recreational solar solutions. With this in mind it is critical that the angle of the photo-voltaic cells, used in harnessing solar energy, is modulated. This is typically done in such a way that accounts for solar positioning throughout the day along a singular axis. However, the accuracy of the solar positioning, and amount of radiation absorbed in a single axis system is negatively impacted during seasonal changes, and other outside system factors. Perhaps the best visual example can be observed from an article that highlights the temperature fluctuations on a home during different seasonal changes[1].

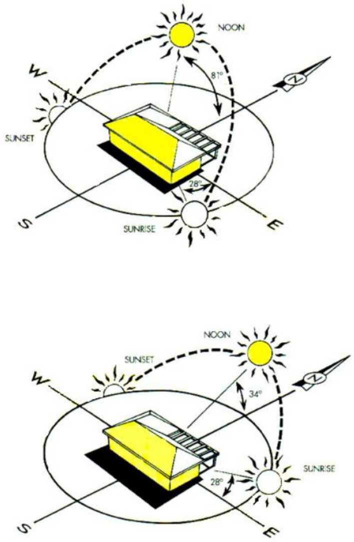

Fig. 1. Seasonal changes of the sun

This gives a clear visual idea of the angular fluctuation not only through out the day, but throughout the seasons as well. In fact according to PVeducation, the positioning of the sun is different depending on the location in which it is being measured. Below Shows the changes in solar positioning in Miami Florida, and Portland Organ[2].

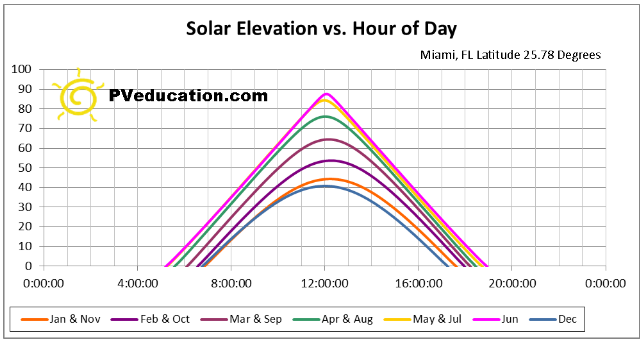

Fig. 2. Sun exposure in Miami

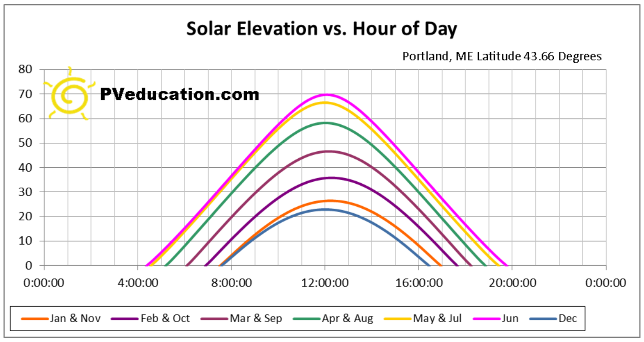

Fig. 3. Sun exposure in Portland

It is obvious based off of the data above that there are many factors that provide the need for a more robust solar tracking solution. A dual axis solar tracking solution, would

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account for all solar positions at any given time across all positions on the earth. When testing these applications, it was found that the mathematical model for a PID controller would be difficult to establish. Do to of the complications, the idea of the fuzzy logic controller was formulated to provide an accurate output to the system [3]. This paper outlines the mathematical model of the dual and single axis solar tracking system to the best accuracy possible. Afterwards using MATLAB and Simulink simulation, the models for PID control and fuzzy logic control were tested. In theory the fuzzy logic controller is designed to be the much more robust system providing more accurate results to the positioning of the sun.

1.1 Design

The basic design from the hardware level would consist of a single 360 angular sensor. The sensor would utilize mesh sensing technology to best determine the angular positioning of the sun. This angular positioning will then be sent to a micro controller in the form of signals at various potentials. The micro controller will then feed into the plant With wither a PID controller, or Fuzzy logic controller for error correction. For dual axis rotations the micro controller will distinguish the axis to adjust, and the system will react to the input. However do to the complexity of the design and the nature of the system, the system was abstracted to just its plant and error correcting control. In theory any input to the system should produce identical results despite the hardware communication. Below is a prototype drawing of the 360 mesh sensor:

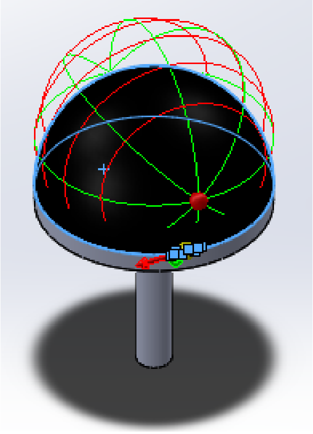


Fig. 4. 360 Mesh sensor

2 MATHEMATICAL MODELS

2.1 Single Axis Model

The first thing to consider for the modeling the plant for the single axis DC motor is the resistive and inductive elements that change the time variance of the plant. These factors are accounted for in following way:

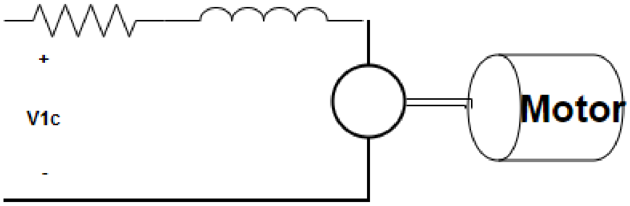


Fig. 5. Single axis model

Using Kirchhoffs Voltage law, the expression for the differential change of current with respect to time can be found:

$$V_{1c} - V_{emf} = L\frac{di}{dt} + Ri(t)$$

Where the emf potential of the DC motor is,

$$V_{emf} = K_b\frac{\omega(t)}{dt}$$

Thus,

$$V_{1c} - K_b\frac{\omega(t)}{dt} = L\frac{di}{dt} + Ri(t)$$

Given the expression for torque, the differential angular rate in respect to time is represented as:

$$\tau(t) = K_m i(t)$$

$$J\frac{d\omega}{dt}^2 + K_f\frac{d\omega}{dt} = K_m i(t)$$

Now that the two equations in the system the transfer function of the plant can be found by finding the laplace transform, and solving for $\omega(s)/V_1c(s)$:

$$V_{1c}(s) - K_b s\omega(s) = LI(s)s + RI(s)$$

$$V_{1c}(s) - K_b s\omega(s) = (Ls + R)I(s)$$

and,

$$Js^2\omega(s) + K_f s\omega(s) = K_m I(s)$$

$$s(Js + K_f)\omega(s) = K_m I(s)$$

Given that $K = K_(m) = K_(b)$, the transfer function is solved by plugging in I(s)K :

$$K(V_{1c}(s) - Ks\omega(s)) = (Ls + R)I(s)K$$

$$KV_{1c}(s) - K^2 s\omega(s) = (Ls + R)I(s)K$$

$$KV_{1c}(s) - K^2\omega(s) = (Ls + R)s(Js + K_f)\omega(s)$$

$$KV_{1c}(s) = (Ls + R)s(Js + K_f)\omega(s) + K^2\omega(s)$$

$$KV_{1c}(s) = (s(Ls + R)(Js + K_f) + K^2)\omega(s)$$

$$K\frac{V_{1c}(s)}{\omega(s)} = s(Ls + R)(Js + K_f) + sK^2$$

$$\frac{\omega(s)}{V_{1c}(s)} = \frac{K}{s((Ls + R)(Js + K_f) + K^2)}$$

In order to develop the constants for the torque and mass inertia to match real world applications, measured values from the International Journal of Engineering & Technology were used[4]:

$$J = 3.2284x10^{-6}(kg)(m^2), K_f = 3.5077x10^{-6}Nms$$

$$K_b = 0.0274V sec/rad,$$
$$K_m = 0.0274N^2 m/amp, R = 4\Omega, L = 2.75\mu H$$

Thus plugging in the constants, the Plant transfer function is:

$$\frac{\omega(s)}{V_{1c}(s)} = \frac{.0274}{s((2.75\mu s + 4)(s3.2284\mu + 3.5077\mu) + (.0274)^2)}$$

$$\frac{\omega(s)}{V_{1c}(s)} = \frac{.0274}{s(8.88 * 10^{-12}s^2 + s12.91\mu + 14.03\mu + 750.76\mu)}$$

$$\frac{\omega(s)}{V_{1c}(s)} = \frac{.0274}{8.88 * 10^{-12}s^3 + 12.91\mu s^2 + 76.48\mu s}$$

2.2 Dual Axis Motor Model

The mathematical model for the dual axis motor in this case will resemble the single axis model. However, the way the plant is controlled may vary depending on if the control for each mode is independent from each other. If each plant is considered independent, and one controller is used to control for the whole system, the fundamental design of the controller, and system will need to change. Regardless, it is safe to say if the physical parameters of both DC motors remain the same the transfer function of each should match, and the way they react to a particular input should be relatively similar.

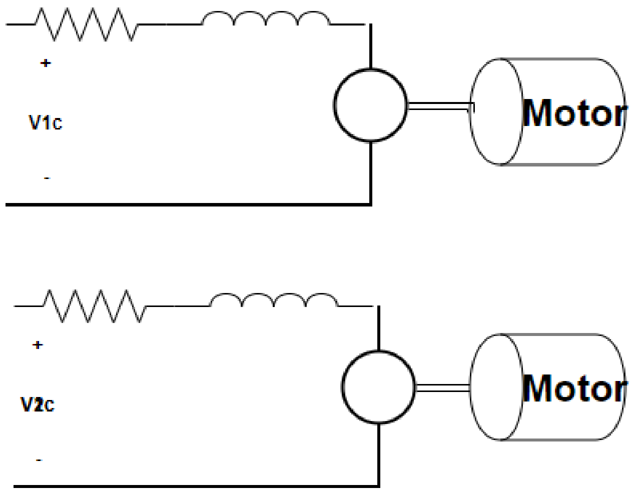


Fig. 6. Dual Axis model

2.3 PID Controller

The proportion derivative integral controller is modeled in such a way that provides zero steady state error, limited overshoot, and a better transient response to the system. This is done by providing the current adaptations to system. The P controller provides a scaler value Kp to the system which modulates the DC gain considering it has no sway on the poles or zeros of the system. The Integral control of the PID controller uses the ingratiator to add a pole to the system (1/s) scaled by Ki, thus providing a steady state error of zero. The Derivative portion of the controller provides the faster transient response by adding a zero to the system scaled by the value of Kd. Thus, the PID controller can be modulated by its K parameters to adjust each element of the controller:

$$u = K_p.e + K_i.\int e.dt + K_d.\frac{de}{dt}$$

Fig. 7. PID equation

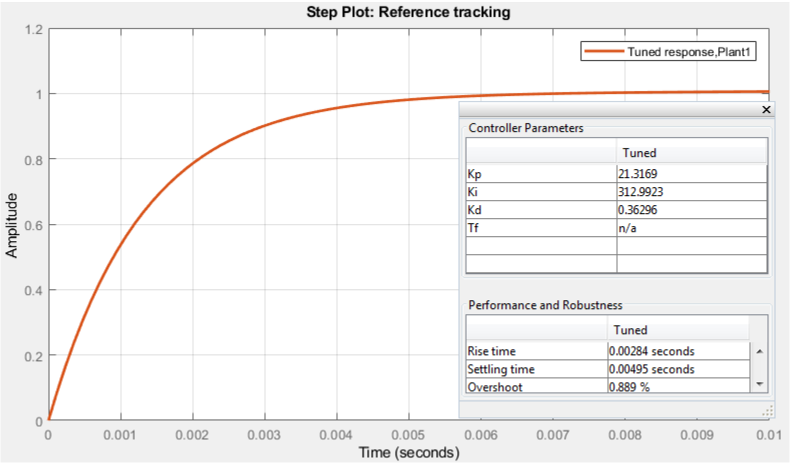
The function can also be written as controller based off a Laplace transform,

$$C(s) = K_p + K_i\frac{1}{s} + K_d s$$

3 SIMULATION

3.1 PID Tuner MATLAB control

In order to accurately control the system when there is a change in angle in the sun, the PID tuner was used. This was used to modulate the coefficients of K$_P$, K$_I$, and K$_D$ to achieve limited overshoot and steady state error. Most importantly the factor of rise time was consider and modulated in such a way so that the delay would be robust enough to match positioning from the sensor.



Controller Parameters

	Tuned
Kp	21.3169
Ki	312.9923
Kd	0.36296
Tf	n/a

Performance and Robustness

	Tuned
Rise time	0.00284 seconds
Settling time	0.00495 seconds
Overshoot	0.889 %

Fig. 8. MATLAB PID tuned result

3.2 Similink MATLAB PID

Due to the physical functionality the input to the system will be dependent on the angle of the the position of the sun. This can be achieved though a non-stationary light sensor that will track variations potentials due to the amount of solar radiation. The micro controller will the send a response to the system and it will control the positioning of the PV cell until the maximum potential is achieved. By abstracting away from the hardware element of this concept, the simulated reaction in theory can be tested though MATLAB and the calculated plant:

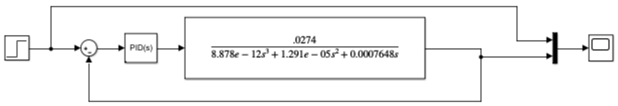


Fig. 9. Similink system layout

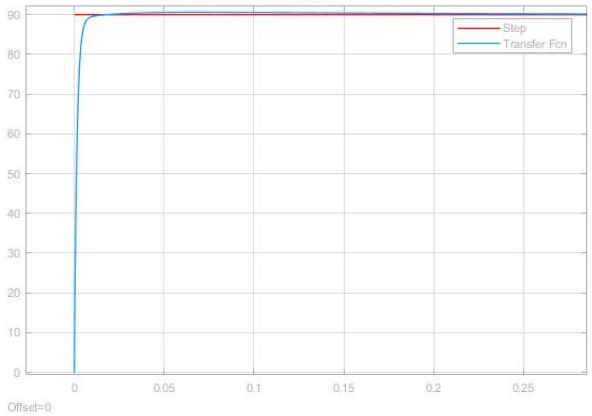


Fig. 10. System PID result to step

Consider the systems response to the step function from a fast variation in degree (0-90°). The PID control is adjusted in to eliminate the amount of error in the the response of the system. Ideally, the input to the system would be a very slow and parabolic in nature.

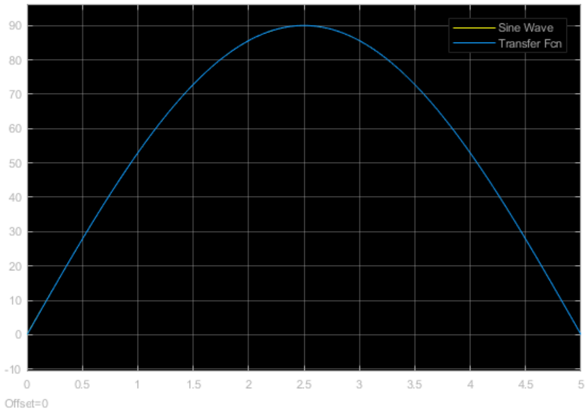


Fig. 11. Parabolic response to PID system

As observed from Figure 11 the angular positioning of the single axis closely follows that of the input signal based off of the PID control. This will provide a really robust system when considering the second input for seasonal variation in solar position.

3.3 Fuzzy logic MATLAB

The fuzzy logic controller is a more ideal way of modeling a system. This is true when the parameters and and physical model of the system is not direct, or are very complex and in need for more robust control. Using MATLAB the fuzzy logic controller accepts two inputs:

- Angular positioning due to the time of day
- Seasonal angular positioning at peaks of the solstices.

The outputs for the fuzzy logic controller provides the angular compensation for the DC motor to rotate to a particular angle.

- Hourly Angular rotation of the DC motor.
- Seasonal angular rotation of the DC motor.

After the member functions were formulated to fit the peak times and angles for the seasonal solstices, the rules were formulated. This was done in such a way that accounts for all hours at any given time, and all given seasonal changes at any given time equating to a total of nine rules. These rules were used to create the proper output as seen in the figures below showing the graphical representation of the Fuzzy control.

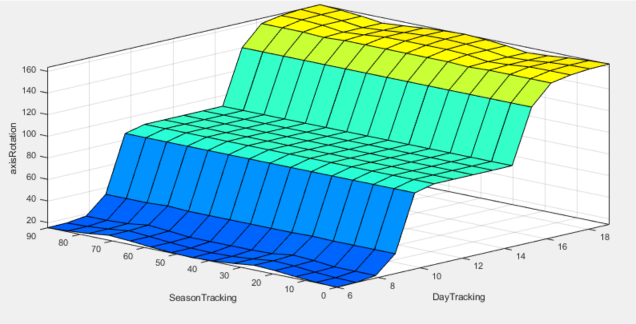


Fig. 12. Angular rotation through out hourly tracking

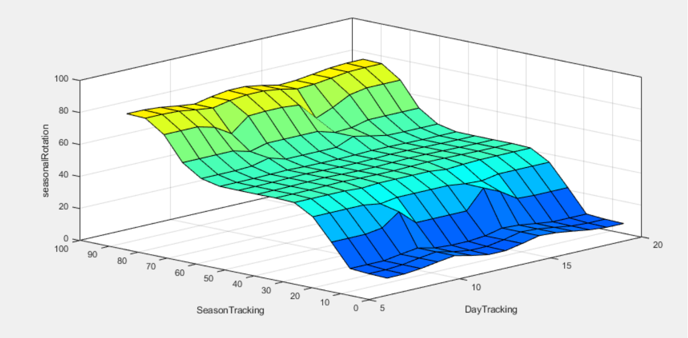


Fig. 13. Angular rotation through out seasonal tracking

As seen in the data below (Figure 14) the variations in both inputs accounts for the corrections in the angular rotation of each axis to ensure that maximum solar radiation is captured at any given time. This is of course based off the solar sensor reading. The fuzzy logic controller will accept an input in this case roughly 12pm at a large seasonal angle of 87.3 degrees. Thus, the outputs are accounted for and give the angles of 90 and 86.3. these values are relatively accurate for the application of dual axis solar tracking.

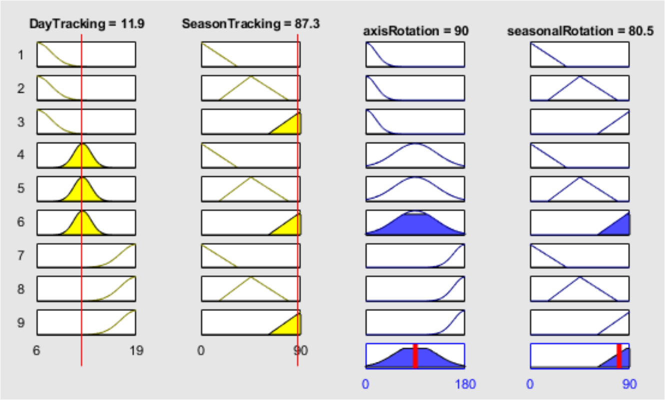


Fig. 14. Data showing the Fuzzy control

4 CONCLUSION

Solar tracking on a dual axis system provides many challenges that can prevent the implementation of specific control systems. Due to the suns nature the uncertainty of the exact specifications of the mathematical model of the plant, it is difficult to simulate a real world PID controller for the system. Despite that fact the plant was calculated off of a DC motor and the PID was formulated though simulation. It is clear that the PID plant simulation is not as robust as fuzzy logic, and may not encompass all of the variables of the complicated system as a whole. The fuzzy logic controller produces an output, or set of outputs that can provide insight on many different angles at various times of day, and produce close adjustments on the DC motor. It is these reasons why the fuzzy logic controller would be more robust in nature, and provide for a better alternative than PID.

REFERENCES

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