# Solar Tracking Systems and A Two-Axis Active Prototype With Stepwise Movement

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## ABSTRACT

In this work, criteria for a two-axis solar tracking system that provides a higher voltage and power output than a fixed solar panel, are determined and a prototype is realized with stepwise movement. From that point on, to design a practical solar tracker, extensive research studies were conducted which resulted in determination of optimal techniques and components. As a result, by using a small scale solar panel, servo motors as drive elements, Arduino processor as the controller, and a wireless transmitter that transmits voltage feedback to the controller, a two-axis active solar tracker is developed which moves in pre-determined steps.

***Keywords:*** *Solar Panel, Two-axis tracker, Active Solar Tracking System, Stepwise Adaptation*

## 1. INTRODUCTION

In the beginning, solar energy is used only in heating purposes and for getting hot water in both residential and industrial domains. However, in recent times, it became a fundamental source of electrical power as a result of rapidly developing technology of solar cells, namely photovoltaic cells, that basically convert sun light into electricity. Solar cells that are used for generating electrical power are called photovoltaic, that the term itself explains the obtainment of voltage from photons. Photovoltaic solar cells, can be employed flexibly, as in simple series and/or parallel connections and/or combinations, according to current and/or voltage requirement, therefore according to the power demand of consumers and to the specific purposes of many kind of appliances.

Solar tracking can be achieved by single-axis or to increase susceptibility and efficiency by two-axis motion mechanisms. For solar trackers with two-axis mechanism, there exist two types of techniques. These techniques are known as, polar or ecuatoral tracking and elevation or inclination tracking, in the solar energy literature. From physics, it is a well-known fact that, highest energy can be obtained when the photons of solar radiation coincide with the converter, the solar panel, perpendicularly. Thus, solar tracking systems aim maximizing the energy output by adjusting the position of the cell in order to get the solar radiation in an optimal perpendicular angle. Although the optimal performance depends on the sharpness of the coinciding angle, high resolution in motion mechanism is not essential. As a matter of fact, experiments

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show that a 10 degrees of deviation from the optimal angle decreases the efficiency to a value of 98.5%.

Up to 2002, development of two-axis solar tracking systems was not taken seriously, thus, works and experiments were only conducted by academic researchers and hobbyists. In 2002, first patent was granted and commercial productions became the current issue. However, at this point, several difficulties of experience came up. For instance, control of second axis complicates the overall system. Besides, mechanical drawbacks emerge as the system gets more complicated.

Although, it is not necessary to incorporate solar tracker systems in all kinds of solar cell installations, to increase the efficiency and the performance in generation of electricity, it is a requirement. Solar tracking mechanisms have drawbacks such as, increase in cost, reliability, energy consumption of control circuitry, and need for maintenance, notwithstanding the aforementioned benefits, i.e. increase in efficiency and performance.

In common, solar tracking systems share characteristics listed below, partially and/or completely.

- Single column architecture or parallel, console like structure,
- One or more driving motor,
- Light sensing unit,
- Autonomous or auxiallry power supply,
- Light tracking or tracking based on a database,
- Continuous or stepwise discrete movement mechanism,
- Adjustment of inclination and/or declination angle.

There are several solar tracking methods proposed in the present literature for practices like solar cells, solar radiation collectors, condensers and telescopes, where it is essential to get the solar radiation from a perpendicular angle. An ideally constructed solar tracking system ought to provide orientation of the photovoltaic solar cell directly to the direction of the radiation coming from sun. To accomplish this task, horizontal and vertical movement of the solar panel is needed. Solar tracking systems can be classified into two major categories accordingly. These classes are, passive tracking systems which employ mechanical and/or hydraulic driving mechanisms, and active tracking systems which incorporate electrically driven and, not necessarily, electronically controlled designs.

## 2. METHODS

In literature on solar radiation is, in general, assumed as spherical wavefronts coincide with a horizontal plane, in a similar manner with far field modeling approach. Based on this, solar cells or cell banks are positioned on horizontal plane with slope, to get the wavefronts with vertically perpendicular angles. As everyone knows, sun moves in the sky during the day.
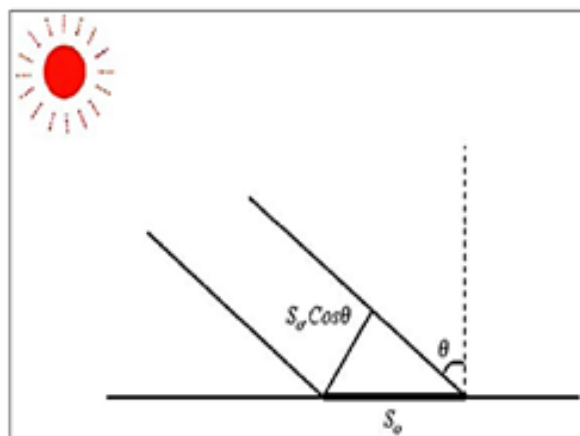


**Figure 1.** *Inclination angle, θ, of solar radiation*

For a fixed solar collectror and/or panel, as can be seen from Figure 1, projection of receptive field on the plane is determined by the cosine of the incoming light. As the angle of the incoming solar radiation, "θ", increase, power output of the solar cells decrease.

## A. PASSIVE TRACKING

Principle of operation of a passive solar tracking system relies on thermal expansion of a material, usually Freon, or alloys that have form memory which remember its former shape.

In general, these type of tracking systems are made up of a couple of actuators that make inverse movements of each other. When both actuators are equally illuminated, they stay in equilibrium position. Illumination differences of these actuators result in an unbalance of forces. By this way, inclination of the tracking system can be accomplished. Consequently, actuators reach new equal lighting levels, and therefore tracking system comes up to a new equilibrium position.

Passive solar tracking systems have less complex structures than active solar tracking systems, if we compare, and they operate in a lower efficiency.

Besides, there exists the risk of not working in low temperatures or quitting operation. Existing experimental studies in the literature show that, passive mechanical systems are comparable with electrically controlled active systems in performance scores. Mostly passive solar tracking systems are not demanded much by the consumers yet, although they have less cost. This tendency would change accordingly to the developments in the mechanical fronts. From Figure 2, a passive solar tracker mechanism designed using computer aided

methods can be seen. In this passive solar tracking system application, two pieces of double alloy metal rods of aluminum and steel are used. In this application, the principle of operation was that although the inclinations of the expanding metal rods are small, corresponding mechanical forces due to these inclinations are large.
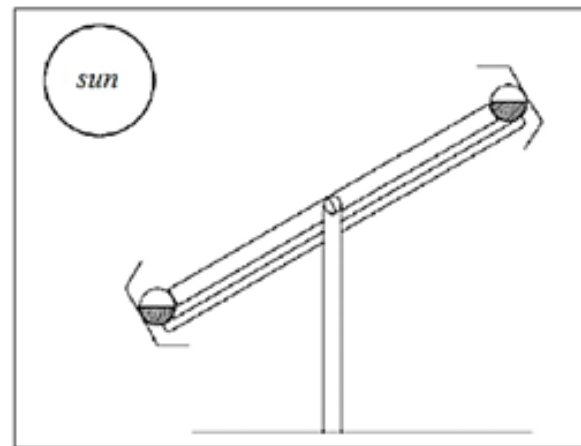


***Figure 2.*** *Passive Solar Tracker*

These double alloy metal rods are positioned bilaterally on wooden frames. Their positions are symmetrical to the center of the horizontal axis. In addition, the passive solar tracking system is also equipped with a damping mechanism in order to prevent oscillations and/or slowdowns in motion. Finally, by the solar panel with passive solar tracking system, it is statedthat the efficiency can be increased by a ratio of 23%.

## B. ACTIVE TRACKING

From a general perspective, active solar tracking systems can be classified in three categories as, microcontroller and electrical or optical sensor based, computer controlled, date and time based and using an auxillary two-sided solar cell. It is also possible to inlude a hybrid class where three categories listed above are combined.

Electrical or optical sensor based solar tracking systems are commonly include at least a couple of anti parallel connected photoresistors or photovoltaic solar cells. Both of the sensing elements reach an electrical equilibrium under equal light intensities. This is the main principle of operation of these solar tracking systems. Therefore, control signal that is required to operate the driving motor, is never used or used in a negligible ratio.

In solar tracking systems that involve auxillary double-sided solar cell, double-sided solar cell achieves sensing and driving task, that is serves for the system to track the desired position. In computer controlled, date and time based solar tracking systems, using databases as well, solar positions are calculated for daily and annually by algorithms and control signals are generated.

In general, microprocessor based solar tracking systems, need two motors as actuators and two solar cells. For a microcontroller based solar tracker, three distinct tracking algorithm can be listed as below.

- First algorithm moves the solar cell using global coordinates in a circular manner. Aim is defened as to determine the point that provides optimal voltage within this pre-defined circle. The circle is to be defined by the radius chosen by the user.

- In the second algorithm, solar panel is moved in a squre pattern. By this, solar tracking system tries to find the maximal voltage level.

- The third and the last algorithm involves the method in the second algorithm and determines the parameters for optimal days in a year, and hours in a day. These parameters are incorporated in predicting the next position of the sun, thus the solar tracking system.
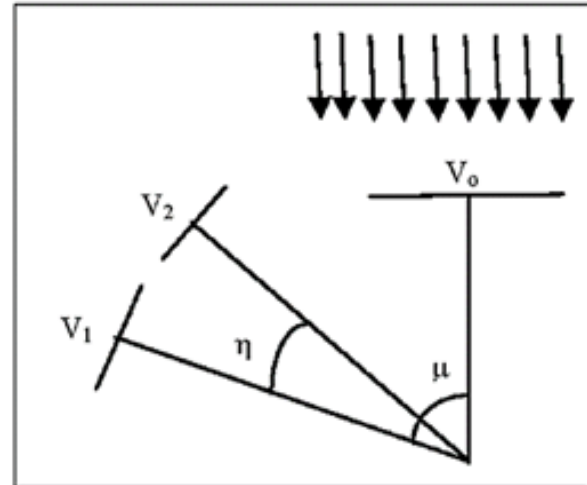


***Figure 3.*** *Operation principle of a solar tracker*

A typical calculation of operation is shown in Figure 3 and described here. Assuming that there are two voltage values measured from solar panels, V1 and V2 present. These voltage levels and/or solar panels are being separated from each other by an angle of η. Besides, V0 and V1 voltages are also separated from each other by an angle of μ. Here, V0 voltage level stands for the possible voltage level that could be measured when solar panel is positioned perpendicularly according to the sun and/ or light source. If V1, V2 voltages and η angle is known, μ angle can be calculated as follows.

$$\mu = \arctan\left(\frac{V_2 - V_1 \cos\eta}{V1\ \sin\eta}\right) \quad (1)$$

This equation can also be written from Figure 3, as it is actually a geometrical interpretation. In the overall, developed algorithm is programmed and uploaded to the microcontroller, where driver circuits of actuators are also connected to the

microcontroller, thus linking the code to sensing and driving elements. From sensors employed, highest resolution measured was 6°.

Under the light of obtained findings, 1° deviation from perpendicular angle results in measurement of 99,98 % of the maximal voltage level as well as 10° deviation from perpendicular angle results in measurement of 98,5 % of the maximal voltage level is concluded.

## 3. PROTOTYPE

Developed active solar tracking system in this work can be seen from Figure 4 with its final view. This tracker has not designde for a continuous-motion, thus for continuous controlling perspectives are not concerned. Step-wise movements, that are determined according to the measurements, yield adequate performance, therefore, it becomes more practical to implement the control mechanism and/or to decrease the installation costs.

Besides, terminal connections of the servo motor that is located beneath the lower plane do not contribute any problems to the rotational motion. However, rotating upper plane, which is controlled by a single servo motor, has connections with the fixed plane, thus inhibits infinite rotation. In order for these terminal connections not to block rotational motion, by eliminating recurrent positions that come up in several angle combinations, and by including all possible positions for lower and upper planes, rotational movement of the lower plane is limited 90° rotation of the lower plane provides all possible positions. Therefore it was adequate to limit rotation of the lower plane to 90°, and the design was realized accordingly. For also the upper plane,it was not necessary to have motions in

large angles. For instance, it is useless to have a 180° rotation because the main purpose is to make perpendicular angles with the incoming solar radiation. As a result, rotational motion of the upper plane is limited between 30° angles.

Active solar tracking system developed in this work, employs voltage level that the solar cell bank produces as the feedback criterion. Therefore, obtainment of the optimal voltage value is the main purpose of the closed loop tracker system. Voltage information is being transferred to the controller unit via a wireless transmitter operating in 2.4 GHz radio frequency. Wireless transmitter card also include an analog-to-digital converter, where analoguously obtained voltage values are converted to digital data before wireless transmission.
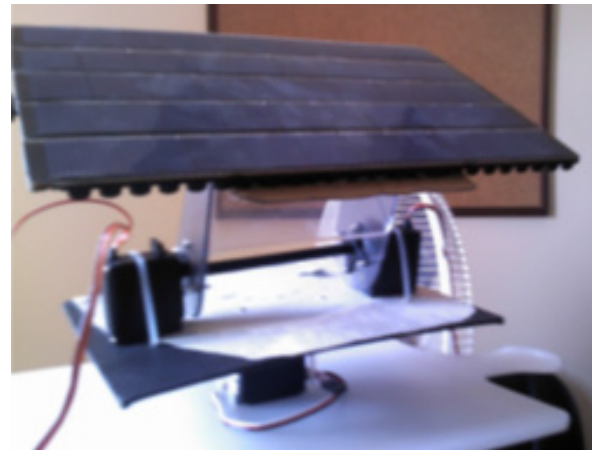


**Figure 4.** *Developed Solar Tracker*

In control unit, which is also checked by a Matlab code, feedback voltage information data are visualised. Digital voltage information data are made of numbers between 0 and 1023. These values correspond to voltage levels between 0 and 5 volts. A sample voltage recording can be seen from Figure 5. In this figure, recorded data are again converted to

voltage levels between 0 and 5. Horizontal axis represents time in seconds and the sample recording shown here lasts approximately 6 minutes - 350 seconds. A fluctuation between 4.5 volts is observed during this sample recording. When investigated in detail, ripples can be seen better as shown in right bottom corner of the Figure 5. In short-term operations, these fluctuations result from passing birds or clouds, and can be interpreted as noise. These fluctuations, which one can assume them as system noise, have an average magnitude of 0.25 volts. Because of its low order of magnitude, it can be neglected, and it is not required to be overcame.
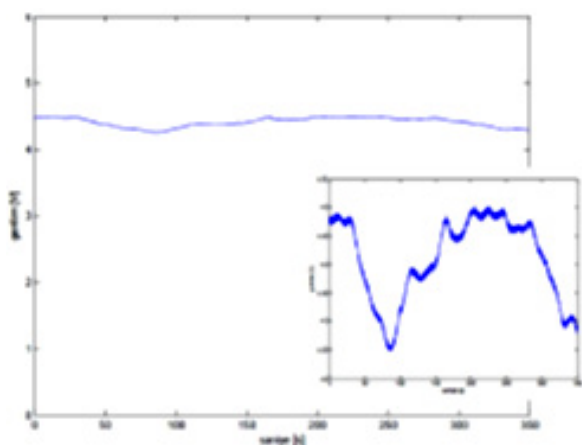


**Figure 5.** *Voltage level fluctuations*

In the active solar tracking system designed, instantaneous and/or short-term fluctuations are omitted and therefore, instead of a continuously controlled design, stepwise movements are appreciated as mentioned before. In the closed loop active tracker developed, three action plans were determined, and these action plansa re valid for noon, before-noon, after-noon. During the daytime, within time intervals for these action plans, measurements should be done and optimal position should be determined. These positions might be different from day to day and/or year to year. According to our stepwise design,

our control system has 9 different pre-defined positions. These positions are determined by adding and subtracting 15 degreed angles of the solar panel in x and y axes. Therefore, for an action plan to be chosen, feedback from each of these nine positions are evaluated and maximal voltage value is chosen.

## 4. CONCLUSION
In this work, criteria for a two-axis solar tracking system that provides a higher voltage and power output than a fixed solar panel, are determined and a prototype is realized with stepwise movement. From that point on, to design a practical solar tracker, extensive research studies were conducted which resulted in determination of optimal techniques and components. As a result, by using a small scale solar panel, servo motors as drive elements, Arduino processor as the controller, and a wireless transmitter that transmits voltage feedback to the controller, a two-axis active solar tracker is developed which moves in pre-determined steps. Developed system is pretty original, when compared to the previous approaches in the literature. As a consequence of stepwise motion and control strategy comprising of pre-determined action plans, sensing, driving and control circuits of the overall system consume quite low quantities of power and energy.

**Table 1.** *Daily measurements*

| before-noon 11:00 | horizontal | | |
|---|---|---|---|
| | -15⁰ | 0⁰ | 15⁰ |
| vertical 15⁰ | 5,85 | 5,81 | 5,73 |
| vertical 0⁰ | 5,78 | 5,70 | 5,59 |
| vertical -15⁰ | 5,66 | 5,61 | 5,47 |

(a)

| noon 14:00 | horizontal | | |
|---|---|---|---|
| | -15⁰ | 0⁰ | 15⁰ |
| vertical 15⁰ | 5,90 | 5,93 | 5,89 |
| vertical 0⁰ | 5,82 | 5,89 | 5,84 |
| vertical -15⁰ | 5,79 | 5,81 | 5,78 |

(b)

| after-noon 17:00 | horizontal | | |
|---|---|---|---|
| | -15⁰ | 0⁰ | 15⁰ |
| vertical 15⁰ | 5,70 | 5,79 | 5,83 |
| vertical 0⁰ | 5,59 | 5,68 | 5,74 |
| vertical -15⁰ | 5,48 | 5,57 | 5,62 |

(c)

(a) Before noon at 11:00 (b) Noon 14:00 (c) After noon 17:00

From Table 1, measurement data can be seen recorded in a sunny day in August. As it is mentioned before, there are three action strategies in a day that depends on solar positioning. Therefore, the first one is shown in table (a), where measurements that are conducted before noon (11:00 a.m.) included. Here, optimal position, namely the position that provides maximal voltage level is obtained by 15° vertical and minus 15° horizontal angles. In (b), best position

is obtained by selecting 15° vertical and 0° horizontal angles. The last table, (c), shows measurement results at afternoon, and by 15° vertical and 15° horizontal angles maximal voltage level is obtained.

Active solar tracking system developed here, uses the selected position out of 9, and holds that until next day time and/or action plan. Therefore, neglectible voltage fluctuations during one action plan, i.e. afternoon, as measured and plotted in Figure 5, do not cause any negative effect.

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