Automatic System and Energetic Efficiency Optimization Algorithm for Solar Panels on Mobile Systems

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***Abstract**: The system described in this paper is aiming to solve the non-optimal energy conversion in solar panels due to the angle bias of the panel surface orientation related with radiation source.*

Because the device is intended to function on a mobile system with unpredictable moves, the orientation algorithm works in an adaptive manner. The mathematical background of the algorithm use geometric 3D vector objects and the goal is to maximize the light energy incident on the solar panel surface (which is equivalent with maximizing the scalar product of a pair of normal vectors).

The geometric problem of orienting a plane surface in space has two degrees of freedom, so it can be mechanically resolved by two motors. These motors will individually make a rotation of the device around the two central axes of the square panel. In this regard, the orientation system receive at its input minimum three signals representing information about the spatial angle position of the power panel relative to light source and outputs two signals which controls the mechanical movement made by the motors.

For simplicity reasons, the sensors used to detect the angle position are actually small solar cells identical with the cells that form the power panel, disposed beside the four sides of it and with a fixed zenith angle. This angle determines a different illumination (influenced by the position of the light source) which leads to the desired positional information.

Due to the symmetry of the system and the alignment of the sensors with the rotational axes of the motors, the orientation algorithm can be made simply and independently on the two motors. With a fixed number of motor steps per algorithm cycle, the only decision that must be made is the sense of rotation. This decision is computed immediately by comparing the signals produced with the corresponding pair of sensors

1. INTRODUCTION

Photovoltaic panels, generating "green power" are increasingly being used on various mobile or fixed systems to produce electricity directly. Because a solar panel (Figure 1) converts a certain amount of light energy in a quantity of electricity, optimizing the flow of light incident on the panel is an important issue in obtaining a maximum efficiency. Incident light flux depends on the spatial position of a surface relative to a given direction (corresponding to the light ray).

One can easily see that the orientation in space of a surface in order to maximize the projection area with a plane is a geometric problem with 2 degrees of freedom.

Conversion efficiency of photovoltaic cells depends directly on the angle of incidence of light rays with its plane surface. The maximum of it is at an angle of 90 degrees. This problem of maximizing the efficiency of a mobile system can be described effectively using mathematical concepts of 3D vector geometry. One can easily see that the orientation in space of a surface in order to maximize the projection area with a plane (representing the light flux) is a geometric problem with 2 degrees of freedom.

2. THE DESCRIPTION OF THE SYSTEM HARDWARE

Since a space position can be described by 3 parameters, the orientation system needs at least 3 sensors to provide information.

In a practical system, the sensors number will be increased to 4, on the one hand because of the shape of rectangular solar cells, on the other hand due to decrease of the volume of calculation required to implement the algorithm.

The system consists of photovoltaic cells disposed on a mechanical stand and interconnected together in series or parallel according to the technical power specification imposed by the user.

On each of the four sides of the panel are disposed a transducer (A, B, C, D) at an angle of 30 degrees to the surface plane as represented in figure 2.

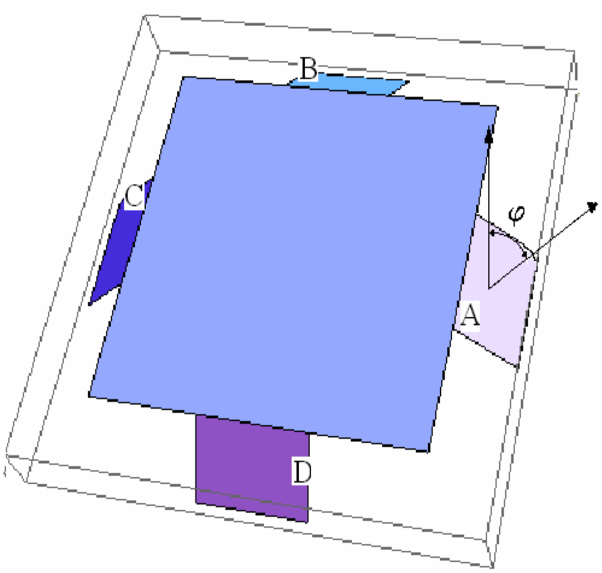


Figure 2. The placement of detection cells unto main solar panel at an angle of $\varphi = 30^o$

These are geometrically arranged so that the vector normal to their surface forms an angle with the normal vector of the main panel. Due to different angular positions, the light flow that falls on each detection cell is dependent on the angle of incidence of sunlight rays.

The whole system (photovoltaic cells + sensors) is placed on a mechanical articulated structure with two degrees of freedom and is moved by 2 step-by-step motors through mechanical demultiplication. The control of the system is done by a PIC16F684 microcontroller and some specialized circuits in accordance with the schematic illustrated in Figure 5.

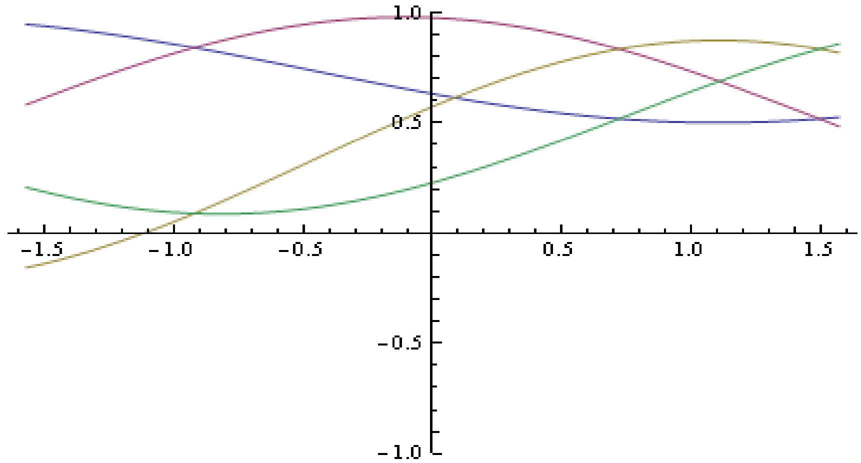
The electronic control system modifies the orientation of the solar panel by taking information received from sensors, information depending on the spatial position of the ensemble relative to the source of light and generates at the output two action signals for the two motors.

The orientation system is based on signals generated by the four cells exterior to the power panel. Since each detection cell is tilted with a different angle, signals generated as a function of angular position of the entire ensemble will differ among themselves.

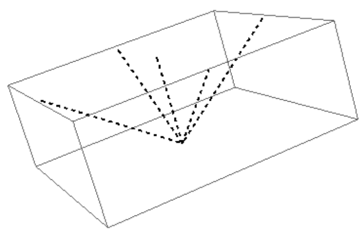
Spherical coordinates of normal vectors to the surface of detectors are: $(r, \theta, 0)$, $(r, \theta, \pi / 2)$, (r, θ, π), $(r, \theta, -\pi / 2)$.

To develop algorithms to control the movement of the panel on the two degrees of freedom one makes the following observations (Figure 3):

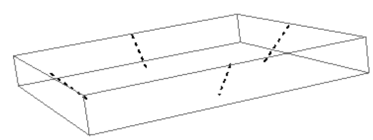
a. symmetry and orthogonally of the angular positions which will simplify a lot the algorithm of guidance;
b. optimal position (maximum efficiency) of the solar panel is when the vector associated with the sun rays is parallel to the vector normal to the surface panel
c. signals generated by detection cells depends on the incident light flow which is proportional with the module of the projection vector incident on normal vector (and is equal to the scalar product of the two vectors)
d. In figure, there are represented the scalar products between the vectors normal to the detectors planes and the incident vector (the sun rays) as a function of angular position from a side of power panel (Ox or Oy axes in Cartesian representation)
e. Because of the symmetrical arrangement of detection cells, the optimal position of the solar panel corresponds to the equality of all detectors signal (considering that the detection cells are identical)
f. the optimal position is not at a maximum or a minimum of a signal (as seen in the figure) but at the intersection of four curves
g. if the motors are positioned so that one rotates the system around the axis Ox and the other around the axis Oy, information about the optimal position obtained by a group of two signals is decoupled from information given by other group (Figure 4)



a)



b)



c)

Figure 3. Graphs for the normal vectors to the detector cells planes and the function of scalar product of them with one random spatial (3D) vector: a)- scalar products of normal vectors and one random versor in space with rotation of the base plane (plane of main solar panel); b)- normal vectors translated in space such that each of them have the same initial point; c)- normal vectors to the detector cells planes

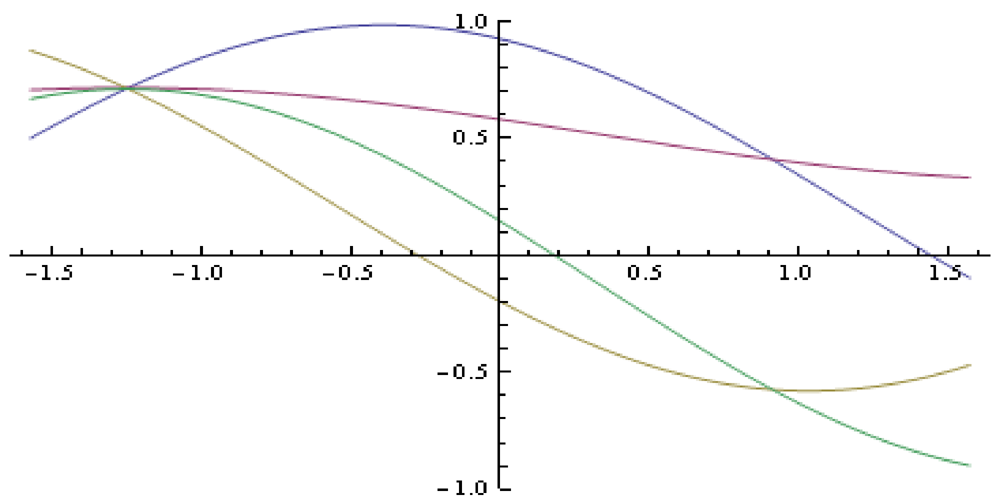


Figure 4. The scalar product between normal vector of each detection cell and the vector of a solar ray in condition of full rotation of one motor; because in some point the 4 curves are intersecting that point represent the optimal position.

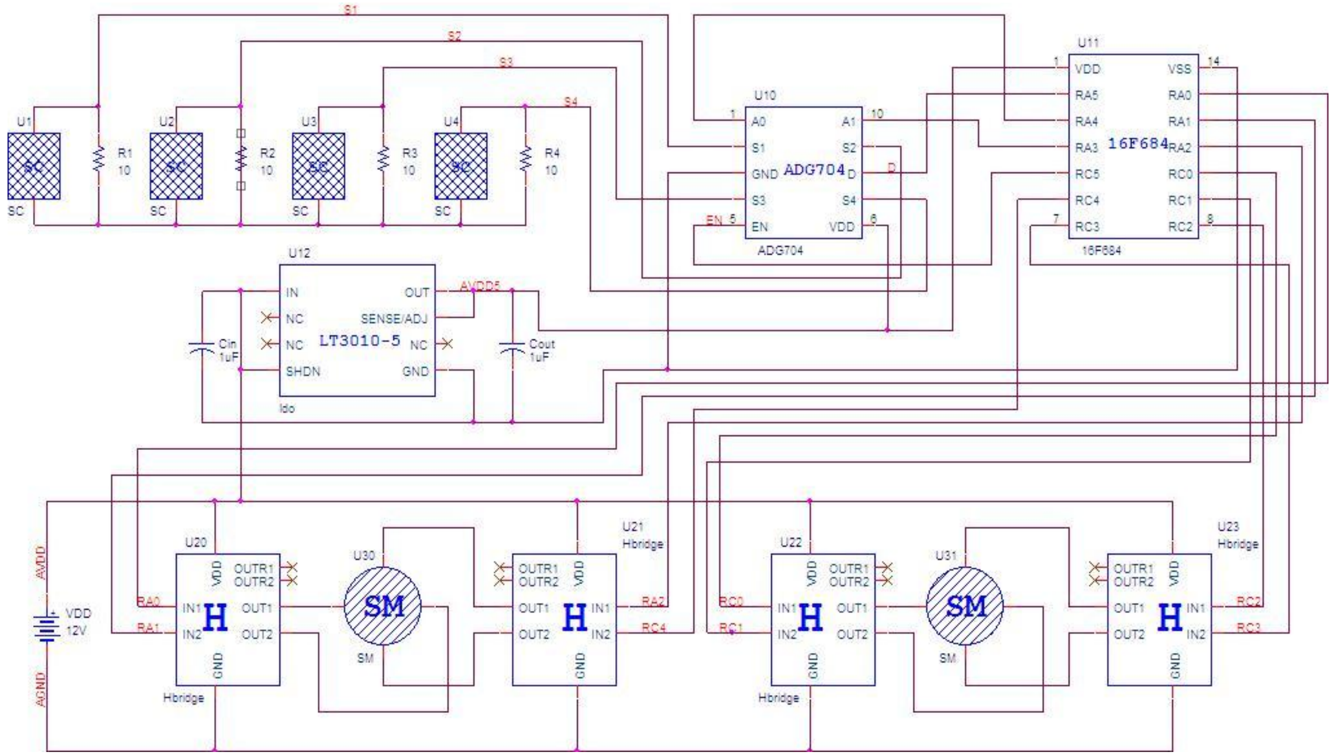
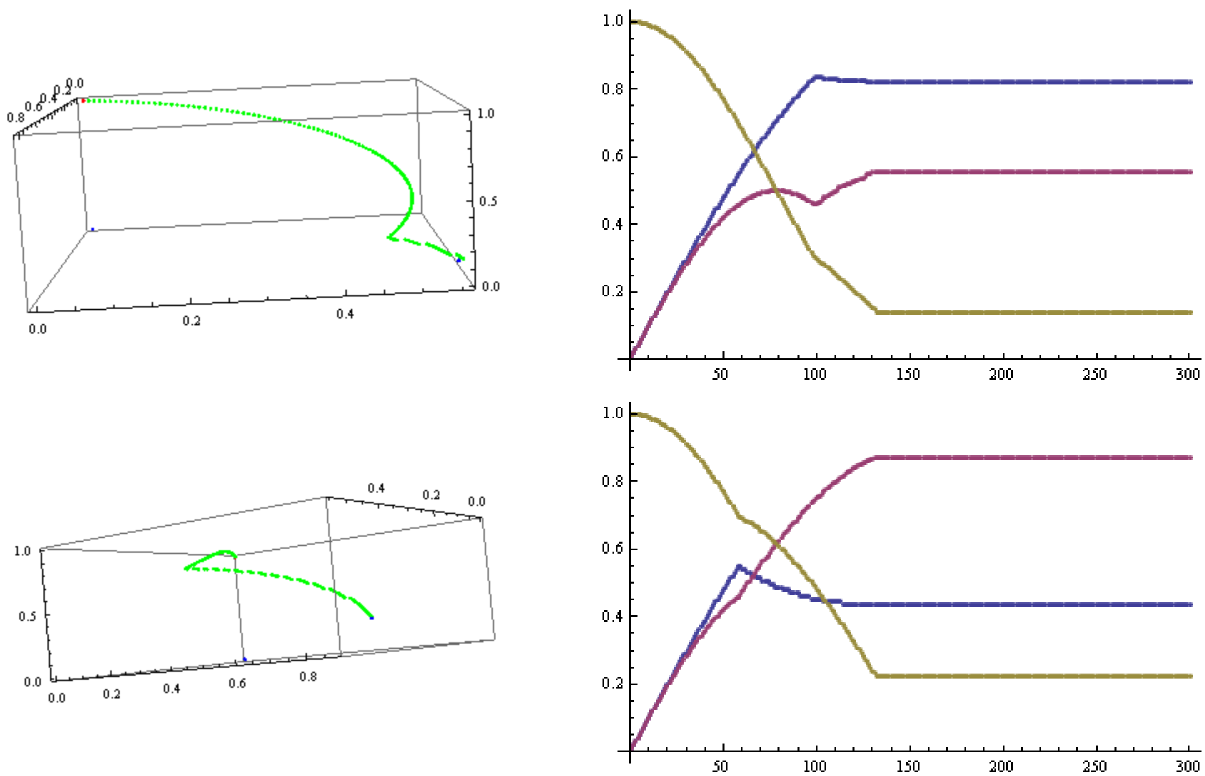


Figure 5. The electronic circuit diagram of the system



a) b)

Figure 6. Time evolution of the proposed algorithm; a- coordinates of the unit vector normal to the panel surface; b- time evolution of normalized signals from transducers.

3. PROGRAMMING ALGORITHMS

The correspondence between signals and motors is as follows: cells attached on the panel side parallel to the main axis Ox affect the movement of the motor that rotates the system around the axis Ox; similarly, for the other motor.

In these circumstances, the algorithm will run as follows:

a) read the signals from two opposing detection cell
b) compares the two values and determines the direction of rotation of the motor corresponding to the group of cells; if those are equal the motor will not rotate
c) the motor rotates a number of steps in the proper direction (if values are different)
d) same steps for the other motor and group detection
e) jump to step 1.

The algorithm can be influenced only by changing the number of steps done by motors at each cycle (which actually change the mechanical resolution).

A small number provides a high resolution and a good approximation of the optimal position, but the algorithm extends the time needed to reach that position.

A greater number accelerates the algorithm but the accuracy obtained is low.

4. RESULTS

The resulting algorithm converges, the speed and precision of it being modified by changing the number of steps per cycle. This parameter will be chosen according with the mechanical structure, the desired speed of the algorithm and the precision in finding the optimum position. Also the zenith angle of the sensors will be fixed according with the desired variation sensibility of received signal illumination

5. CONCLUSIONS

a) The figures above were obtained by the assumption that the signal voltage of cell detection is proportional to the flux of light incident on them.
b) This may not be strictly true in practice, but because the conversion (light flow -> voltage) is a monotonic function (voltage is always higher for a higher luminous flux) the general algorithm operation does not change.
c) Another parameter to be chosen in the construction of the system is the angle of inclination of the detection cells from the main panel.
d) Working with ideal detectors (proportional conversion), this angle does not influence the evolution of the system as long as it is chosen between 0 and $\pi / 2$.
e) With the minimum value of 0, the four cells provide exactly the same signals, so they will not provide useful information.
f) With the value of $\pi / 2$, cells do not receive light so the optimal algorithm may not converge when it is very close to that point.
g) At higher angle values cells enter in the dark, being covered by the panel and therefore, will not work.
h) The choice of the inclination angle of the detector will be made taking into account the conversion feature and will seek a maximum variation of the signals around the optimum point (which will maximize the sensitivity of the system).
i) The choice of the number of motor steps that are done at each algorithm cycle will be made taking into account the desired accuracy (the proximity to optimal point), the algorithm speed and the actual mechanical structure (which may include rotation demultimplications to increase the mechanical force).

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