

LOW-COST SENSOR FOR THE SOLAR PANEL ADAPTIVE COMMAND

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ABSTRACT: Until recent, the humanity relied heavily on fossil fuels to produce the needed energy. At the beginning of the industrial revolution, coal was used to produce steam used to produce mechanical power. A hundred years ago the oil came into action. Up to this day, humanity relies on oil for many reasons. Another fossil fuel used is the natural gas. Up until this day, this one is used even to heat up many houses but also for water heating. Latest developments reveal the so-called climate-change. Several years ago, polar caps melting have been noticed due to temperature rise. Scientists have also determined a rise of the CO_2 concentration. To limit the effects of the CO_2 increase, several countries have been agreed to reduce CO_2 emissions. One possible way to reduce them is to limit the use of the fossil fuels. Using the natural energy (produced by the sun) is a way to achieve this reduction.

This paper presents a control system which can be used to rotate a solar panel (for hot water or electricity production) to increase the absorbed energy. A low-cost sensor is the central piece in this system. A microcontroller-based system is used to control the two motors to rotate the panel. System parts are described and conclusions are drawn.

KEYWORDS: Control, Green Energy, CO_2 emissions

1. INTRODUCTION

Even now the humanity relies heavily on the fossil fuels to produce the much needed energy. The industrial revolution used coal to produce the steam used in motors to deliver mechanical energy. Almost the same principle is used to produce electrical energy in the coal power plants.

Today, the coal's place is held by the oil. Used to deliver mechanical energy to cars, trains, boats, etc. (but also to produce many others) this modern commodity fuels the world economy today.

Recent research has demonstrated an increase in CO_2 concentration in the atmosphere. Despite the fact that this gas is not pollution (and not considered to be - after all, plants and trees consume CO_2 and converts it into oxygen), it acts like a greenhouse gas, causing a temperature rise. Its concentration increase will only make things worse. Among the effects one can mention: polar caps melting, sea level rising (as a direct effect), an increase in the captured heat, atmosphere instabilities, the increase in storms and hurricanes damage, etc. The increase of CO_2 emissions can be seen in figure 1.

In an attempt to counter the above-mentioned consequences, several countries have signed the so-called Kyoto Accord. This document stated the decrease of CO_2 emissions. This purpose is achievable by: reducing the use of fossil fuels, developing devices which ensured low emissions, etc.

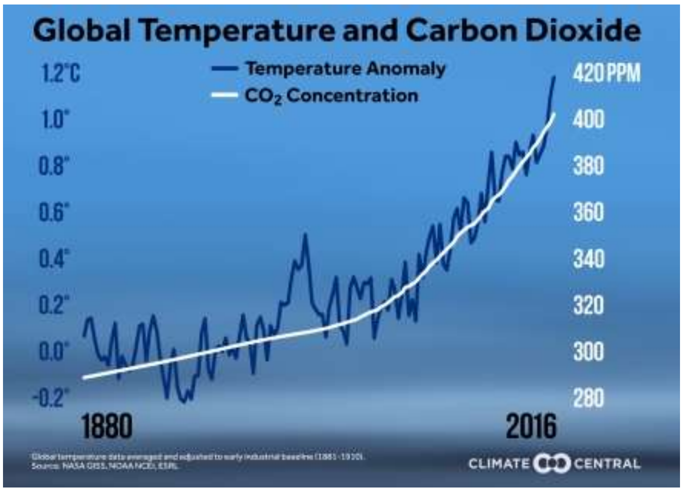

Figure 1. The increase of concentration of CO_2 (from: http://www.climatecentral.org/gallery/graphics/co2-and-rising-global-temperatures)

According to some studies, the measures taken are already producing results (they can be seen in figure 2). According to them, the CO_2 emissions have reduced in 2015.

The above-mentioned prove that humanity can take measurements to improve the situation.One way to reduce carbon dioxide is use the sun radiation for hot water production. This idea is not new, however is not largely implemented.

The solar radiation can reach up to $1000W/m^2$, [1]. Its impact on earth can be seen in figure 3. In this figure one can see that countries located below 45° parallel receive at least $1000kWh/m^2$. In certain conditions such amount of energy can replace the use of fossil fuels. Several convenient ways to do that are mentioned here: hot water generation, electricity, and more recently.

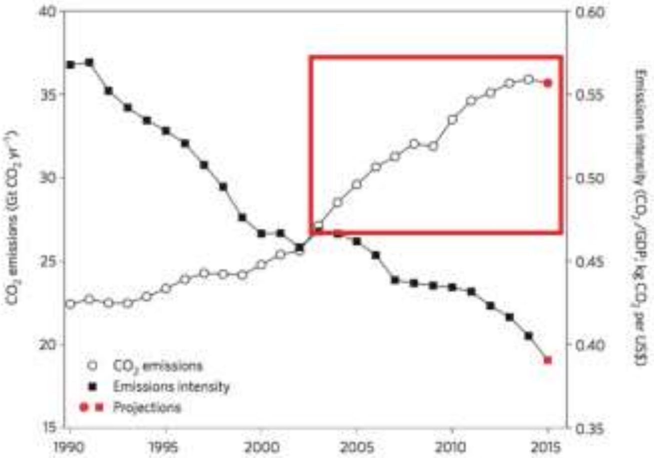

Figure 2. Decreasing the amount of CO_2 emissions (from: http://www.slate.com/blogs/bad_astronomy/2015/12/08/global_warming_co2_emission_dropped_globally_in_2015.html)

Researchers are interested in maximizing the received energy. There are several way to do that: rotate the solar panels, predict the solar radiation [2], [3], [4], [5], etc.

Figure 3. Solar radiation in Europe. It can be seen that countries located below 45° receive more than 1000kWh/m^2 (downloaded free from: http://solargis.com/products/maps-and-gis-data/free/download/europe)

Some researchers are concerned with solar radiation prediction. Karoro et al [2] use five years of solar radiation data to estimate the monthly average of global radiation on a surface. To achieve this result, they employ an artificial neural network. The model they develop generated results with a mean square error of 0.521MJ/m^2.

Other researchers try to predict the solar radiation in places where no measurement data is available. Nine years of solar radiation measured data is used by Gupta and Singhal [2] to estimate the solar radiation in geographical locations with no measurements. To achieve this purpose, they employ Artificial Neural Network (ANN) for interpolation and estimation.

The sun energy is being used in desalinization systems as well [6], [7], [8]. In order to produce more fresh water, their systems need to absorb as much solar energy as possible.

2. SOLAR SYSTEMS

The solar energy may be transformed into electricity or thermal. The first generate electricity which is received by the power grid/network. Such systems can be seen in figure 4.

Figure 4. An electricity solar power plant (source: the internet)

Such a panel, generated electricity when exposed to sunrays. This is either stored into batteries or converted to AC and pumped into the power network.

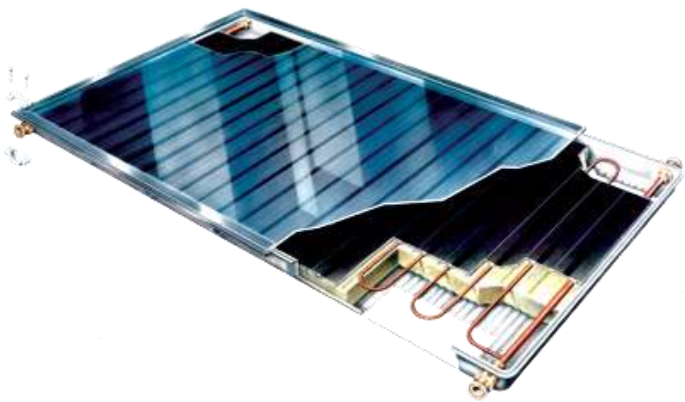

Figure 5. Hot-water solar panel. (source: the internet)

The second panel type heats up the water. Such a panel can be seen in figure 5. A pipe conducting the thermal agent is placed in a panel, covered with glass (in the simplest construction form) and exposed to the sunrays. The thermal agent is conducted to water tank in order to deliver the heat captured from the sun. The schematic of such a system can be seen in figure 6. Basically, a tank is used to produce the needed water using two serpentines (one for the solar panel, and one for the conventional heating system - this is used when the solar panel is not usable). When using the solar radiation, a control system starts the pump and circulates the panel's thermal agent to heating up the water in the tank. If the temperature difference is no longer significant (for example during the night or once the panel's hot water is in the tank's serpentine), the pump stops.

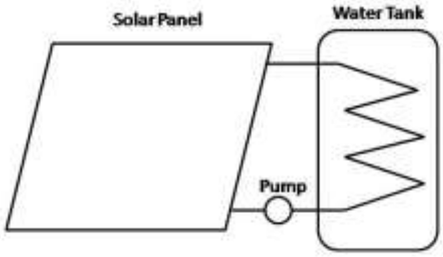

Figure 6. The schematic of a solar hot water system

To increase the absorbed energy, the solar panel can be rotated in horizontal and vertical planes such as the solar radiation is (almost) all the time perpendicular to its surface. In order to do that a sensor is needed. The design and construction of this sensor is presented in the next section.

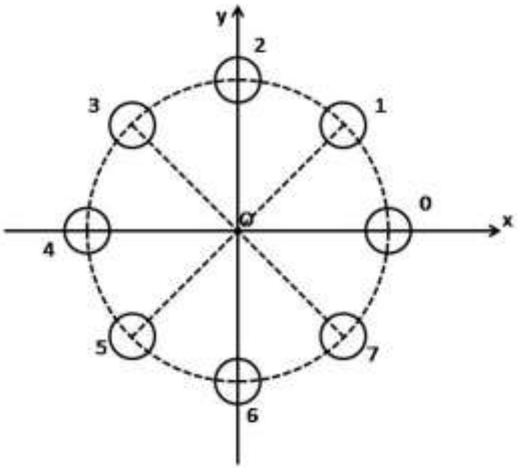

Figure 7. The solar sensor: eight photo resistors are placed on a circle and numbered in the counter clockwise direction

3. THE SOLAR SENSOR

In order to detect and track the sun motion on the sky (despite the fact that the Earth rotates around the sun, in a reference system fixed tot Earth the sun moves) one should use a sensor. To be of value, this will be mounted on the panel. A low-cost sensor design and control technique are presented in this section.

3.1 The sensor design

A digital system based on the ATmega 2560 was employed for solar panel control. The solar panel was to be rotated in horizontal and vertical planes by two DC motors. In order to control the angular position of the solar panel (which is analogue), a conversion of some type has to be performed. One possible way is to measure these two angles and convert them in digital form. However, this is complicated enough. As such, a simpler solution was sought. One could use two potentiometers to detect and measure the two angles. However, these low-cost tools are centered around a sliding contact. As such, dust (or other dirt), rain, etc. may affect their functionality.

Figure 8. The practically realized sensor for the solar panel

A much simpler (proposed) idea is to placethe eight photo resistors (PGM5560) in a plane and ensure an easy convert of their outputs into a number. The idea needs no analogue to digital convertersfor the two angles. It needs no calibration (since the output is already digital). The eight photo resistors are placed on a circle (figure 7) as the cardinal points (N, S, E, W, NE, NW, SE, SW). In figure 7 they are numbered from 0 to 7.

Among the things considered when choosing the photo resistor were its price and the trivial interface design.

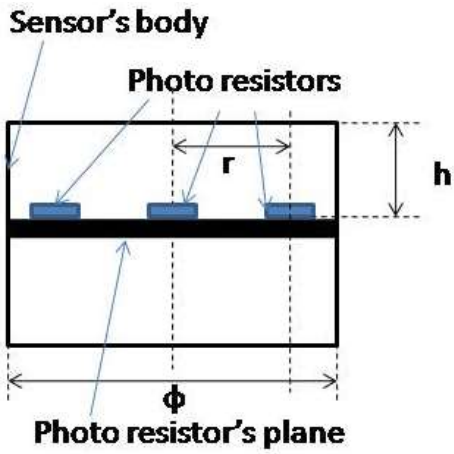

Figure 9. The shadow hits a photo resistor once the sunrays no longer fall perpendicular to the sensor's plane (only the N, S, E, W photo resistors are displayed in the above figure)

The entire ensemble is placed in a cylindrical enclosure which extends about 10 millimeters over the photo resistors mounted plane. This creates a shadow on a particular photo resistor moments after the sunrays do not fall perpendicular to the sensor's plane. A schematic of this situation can be seen in figure 9.

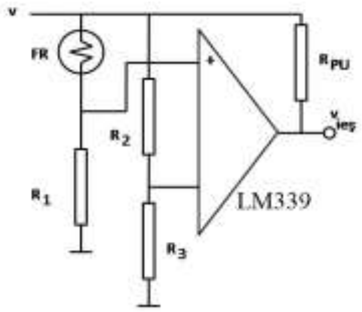

Figure 10. The hardware interface using the comparator LM339

A hardware interface delivers the digital output (1 or 0) to each line of the ATmega 2560 microcontroller. The schematic uses the LM339 comparator in a simple configuration (no hysteresis). The output is 1 if the sunrays hit the photo resistor. The hardware interface is the same for each channel (photo resistor) and it can be seen in figure 10. The way is works is simple (as the schematic is). When the sunray hits it, its resistance value decreases.

The voltage of the comparator's non-inverting input increases and exceeds the voltage of the other one. Therefore, the comparator's output switches to 5V (logic level 1). When the photo resistor is no longer hit by the sunrays, its resistance increases. Therefore the voltage of the non-inverted input decreases below the voltage of the other inputs. This causes the comparator's output to switch to 0V (logic level 0). Since there is a program that controls the motors, in order to simplify the hardware as much as possible to reduce the system's cost, there is no noise protection.

There are many sources able to generate noise in such an application. Different clouds, water drops, shadows, flying objects (kites, small airplanes), etc. are only a few mentioned here.

Table 1. The panel motors functionality based on the value received the microcontroller's port

Decimal Port Value	Hexadecimal Port Value	Action	Motor
255	0xFFH	NO ACTION	-
254	0xFEH	Horiz. Mot. Sense 1	Sensor 0
253	0xFDH	Both Motors Sense 1	Sensor 1
251	0xFBH	Vert. Mot. Sense 1	Sensor 2
247	0xF7H	Horiz. Mot. Sense 2 Vert. Mot. Sense 1	Sensor 3
239	0xEFH	Horiz. Mot. Sense 2	Sensor 4
223	0xDFH	Both Motors Sense 2	Sensor 5
191	0XBFH	Vert. Mot. Sense 2	Sensor 6
127	0x7FH	Horiz. Mot. Sense 1 Vert. Mot. Sense 2	Sensor 7
0	0x00	LOW LIGHT	ALL

Noise may cause any line of port to oscillate. A hysteresis comparator does solve the problem up to a certain noise level, but also increases the price of the entire system. However, the program controlling the motors can filter out the toggling situations. Indeed, the microcontroller may read the port several times and compare the values. If the values obtained from the port are different, the microcontroller keeps reading instead of commanding the motors. Once the port value is stabilized (the values are no longer different), the microcontroller moves towards the motor control routine.

3.2 The control technique

Depending on the sensors hit by sunrays, the inputs (coming from the hardware interface lines) form a number between 0 and 255. The port values (decimal and hexadecimal) and the action to be taken by the microcontroller can be seen in Table 1. For example, when all the photo resistors are hit by the sun, the hardware interfaces outputs are all 1. Therefore the microcontroller reads a port value of 255 (the first value in table 1). Assuming that sunrays no longer hit the photo resistor 0 (figure 7), its output will become 0. As such, the port value is going to be now 254. When this value is going to be stable, the microcontroller would start the horizontal motor (the photo resistor is located on the x axis as shown in figure 7) to rotate the panel and bring it back under the sunrays. If, for example, the photo resistor marked with 1 (figure 7) is no longer hit by the sunrays, its output is going to be 0. The port value is in this case 253. When this value will be stable, the microcontroller will command both horizontal and vertical motors. They will be turned off, when photo resistor 1 will receive the sunrays.
The above being said, a schematic block diagram of the program running the panel control can be constructed.

4. SOLAR SENSOR DESIGN CONSIDERATIONS

In the design consideration it is assumed that the hardware interface does switch from 1 to 0 and vice versa when the photo resistor is half covered by sunrays. A delay has to be implemented in the program to extend the motor control in order to ensure that the entire photo resistor surface will be hit by sunrays by the time the motor is stopped.

The schematic in figure 11 is used to design the panel sensor. Due to the fact that the hardware comparator may not trigger when the shadow is covering half the photo resistor's surface, a sharp angle design was chosen (the sensor's dimensions can be seen in figure 11).

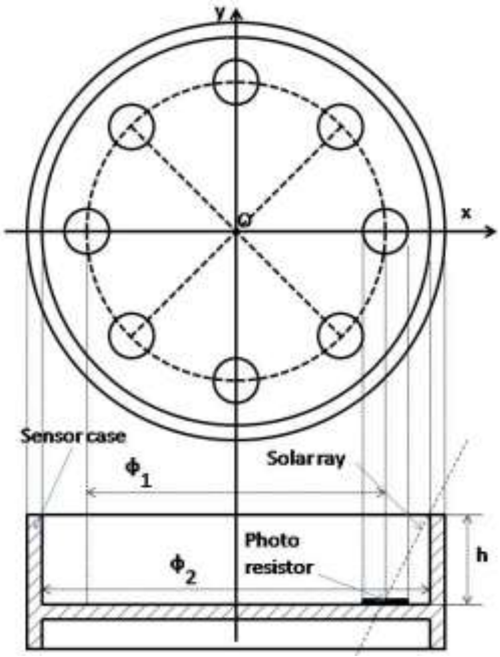

Figure 11. The sensor dimensions for the solar panel

- middle of the photo resistor (figure 11) makes with the horizontal an angle α

A front and cross-section view of the sensor is shown in this figure. Several design dimensions are also presented. A solar ray hitting one photo resistor is also shown. The diameter of the photo resistor's center is:

$$\Phi_1 = 30mm \quad (1)$$

The casing interior diameter is

$$\Phi_2 = 34mm \quad (2)$$

The casing height from the top to the photo-resistor's plane is h = 15mm.

Due to the slow motion of the sun in the sky (in the terrestrial reference system), the transition from full light to shadow can be accompanied by noise. This requires the creation of a hysteresis comparison circuit.

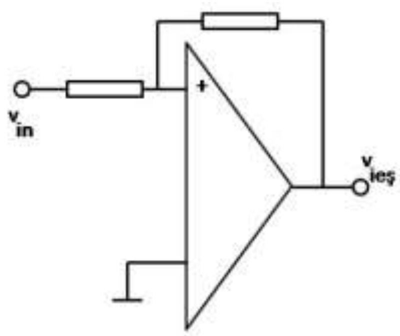

Figure 12. The diagram of the hysteresis comparatorprinciple

The feature of a hysteresis comparator allows for a certain noise rejection. However, even passing a cloud on the sky or the shadow of a bird could be included in the noise category. In this case, although the comparator is firmly switching the microcontroller would start the engine / motors. This would be wrong. As a result, although reliable, a hysteresis comparator only partially solves the noise problem.

The requirements of the drive system are the slow rotation of the solar panel according to the intensity of the sunlight. This implies:

- An optical sensor that informs the system about the sun position on the sky,
- A microcontroller making decisions (various „noises" may exist - passing clouds),
- A power module who orders the motors.

Although a numerical output sensor could have been used, it was preferred to design a sensor that uses photo-resistors (cheap and reliable devices). The sensor offers eight on-off outputs that are brought to one of the microcontroller ports. Based on this information, the microcontroller chooses to activate one or both engines in the desired sense. The reading of the port is iterative. The logic scheme of the program is shown in figure 13.

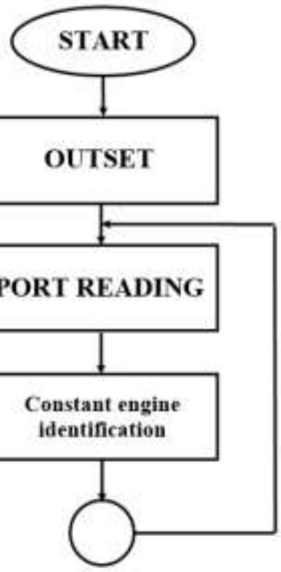

Figure13. The logic scheme of the control program

For the program developing, was used the Arduino IDE development environment. The logic scheme of the control program can be seen in figure 13. The first part deals with microcontroller initializations and settings. After the settings, the microcontroller reads the information from the optical sensor through the port. The read information is then checked to identify the action to be taken. The command is then sent to the engines via a port. The program has been tested, compiled and loaded into the Arduino IDE microcontroller.

5. SYSTEM STARTUP

The startup was place through a beam of light generated. The photoresist signal gives command in the module made up of 2 comparators LM 339, which in turn sends the signal to the ATMEGA 2560 microcontroller. By means of the written code, the motors can be put into operation, according to the maximum intensity of the sun.

The testing has been done by measuring each component integrated into the assembly circuit of the entire assembly and checking each connection between the components, the quality of the aluminum profile and its mounting, the panel support shaft, the balancing rollers and the rotation of the panel.The major contribution was through the construction of the whole support frame of the panel and the lens, the circulating coil of the domestic water heating agent, as well as the recycling from the CD-ROM or DVD-ROM optical system of the guiding system consisting of motor 5v dc and engagement pinions.

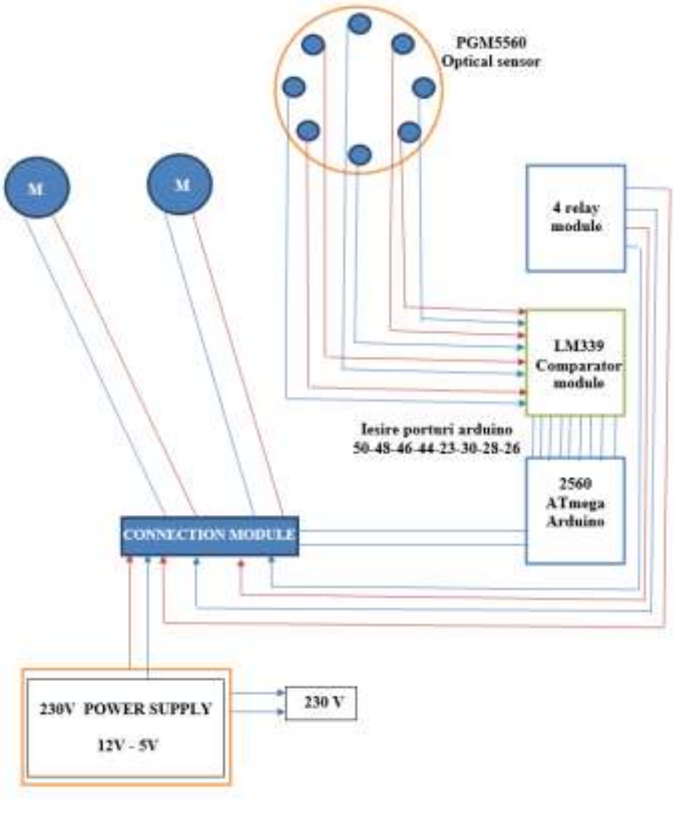

Figure 14. Block schema of solar panel

6. CONCLUSIONS

The adaptive command of the solar panel is made in a nonconventional, but very efficient, with a design good to ensure the panel's optimal position in relation to the solar source. The simplified system, consisting mainly of an optical sensor, the microprocessor control and control module, the drive motors and the power supply system, was carried out with much less cost and effort than commercially available automation systems, possibly equipped with a Interface circuit with an analog or even digital output. The system is non-polluting, environmentally friendly and favors the use of a solar panel for both hot water and power generation. The paper also highlights the operability with which the system can be tested under simulated light source assurance. Research will continues with new applications, such as adaptive control of the pumps in the heat pump from the circulation system of solar panels.

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