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Sun Altitude Sensor

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Abstract - **The paper proposes a new solution of a solar position sensor based on a linear sensor array and non-transparent partitions with different configurations which can be used in sun tracking systems. A basic principle of measuring the angle of surface illumination is the quantifying of the length of the shadows produced by the non-transparent partitions. The partitions will create a shadow over a certain number of pixels and the signal coming from the photo receiver will provide exact measurable dark and light sections.**

The paper gives account of the performed analyses and calculations and presents the block-scheme of the realized technical solution. The latter provides for obtaining the numerical value of the sun altitude angle along with the related illumination. A base component of the scheme is a PIC family microcontroller. The latter controls the sensor functions; the LCD display; the buttons and further communicates with a Personal Computer over the USB interface.

Keywords – **solar position, solar orientation, sun altitude sensor, linear sensor array.**

I. Introduction

The man-made changes of concentration of carbon-dioxide, methane and nitrous oxide are the principal factors that stimulate interest in increasing renewable energy production. The main topics include photovoltaic, solar thermal energy, geothermal energy, wind energy, wave energy, bioenergy and hydrogen technologies.

Solar energy systems have emerged as a viable source of renewable energy over the past three decades, and are now widely used for a variety of industrial and domestic applications. Such systems are based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy. In general, the power developed in such applications depends fundamentally upon the amount of solar energy captured by the collector, and thus the problem of developing tracking schemes capable of following the trajectory of the sun throughout the course of the day on a year-round basis is essential. Photo-voltaic systems that follow the Sun yield up to 40 % additional energy compared to the static ones [1, 2].

II. Sun Tracker Control Systems

The ideal Sun tracker system is one that allows tracking along two axes, by means of a simple mechanism, which is manufactured with commonly used industrial components and which requires low-level of maintenance. Sun tracker control systems use two major strategies:

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- Sensor control: the Sun's position is specified using two coordinates and the optimum position is estimated using photo-sensors signals.
- Sensorless control: the optimum values of the Sun coordinates are calculated for every moment of the day, all year long, in case of a fixed location of the solar collector. Using this data, the tracking system moves the collector to the optimum position.

A major shortcoming of the second approach is that the position data base must be calculated for every possible geographical location of the Sun collector.

More solar energy is collected if the solar receivers are installed with a tracker system. For a planar receiver, the receiver plane must be perpendicular to the direction of the solar flux irradiance. The solar energy collected is proportional to the cosine of the angle between the incident beam and the normal of the plane of the collector

To implement a sun-following system a sensor is needed that estimates the Sun's eminence towards the horizon, respectively the falling angle of the sun beams.

The sun tracking controllers were developed following the classical control system closed-loop approach by integrating a sun sensor able to provide pointing-error signals, one per tracking axis. This in turn generates actuator correction movements. Each sun sensor comprises a pair of photo receivers, which generate different photocurrents whenever the sensor is not aligned with the local sun vector. The phototransistors may be mounted on tilted planes in order to increase sensitivity. In some applications, shading devices are provided. Some basic types of Sun sensor are shown in Fig.1 [1].

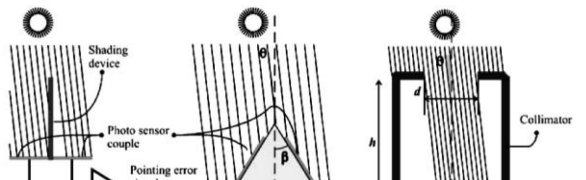

Fig.1. Basic types of sun sensor.

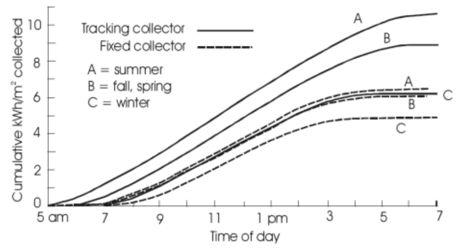

Fig. 2. The collected energy for fixed and tracking energy

In this paper an optoelectronic solution of a sensor, designed to measure the current state of the sun eminence is presented. It is based on a conventional linear sensor array and mechanical partitions and diaphragms with different configuration. A linear sensor with large dimensions of the photosensitive area is used. The total number of the elements on one line is 128. To estimate the angle of eminence it is necessary to measure the length of the partition shadow with a precision to parts of the pixel. Depending on the dimensions of the partition and its position the photosensitive part of the linear sensor array is lighted in a different way. Consequently, the generated signal has different shape and parameters. The information for the angle of incidence is acquired after processing the consequent output of the voltage of every photosensitive element.

III. DIFFERENT APPROACHES FOR THE SENSOR DESIGN, BASED ON LINEAR SENSOR ARRAY

A. The linear sensor array TSL14XX

For the implementation of the optoelectronic device a linear sensor array is chosen from the TSL14XX family offered by the company TAOS. It consists of 128 photodiodes (pixels) arranged in a row. When lighted, they generate electrical current, which is integrated over a given time. During the time of integration a capacitor is connected to the output of the integrator for every photodiode via an analogical switch. The quantity of the electric charge accumulated by every pixel is proportional to the intensity of the light and the integration time. The block-scheme of such a sensor is shown on fig.3.

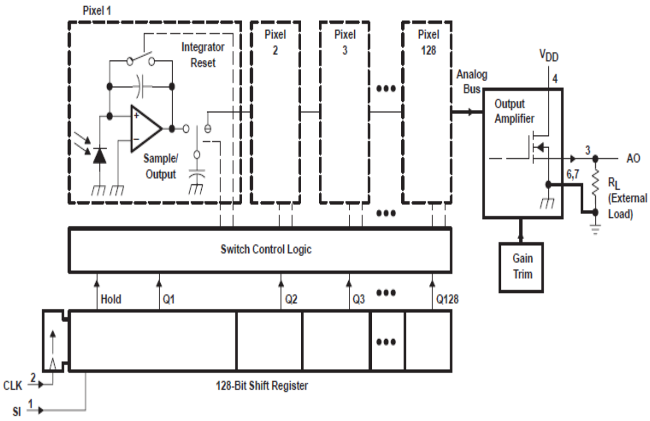

Fig.3. Inner structure of the linear sensor array TSL14XX.

The linear sensor is controlled only by two signals. One of them is a timing signal GLK. Over a specified period the second SI puts the capacitor in a "charging" condition and "walking" through all the pixels via the shifting register. Through change of the period for submitting the SI signal the integration time or the amplitude of the output analogical signal AO from the pixels is set. The possibility to control the linear sensor only by two sequences of impulses allows for the resources of the microcontroller to be freed and the algorithm for absolute measurement of the altitude angle to be implemented.

The geometrical dimensions of the 128 photosensitive elements are: height 63.5 µm, width 55.5 µm and spatial step of 63.5 µm. The total length of the photosensitive straightedge is 8.4 mm.

B. Usage of mechanical partitions

As to realize this principle of measurement, it is necessary to position the opaque partition vertically to the photosensitive surface. Applied to the linear photoreceiver of the TSL14XX type we obtain the combination presented on fig. 4. The partition is with small thickness (in the order of the magnitude of the width of a singular photodiode) and is centered toward the middle of the linear sensor array. In this case, when the angle of incidence of the sunlight is 90°, all photodiodes are illuminated. At an angle different from 90° the photodiodes on one side of the partition are illuminated but on the other side the photodiodes closest to the partition are in its shadow. Depending on how many photodiodes there are in the shadow we can evaluate the angle of incidence of the sunlight.

An oscillogram of the output voltage generated in the photodiodes is displayed on fig. 4. On one side of the partition the photodiodes are completely illuminated and the generated voltage is proportional to the intensity of the sunlight and the integration time. On the other side of the partition a part of the photodiodes are shadowed and their voltage is lower as they are not directly illuminated.

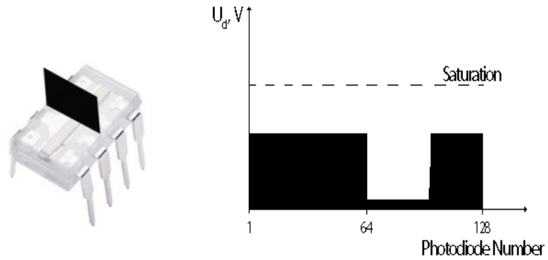

Fig. 4. Sensor TSL 1401 with a partition in the middle of the photodiode array and oscillogram of the output signal.

Part if the photodiodes have an intermediate level of voltage – those are the pixels at the rim of the shadow. This effect is observed, when the shadow does not envelop all the pixels at the rim, but just a part of the last one, which in the process of integration cannot be charged to the same value as the others.

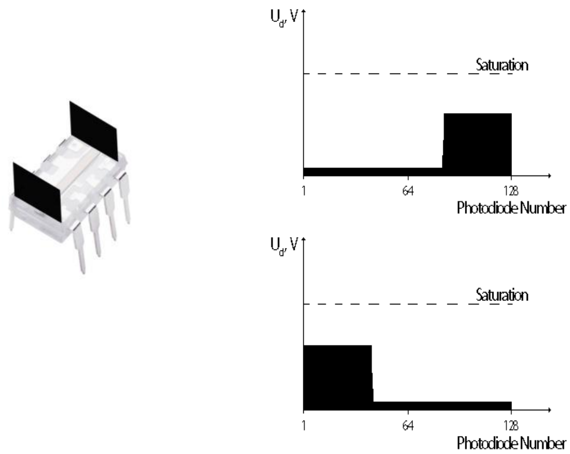

Fig. 5. Sensor TSL 1401 with partitions at both ends of the photodiode massive and an oscillogram of the output signal.

The mechanical partitions can be two, positioned at both ends of the linear sensor array, as it is shown in fig. 5.

In this case, when the angle of incidence of the sunlight is 90°, all photodiodes are illuminated. At an angle different from 90°, the shadow of one of the partitions falls on the photodiode massive, and the shadow of the other partition falls outside the sensitive part of the chip. Depending on which side and how many of the pixels are shadowed, we can determine the angle of altitude of the sun.

Two partitions can be placed at 1/3 and at 2/3 of the scale of the linear sensor array, as it is shown in fig. 6.

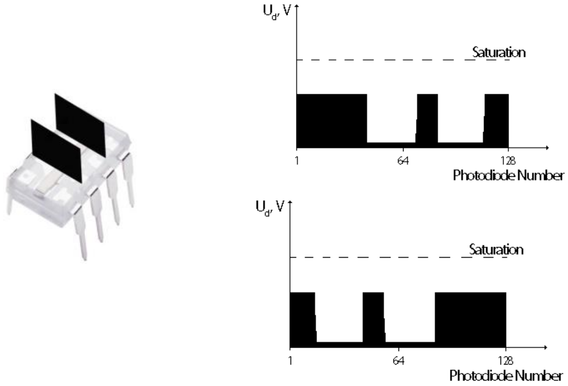

Fig. 6. Sensor TSL 1401 with partitions in the middle of the photodiode massive and an oscillogram of the output signal.

In this case, when the angle of incidence of the sunlight is 90°, all photodiodes are illuminated. At an angle different from 90°, the shadows of both the partitions fall on the photodiode array. In this case the measurement is done in the same way as in case A, with the difference that two measurements are conducted simultaneously, but for each one of them only a 2/3 of the photodiode massive is used.

The advantage of this approach is that two independent measurements are made and so error can be reduced. The disadvantages are the difficulties of finding 2 similar partitions and the usage of only 2/3 of the scale for each measurement.

C. Usage of a mechanical diaphragm of measurement

A diaphragm with a slit in the middle is shown in fig. 7. It is situated in front of the linear sensor array. In the case of direct illumination, the light spot falls in the middle of the photodiode massive. At an angle different from 90° the light spot shifts from the middle position, and depending on this displacement we can determine the angle of incidence of the sunlight. Figure 7 shows the light spot, for an angle of incidence smaller than 90°, for a larger angle the light spot should shift to the left.

IV. Sensor Implementation

A. Block scheme of the camera

Fig. 9 shows the block scheme of the sensor for measuring the altitude angle. A main component of it is the microcontroller of the PIC family. It is designed to control the sensor, by feeding tact frequency and start impulses. It transforms the information from the analogue output of the sensor into digital, and calculates the position of the shadow.

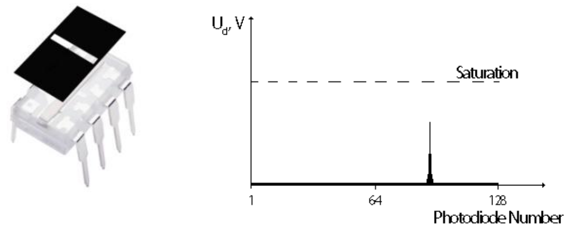

Fig. 7. Sensor TSL 1401 with a diaphragm in the middle of the linear sensor array and an oscillogram of the output signal.

The microcontroller controls the sensor, the LCD display and through the USB interface it can control another device. On the other hand it can be controlled by using the keyboard or the USB interface of a personal computer.

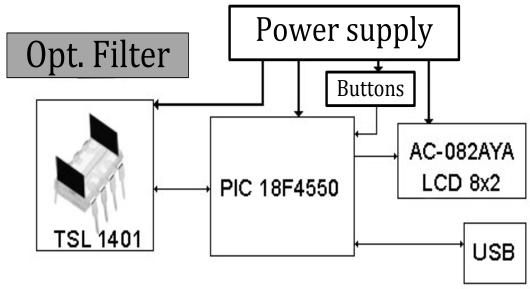

Fig. 8. Block scheme of the sensor.

The optical filter is used to let through rays with wave length near 0.4µm. In this spectral range the sunlight cannot cause oversaturation of the sensor. The buttons are used to control the microcontroller. The measurement results are shown on the LCD display.

B. Schematics of the sensor system

The linear sensor array and the elements for communication and programming are connected to the microcontroller with connectors.

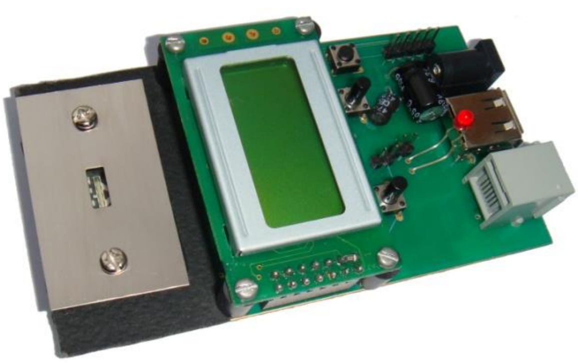

Fig. 9. Experimental model of the implemented sensor.

The scheme is with low consumption and is compatible with all USB devices. With an appropriate program support the sensor can work together with a personal computer or independently. Fig. 10 shows the experimental model of the implemented sensor. The mechanical diaphragm is manufactured from inox with a thickness of 0.5 mm. It is situated at a height of 3 mm above the sensor array. The display used for carrying out the experiments is positioned on the main board.

C. Electric signal from the photodiode straightedge.

For the normal performance of the camera it is necessary for the signal generated by the sensor to be in the range of the analogue-digital transformer. Due to the used microcontroller and the feeding voltage of 5V, the maximum of the signal must be in the range of 4V – 4,5V. Unless this requirement is met, the algorithms for the frame processing cannot work effectively.

The output signal of the photodiode straightedge depends on the illumination of the photodiodes and the exposure time:

$$V_{out} = V_{drk} + S_{hole}.t_{exp}\int_{\lambda_{min}}^{\lambda_{max}} R_e(\lambda).E_e(\lambda).d\lambda$$

Where:

V_{out} – output voltage from the sensor pixels,
V_{drk} – output voltage of the sensor in the dark (0.1V);
S_{hole} – surface of the pinhole lens;
t_{exp} – exposure time;
$R_e(\lambda)$ – spectral sensitivity of the photodiodes;
$E_e(\lambda)$ – incident irradiance.

The exposure time is controlled by the microcontroller, through the interval of appearance of the logical signal SI. Depending on the clock frequency of the microcontroller that time can be in the range from 0.5µs to 100 ms and a great sensitivity of the sensor is reached.

The spectral quotient of throughput of the optical filter is calculated in order to isolate the near IR radiation, avoiding overheating of the sensor. The other tasks to be completed are: isolation of the UV range, prevention of possible outside interference and decreasing the possibility of oversaturation of the pixels.

In order to avoid situations in which the signal is very weak or oversaturated a procedure is designed for finding the optimal value for the time interval SI. This procedure is periodically activated. After this the algorithm works for some time with the thus calculated value.

V. PERFORMANCE ALGORITHM AND PROGRAM SUPPORT

The microcontroller which is used is with a built-in USB module, so that it can exchange information with the computer more easily. The measured angle of altitude is indicated with the LCD display and a sound signalization. An additional RS232 interface is also provided.

Software for PC has been developed in order to process the image from the sensor and to present it in the form of graphics. This software communicates with the device through the USB interface.

For software development and programming of the microcontroller the products Microchip MPLab, Microsoft Visual Studio C# 2010 are used.

VI. CONCLUSION

A new approach for the implementation of a sun altitude sensor, based on a linear sensor array is proposed. The sensor is robust, low cost and allows for a simple digital control of actuators of sun tracking systems.

The above considered variants of mechanical partitions and diaphragms in combination with a linear sensor array make it possible to design different sensor configurations. The suggested implementation consists of a minimal number of components and is highly reliable.

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