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A DEVELOPMENT SYSTEM FOR THE SUNSHINE DURATION ESTIMATION

BY

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Abstract. In this paper a system for evaluating Sunshine Duration is presented which is operating using the contrast methods. The sensing element consists of 8 light sensors mounted at 45^o on the circumference of a circle with 30 mm diameter. A barrier that will create shade is placed in the center of the circle. The system must be placed on a horizontal surface and does not require further adjustment. The amount of Sunshine Duration is calculated using the following algorithm: maximum measured illumination exceeds 2,500 lux and the ratio of maximum and minimum measured illuminations must exceed 1.25. The obtained accuracy of Sunshine Duration measurement is ± 10%. The system can also measure global irradiance, humidity and temperature. The proposed system consists of a sensor module and a monitoring module which communicate to each other through an RF Link. The system is flexible and easily adaptable to measure other quantities or for building wireless sensor networks (WSN) by adding new modules.

Key words: sunshine duration; global and diffuse solar radiation; illuminance; Angstrøms model.

1. Introduction

Sunshine Duration (SD) is an indicator measuring duration when the direct solar radiation is not blocked by clouds in a given location on Earth and in

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a given period (usually, a day, a month or a year). Measurement of this parameter is important in several areas: meteorology (weather characterization), tourism (to indicate favourable period for specific activities), health (for recommending treatment periods), agriculture (for study, plant and livestock study and growth), architecture (building insulation, building cooling and heating), solar photovoltaic and thermal technologies (solar water heating, systems solar home lighting systems, solar water pumping systems).

SD measurement is even more important in the context of global warming. In this sense, in the last years there is an active research which is monitoring the global evolution of weather, one of the analysed parameters being the SD (Rivington *et al*., 2005; Sanchez-Lorezo *et al*., 2009; Wang *et al*., 2012). There are many methods used to measure SD, summaries of the main measurement methods, indicating specific characteristics, being presented in reports (Massen, 2011; WMO, 2008).

The first devices used for SD measurements were the Campbell-Stokes SD recorders. The devices are made of a glass sphere that focuses direct solar irradiance, *I*, to a time-graded paper card. If *I* is greater than a threshold then on the paper card appears a burned trace. Summing the lengths of the burnt traces, the SD can be estimated. The precision of Campbell-Stokes devices is modest because the thresholds of the irradiance from which the burning begins varies in a large value range (106…285 W/m^2).

The pyrheliometer is a special SD measurement device that directly measures Sun Direct Irradiance, *I*. The main features of the pyrheliometer are: aperture angle under 30^o, the sensing element is made of an array of thermocouples covered by a black material, device position needs a permanent adjustment with sun position. The WMO (World Meteorological Organization) standards specify that the sun is present if the measured I > 120 W/m^2.

Another category of devices for measuring SD is based on contrast. The sensing element consists of at least two photodiodes, one uncovered measuring the whole sky global solar irradiance, *G*, and one overshadowed that measures whole sky diffuse solar irradiance, *D*. If the unit is mounted on a horizontal surface then reflected irradiances measured by the device are negligible and the relationship between *G*, *D* and *I* is given by expression

$$G = D + I \sin h = D + I \cos z, \;\; h + z = 90°, \tag{1}$$

where: *h* is the solar elevation angle (the angle between the horizontal axis and the sun beam) and *z* is solar zenith angle (the angle between the vertical axis and the sun beam). The angles *h* or *z* can be computed based on relations available in literature and thus we can determine *I* from (1). In order to get the SD we need to count the time for which I > 120 W/m^2. We can mention the devices BF1, BF2, BF3 and BF5 manufactured by AT Delta-T which are operating based on the before mentioned principle. BF1 is using two photodiodes and a band to achieve shadow. It is necessary to position the device on a horizontal surface, orient it to the North and make continually adjustments of the band creating the shade and corrections of D due to the shadow creation. BF2, BF3 and BF5 use seven photodiodes and a specifically designed mask for creating the shadow (Wood *et al*., 2003). The devices need to be installed only on a horizontal surface, require no further adjustments and measure G, D and SD.

Another trend for SD measurement is using pyranometers, the devices commonly used in solar irradiance measurements. The most popular methods are those that use one or two pyranometers.

The method that uses two pyranometers (one uncovered measuring G and the other shadowed measuring D) is similar to that of the photodiode-based devices. In this method SD is computed using relation (1), a ring or sphere is used to create the shadow and there are necessary corrections of component D due to the shadow creation (LeBaron *et al*., 1990; Muneer & Xiaodong, 2002). Among the main manufacturers of precision pyranometers we can mention Kipp & Zonen with their CMP series.

In conjunction with methods that use a single pyranometer, there are two main trends: one based on Angstrøm-Prescott relationship and one based on the behavior of global irradiance in a certain amount of time.

The Angstrøm-Prescott relationship is given by the expression

$$\frac{H}{H_0} = a + b\frac{\mathrm{SD}}{\mathrm{SD}_0}. \tag{2}$$

and characterizes SD on a period of time, usually the monthly mean daily.

In this relation: H is monthly mean daily global radiation energy on horizontal surface (MJ/m^2 day or W.h/m^2 day), H_0 is monthly mean daily extra-terrestrial radiation energy on horizontal surface (MJ/m^2 day or W.h/m^2 day), SD is monthly average daily bright sunshine duration (hours) and SD_0 is monthly average maximum possible daily sunshine duration (hours). For H_0 and SD_0 we can find computing relations based on the geographical position of the measurement point, sun elevation, day of year, etc. H is measured with a pyranometer and using relation (2) we can estimate SD. The main difficulty related to the use of relation (2) is to determine the values of the regression coefficients, a and b. They depend on geographic location and are determined by measurements performed on long periods of time (several years). Expression (2) can be used to determine the parameter H if SD is measured. Several such attempts, with various options proposed for expression (2), are presented by Yakubu & Medugu, (2012), Besharat *et al*., (2012), Rajput *et al*., (2012) and Ibeh *et al*., (2012).

SD assessment can be done by reading and recording data from a pyranometer (usually using global irradiance, G) in a certain period of time (half-hour readings, 10 min. readings or 1 min. readings). Then the variation of G along the logging interval is considered and, depending on the algorithm used, the value for SD is determined. There are many algorithms used, such as:

Oliviéri algorithm, Slob & Monna algorithm, Hinssen & Knap algorithm, Louche algorithm, etc.

Current researches are considering embedding the SD measurement in complex measurements made by meteorological satellites. Measurements are based on observation of cloud distribution over different geographical areas (Bertranda *et al.*, 2013; Kothe *et al.*, 2013).

2. System Overview

The block diagram of the proposed SD measurement system is given in Fig.1.

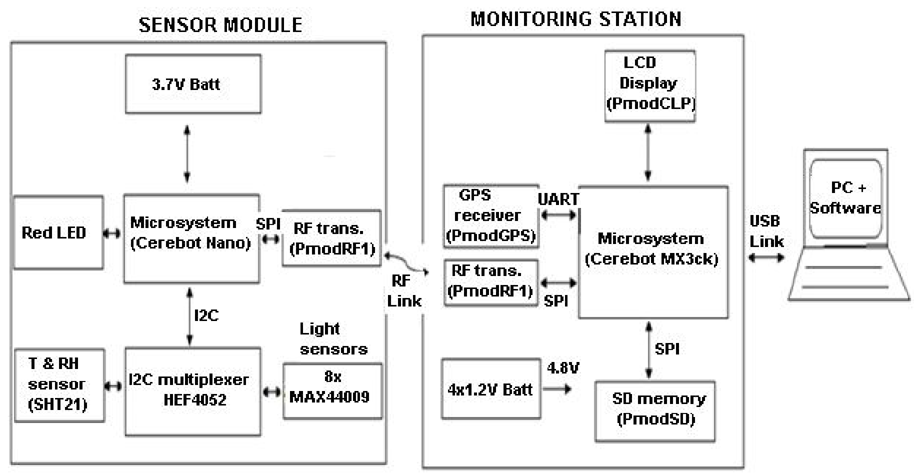

Fig.1 –Block diagram of the SD measurement system.

The proposed system is made of two modules, the Sensor Module (SM) and the Monitoring Station (MS) which communicate using an RF link.

The SM is designed around a microcontroller based development board with the role of coordinator to which are attached eight light sensors, a humidity and temperature sensor, an RF communication module, a red LED and a battery. Sensors are I2C compatible and are connected to the microcontroller *via* a I2C multiplexer. The red LED is used to indicate the module operation and the exchange data rate between SM and MS. Data exchange with the MS is done *via* wireless link using the RF transceiver.

The MS is built also around a microcontroller which coordinates the module operation and also permits connection to a PC. Apart the microcontroller, the microsystem is made of a GPS receiver (that will get information on geographic coordinate, time and date, etc.), local memory for data storage, an LCD for local data display and an RF transceiver for communication with SM. The MS can connect to a PC that can verify system operation and can download and further process collected data.

The SM and MS modules use various peripheral modules (Pmods) manufactured by Digilent.

3. The SM Module

The schematic diagram of the SM is given in Fig. 2. The microsystem is based on the Cerebot Nano development board built with the Atmel ATMEGA168 microcontroller. The program running on SM was written in C-language using AVR Studio 4 programming environment.

The microcontroller reads data from the sensors *via* the I2C interface. The light sensors are MAX44009 sensors manufactured by Dallas Maxim. The main parameters of the MAX44009 sensor are: less than 1 μA operating current, ultra-wide 22-year bit dynamic range from 0.045 lux to 188,000 lux, I2C interface (maximum clock frequency 400 kHz, two slave addresses 1001010R/$\overline{W}$ and 1001011R/$\overline{W}$), a spectral sensitivity similar to that of human eyes (CIE curve).

The temperature and humidity sensor is an SHT21 type sensor produced by Sensirion. The main parameters of the sensors are: for relative humidity measurement, RH, [%] – measurement range 0…100%, 12/8 bit resolution, *i.e.* 0.04/0.7%, response time 8 s; for temperature measurement, T, [°C] – measurement range –40°C…125°C, 14/12 bit resolution, *i.e.* 0.01/0.04°C, response time 5 s, I2C interface (400 kHz maximum clock frequency, slave address 1000000R/$\overline{W}$).

We can connect multiple slave devices on a I2C bus provided that they have different addresses. For the MAX44009 sensors there are available only two slave addresses. In order to use eight such sensors we have multiplexed by four the I2C interface using the HEF4052 analog multiplexer. The SHT21 temperature sensor may be placed on any of the four I2C branches thus created. Data taken from the sensors (eight levels of light, humidity and temperature) and the battery level (on a scale of 1…10, 10 – maximum) are transmitted to the MS through the RF link. The RF transceiver module, PmodRF1, is based on the Atmel AT86RF212 chip. The main parameters of this chip are: a low-power radio transceiver, IEEE 802.15.4 certified, 700/800/900 MHz ISM Frequency Band, 250 kbits transfer rate, 8 bit identifier ID, 10 dB.m Power Output, communicating at a range of 6 km, SPI interface (mode 0, 7.5 MHz maximum transfer rate). The rates at which measurements are made and transmitted to the MS are set by MS. This rate is indicated by a red LED (with emitted spectrum outside the measured spectrum). The module is powered by a 3.7 V/1,000 mA.h phone battery.

The electronics and battery are mounted on a circular shaped support, made out of a printed circuit board. The support is introduced into a housing which is sealed at the bottom and upside by a transparent dome. In the middle of the support is mounted an obstacle which will create the shade. Inside the obstacle is placed the PmodRF1 antenna module. The MAX44009 light sensors

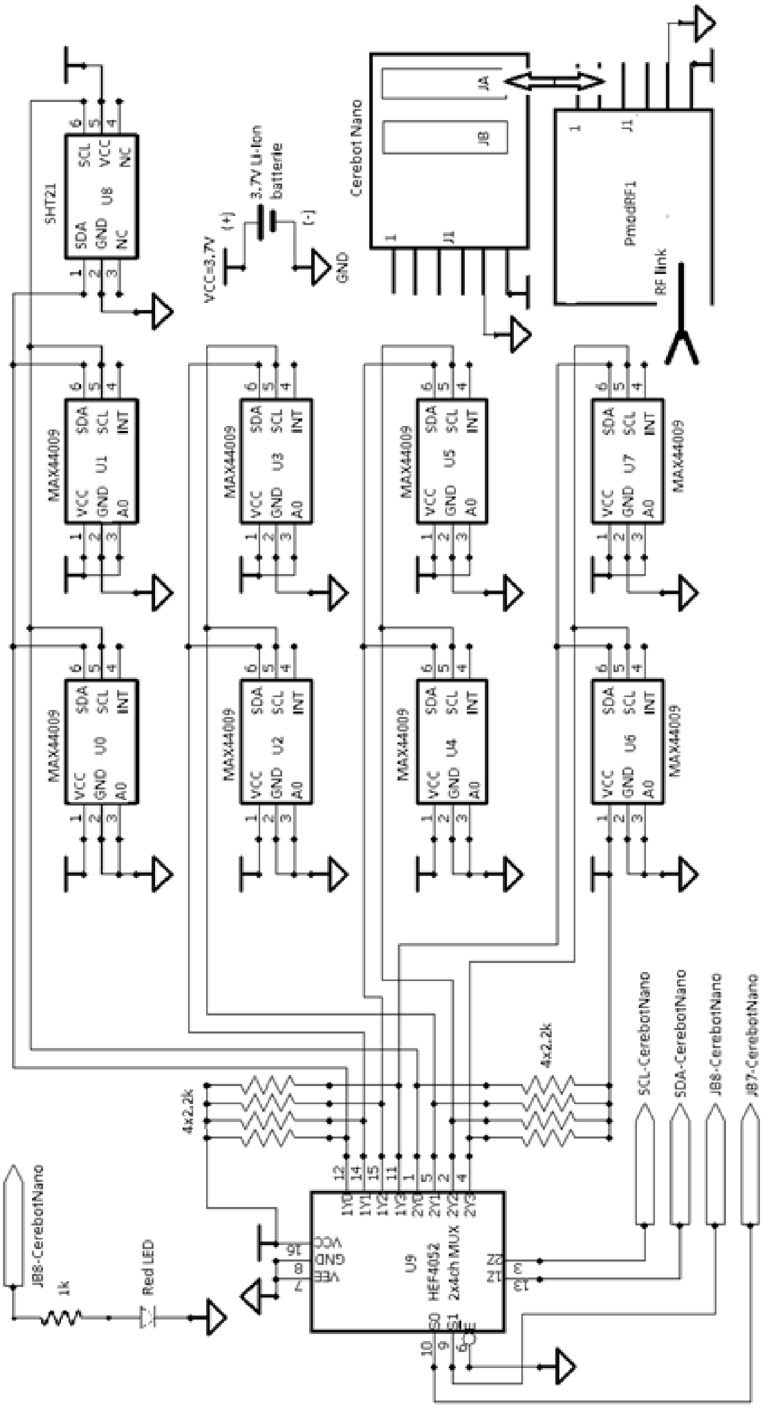

Fig. 2 – Schematic diagram of SM.

are placed on the visible part of support, on the circumference of a circle with 30 mm diameter at angles of 45°. The red LED and the SHT21 sensor are also mounted on the visible part of SM. To avoid reflections, the top of the support is painted black. The picture of the SM module is given in Fig. 3.

Fig. 3 – Sensor Module: *a* – front view; *b* – opened, back view.

4. The MS Module

The MS module is built around the Cerebot MX3ck development board, which has the following features: based on PIC32MX320F128H 32 bit microcontroller, 128 kB Flash memory, 16 kB RAM memory, 80 MHz max operating frequency, 42 totals I/O pins, etc. The role of the microsystem is to coordinate the entire operation of the MS module. The program running on the microcontrollers was developed using MPIDE (Arduino development system modified for Microchip PIC32 microcontrollers). The program uses 50 kB of the Flash memory.

Fig. 4 –An example of data presented on the LCD display.

For data acquisition, the module MS sends a request data message to the SM module *via* the PmodRF1 transceiver. Data received from the SM module are then processed. First, the eight levels of light illumination are used to determine the maximum (L_{max}) and minimum (L_{min}) light levels. Based on the algorithm to determine the presence or absence of sunlight the SD is determined. Data received from the SHT21 are used to compute temperature, T, and humidity, RH. This data, together with the battery level, is presented on an LCD display. Fig. 4 shows an example of a data display (on the first line: 10 – battery level, 21C – the temperature is 21°C, 53% – relative humidity RH is 53%, NoSun – the sun is not present and so SD = 0; the second line: 187 L – maximum illumination L_{max} is 187 lux, 91 L – minimum illumination L_{min} is 91 lux).

The geographical coordinates are determined using the PmodGPS module equipped with GPS GPSMediaTek MT3329 receiver. The main parameters of the module are: integrated ceramic GPS antenna, 1 Hz to 10 Hz update rate, 3 m 2-D accuracy without aid, ultra-high sensitivity: –165 dB.m, a 515 m/s maximum velocity and 18,000 m maximum altitude, etc. The module generates a 1 s periodic signal synchronized with GPS time in the case it has a fix. This signal will be used by the microcontroller to control the rate of measurements and data transfer by SM module. This rate will be set at multiple intervals of 1 s and only when GPS signal is correct. The module is easy to control using the UART interface. The PmodGPS uses sentences based on the National Marine Electronics Association (NMEA) protocols for data output. One can program multiple output sentences, in our implementation the used output sentence is the RMC (Recommended Minimum Characteristics) type that contains most of information in a concentrated form. An example of output RMC sentence is given bellow:

```
$GPRMC,031817.000,A,4710.2040,N,02735.9706,E,0.02,65.70,300413,,,A*5E
```

The significance of this output sentence is given in Table 1.

Table 1
RMC Output Sentence

Example	Description
$GPRMC	Message ID
031817.000	UTC Time (hhmmss.sss)
A	Status (A = data valid)
4710.2040	Latitude (ddmm.mmmm)
N	N/S indicator
02735.9706	Longitude (dddmm.mmmm)
E	E/W indicator
0.02	Speed over ground (knots)
65.70	Course over ground (degrees)
300413	Date (ddmmyy)
	Magnetic Variation (degrees)
	E/W indicator
A	Mode (see GlobalTop manual)
*5E	Checksum
<CR><LF>	End of message indicator

The data displayed on the LCD display together with data received from the GPS receiver are recorded on a SDcard memory. For this purpose the PmodSD module from Digilent was used. The recording rate can be the same as the rate of measurement and data transfer of SM module. The recording format is CSV (comma separated value) with the advantage that it can be processed directly in Excel or other data processing software.

Bellow is an example of a data recording on the SDcard:

```
10,21,53,0,187,91,$GPRMC,031817.000,A,4710.2040,N,02735.9706,E,0.02,65.70,3004
13,,,A*5E
```

The first six data are displayed on the LCD display, 0 in the fourth position means "NoSun". All information handled by MS is accessible through a UART/USB user interface and can be transferred to a PC. The elements of the MS module are powered by the microsystem which contains the 5 V and 3.3 V voltage stabilizers. The microsystem is powered either from the USB when connected to a PC or from a suitable battery set (4 × 1.2 V/1,900 mA.h). The MS module is depicted in Fig. 5.

Fig. 5 –The MS module.

5. System Operation

The measurement system operation is mainly based on the contrast measurement methods for SD. Thus, the SM module is equipped with eight light sensors arranged in a circle at 45°. In the center of the circle there is a barrier for the creation of the shadow. The SM module must be mounted on a horizontal surface and away from other obstacles to have the visibility of the whole sky. In this way, at least one light sensor will receive maximum illumination, L_{max} , and at least one light sensor will receive minimum illumination, L_{min}. The maximum illumination, L_{max} , will be proportional to the whole sky global solar irradiance, G, and minimum illumination, L_{min} , will be proportional to the whole sky diffuse solar irradiance, D. Knowing angle h or z, based on the relation (1) we can determine sun direct irradiance, I. Further on, for $I > 120$ W/m^2, SD can be considered to be 1 on the interval between two measurements. The difficulty of using relation (1) results from not knowing exactly how big is the solar irradiance diffuse attenuation, D, received by lighting sensors in the shadow. For this reason, we they tried to find an algorithm to determine the maximum illumination value SD based on L_{max} and the ratio, k, between the maximum and minimum illumination (L_{max}/L_{min}). Experimentally, by measurements taken on long time intervals, it was concluded that the sun is present (SD = 1) in situations when

$$L_{max} > 2{,}500 \text{ lux}, \; k = \frac{L_{max}}{L_{min}} > 1.25. \tag{3}$$

Maximum SD measurement error resulting from using the relation (3) is ±10%. Additionally, global irradiance, G, can be measured. This requires calibration using a pyranometer to find the coefficient of proportionality between L_{max} and G. Normally the SHT21 sensor measures humidity and temperature inside SM to specify the conditions under which measurements were made (dry air, moist air, difference from dew point or existing, condensation). To prevent condensation the system needs an electrical resistance for heating (case not taken into consideration in this project). If the dome is removed, the SHT21 sensor will measure the actual temperature and humidity of the environment where the SM module is placed. This opens for the system new possible uses in environment parameter measurement applications.

5. Experimental Results

Using the system described in this paper, several measurements were made. The information recorded on the memory SDcard was downloaded to the PC and processed in MS Excel. In order to determine SD the relation (3) was used. Measurements were made on 30.04.2013 from 6:00 to 20:00. The actual period of the registration was 31824 s, meaning 8.84 hours. During this period, the presence of sun was detected for 29,180 s, meaning 8.08 hours. The results are presented in Figs. 6,…,9.

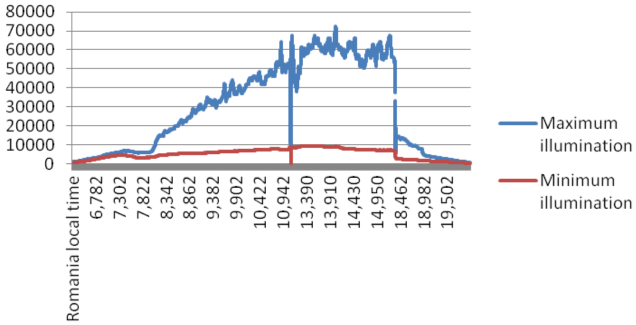

Fig. 6 – Maximum, L_{max} , and minimum, L_{min} , illuminance variation.

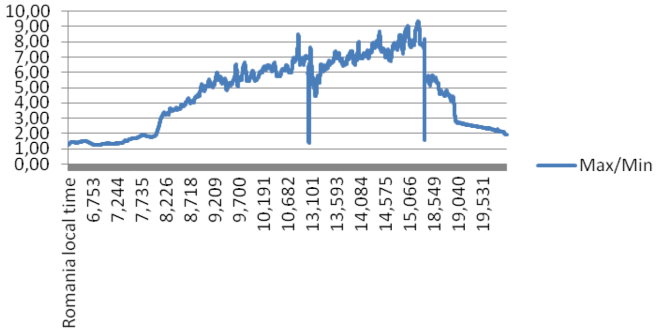

Fig. 7 – Ratio L_{max}/L_{min} between maximum and minimum illuminances.

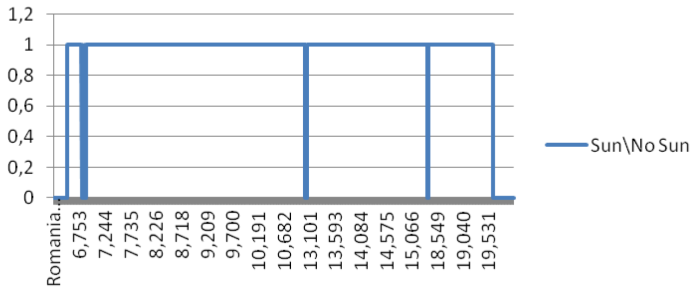

Fig. 8 – Sunshine Duration, SD.

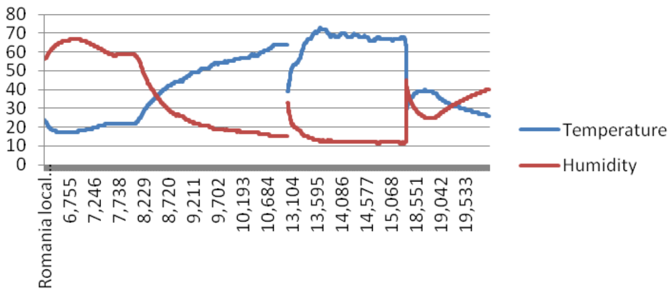

Fig. 9 – Temperature and humidity inside SM.

6. Conclusions

Sunshine Duration (SD) measurement is important in meteorology, tourism, health, agriculture, architecture, solar photovoltaic and thermal application. To measure this parameter there are several principles and methods which are at the base of the design of various devices. The measurement system proposed in this paper relies on SD measurement methods based on contrast. In our case the SM module uses eight light sensors mounted on the circumference of a circle at 45° and in the center of the circle is placed a barrier that creates the shadow. When the SM is placed on a horizontal surface from the eight measured illuminations the system extracts the maximum and minimum. The experimental results showed that we can consider that the sun is present (SD = 1) when $L_{\max}$ exceeds maximum illumination 2,500 lux and the ratio, k, of the maximum, $L_{\max}$, and minimum, $L_{\min}$, illumination is greater than 1.25. The obtained measurement accuracy was better than ±10%. To increase measurement accuracy, further research will consider finding a relationship between the ratio, k, time of day, date, place of measurement, etc. By proper calibration the proposed system can measure also the global irradiance, G. Just by removing the dome seals the SM module the system can measure temperature and humidity of the environment where the SM is positioned.

For further data analysis, the system allows recording data on a local SDcard memory complemented with time stamps and geographical coordinates of the SM monitoring station. The system can be easily adapted to various applications for data collection and recording. An example of application is the realization of WSN (Wireless Sensor Network) that communicate using a proprietary or standard protocol (Zigbee, Miwi, etc.).

REFERENCES

Bertranda C., Demaina C., Journéea M., *Estimating Daily Sunshine Duration over Belgium by Combination of Station and Satellite Data*. Remote Sensing Letters, **4**, *8*, 735-744 (2013).

Besharat F., Dehghan A.A., Faghih A.R., *Empirical Models for Estimating Global Solar Radiation in Yazd City., Iran.*, Proc. of the Internat. Conf. on Solar Energy for MENA Region (INCOSOL), Amman, Jordan, October 22-23, 2012, INOSOL 2-1 2-8.

Ibeh G.F, Agbo G.A, Ekpe J. E, Chikwenze A.R., Ugbor D.O, *Correlation between Sunshine Hours and Global Solar Radiation in Warri-Nigeria with Artificial Neural Network*. J. of Chem., Biolog. a. Phys. Sci., **2**,*4*, 2028-2035 (2012).

Kothe S., Good E., Obregón A., Ahrens B., Nitsche H., *Satellite-Based Sunshine Duration for Europe*. Remote Sens., **5**, 2943-2972 (2013).

LeBaron B.A., Michalsky J.J., Perez R., *A Simple Procedure for Correcting Shadowband Data for all Sky Conditions*. Solar Energy, **44**, *5*, 249–256 (1990).

Massen F., *Sunshine Duration from Pyranometer Readings.* http://meteo.lcd.lu/papers/sunshine_duration_from_pyranometer/Sunshine_duration_from_pyranometer_readings.pdf, 2011.
Muneer T., Xiaodong Z., *A New Method for Correcting Shadow Band Diffuse Irradiance Data.* ASME J. of Solar Energy Engng., **124**, *1*, 34-43 (2002).
Rajput A.K., Tewari R.K., Sharma A., *Utility Base Estimated Solar Radiation at Destination Pune, Maharashtra, India*. Internat. J. Pure Appl. Sci. Technol., **13**, *1*, 19-26 (2012).
Rivington M., Bellocchi G., Matthews K.B., Buchan K., *Evaluation of Three Model Estimations of Solar Radiation at 24 UK Stations*. Agric. a. Forest Meteorol., **132**, 228–243 (2005).
Sanchez-Lorenzo A., Calbo J., Brunetti M., Deser C., *Dimming/Brightening over the Iberian Peninsula: Trends in Sunshine Duration and Cloud Cover and their Relations with Atmospheric Circulation*. J. of Geophys. Res., **114**, D00-D09, (2009).
Wang K. C., Dickinson R. E., Wild M., Liang S., *Atmospheryc Impacts on Climatic Variability of Surface Incident Solar Radiation.* Atm. Chem. Phys., **12**, 9581-9592 (2012).
Wood J., Muneer T., Kubie J., *Evaluation of a New Photodiode Sensor for Measuring Global and Diffuse Irradiance, and Sunshine Duration*. J. of Solar Energy Engng., **125**, 43-48 (2003).
Yakubu D., Medugu D. W., *Relationship between the Global Solar Radiation and the Sunshine Duration in Abuja, Nigeria*. Ozean J. of Appl. Sci., **5**, 3 (2012).
* * * *Guide to Meteorological Instruments and Methods of Observation.* World Meteor. Org., WMO-No.8, Seventh Ed., 2008.

SISTEM DE ESTIMARE A DURATEI PREZENȚEI SOARELUI

(Rezumat)

Se propune un sistem de estimare a duratei prezenţei soarelui pe cer neobturat de nori. Măsurarea acestei durate are importanță în meteorologie, turism, sănătate, arhitectură, tehnologiile de obţinere a energiei pe baza radiaţiei solare etc. Sistemul propus se bazează pe metodele de contrast. În acest caz, un senzor măsoară radiaţia globală iar alt senzor, aflat în umbră , va măsura radiaţia difuză. În lucrare este propusă o metodă de estimare a prezenţei soarelui pe baza a două condiţii: radiaţia globală să depăşească o anumită valoare, la fel, raportul dintre radiaţia globală şi cea difuză să depăşească o anumită valoare. Sistemul propus oferă precizii de măsurare mai bune de ±10%. Cercetările ulterioare vor avea în vedere creşterea preciziei de măsurare printr-o corelare dintre raportul menţionat şi momentul şi locul măsurării. Sistemul este flexibil şi poate fi uşor adaptat pentru măsurarea altor mărimi sau realizarea unei reţele de măsurare. Sistemul propus este realizat din două elemente sau noduri ce comunică între ele prin RF. Acest sistem poate fi uşor dezvoltat prin creşterea numărului de noduri ce comunică între ele pe baza unui protocol. O altă facilitate a sistemului o reprezintă înregistrarea locală a datelor într-o memorie de mare capacitate, cu precizarea locului şi momentului înregistrării.