Arduino-Based Embedded Software Controlled Solar Radiation Processes and Calculation System

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ABSTRACT

Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium and it is measured by a generic device called a radiometer. A researcher has developed a manual calculation model for measuring the solar radiation of a location due to unaffordability of a radiometer, but this model is prone to mathematical errors which lead to inaccuracy of results. To overcome these problems, we developed a low cost extraterrestrial solar radiation and sunshine detector, which is made up of solar panel (photovoltaic cell), Arduino Uno R3, and SD card and programmed with Arduino language for processes and calculations. After the analyses of the module which was carried out at Ilorin Nigeria on 1st of November 2018 and 23rd of February 2019 respectively and then compared for its accuracy with Angstrom Prescott model, the result shows that the new system is valid with accurate readings, and recommendable for private or public use.

Keywords: Embedded Software, Solar, Radiation, Algorithm, Processes, Arduino and Systems.

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1. INTRODUCTION

Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium. (Weisstein E W, 2014). The sun is the seat of thermonuclear processes and produces a vast amount of energy. The energy emitted by the sun is called solar energy or solar radiation. The amount of solar radiation intercepted by the earth is called extraterrestrial radiation. As it makes its way towards the ground, it is depleted when passing through the atmosphere. On average, less than half of extraterrestrial radiation reaches ground level. Even when the sky is very clear with no clouds, approximately 20 % to 30 % of extraterrestrial radiation is lost during the down welling path. A good knowledge of the optical properties of the atmosphere is necessary to model the depletion of the radiation. The role of the clouds is of paramount importance: optically thin clouds allow a small proportion of radiation to reach the ground, while thick clouds create obscurity by stopping the radiation downwards. In clear skies, aerosols and water vapor are the main contributors to depletion. (Lucien W, 2007)

The science of electromagnetic radiation measurement is called radiometry. The generic device is named radiometer. Due to the financial difficulties of getting a radiometer, Prescott in 1940 modified a model for calculating the daily extraterrestrial radiation and sunshine duration of a location. (Prescott, 1940). This model is said to give the maximum estimated daily extraterrestrial radiation value of a location, But due to the stress in manual calculations which also leads to inaccuracy of results, and the model also isn't capable of giving the daily sunshine duration. We (Researchers) have introduced instruments to overcome the errors while using the model and as well ease users that need the data.

Chemical and electrical instruments have been made to measure the accurate daily extraterrestrial radiation and sunshine duration of a location with little stress after full installation of the tools. Pyranometer and net radiometer are the main instruments used to measure the daily extraterestrial radiation and sunshine duration of a location. This instrument requires technical trainings and professional installations for adequate readings and as well more expensive to afford by low scale agricultural business, schools and other weather dependent sectors.
In this paper, we present a low cost extraterrestrial solar radiation and sunshine duration detector, made up of solar panel (photovoltaic cell) for radiation sensor, Arduino Uno R3 as the main processor for controlling the components and SD card for saving data. This detector is affordable, reliable, mobile, user friendly and recommended for all kinds of sectors that depend on weather.

1.1 Objectives

The aim of this research is to develop a low cost multi-detector controlled by embedded software that is capable of measuring daily extraterrestrial solar radiation and sunshine duration of a location. The change of weather plays a vital role on earth especially to human beings as it has direct influences in all kinds of business in the world, like agriculture, aviation, life science, schools, weather forecast stations and indirectly personal use. Most of these business sectors are of different levels and capabilities just as they depend on this radiation data at different levels. Angstrom presscott model has been their basis for calculating daily extraterrestrial radiation of a location which is more likely prone to errors due to miscalculations and incorrect manual readings but in other to overcome this errors, it cost them a lot to buy the main tools and as well understand the usage of this tools like pyranometer and net radiometer, which has made some business, schools, personal aviation and farmers helpless but to wait for the media forecast which might not be out at the exact time needed. Some are even using obsolete systems such as Gunn Bellani radiometer, Campbell-stokes sunshine recorder, etc.

In other to overcome all these problems, we introduce easy to use, low cost daily extraterrestrial solar radiation and sunshine duration, which is very much affordable and recommendable to all kinds of sectors and personal use. It's mobile and can be taken to anywhere in the globe to read solar radiation as required in a location. This detector is accurate, efficient and reliable just as the other main tools.

2. RELATED WORKS

Before the satellite age TSI calculations were based upon balloon and sounding rocket measurements. (Richard, 1981). Nigerian Meteorological agency (NIMET) measures their solar radiation through the use of Gunn Bellani radiometer (GB). This method is simple, quite cheap, and easy to maintain as it is available in two forms: water filled for daily radiation up to 6.28Mjm^{-2} and alcohol filled for daily radiation of up to 37.68Mjm^{-2}. The liquid is contained in a thin walled copper sphere blackened externally. Sealed into this, with its upper end above liquid level, is the distillation tube. The latter collects liquid distilled from the bulb in its lower section, which is graduated in 0.1 ml divisions. The bulb holds about 42 ml of the working fluid. Initially, the liquid is transferred to the copper sphere by inverting the instrument, and the level remaining in the graduated receiver is noted. When exposed to solar radiation, the fluid in the blackened copper sphere vaporizes and condenses in the graduated receiver. Periodically, or at the end of each day, radiation level is recorded. (Folayan, 1988) calibrated GB readings with pyranometer readings and came up with a conversion factor, which may be mathematically expressed as:

$$1ml_{GB} = 1.357\ (\pm\ 0.176) Mjm^{-2}$$

The maximum and minimum thermometers are used to measure the highest and lowest temperature reached by air in a day at the Nigerian meteorological agency. These are kept at a height of 1.5 meters above the ground in a white wooden louvered shelter called Stevenson screen. Maximum and minimum thermometers are liquid in glass thermometers used for determining daily maximum and minimum temperatures.

At the meteorological agency, sunshine hour data is obtained using the Campbell-stokes sunshine recorder. It was invented by John Francis Campbell in 1853 and later modified in 1879 by Sir George Gabriel Stokes. The device is designed to record the hours of bright sunshine that will burn a hole through the card. It is of great importance to install the device in an area where the sun will not be blocked by buildings, trees or other obstructions. (Kolebaje and Mustapha, 2012).

This method is too obsolete and also consumes frequent financing of alcohol for daily readings compared to using of other modern tools like pyranometer and net radionmeter. Since the Sun radiance varies to some extent over short and long periods (Fröhlich,1991), the solar constant does not remain steady over time. In a point at the top of Earth's atmosphere, the beam of nearly parallel incident sunrays is referred to as extraterrestrial radiation (ETR). ETR fluctuates about 6.9 % during a year (from 1412.0 Wm^{-2} in January to 1321.0 Wm^{-2} in July) due to the Earth's varying distance from the Sun. (Gueymard and Myers, 2008). Based on data collected over 25 years from terrestrial to space observations, the actual best estimate of the average solar constant is GSC = 1366.1 Wm^{-2} (Gueymard 2004).

3. METHODOLOGY

The basic components needed consist of a photovoltaic cell, Arduino and data logger and SD card which will be driven by the software that will be developed and embedded in the system to control the system for easy access to weather forecast compare to the old systems. The only factor that can affect this module is unstable power supply, as it needs a stable power supply for effective functionality and accurate readings
The procedure at which this research is done is categorized into two parts, the software and the hardware part. It has been proven that photovoltaic cell is a good module for solar power and as well sunshine detector and Arduino is a reliable microcontroller for electronics and as well a good meter for reading voltage as it has its own formula for converting photovoltaic input to voltage.

3.1 Hardware required

The necessary hardware needed are; Arduino Uno R, Photovoltaic cell, Arduino Data logger shield, SD card, Resistors, Breadboard, Jumper wires, Computer, and 9v-12v Power supply

3.2 Software required

The required software are**;** Arduino Language, Arduino IDE, Microsoft Excel, Arduino SD and RTC library

3.3 Arduino UNO R3 Programming

The Arduino UNO R3 is programmed and integrated with Arduino Language. The Arduino language is merely a set of C/C++ functions, saved with .ino format, it undergoes a preprocessing which automatically turns the written program into a C++ program and then compiled by avr-g++ and avr-gcc. So all standard C and C++ constructs supported by avr-g++ work in Arduino.

3.3.1. Steps Taken in the Making of the Hardware Module

i. After getting all the necessary requirements insert the SD card to the data logger shield and attach it to the Arduino Uno R3.
ii. Make a voltage divider circuit load with the resistors that will produce the maximum voltage of 4.9 volt when the solar panel reaches its maximum power point (MPP). As shown in the figure 1.

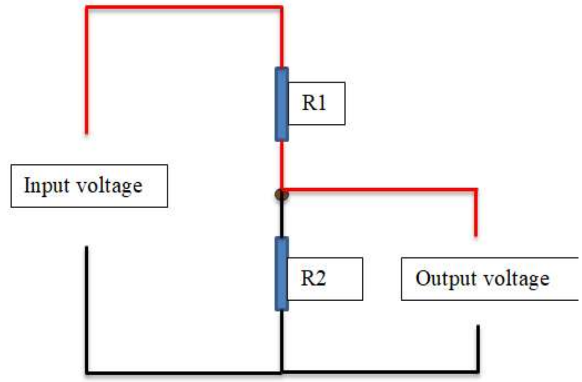

Figure 1: Voltage divider circuit

iii. Connect the solar panel as the input voltage to the voltage divider as shown in the figure 2.

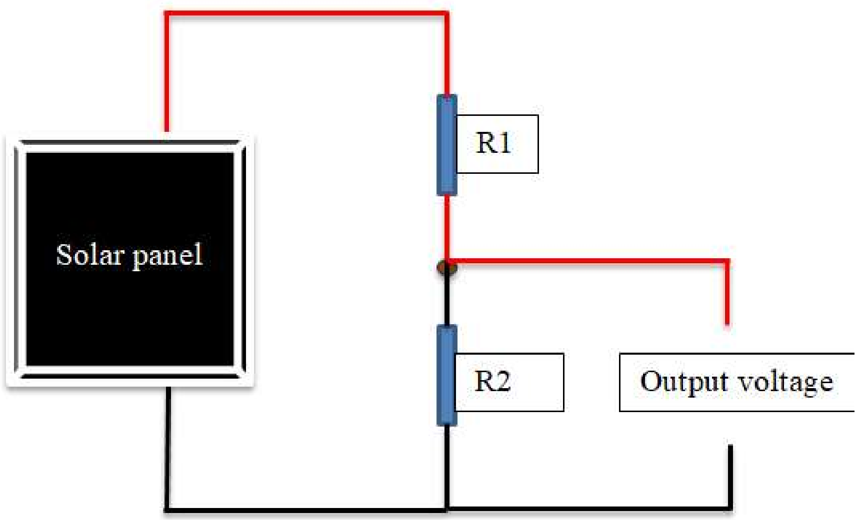

Figure 2: Solar panel connection

iv. Connect the Arduino Uno R3 to the computer and go to the Arduino IDE program on the computer to program it.
v. Create a sketch in the Arduino IDE and write a correct program for the execution of the Arduino. Note: The desired log interval, location latitude and day's number in the year should be included in these sketch.
vi. Install the libraries to the Arduino IDE for the sketch to work perfectly
vii. Run the sketch and upload to the Arduino Uno R3.
viii. Eject the Arduino from the computer,
ix. Connect output of the voltage divider to the input of the Arduino Uno R3 as stated in the sketch as shown in Figure 3.

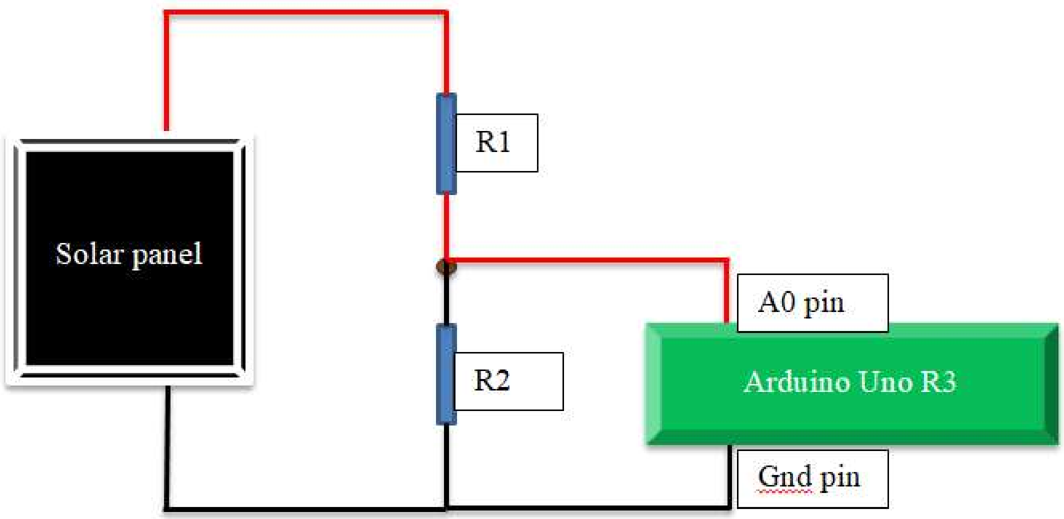

Figure 3: Arduino connection

x. Take the solar panel outside to see the sun without any kind of shade obstructing it.
xi. Connect the 9v power supply to the Arduino to start.
xii. After reading the radiation, disconnect the 9v power supply from the Arduino Uno R3.
xiii. Remove the SD card from the data logger.
xiv. Insert the SD card to the computer.
xv. Open the files in it with Microsoft excel.
xvi. Then edit files if required.
xvii. Then save and copy files to another drive to free the SD card memory.
xviii. Remove the card and insert it in the data logger again.
xix. Connect the 9v power supply to the Arduino Uno R3 again to start recording new solar radiation.

3.3.1 Algorithm

- ✓ Start
  - → Start timing
- ✓ If timer is equal to the log interval
  - → Read the solar value (voltage)
  - → Calculate the solar radiation
  - → Save data.
- ✓ End
- ✓ Restart timer

Note: Timer reads in milliseconds and the log interval depends on the desired seconds programmed by the user in milliseconds.

3.3.4 System Flow chart Diagram

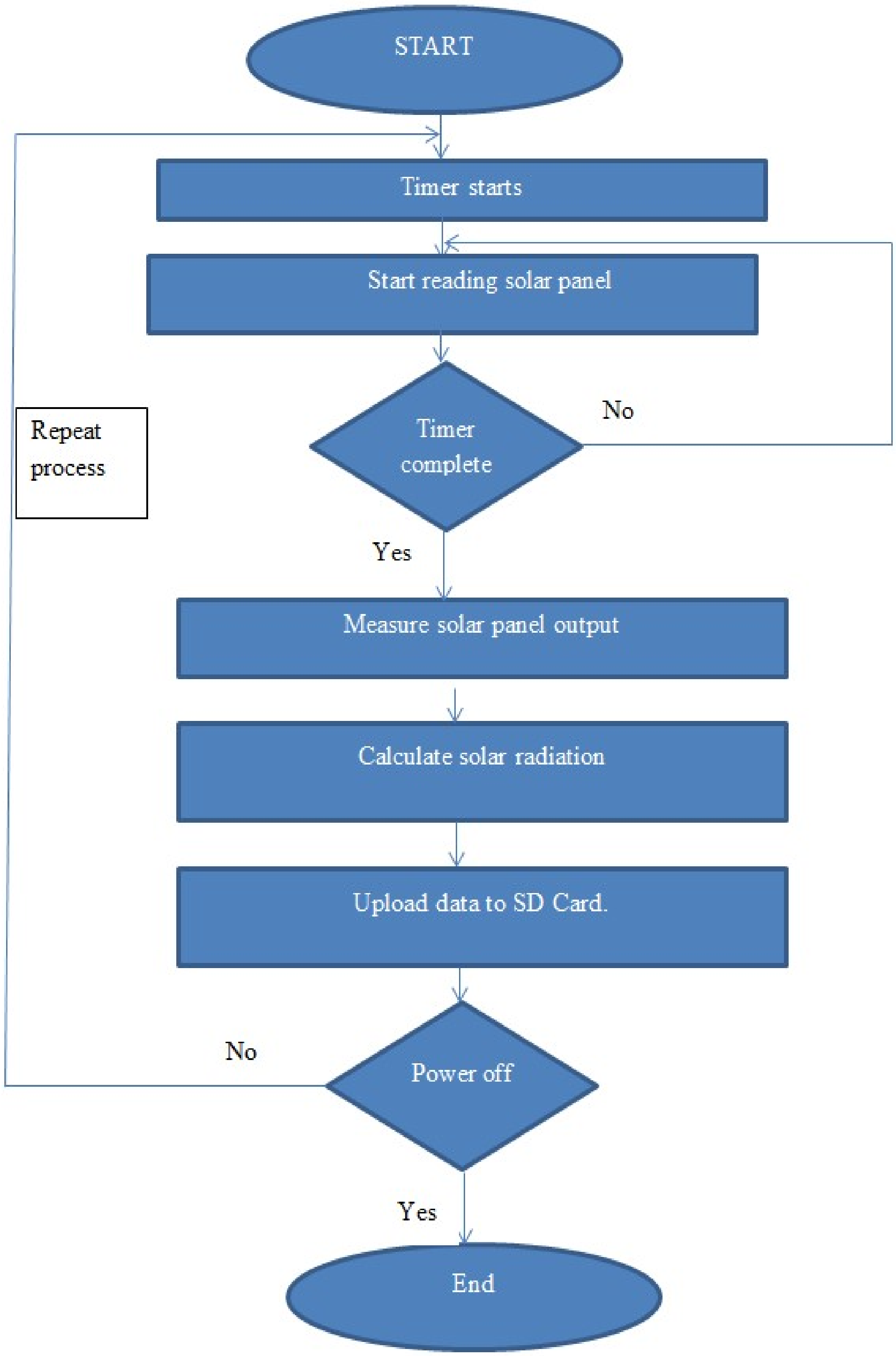

Figure 4: Flow Chart

3.5 System Block Diagram

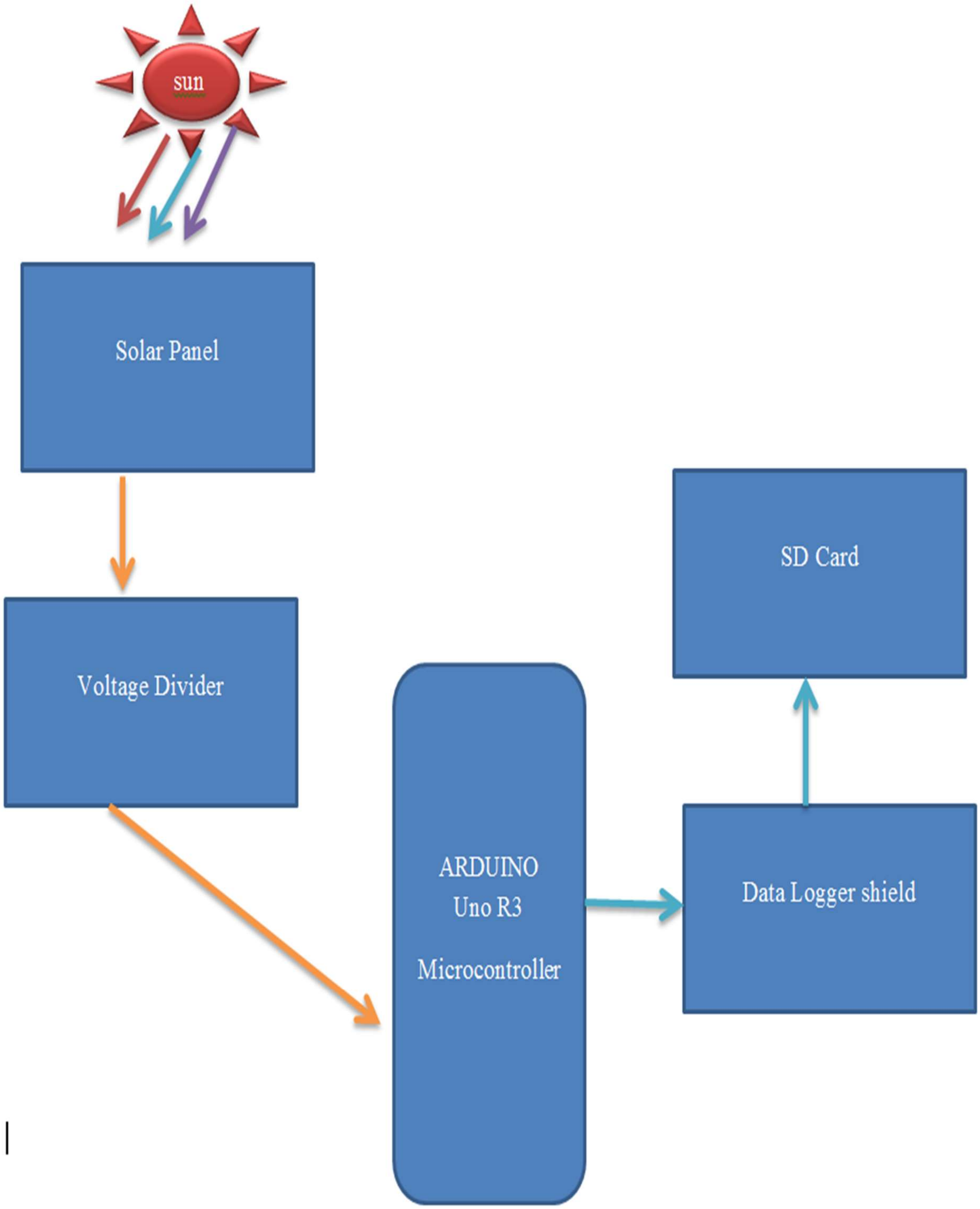

Figure 4: Block Diagram

4. HOW THE SYSTEM WORKS INTERNALLY

i. When the system is turned on, it first detect if every components are well connected and check if the SD card detectable, if the SD card isn't detected, it will display a red light as an error message , otherwise, the system will start automatically.
ii. The solar panel (PV Cell) detects the radiation from the sun and converts it into electrical current. Since it doesn't store electric current, the current will the flow straight to the Microcontroller through the voltage divider.
iii. The voltage divider contains two resistors that reduce the voltage coming from the PV Cell to a readable and appropriate voltage that the microcontroller can receive, because the microcontroller can only read voltage from 0 – 5V and any voltage above 12V can damage the microcontroller. So, the voltage divider serves as a regulator, then after dividing the voltage coming in from the PV Cell, it goes straight to the microcontroller.
iv. The microcontroller then wait for the timer to complete and then takes the output value from the voltage divider then calculate the value back to the normal input of the voltage divider (the total voltage drop) using Kirchhoff voltage law (KVL). Then calculates the solar radiation from the total voltage and store it to the SD card.
v. The SD card will then store the data and save it.
vi. This continues till the microcontroller is turned off or the SD card is removed.
vii. Then all data will already be saved in SD card for further processes needed by the user.

5. RESULTS AND DISCUSSION

This module was tested at Ilorin, Nigeria for two days and compared with Angstrom Prescott model for data accuracy. The calculation on how to get the daily extraterrestrial radiation value from the data collected should be by adding up all the data together and dividing them by the total number of data to get their average. But due to unstable power supply which makes the system stop for some time, it wouldn't be possible to get the complete data in seconds or minute for a day, but the best way to get an accurate result in this situation is to divide the day into 6 in a way that the off-peak time hours would be balanced along with the peak time hours. Like 24pm = 0am, 4am, 8am, 12pm, 4pm, and 8pm and then divide them by 6 to get their average.

For accurate reading, the solar panel should face only the sunlight and no other kind of light should reflect to it.

5.1 54th Day Data of 2019

i. Day = 54.
ii. Date = 23rd February 2019.
iii. Location = Al Hikmah University Ilorin
iv. Latitude = 0.148 radian.
v. Log time interval = 18000000 milliseconds (30 minute).
vi. Angstrom-Prescott equation model daily extraterrestrial radiation value = 34.72 $MJm^{-2}d^{-1}$

Table 1: 54th Day Data of 2019

Date	Day	Time	Voltage	Sensor-Vol	Sensor-Rad	Angstrom Model $MJm^{-2}d^{-1}$
23.2.2019	Saturday	0:0:0	0	0	0	34.72
23.2.2019	Saturday	0:30:0	0	0	0	34.72
23.2.2019	Saturday	1:0:0	0	0	0	34.72
23.2.2019	Saturday	1:30:0	0	0	0	34.72
23.2.2019	Saturday	2:0:0	0	0	0	34.72
23.2.2019	Saturday	2:30:0	0	0	0	34.72
23.2.2019	Saturday	3:0:0	0	0	0	34.72
23.2.2019	Saturday	3:30:0	0	0	0	34.72
23.2.2019	Saturday	3:30:0	0	0	0	34.72
23.2.2019	Saturday	4:0:0	0	0	0	34.72
23.2.2019	Saturday	4:30:0	0	0	0	34.72
23.2.2019	Saturday	5:0:0	0	0	0	34.72
23.2.2019	Saturday	5:30:0	0	0	0	34.72
23.2.2019	Saturday	5:30:0	0	0	0	34.72
23.2.2019	Saturday	6:0:0	0	0	0	34.72
23.2.2019	Saturday	6:30:0	0.05	0.27	0.01	34.72
23.2.2019	Saturday	7:0:0	1.34	7.5	9.55	34.72
23.2.2019	Saturday	7:30:0	2.68	14.95	37.91	34.72
23.2.2019	Saturday	8:0:0	3.05	17.02	49.16	34.72
23.2.2019	Saturday	8:30:0	2.95	16.48	46.06	34.72
23.2.2019	Saturday	9:0:0	2.93	16.37	45.45	34.72
23.2.2019	Saturday	9:0:0	2.93	16.37	45.45	34.72
23.2.2019	Saturday	9:30:0	3.51	19.59	65.08	34.72
23.2.2019	Saturday	10:0:0	3.36	18.8	59.93	34.72
23.2.2019	Saturday	10:30:0	3.44	19.21	62.57	34.72
23.2.2019	Saturday	10:30:0	3.44	19.21	62.57	34.72
23.2.2019	Saturday	11:0:0	3.61	20.19	69.13	34.72
23.2.2019	Saturday	11:30:0	3.35	18.71	59.41	34.72
23.2.2019	Saturday	12:0:0	3.26	18.2	56.17	34.72
23.2.2019	Saturday	12:30:0	3.39	18.96	60.98	34.72
23.2.2019	Saturday	12:30:0	3.39	18.96	60.98	34.72
23.2.2019	Saturday	13:0:0	3.4	18.99	61.16	34.72
23.2.2019	Saturday	13:30:0	3.19	17.84	54	34.72
23.2.2019	Saturday	14:0:0	3.89	21.72	79.99	34.72
23.2.2019	Saturday	14:30:0	3.41	19.04	61.51	34.72
23.2.2019	Saturday	14:30:0	3.41	19.04	61.51	34.72
23.2.2019	Saturday	15:0:0	3.04	17	49	34.72
23.2.2019	Saturday	15:30:0	3.39	18.93	60.81	34.72

Date	Day	Time	Voltage	Sensor-Vol	Sensor-Rad	Angstrom Model $MJm^{-2}d^{-1}$
23.2.2019	Saturday	16:0:0	3.95	22.07	82.63	34.72
23.2.2019	Saturday	16:30:0	3.03	16.94	48.69	34.72
23.2.2019	Saturday	17:0:0	3.44	19.21	62.57	34.72
23.2.2019	Saturday	17:0:0	3.44	19.21	62.57	34.72
23.2.2019	Saturday	17:30:0	3.03	16.94	48.69	34.72
23.2.2019	Saturday	18:0:0	2.82	15.74	42.03	34.72
23.2.2019	Saturday	18:30:0	2.26	12.6	26.95	34.72
23.2.2019	Saturday	19:0:0	1.45	8.08	11.06	34.72
23.2.2019	Saturday	19:30:0	0	0	0	34.72
23.2.2019	Saturday	19:30:0	0	0	0	34.72
23.2.2019	Saturday	20:0:0	0	0	0	34.72
23.2.2019	Saturday	20:30:0	0	0	0	34.72
23.2.2019	Saturday	21:0:0	0	0	0	34.72
23.2.2019	Saturday	21:30:0	0	0	0	34.72
23.2.2019	Saturday	21:30:0	0	0	0	34.72
23.2.2019	Saturday	22:0:0	0	0	0	34.72
23.2.2019	Saturday	22:30:0	0	0	0	34.72
23.2.2019	Saturday	23:0:0	0	0	0	34.72
23.2.2019	Saturday	23:30:0	0	0	0	34.72
23.2.2019	Saturday	3:59:59	0	0	0	34.72

Legend:

i. **Date** - The date of experiment
ii. **Day**- The day of the week.
iii. **Time** - The time of reading the solar panel output.
iv. **Voltage** – The voltage measured after voltage divider (the total voltage an Arduino Uno R3 can read is between 0 to 5v which is represented as 0-1024 in integer value). So voltage cannot be more than 5v due to the voltage divider circuit used.
v. **Sensor-vol** – The total amount of voltage the solar panel detected at the particular time.
vi. **Sensor-Rad** – The total solar radiation at the particular time.
vii. **Ansgstrom Model** – Angstrom-Prescott equation model daily extraterrestrial radiation value in $MJm^{-2}d^{-1}$.

Calculations and comparison

After dividing the day by 6, we choose 0am, 4am, 8am, 12pm, 16pm, 20pm and the time equivalent to the desired time are the same

Which are:

0:0:0 am = 0
4:0:0 am = 0
8:0:0 am = 49.16
12:0:0 pm = 56.17
16:0:0 pm = 82.63
20:0:0 pm = 0

The average of the data received is
0 + 0 + 49.16 + 56.17 + 82.63 + 0 = 187.9
187.96 / 6 =31.33 $MJm^{-2}d^{-1}$
Therefore;

i. Solar Radiation of the day (23rd February, 2019) = 31.33 $MJm^{-2}d^{-1}$
ii. The extraterrestrial radiation equation value = 34.72 $MJm^{-2}d^{-1}$
iii. The total sunshine hour is from 7am to 7pm = 12 Hours.

6. DISCUSSION OF THE RESULTS

A new solar radiation and daily sunshine detector has been designed, tested and implemented in this project. The project construct is far better and reliable to the earlier implementations, whereby power consumption, cost affordability, and accurate result were highly considered. The system has been tested for its efficiency and accuracy and the speed at which the system reads the radiation varies, because the user is the one to assign the desired log interval. Due to this problem, the user has to be careful in keying in the log interval in milliseconds. The test and analysis above shows the data result of the 23rd of February, 2019, after all the necessary calculations and comparisons, the total difference between the solar radiation value of the module and the extraterrestrial radiation formula (Angstrom Prescott model) is 3.39 on the 23rd of February, 2019. With this result, the module has proven its accuracy because normally, the extraterrestrial radiation formula (Angstrom Prescott model) value is a constant value every year of the same day so it is less possible to have the same value in both sides.

7. CONCLUSION

This report presents some of the existing tools used in measuring solar extraterrestrial radiation of a location in the literature in order to compare their cost with this detector and this detector has been particularized for the conditions specified for a certain location, namely Ilorin. Validation of this model was performed. Photovoltaic Cell used in this project can be considered as a reliable detector for measuring solar radiation and for detecting daily hours of sunshine. The system is well designed and tested for the benefit and to the taste of users. It is constructed with Arduino which is considered as one of the reliable, affordable micro controller we have today. The micro controller is programmed using its programming language more like the combination of C and C++ which is an easy learning High level language and easy to understand.

This detector has met all necessary requirements with its accurate and reliable results, affordability, mobility and efficiency. Therefore, this system is tested compared with the existing one (angstrom Prescott Model) and confirmed as an accurate solar radiation and daily sunshine detector and this can be used by any organisation publicly or privately.

8. RECOMMENDATIONS

This type of system is recommended for schools, agricultural sectors and other weather or solar related organizations. For accurate reading, the solar panel should face only the sunlight and no other kind of light should be in its vicinity.

9. FUTURE WORKS

Addition of GPS module for auto detection of the latitude of any location; Installation of keypad and Digital display for users ability to input their desired logging time and as well Day number in the year without going through editing of source code. Humidity, rain and temperature detector should be added for a complete weather station. And cloud storage for ease of access anywhere and storing of large files compared to a SD card should be implemented.

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