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Measurement of solar energy parameters project in the facilities of the Universidad Tecnológica de Altamira

Proyecto de medición de parámetros de energía solar en las instalaciones de la Universidad Tecnológica de Altamira

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Abstract

The objective of this research is to develop and design an experimental prototype that allows the capture and storage of irradiance data in real time. Access to this data is through public Mathworks web servers allowing entry from any device. The prototype includes an ESP32 development board, a photovoltaic cell, two temperature sensors and a current sensor, the main function is to measure irradiance, this being the amount of radiant energy received per specific area. This is achieved through the use of a photovoltaic cell, which transforms solar energy into electrical current, the current sensor provides an indirect measure of irradiance by recording the current produced by the photovoltaic cell. Temperature sensors are used to compensate for measurement differences caused by temperature changes in the environment. To get accurate readings, these sensors are strategically placed near the photovoltaic cell. The prototype is connected to the internet, which allows access to irradiance data, showing a practical solution for collecting and monitoring in real time, being useful in applications design and combination of technologies, such as a board of solar energy systems and in precision agriculture.

Irradiance, irradiation, temperature sensor, current sensor, photovoltaic module, solarimeter, ESP32 and ThingSpeak

Resumen

El objetivo de esta investigación es desarrollar y diseñar un prototipo experimental que permita la captura y almacenamiento de datos de irradiancia en tiempo real. El acceso a estos datos es a través de servidores web públicos de Mathworks permitiendo el ingreso desde cualquier dispositivo. El prototipo incluye una placa de desarrollo ESP32, una celda fotovoltaica, dos sensores de temperatura y un sensor de corriente, la función principal es medir la irradiancia, siendo esta la cantidad de energía radiante recibida por área específica. Esto se logra mediante el uso de una celda fotovoltaica, que transforma la energía solar en corriente eléctrica, el sensor de corriente proporciona una medida indirecta de irradiancia al registrar la corriente producida por la celda fotovoltaica. Los sensores de temperatura se utilizan para compensar las diferencias de medición causadas por cambios de temperatura en el entorno. Para obtener lecturas precisas, estos sensores se colocan estratégicamente cerca de la celda fotovoltaica. El prototipo está conectado a internet, que permite acceder a los datos de irradiancia, mostrando una solución práctica de recopilación y monitoreo en tiempo real, siendo útil en aplicaciones diseño y combinación de tecnologías, como una placa de sistemas de energía solar y en agricultura de precisión.

Irradiancia, irradiación, sensor de temperatura, sensor de corriente, módulo fotovoltaico, solarímetro, ESP32 y ThingSpeak

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Introduction

The use of solar energy is conditioned by the availability and intensity of solar radiation at a specific location. Irradiance, expressed in units of W/m², represents the magnitude of radiant energy deposited on a given surface per unit area. In the context of this study, radiation is considered to interact with a plane during a defined time interval, resulting in the transfer of a specific amount of energy. This energy transfer, quantified as the amount of energy received per unit area during a given period of time, is called irradiance (Falcón, N.; Peña, F. & Mavo, H., 2001).

Accurate and reliable irradiance records are therefore of vital importance and play a fundamental role in the design and optimisation of devices and systems that use solar energy. These records allow the assessment of the technical and economic feasibility of solar applications, as well as feasibility studies and performance modelling. This study contributes to the advancement of the field of solar energy by providing a solid basis for data collection and accurate interpretation of irradiance through a prototype solar energy meter whose purpose is to communicate information via the internet to databases that can be queried from anywhere in real time.

The hypothesis is that there is a relationship between the current and voltage values of a solar cell and the calculation of irradiance and solar irradiation. For this purpose, a circuit was fabricated that operates at the nominal allowed values, a cell connected to a current sensor, two temperature sensors, and a load equivalent to the nominal output value of the source data sheet.

The values are collected in an analogue-digital way and the main purpose is to be able to communicate these values wirelessly, to be able to use them in scripts whose function is to transform the data obtained into interpretations that can be taken as a reference in area studies, for the implementation of renewable energies.

Background

1.1. Microcontroller

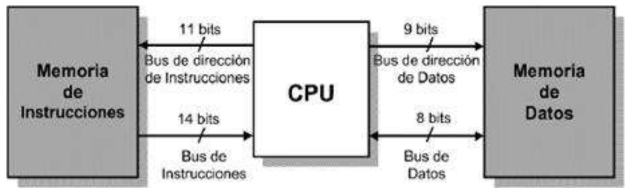


Figure 1 Operation of the Solarimeter
Source: http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S1019-94032020000100048

It is an integrated circuit, whose interior has an architecture similar to computers, with components such as RAM, EEPROM, CPU and input and output peripherals or also called I/O.

It has the ability to replace a large number of circuits that use logic to function, for example, gates, decoders, timers, converters, etc., reducing the design to a simple PCB (Diaz, 2020).

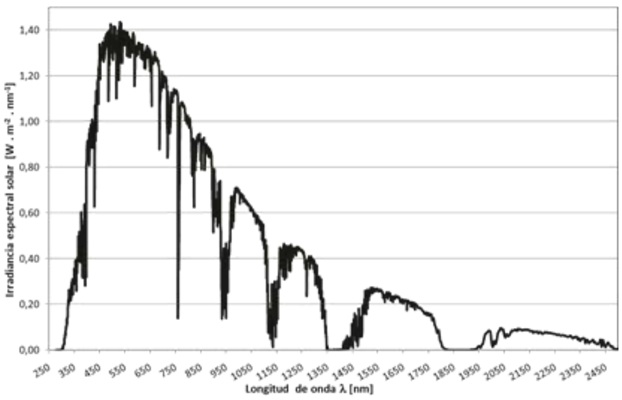
1.2. Solar radiation

The global solar radiation obtained in any area is composed of two fundamental elements: direct radiation and diffuse radiation. Direct radiation refers to the solar radiation that reaches a surface unchanged in its original direction, coming directly from the Sun. In contrast, diffuse radiation is radiation that reaches the surface after being scattered or reflected, including also infrared radiation emitted by molecules after undergoing heating due to absorption of solar radiation.

Proper analysis of direct and diffuse radiation provides valuable information for the development of efficient strategies to capture and use solar energy in various applications (Wright, 2008).

1.3 Irradiance

Irradiance can be described as the measure of the intensity of solar radiation per unit area. In the international system, the unit of measurement used for irradiance is the Watt/square metre (W/m²). This magnitude exhibits minor temporal fluctuations related to solar activity, while its long-term average value is known as the solar constant, Gsc (Laguarda, 2021).



Graph 1 Solar spectral irradiance, ground level
Source:*https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-77432018000200209*

Description of the method

From the hypothesis of the existence of a way to measure the profitability of a photovoltaic module through its own performance, the idea of using a load in the circuit to be able to use a current sensor that is also capable of accurately calculating the voltage thanks to a shunt resistor was born, giving rise to the planning and subsequent search for materials to be used, as well as the correct way to connect each component in the circuit.

The next phase of the research belonged to the technical and practical, we had a 3W cell ideal for making a sensor, to which open-circuit measurements had to be made by means of a pair of resistors. A basic multimeter was used to check the data provided in the description of the cell and to obtain its real nominal values experimentally.

In the first instance, the sensors were tested on an Arduino R1 board, given the ease of finding compatible codes that would work as an example. Once the operation of the sensors and their potential usefulness had been verified, an equivalent programme compatible with the ESP32 development board was created.

The circuit consists of connecting the photovoltaic module in series to a resistor, to subsequently record the current and voltage drop every minute, from 5:00 a.m. to 08:00 p.m., to make comparisons with a calibrated solarimeter, which is currently owned by the Technological University of Altamira.

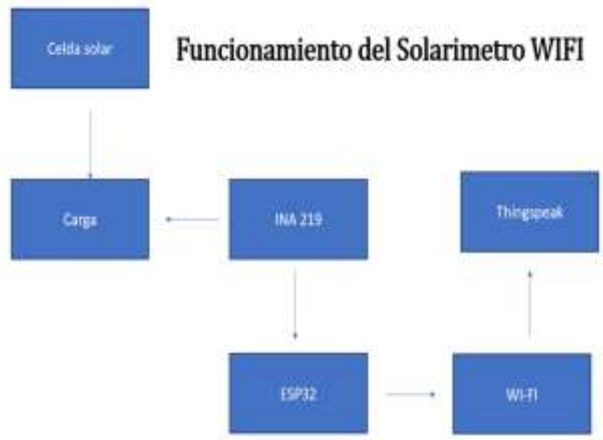


Figure 2 Operation of the Solarimeter
Source: Own Elaboration (2023)

The data collection part did not represent a great challenge for the purpose of this research, the most challenging part, due to the initial inexperience, was to elaborate the circuit that would allow measuring the data needed for the linearity calculation, i.e., in terms of programming, the sketch is relatively simple, however, the nature of the data will be mentioned later.

It is worth mentioning that the data received from the sensor was raw product that still needed to be processed to obtain relevance against a conventional solarimeter, it should be remembered that what was obtained, were powers calculated based on voltages and currents. Initially, a summation of all the data obtained in a day must be made, being Watts Minute, at the end the data must be converted to more useful units for the study of this article, in this case, Watts Hour, the reason behind this, is that the data consulted in NASA are given in Peak Solar Hours, therefore, the conversion must also be made, first, to Watts by multiplying by 1000 and finally in Watts hour by dividing by 60.

Having said that, the first method used the power values recorded by the prototype to make a comparison with the power data consulted at NASA. This consisted of summing the data provided by the cell for one day, which was then divided by 60 to obtain Watts/hour. However, the resulting number was lower because the cell has a capacity of 3 W compared to the values provided by the Data Access Viewer, which are given in Peak Holar Hours. With these two units in equivalence, a division was performed which gives a factor.

December, 2023 Vol.7 No.17 9-16

The problem was that these factors changed considerably from day to day. From this, the average was calculated and then used as a basis for multiplying the Watts/hour, and finally the accuracy margin was obtained. However, the result was not as expected because the accuracy percentages varied between 90% and 75%, which caused a deviation after several measurements.

Days	WH Sensor	WH NASA	Percentage of Accuracyn	HSP NASA	HSP Sensor
14th June	7673.19444	7330	104.6820524	7.33	7.673194444
16th June	6974.65278	7180	97.14001083	7.18	6.974652778
17th June	7142.43056	7210	99.06283711	7.21	7.142430556
18th June	7933.75	7390	107.3579161	7.39	7.93375
20th June	6889.46429	7200	95.68700397	7.2	6.889464286
21st June	7310.59524	7520	97.21536221	7.52	7.310595238
				Average Accuracy	100.1908638

Table 1. Comparison of NASA data and data collected from the solarimeter (2023)
Source: Own Elaboration

Thus, another way of obtaining the irradiation values was considered, following the previous method with the difference that the comparison was not made with the values provided by NASA, but with those shown in a solarimeter. For this purpose, 10 data obtained every minute were used, following the same procedure as before.

The main advantage was that these values were immediate, so it was not necessary to have a waiting time to make the comparisons and calculate the factors. However, with this method, the accuracy had a large margin of error, so either system was definitely discarded. With the preliminary results and the tests carried out, it was decided to investigate another way of obtaining the irradiance, which consisted of applying the equation that relates the irradiance incident on a module with the temperature at that instant of time. With this new formula, standard temperature values were needed, which is usually 40°C, however, due to the size of the module, this value varied and was not known due to the lack of the DataSheet, so the irradiance results given were minimal with respect to the time they were taken. For the purposes of this study the formula was cleared to calculate irradiance instead of temperature.

$$Tc = Ta + G\frac{TONC - 20}{800}$$

Figure 3 Relationship between module temperature and irradiance (2023)
Source: https://www.helioesfera.com/dependencia-de-la-temperatura-y-la-irradiancia-sobre-el-modulo-fotovoltaico/

Luego del despeje:

$$G = \frac{(Tc - Ta)}{\left(\frac{(TonC - 20)}{800}\right)}$$

Figure 4 Ratio of module temperature to irradiance (2023)
Source: Own Elaboration

For the present study, this data of 800 W/m^2 is more accurate than using the standard 1000 W/m^2, while the TonC variable was obtained experimentally, using a commercial solar meter as a reference irradiance. (2023). Source.

Results

The information contained in the following table is from the public POWER DATA ACCESS VIEWER page, compared to the data collected on the prototype manufactured in this research. A breakdown of irradiation related data is available for the current study area in the form of Peak Solar Hours.

It is necessary to convert the data with the proposed equation. Once this is done, through the rule of 3, a daily precision margin is obtained, from which it is possible to obtain an average, after the census of different days.

The lack of continuity in the days presented in the table was a consequence of the discharge of the prototype's power supply, leaving no margin for the collection of information on the days omitted.

The ESP32 circuit board is a System On chip, designed by Espressif Systems and manufactured by TSMC. The developer itself defines this series as a solution for microcontrollers without connectivity. It is possible to use the ESP32 as a bridge to connect to such boards, and it is capable of running its own real-time applications, which makes it more suitable and capable for probing tasks than other circuit boards, for example, the Arduino R1.

One of the libraries available for free download creates a local web server, which is stored in the microcontroller's memory, its purpose is for the board to generate a request to be connected to a WI-FI network available in the surrounding area.

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In case the ESP32 has already been connected to a WI-FI network available in range, this last step will be skipped and the execution of the program will start, the local server is accessible via computers and mobile devices such as mobile phones and tablets.

The data is stored locally, in the ESP32's flash memory, however, in addition, all data is sent to the cloud whenever internet is available, in this case, to a public server hosted by Thingspeak, a free site that offers students access to customisable private or public clouds, without any kind of initial investment.

The information collected on the site can be downloaded in .csv format, an Excel-compatible file type, through which it is possible to perform the necessary calculations to convert the data.

Figure 5 Public server dedicated to collecting solarimeter data in Thingspeak (2023)
Source*: https://thingspeak.com/channels/2144052*

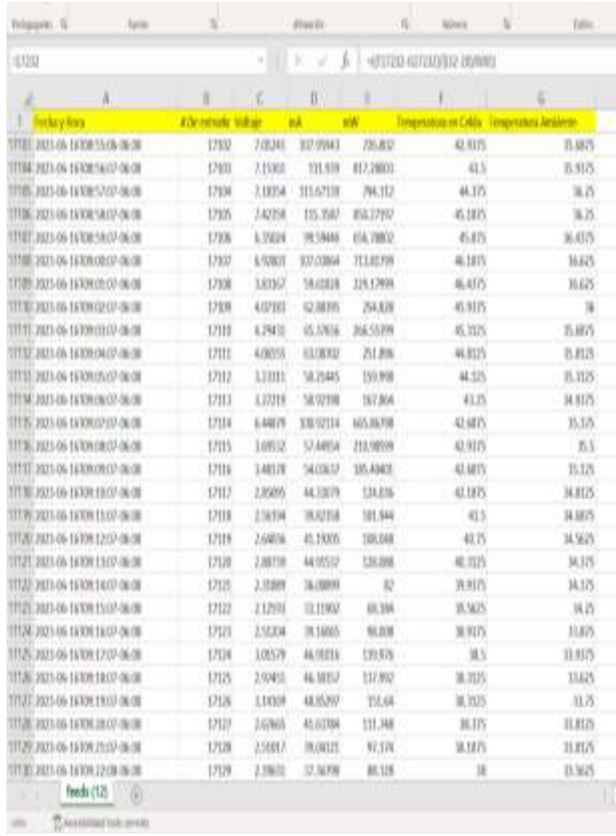
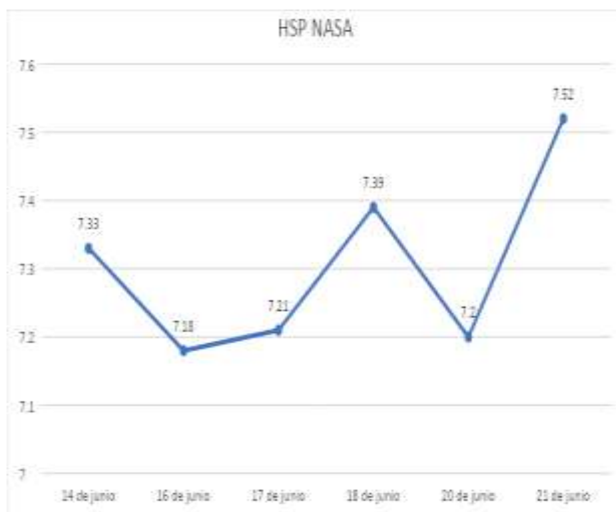
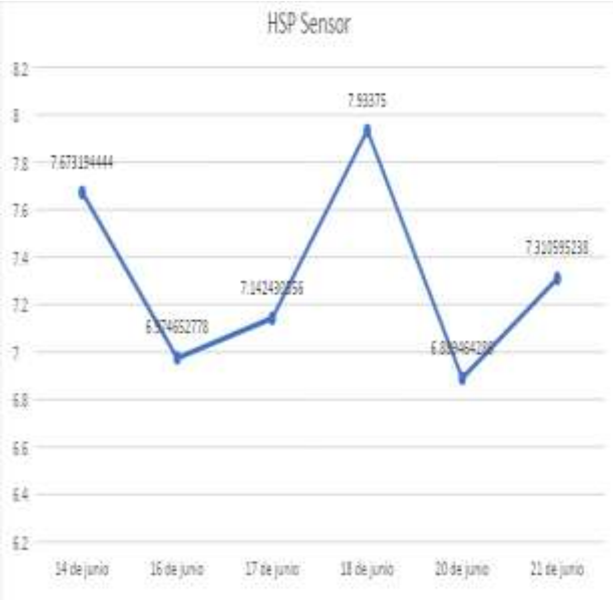


Figure 6 Example of data exported from Thingspeak (2023)
Source: Own Elaboration

With the data collected and worked on, it is possible to create graphs that work best to visually show the relationships between the data.



Graph 2 Graph of Peak Solar Hours from data consulted on the official NASA website (2023)
Source*: power.larc.nasa.gov/data-access-viewer/*



Graph 3 Graph of Peak Solar Hours of the data obtained by the prototype manufactured (2023)
Source: Own Elaboration

Difficulties in the process

During the development of the design, various issues arose that delayed the process, including the fact that the photovoltaic cell used did not have a DataSheet, so the adjustments had to be experimental, based on a sensitivity analysis and by means of calculations. When the resistance value was obtained, there was a problem with it, due to the fact that the ideal value (60 ohms) is not commercial, so it was decided to use a 39 ohms resistor in series with a 22 ohms resistor, reaching the correct value required.

The correct placement of the module and its power supply was of utmost importance to start the data collection, so both had to be accurate. In view of this, a series of tests were carried out to obtain results, which postponed the collection of information.

With regard to data collection, it was necessary to use the memory of the ESP32 sensor to store the information obtained, as otherwise the values would not be recorded if at any time it was disconnected from the selected Wifi network or if any mishap occurred with the electrical service. In terms of wording, certain doubts arose regarding the relationship between the irradiance measured in the photovoltaic cell and the data provided by Data Access Viewer. Also, the values are delayed by five days, so the comparison process requires a considerable waiting time.

Concluding remarks

For the sizing of a PV system, having the HSP parameter in the area is an essential part of the study. This information is key because, during the calculation of the number of modules, it determines the techno-economic feasibility and, above all, the cost of investment in the equipment, which at a business level can make the difference between attracting new customers and having a competitive advantage.

The prototype presented is capable of obtaining an average of 99% certainty with respect to the information consulted in Power Data Access Viewer, with the characteristic of being a database that can be consulted in real time, with an internal storage space and a potential autonomy of 48 hours, with the possibility of expanding this time.

Its application can be directed both to the dimensioning of photovoltaic and photothermal systems. In addition, it is a tool with enormous potential to be implemented in weather stations that combine a greater amount of information.

The advantages offered over a traditional circuit board, for example, the Arduino R1 model are remarkable at the time of setting strategic points, IOT (Internet Of Things) is undoubtedly a revolution in the scheme of the usefulness of current tools, providing great projection to studies such as the one presented in this article.

Summary of results

The data were captured efficiently, within the expected margin, the functionality of the wifi protocol was proven as a useful and powerful tool. Thus opening up the possibility of mapping areas that would normally be inaccessible with complex equipment and optimising methods that require periodic relocation of the equipment in question.

Conclusions

With the results obtained, the project's initiative was fulfilled by creating a solarimeter that works wirelessly to communicate area study data, which can function as a reference in the analysis of the profitability of renewable energy generation projects.

Recommendations

In order to extend the field of application of the present prototype, it is good practice to plan alternative designs and improvements in the field of the body that will use the circuit employed. During the research, it was confirmed that, in order to reach a more advanced level of utility, it is possible to insert a properly measured mechanism that allows the modification of certain parameters such as the installation angle of the photovoltaic module, as well as its orientation, a feature that greatly improves previous studies on the installation of photovoltaic systems.

Adding a charging circuit with a second module can also provide a very extended range of power supply for the circuit presented, regardless of not increasing the size of the battery used.

Further mathematical study can help implement a substantial improvement to the margin of error present, if more accuracy is needed, it is possible to program a percentage delimiter.

Given the wireless nature of the ESP32 board, it is also possible to design an app to be integrated into the operation, opening up the possibility of remote control and subsequent integration of more than one pyranometer per study.

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