

# Development of a meteorological data acquisition prototype: a low-cost and mobile proposal

Paulo Nginga Gaspar<sup>1</sup>, João Pedro Magalhães de Lima<sup>1</sup>, Ligia Maria Carvalho Sousa<sup>1\*</sup>, and Vandilberto Pereira Pinto<sup>1</sup>

<sup>1</sup>Institute of Engineering and Sustainable Development, University of the International Integration of Afro-Brazilian Lusophony (UNILAB), 62790-970, Redenção, Brazil

**Abstract.** The huge use of fossil fuel has been causing a series of environmental problems, such as climate change, global warming, air pollution and acid rain. To solve these problems and save the environment, the renewable energy technologies have been emerged as solution to meet the global energy demand. Photovoltaic (PV) solar energy is a clean and renewable source of energy that uses solar radiation to produce electricity. Its development has been growing very fast in recent years due to technological improvement and government support for this electricity production source. One of the aspects that directly affects the efficiency of photovoltaic generation is the climatic factor, so studying the impact of climatological variables, such as, solar irradiance, ambient temperature, wind speed, temperature of the photovoltaic module, among others, and proposing ways to mitigate such impacts is an important way to further provide for the growth of this source of energy generation. Weather stations are devices equipped with measuring sensors to measure and record weather/climate variables. Due to the often-difficult accessibility of photovoltaic plants, automatic weather stations are considered the most recommended for this application. The typical problem with automatic weather stations is their high cost, which makes it difficult to use them in various applications. In this context, the aim of this work is to build a low-cost, portable weather station with self-sufficient sensors for use in remote areas and/or areas that are difficult to access, for application in photovoltaic power plants and rural properties. Data observation and monitoring can be carried out using an IoT platform, providing gains in terms of travel and agility. Field tests and results show that the proposed station provides satisfactory responses when compared to the commercial weather station. Furthermore, the prototype developed is a low-cost solution compared to the prices of commercial systems available, making it extremely viable for use by owners of small and medium-sized photovoltaic plants and in rural areas.

## 1 Introduction

Due the growing world of population and fast technologic and economic development, human beings need more energy to create a better life environment. In this scenario, traditional fossil fuels, such as coal, oil and gas, are playing lead role to reach this energy demand. In the last decades, systems based on photovoltaic solar conversion for energy generation have become increasingly used. Photovoltaic (PV) solar energy presents itself as one of the most promising energy sources, mainly distributed mini and microgeneration. However, there are aspects that limit the wider popularization of this generation source, such as high initial investment and low system efficiency which, consequently, increases implementation costs. Furthermore, there are other factors that can limit the performance of this technology, such as dirt, shading, photovoltaic module temperature, humidity and air temperature and especially solar radiation [1-3]. The generation potential of photovoltaic cells is strictly dependent on the region's meteorological conditions, mainly on incident solar irradiance. Cell temperature, which in turn is a function of the local microclimate, also significantly influences the performance of photovoltaic

systems. Therefore, the influence of local climatology on the performance of solar photovoltaic (PV) conversion is essential for performance studies, technical/economic feasibility analyses, generation projections and is therefore relevant to decision making [4][5]. Since accurate weather measurement data is a key parameter for monitoring and forecasting energy generation from photovoltaic systems, it is necessary for each photovoltaic plant monitoring system to be equipped with a environment monitoring station.

Weather stations have been improved over the years, resulting in automatic weather stations, which do not require humans to travel to the equipment to collect the data. Factors related to the implementation of these meteorological stations, such as the high cost of equipment and installation in difficult to access locations, have contributed to the scarcity of meteorological data dissemination. In the literature, there is a gap in the development of low-cost meteorological stations solutions. In [6], a solution based on Raspberry Pi has been proposed to communicate with a CR1000 data logger from the manufacturer Campbell Scientific and perform the acquisition, processing and availability of data to the public through tweets and graphics. However, although

\* Corresponding author: [ligia@unilab.edu.br](mailto:ligia@unilab.edu.br)

the strategy used allows the dissemination of information, it does not make available data history tools to enable data manipulation and analysis. In literature, meteorological monitoring systems have been proposed using SCADA (Supervisory Control and Data Acquisition) platform, Arduino or ESP boards, however, most of these solutions has been development without focusing on the final cost and/or has been implemented in small or laboratory-scale PV systems [7-9].

Considering the previously mentioned context, the present work proposes the development of a low-cost and portable weather station prototype for measuring meteorological data aiming application in photovoltaic power plants and rural properties. The prototype has a data acquisition system, based on Arduino Uno and ESP 32 microcontroller boards, and a system supervisory system, that transmit such measurements to the database server via a Wi-Fi (internet) network and make such measurements available remotely via the internet or Bluetooth. It is important to mention that the data acquisition system also stores the weather data on an SD card, providing the option of collecting data locally.

The paper consists of the following parts: Materials and Methods, where the components and design tasks of both the prototype are described; Results, where the collected data and the prototype validation are presented; and Conclusion, where finally the most significant conclusions and consulted references are presented.

## 2 Materials and methods

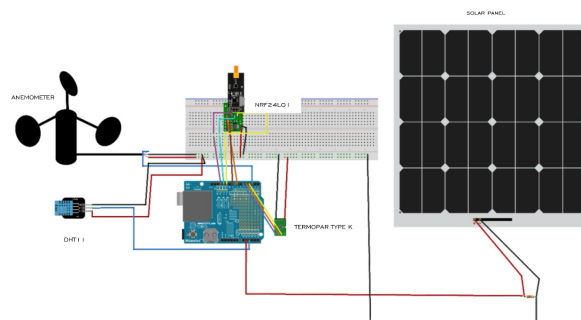
The weather station has been built to provide both solutions like real-time data logging and sharing the measured weather parameter the same as a commercial weather station. The weather variables collected are humidity, wind velocity, global irradiation, ambient temperature, and PV module temperature. The developed weather station is easy to use, lightweight, and low cost as compared the all-weather station available in the market. Next, it will be detailed the development stages of building the prototype, dividing it into hardware and software.

### 2.1 Hardware design

The proposed weather station hardware is composed by the transmitter and receiver. The transmitter collects weather variables and stores them on an SD card or sends them to the receiver via Bluetooth or Internet. It is important to mention that the pyranometer, equipment that measures irradiation, as it is the most commercially expensive item among all the sensors making up the station, was developed by the project team using low-cost items.

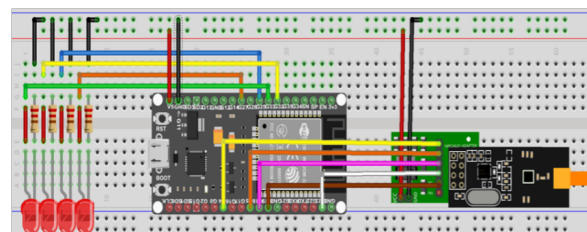
Figure 1 illustrates the scheme developed for the transmitter composed by the following items: DHT11 temperature and humidity sensor, Type K Thermocouple surface temperature sensor, hall sensor to compose the anemometer and measure wind speed, Arduino UNO which collects and stores the data measured by the sensors and sends them to the receiver via wireless through the wireless transceiver module

NRF24L01. As already mentioned, the pyranometer is the instrument responsible for measuring solar radiation and is the most expensive sensor in commercial meteorological stations. Aiming at low-cost weather station, the pyranometer has been developed through an estimation technique that, using a mini-photovoltaic module to measure the level of global solar irradiation on a sample basis, performs the inference of the irradiation incident on it. Since the level of solar irradiation is directly proportional to the value of the short-circuit current ( $I_{sc}$ ) of the solar panel, this directly proportional relationship was used to estimate solar irradiance.



**Fig. 1.** Schematic developed in Fritzing - data collection part of the prototype.

The receiver collects the data sent by the transmitter and displays it to the user in two ways. It sends to the local user equipped with an Android device, via Bluetooth; or it sends it to the database server via Wi-Fi (Internet), using a free IoT platform. Figure 2 illustrates the scheme developed for the data receiving part of the prototype, which is composed by the ESP32 controller and the wireless transceiver module NRF24L01.



**Fig. 2.** Schematic developed in Fritzing – receiver.

The 4 LEDs have been added to inform the user of the following statuses: whether the receiving system is on or not; whether the receiving system is connected with Wi-Fi or not; whether the receiving system has internet or not; whether or not the system is receiving data from the transmitter.

### 2.2 Software – data communication

The software has been designed to offer the communication between transmitter and receiver; as well as to display the weather information to the user in real time and any place.

The software used in the project was developed in the Arduino IDE (Integrated Development Environment) version 1.8.13. The construction of the algorithm begins with reading the ambient temperature, relative humidity, photovoltaic module temperature, solar irradiance, and

wind speed. The code reads the data and transmits it to the receiver's ESP32 controller, through the NRF24L01 2.4GHz Wireless transceiver module. The data received is made available on the internet using the MQTT (Message Queuing Telemetry Transport) protocol. To store this data, the Adafruit.IO IoT platform was used, a very complete tool for connecting hardware to the cloud that has a very simple library and is compatible with various hardware, such as: Arduino, raspberry pi, ESP8266 and NodeMCU. It is important to mention that it is necessary to have Wi-Fi (Internet) connectivity in the location where the receiver is installed for data to be sent to the Adafruit IO website.

### 3 Results and discussions

Figure 3 illustrates the description of the parts that make up the prototype: support (1); pyranometer (2); housing of the temperature and relative humidity sensor (3); anemometer (4); photovoltaic module temperature sensor (5); datalogger and data transmitter (6) and data receiver (7).

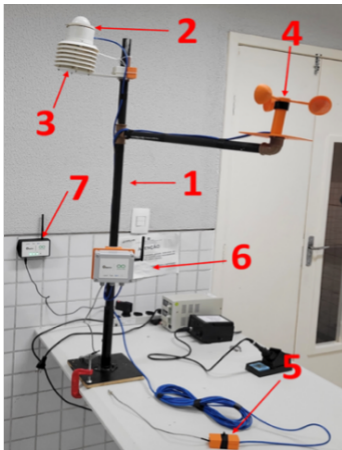


Fig. 3. Physical structure of the proposed prototype.

On the Figure 4, it is possible to see the proposed meteorological station installed next to the commercial station used as validation. The commercial weather station used for comparison and data validation is installed on the Auroras Campus at the University of International Integration of Afro-Brazilian Lusophony (UNILAB), model CR310 from Hukseflux Sigma Engineering [10].



Fig. 4. Proposed prototype installed on the campus.

Figures 5.a, 5.b, 5.c and 5.d show the comparison between the weather data obtained by the commercial weather station (orange line) and the proposed weather station (grey line).

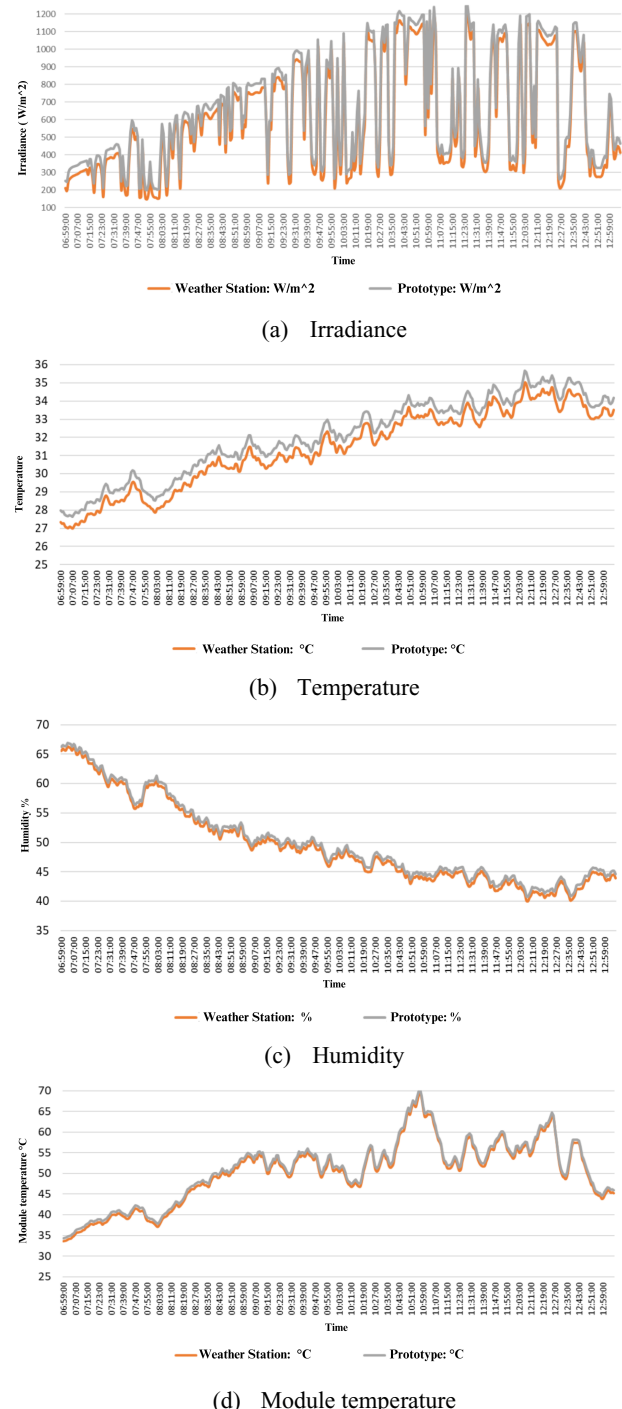
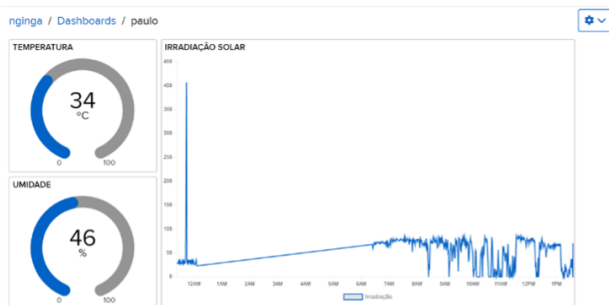


Fig. 5. Comparison (collected weather data) between the commercial station and the proposed prototype.

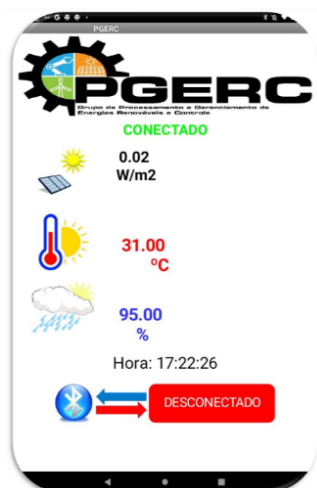
Figure 5.(a) shows a comparison between the irradiation collected by the commercial weather station (orange line) and the proposed prototype (grey line). Figures 5.(b) and 5.(c) illustrate a comparison between the data obtained by the temperature and relative humidity sensor of the commercial meteorological station (EE060) and the temperature and relative humidity sensor of the prototype (DHT 11). It is possible to note, from Figure 5.(a), that the pyranometer

developed can estimate the irradiation and efficiently monitor the variations that occurred during the collection period. And, from Figures 5.(b) and 5.(c), it is possible to observe that the sensor data from the proposed prototype, DHT 11, makes a good assessment of the variables when compared with the data from the commercial station. In the three results, there is a constant displacement (offset) between the curves, a behaviour that is because the station shelters (prototype and commercial) are made of different materials and therefore do not provide shielding in a similar way, thus generating this displacement between the curves. However, this factor can be easily eliminated in the device itself by compensating for the constant difference observed between the curves. Figure 5.(d) illustrates the comparison of temperature data from the photovoltaic module performed by the type K thermocouple sensors of the proposed prototype and the PT100 sensor of the commercial meteorological station. The data from the prototype's K-type thermocouple sensor presented values very close to the meteorological station's PT100 sensor. As in this case, both sensors are not in shelters, it is possible to see that the curves do not suffer from offset, as in the variables analysed previously. Thus, it is possible to observe that the K-type thermocouple sensor of the prototype has high sensitivity and precision.

As already mentioned, the user can monitor the weather data using two ways: locally, via Bluetooth, using an Android device; or remotely using a IoT platform, in case the Adafruit IO, via the Internet. Figures 6 and 7 show climate variable monitoring screens using the Adafruit IO platform and the application developed for Android, respectively.



**Fig. 6.** Screen of the monitoring system via the IoT platform.



**Fig. 7.** Screen of the monitoring system via cell phone application.

Since the premise of this project is the low cost involved in the components in order to facilitate the use of meteorological stations for the purpose of managing photovoltaic plants, it is essential to analyse the cost of the components used in the prototype. The cost of the proposed prototype has been evaluated (Arduino \$ 11, ESP 22 \$ 7, transceptor wireless NRF24L01 \$ 3, temperature and humidity sensor DHT11 \$ 2.4, module MAX6675 + termopar type K \$ 7.9, wind velocity sensor - hall sensor \$ 1, mini photovoltaic solar panel \$ 0.9, miscellaneous and structures \$ 20) and the total cost has been \$53.2 (fifty-three dollars and twenty cents). The cost of commercial weather station is \$11,331.00. The total cost of the prototype represents a value that corresponds to 0.47% of the value of the commercial meteorological station used as a reference. Thus, the prototype appears as a low-cost tool with no major impact on the budget of projects that require measurement systems for meteorological variables, for example, in terms of cost, this alternative would be applicable in the context of photovoltaic plants.

## 4 Conclusions

The present work stands at the frontier of knowledge by proposing a solution that allows climatological data to be estimated and measured, through low-cost photosensitive devices, in a mobile meteorological station, allowing it to be used in remote areas. Data observation and monitoring can be carried out remotely using an IoT platform, providing gains in terms of movement and agility. From the results obtained, it was found that the prototype operated in accordance with the functionalities required for the system to monitor climatological variables: solar irradiance, ambient temperature, relative air humidity, photovoltaic module temperature and wind speed. Communication between the transmission and reception modules occurred satisfactorily throughout the test process. And finally, and just as important, it was observed that the prototype developed constitutes a low-cost solution, compared to the prices of commercial systems available on the market, making it extremely viable for use by owners of small photovoltaic plants, in areas rural areas and in educational institutions. From this proposal, it is possible to envisage many other features that can be implemented to improve the station, such as the use of artificial intelligence techniques to estimate future climate variables. Thus, this project has a strong impact on the prospecting of future research projects, as well as on disseminating and encouraging investment in sustainable energy sources.

Financial support from the Brazilian funding agency FUNCAP (Brazil) [FUNCAP No. 07/2021 - Grant Number 0186003240100/21] is gratefully acknowledged.

## References

1. H. Salimi, H. A. D. Ashtiani, A. Lavasani, R. Fazaeli, Experimental analysis and modeling of weather condition effects on photovoltaic systems'

- performance: Tehran case study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1–13. (2020).  
<https://doi.org/10.1080/15567036.2020.1765902>.
2. S. Chander, A. Purohit, A. Sharma, S. P. Nehra, and M. S. Dhaka (2015), Impact of temperature on performance of series and parallel connected monocrystalline silicon solar cells. *Energy Reports*, 1:104-109. (2015).  
<http://dx.doi.org/10.1016/j.egy.2015.09.00>.
  3. T. Bhattacharya, A. K. Chakraborty, and K. Pal, Effects of Ambient Temperature and Wind Speed on Performance of Monocrystalline Solar Photovoltaic Module in Tripura, India. *Journal of Solar Energy 2014*, Article ID 817078. (2014).  
<http://dx.doi.org/10.1155/2014/817078>.
  4. M. Mussard, and M. Amara, Performance of solar photovoltaic modules under arid climatic conditions: A review. *Solar Energy*, Volume 174, Pages 409-421, ISSN 0038-092X, (2018).  
<https://doi.org/10.1016/j.solener.2018.08.071>.
  5. O. Dupré, R. Vaillon, and M. A. Green, Thermal behavior of photovoltaic devices. *Physics and engineering*, Volume 10, Springer, ISBN 978-3-319-49456-2, (2017).  
<http://dx.doi.org/10.1007/978-3-319-49457-9>
  6. Z. Wofford, Design of Remote Datalogger Connection and Live Data Tweeting System. *Biological and Agricultural Engineering Undergraduate Honors Theses*. University of Arkansas. (2019). Retrieved from <https://scholarworks.uark.edu/baeguht/59>.
  7. B. Soumia, M. K. Nallapaneni, and T. Ali, Data acquisition system: On the solar photovoltaic module and weather parameters monitoring. *Procedia Computer Science*, Volume 132, Pages 873-879, ISSN 1877-0509, (2018).  
<https://doi.org/10.1016/j.procs.2018.05.099>.
  8. W. Sunanda, Y. Tiandho, R. F. Gusa, M. Darussalam, Muhammad, and D. Novitasari, Monitoring of Photovoltaic Performance as an Alternative Energy Source in Campus Buildings. *Instrumentation Measure Metrologie*, Volume 20, Pages 153-159, (2021).  
<http://dx.doi.org/10.18280/i2m.200305>.
  9. M. T. Boyd, NIST Weather Station for Photovoltaic and Building System Research. National Institute of Standards and Technology Technical Note 1913, Gaithersburg, MD, (2016).  
<http://dx.doi.org/10.6028/NIST.TN.1913>.
  10. Hukseflux. Hukseflux Brasil, 2024. Estação Solarimétrica - Hukseflux. Available in: <https://huksefluxbrasil.com.br/estacao-solarimetrica>.