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DESIGN OF A FUNCTIONAL WEATHER STATION FOR SOLAR VARIABLE MEASUREMENT WITH LOW-COST DEVICES

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Abstract

Renewable energies are at the forefront as a partial solution to global warming. Maximizing the benefits of solar rays depends on the understanding of environmental and solar variables in the area of interest. Economically, a commercial weather station is not viable for small projects such as one that could be implemented at UNIMET. This research develops a design for a meteorological information system capable of automatically measuring environmental variables, storing information, and displaying measurement results in real time. The design's integrity is verified with the development of a prototype that measures a set of reduced variables (temperature, humidity, pressure, precipitation, illumination, and wind speed), demonstrating the system's effectiveness in laboratory tests. This paper presents the design and test results of the prototype.

Keywords: meteorological information system; weather station; sensors; remote measurement; real-time measurements; software system; database

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Introduction

Based on the need to implement technologies aimed at protecting the environment and following the proposal of sustainable development, it is necessary to develop research and projects that help us to understand and lean towards the study, implementation and construction of systems capable of producing energy in a clean, sustainable and long- lasting way.

Following this premise, this research proposes the design of a meteorological information system for the measurement of environmental variables that affect production in renewable energy systems. The design of the information system is based on a remote and automatic station that uses low-cost and easily accessible devices and elements, integrated with a software system capable of receiving, storing and visualizing remotely the data generated by the station.

Overview of Relevant Concepts

Meteorological Information System

Rodríguez and Ronda (2006) define an information system as:

> ... a set of elements related and ordered according to certain rules that provide the object system, i.e., the organization it serves, with the necessary information for fulfilling its purposes. It must collect, process, and store data from both the organization and external sources to facilitate their retrieval, processing, and presentation.

A meteorological information system consists of measurement, recording, delivery, and storage elements that maintain reliable information on meteorological variables. Identifying the variables and measurement equipment, as well as data collection, delivery, storage, and retrieval mechanisms, is part of the design process. Based on these needs, it is possible to identify the requirements and functioning of a meteorological information system as described in Figure 1.

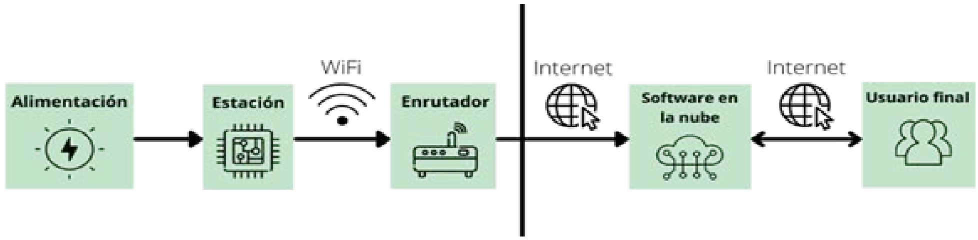

Figure 1: Weather information system block diagram

Environmental Variables and Their Impact on Energy Production

Renewable energies come from clean, inexhaustible natural sources. One such source is the sun, which affects significant climatic elements like temperature, precipitation, wind, humidity, atmospheric pressure, and cloudiness (Navarra.es, n.d.).

Figure 2 highlights the importance of the sun in various energy sources, both renewable and non-renewable.

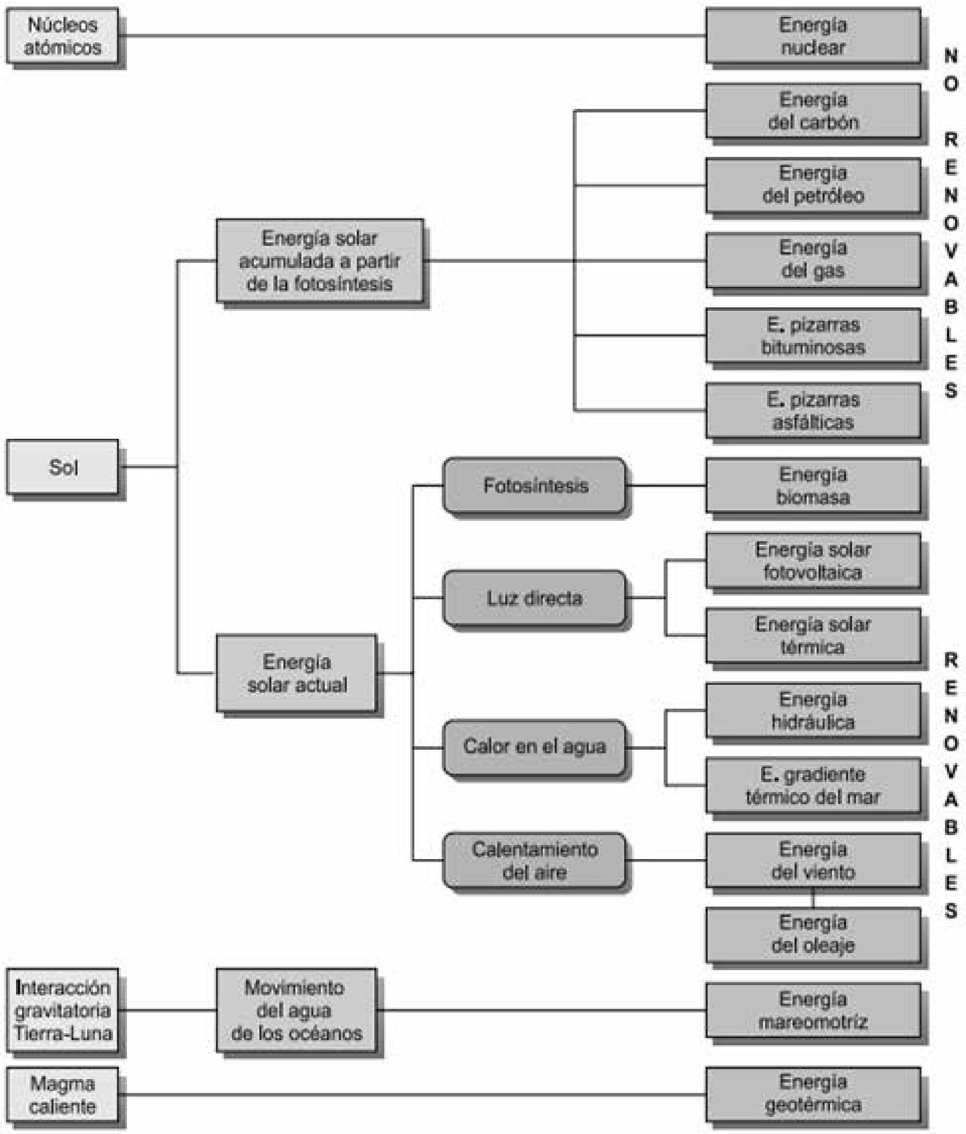

Figure 2: Classification of energy sources. **Source:** González, Pérez and Santos (2009)

Based on the information proposed in Figure 2, it is necessary to highlight that given the importance of the sun in a large part of both renewable and non-renewable energies, there is a close relationship between climate variations and the energy production process.

By 2020, renewable energy capacity expansion was more than twice as large as that of fossil fuels compared to 2019. Energy based on solar and wind sources have seen the largest expansion of renewable capacity (UN, 2021).

The International Renewable Energy Agency (IRENA) in its Renewable Capacity Statistics 2020 report indicates that, of all renewable energy production capacity expansion, 72% is shared among hydro, wind, solar, geothermal and bioenergy generation sources (IRENA, 2020).

Weather Station

The concept of meteorological station is defined as

> "the place where measurements and punctual observations of the different meteorological parameters are made using appropriate instruments in order to establish the atmospheric behavior" (PCE Instruments, n.d.).

The interpretation of the environment is achieved through the use of sensors. A sensor is defined as "an input device that provides a manipulable output of the measured physical variable" (Corona, Abarca, Mares, 2014, pg 17). Through the transmission and processing of electrical signals produced by sensors, it is possible to measure and quantify the physical environment.

The following table lists a set of variables and the corresponding sensors to interpret them.

Variable	Definition	Measuring Instrument
Ambient Temperature	Thermal level of the atmosphere	Thermometer, Temperature Sensor
Precipitation	Moisture falling on the earth's surface in liquid or solid form	Rain Sensor
Solar Radiation	Propagation of energy emitted by the sun as electromagnetic waves	Pyranometer
Wind Speed	Speed and direction of air flow in the atmosphere	Anemometer
Illuminance	Intensity of light incident on a surface	Luxmeter, Light Sensor
Relative Humidity	Ratio between the amount of vapor in the air and the maximum it can hold	Hygrometer, Temperature and Humidity Sensor
Atmospheric Pressure	Pressure exerted by the atmosphere on the earth's surface	Barometer, Piezoresistive Pressure Sensor

Table 1: Meteorological variables and the type of sensor to measure it.
Source: Own elaboration based on the definitions of the Oxford dictionary

The signals sent by the sensors are interpreted by a microcontroller which is a small computer that can perform multiple tasks, but with limited functionality and resources (GSL Industries, 2021).

In order for a microcontroller to understand the measurements taken by the sensors, communication protocols are needed, which allow the transfer of data between the two. One of the methods used to achieve this correspondence between devices is serial communication, this type of communication allows the continuous sending of data from one port to another, as shown in Figure 3 (SMELPRO, 2019):

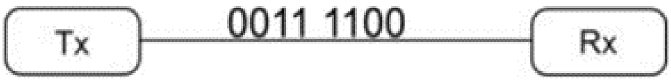

Figure 3: Serial connection diagram.
Source: SMELPRO. (2019).

In order for the data collected to be subsequently broken down and interpreted, it is necessary to maintain an order. IBM (n.d.) concludes that "a format can be assigned to the data in a report in order to facilitate its reading" in this way the data will have great flexibility and agility in the whole process of handling, sending and receiving the information.

One way to format data is through the structure proposed by JavaScript Object Notation (JSON) "a text format that is completely language independent, but uses conventions that are familiar to programmers in the C family of languages, including C, C++, C#, Java, JavaScript, Perl, Python and many others" (IBM, n. d.).

Local information storage service

Melo (2021) defines local storage as "the process of storing digital data on physical storage devices, such as hard disk drives (HDD), solid state drives (SSD), or external storage devices."

Flash memory cards, also known as SD, microSD or nano SD cards, SD being the acronym for Secure Digital, are one of the most widely used storage devices in the world (Sierra, 2020). Both elements allow to facilitate the backup, protection, transfer or use of certain digital information, so it can be processed through the use of other hardware peripherals such as computers or card readers.

Communication system

> "... the fundamental objective of an electronic communications system is to transfer information from one place to another" (Tomasi, 2003).

Therefore, a communications system can be described as the transmission, reception and processing of data between two or more locations.

Network protocols are used to send information from the station. These are defined as a formal standard and a policy consisting of limits, procedures and formats that define the exchange of information packets to establish communication between two servers or multiple devices in a network (KIO Networks, 2020).

Therefore, it is possible to communicate between the physical station and the software system through the use of several of the protocols that are executed in the different layers of the tcp/ip model (IBM, n.d.), such as HTTP, TCP and IP (IPv6 and IPv4).

Software System

To make the information system work, it is necessary to implement application software, which is defined as a series of

> "isolated programs that solve a specific business need. Applications in this area process business or technical data in a way that facilitates business operations or administrative or technical decision making." (Pressman, 2010, p. 6).

Development Tools

The construction of a software system requires a set of tools that provide a good development environment and facilitate the use of good practices, which is why it is possible to highlight a set of tools necessary for the development of software for an information system among them:

- Programming languages

  The means of communication between a programmer and a machine is the programming language, which can be defined as "a formal language that, through a series of instructions, allows a programmer to write a set of commands, consecutive actions, data, and algorithms to thereby create programs that control the physical and logical behavior of a machine" (Rockcontent 2019).

- Database manager

  "It is a system that allows the creation, management and administration of databases, as well as the choice and management of the structures necessary for the storage and search of information in the most efficient way possible." (Martin. 2019)

- Version Controller

  "A version controller is a system that records changes made to a file or set of files over time, so that you can retrieve specific versions later" (Git, n.d.). This kind of systems are of utmost importance when developing and testing the operation of a software since, mainly, they allow to have a good management of the changes made and also keeps the code available for use in previous or current versions in the system repository.

- Servers

  When it comes to IT, there are two different definitions of a server. First, hardware-based servers which they define as “a physical machine integrated into a computer network on which, in addition to the operating system, one or more software-based servers run.” (IONOS, 2020). Second, software-based servers correspond to a program that offers a special service that other programs called clients can use locally or over a network. (IONOS, 2020).

- Virtual machines

  A virtual machine or Virtual Machine (VM) consists of the virtualization of the operation of a physical computer, i.e., “While the components of your PC (called hardware) are physical and tangible, virtual machines are often considered virtual machines or software-defined computers inside physical servers, where they exist only as code.” (Azure, n.d.).

Data Transmission to Users

Based on what is described by Testa (2020), it can be inferred that the systems that include information processing must mainly comply with three characteristics. First, information input, i.e., data collection. Next, data processing, which corresponds to data treatment. Finally, there is the output, which is defined as the transmission of data in the form of information to users.

Therefore, it can be stated that the transmission of data in the correct format to the user is the output point of the proposed information system and corresponds to displaying the information collected by the physical station in a format composed of real-time graphics for each variable measurement.

Detailed System Design

For the design of the meteorological information system, a research and bibliographic review process was carried out from which the main operating characteristics for a meteorological station capable of sensing and sending the information obtained were extracted, as well as the development of a communication system. accompanied by software capable of receiving, interpreting and displaying the measured data. In this way, a proposed solution was prepared to meet the requirements of a meteorological information system. This was the starting point to expand the proposed solution and thus design in detail each of the parts that make up said system. Figure 4 shows the architecture of the weather station information system according to the design of this research.

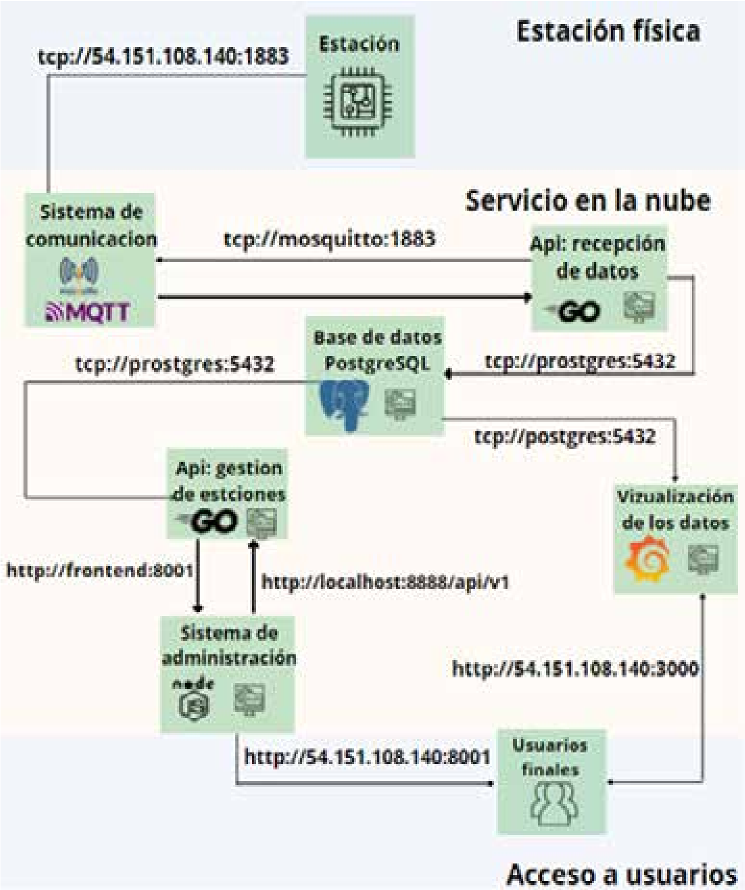

Figure 4: System architecture
Source: self made

As Nascimento, Huback, Schaeffer, et.al (2017) point out, the power output of PV power plants depends on the incidence of solar radiation, which can fluctuate with the passage of clouds. But power production from solar energy is also seen to be affected by other climatic factors such as: humidity, atmospheric pressure, ambient temperature, among others affected by other climatic factors such as: humidity, atmospheric pressure, ambient temperature, among others.

Method of acquiring and processing information

After the documentary research and, according to the needs established for the design, it was possible to establish a design for the physical station and the programming in charge of creating a series of instructions for the station to be able to sense the meteorological variables, save them in a JSON type data, connect to the internet via wifi and send the information through the use of the MQTT protocol. The sending is done in parameterized intervals, preferably between 1 and 5 minutes, since the measurement of environmental variables of this type does not change state abruptly, thus allowing not to strain the core of the microcontroller to perform repetitions with more time slack. In addition, in case of any communication failure, the station has a local storage system, allowing the information to be saved on an SD memory card.

Figure 5 shows the connection design of a weather station that will be used for the construction of the prototype to be developed for system integrity testing in the laboratory.

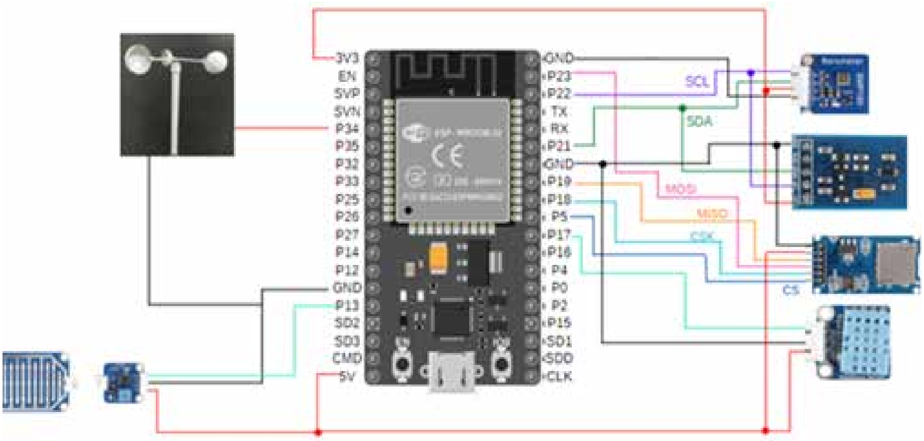

Figure 5: Connection diagram of the physical station based on the design
Source: self made

Cloud Service System Architecture

For the development of the apis corresponding to the data reception and the backend of the station monitoring system, Go was selected as the programming language. For the development of the frontend of the user interaction software, Go was chosen as the programming language Javascript, specifically the ReactJS and Redux libraries, designed for the creation of user interfaces with ease and simplicity.

Thus, with respect to the communication system, the MQTT (Message Queue Telemetry Transport) network protocol was selected, which is considered the "de facto" standard for communications in IoT (Internet of Devices) projects. MQTT is built and executed on top of the TCP/IP model (IBM, 2017). The Eclipse Mosquitto messaging agent, was selected for the implementation of MQTT since, “it is lightweight and suitable for use on all devices, from low-power single board computers to full-fledged servers.” (Eclipse, 2021).

On the other hand, PostgreSQL was chosen as the relational database system for the implementation of the data in the software system because in conjunction with Go it is possible to manage the data in a simple way (PostgreSQL, 2021). In addition, Grafana was selected for the translation of the data into valuable information for the user, since it is a software that allows the creation of interactive and controlled dashboards in an efficient and simple way (Grafana, 2021).

Docker was selected as an integration tool because it allows software to be packaged into standardized units known as containers, which run on top of a virtualized operating system. Docker includes libraries, integration and orchestration tools (AWS, 2021). To manage the different Docker containers created, Portainer was used, which is a simple and publicly available open source tool.

Finally, the system was integrated on an AWS virtual machine, where Docker, Portainer and the different containers that constitute the created system were installed.

Prototype Development

Based on the strategies and requirements of the proposed design and, as a way to test that the components of the meteorological information system are feasible, a smaller scale prototype was developed to perform integrity tests to the proposed solution.

The prototype uses an ESP32 microcontroller, to which sensors were attached to obtain measurements of temperature, humidity, atmospheric pressure, wind speed and presence of rain.

A micro SD card module was used as a peripheral element to have local storage of the information. The microcontroller is programmed to acquire the measurements from the sensors, encapsulate the data in a JSON type format and make use of the MQTT protocol so that they reach a reception API where they are processed to be stored in a database and translated into graphs becoming valuable information for users who can observe the variables measured in real time.

Once the prototype was built, the entire system was tested, including data transmission and database storage.

Results and Analysis

An evaluation of the simulations applied to the development of the research was carried out for both the physical station and the software architecture. In addition, the results obtained using the unified prototype of the developed meteorological information system were analyzed.

Evaluation of the Physical Station

The sensors and peripheral elements of the physical station were evaluated to elaborate their correct connection. At the same time, internet connection and communication establishment tests were carried out based on MQTT with a message handler installed in a cell phone using Anshul Katta's "MQTT Broker APP" application. With this, the connectivity capacity of the station was corroborated and the existing limitations were established, such as the maximum length (bytes) of the message to be sent, the response time between the publisher/subscriber and the repetition time between sending messages and taking measurements to avoid erroneous readings.

Software System Evaluation

A simulator was performed on a local machine capable of emulating the sending of data from 1000 stations sensing every minute, each with 6 devices. Communicating with the cloud software through the previously established MQTT based communication system, with the purpose of evaluating its integration with the system. The simulator was run for 3 hours and an average CPU utilization of 28.8% was measured.

The result of the above tests determined the parameters to be used to achieve the successful integration of the physical station and the software system. In this way it was possible to measure the environmental conditions for the current location of the prototype station and to determine the performance of the complete information system.

Figures 6 to 9 below show the graphs of the measurements taken by the station in real time for the last 24 hours between November 3 and 4, 2021. It should be noted that the station, still at the prototype stage, was not suitable for outdoor environments, so the tests were conducted in a controlled environment. For the precipitation and wind speed measurements, the conditions were recreated with water and a fan.

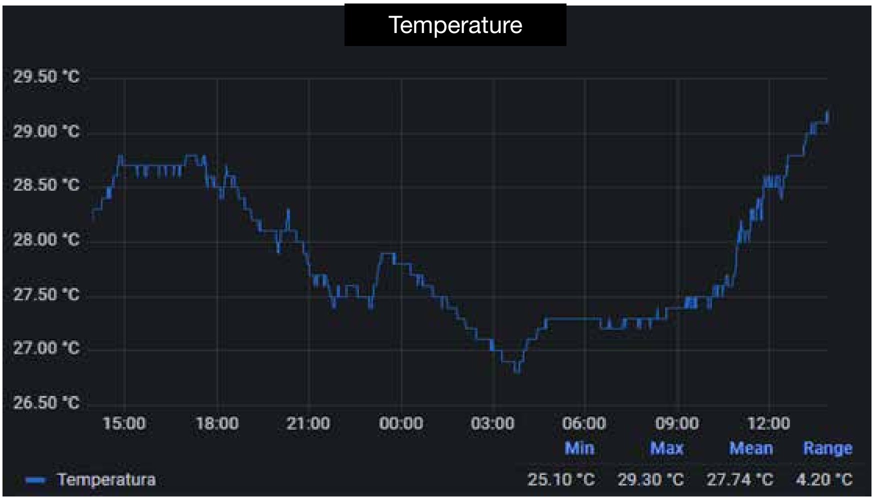

Figure 6: Temperature panel on the data visualization dashboard.
Source: Own elaboration (Grafana)

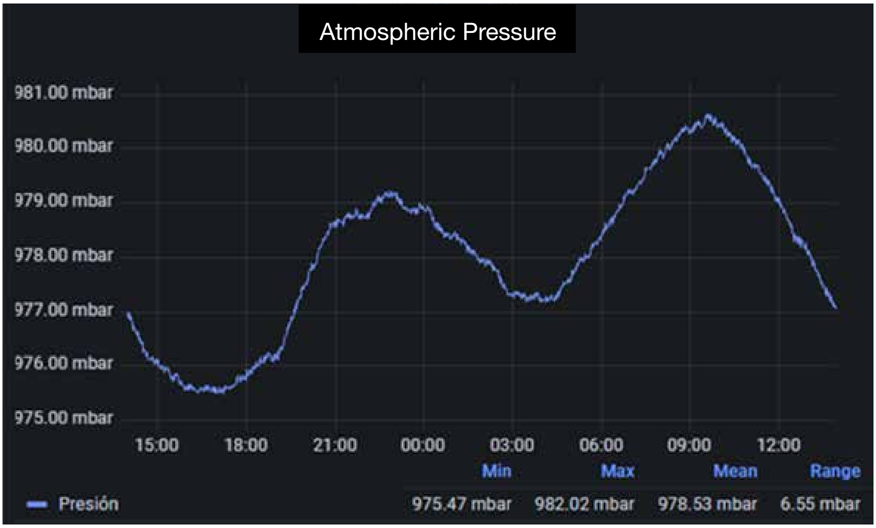

Figure 7: Atmospheric Pressure Panel in the data visualization dashboard.
Source: Own elaboration (Grafana)

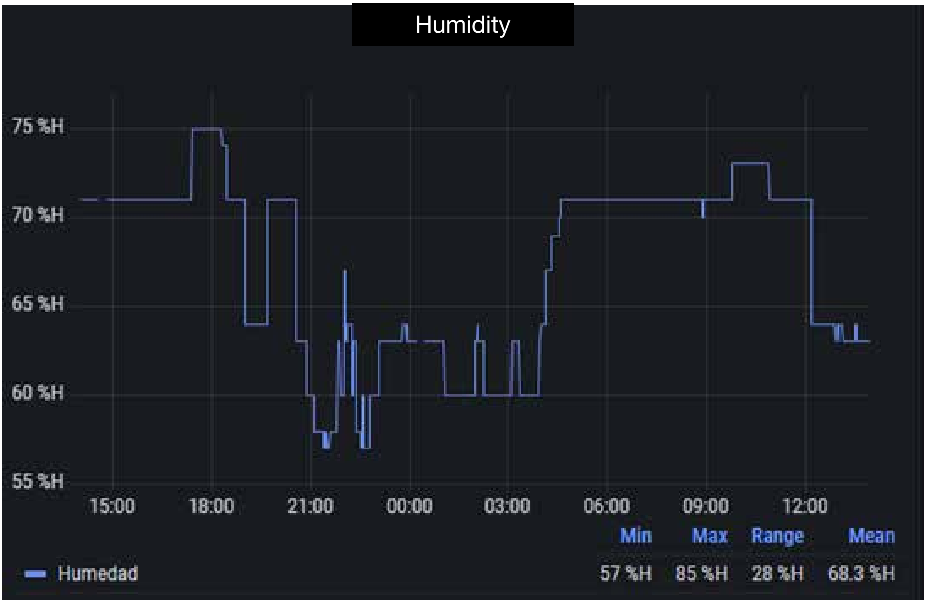

Figure 8: Humidity panel in the data visualization dashboard.
Source: Own elaboration (Grafana)

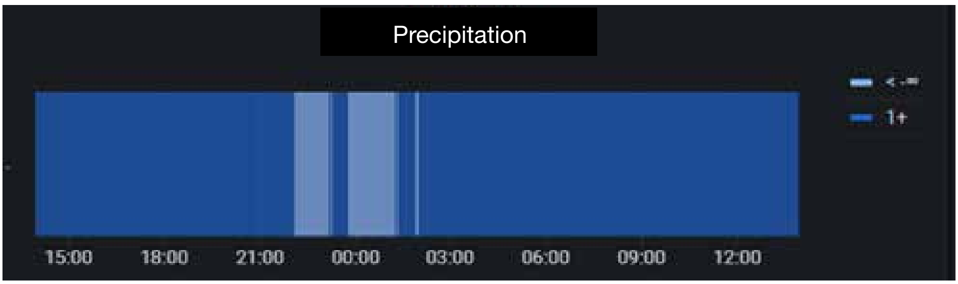

Figure 9: Precipitation panel in the data visualization dashboard.
Source: Own elaboration (Grafana)

In figure 9, the dark blue area corresponds to state measurements without rain and the light blue area corresponds to moments of rain.

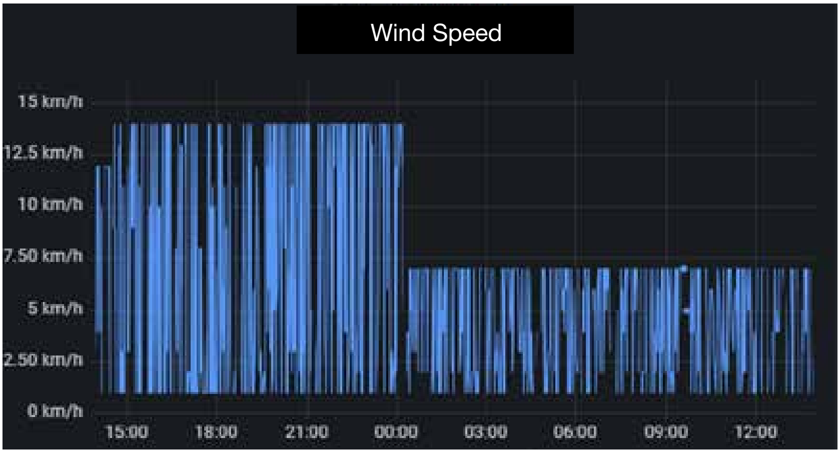

Figure 10: Wind Speed panel in the data visualization dashboard.
Source: Own elaboration (Grafana)

In figure 10, making a comparison between the data obtained and the Beaufort scale, it is possible to classify the wind speed as "very weak breeze" or "weak breeze", which agrees with the approximate wind speed for a fan. homemade (Barcelona world race, s. f.).

Cost Structure Analysis

A cost evaluation of the meteorological information system components compared to similar prefabricated commercial systems is presented:

Measured Variable	Devices Used	Approximate Market Price ($)	Commercial Device	Approximate Market Price ($)
Relative Humidity	DHT11	2.00	Hygrometer	30.00
Temperature	BMP180	3.00	Thermometer	25.00
Atmospheric Pressure			Barometer	30.00
Precipitation	Rain Sensor Module	7.00	Rain Collector	75.00
Wind Speed	DC Motor (3V)	4.00	Anemometer	50.00

From the above comparison, it is possible to notice the cost difference between essential station components and commercial devices used to measure the same variables. Essentially, the cost of the components used is approximately one order of magnitude lower than that of commercial components measuring the same variables. This cost difference would allow for station improvement while maintaining competitive costs. The above comparison does not consider the functionality of internet connection for sending, storing, and displaying data.

On the other hand, the price of a commercial station with similar functionality, such as the Davis Instruments model 6120, ranges between 300 USD and 500 USD. In this case, we see that the commercial cost is approximately two orders of magnitude higher than the constructed station. Again, there is ample cost margin to improve the constructed prototype.

Conclusions

- Real-time measurement of environmental variables is essential for the production of renewable energy, making it crucial to have meteorological information systems in energy generation centers.
- Under the needs demanded by the implementation and operation of projects focused on energy production based on renewable energies, a low-cost meteorological information system was designed capable of measuring the meteorological variables involved in such projects.
- It was possible to measure specific environmental variables for a location in real-time by implementing a functional prototype of a weather station built from low-cost sensors.
- The adaptability and robustness of the meteorological information system allow for flexibility in design. This represents an important feature as the proposed solution can adjust according to future needs, giving it sustainability and durability over time.
- The durability of the station and its low production cost translate into gains when investing in a project focused on renewable energy generation.
- The proposed design for the implementation of the meteorological information system provides a solution with sufficient validity and reliability in its measurements.

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