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# **MASTER THESIS**

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by

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## **Title**

**IoT Device for Real-Time Monitoring of Solar Stations**

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## Abstract:

Solar photovoltaics are a rapidly growing renewable energy technology that will play a significant role in global electricity production. This project aims to develop a system for measuring and monitoring the parameters of solar panels using IoT technology. The Internet of Things (IoT) connects sensors and systems to exchange data via the Internet. This project measures five parameters: temperature, light intensity, voltage, current, and rain. A temperature sensor measures the temperature, an irradiation sensor measures the light intensity, a voltage divider measures the voltage, and a current sensor measures the current generated by the solar panel. Rain detection is carried out with a specific sensor. An Arduino collects this data, which is sent to a computer via Wi-Fi thanks to the ESP8266 and then visualized in the form of diagrams with Python software.

**Keywords:** Photovoltaic, Embedded Systems, Internet of Things, Wifi, Arduino, Python.

## Résumé:

Le solaire photovoltaïque, est une technologie d'énergie renouvelable en forte croissance, jouera un rôle majeur dans la production mondiale d'électricité. Ce projet a pour objectif de développer un système de mesure et de surveillance des paramètres des panneaux solaires à l'aide de la technologie IoT. L'Internet des objets (IoT) connecte des capteurs et des systèmes pour échanger des données via Internet. Dans ce projet, cinq paramètres sont mesurés : la température, l'intensité lumineuse, la tension, le courant, et la pluie. Un capteur de température mesure la température, un capteur d'irradiation mesure l'intensité lumineuse, un diviseur de tension mesure la tension, et un capteur de courant mesure le courant généré par le panneau solaire. La détection de la pluie est effectuée avec un capteur spécifique. Ces données sont collectées par un Arduino, envoyées à un ordinateur via WiFi grâce à l'ESP8266, puis visualisées sous forme de diagrammes avec le logiciel Python.

**Mots clés :** Photovoltaïque, Systèmes embarqués, les objets connecté, Wifi, arduino, Python.

:

### ملخص

الخلايا الكهروضوئية الشمسية ، وهي تقنية طاقة متجددة سريعة النمو ، دورا رئيسيا في إنتاج الكهرباء العالمي. الهدف من هذا المشروع هو تطوير نظام لقياس ومراقبة معلمات الألواح الشمسية باستخدام تقنية إنترنت الأشياء. يربط إنترنت الأشياء أجهزة الاستشعار والأنظمة لتبادل البيانات عبر الإنترنت. في هذا المشروع ، يتم قياس خمس معلمات: درجة الحرارة ، شدة الضوء ، الجهد ، التيار ، والمطر. يقيس مستشعر درجة الحرارة درجة الحرارة ، ويقيس مستشعر الإشعاع شدة الضوء ، ويقيس مقسم الجهد الجهد ، ويقيس مستشعر التيار التيار الناتج عن الألواح الشمسية. يتم الكشف عن المطر باستخدام مستشعر معين. يتم جمع هذه البيانات من قبل اردوينو ، وإرسالها إلى جهاز كمبيوتر عبر واي فاي بفضل إسب 8266 ، ثم تصور في شكل الرسوم البيانية مع برنامج بيثون.

**كلمات مفتاحية :** الطاقة الشمسية ، الانظمة المدمجة، إنترنت الأشياء ، واي فاي ، اردوينو ، بايثون.



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## *Dedications*

*I dedicate this work to:*

*My dear **parents**, who guided me during the most  
challenging moments,*

*My **mother**, who has been by my side and supported me  
throughout my life,*

*And my **father**, who sacrificed his whole life to see me  
become who I am,*

*My brothers and my sisters.*

*To all my friends. All those who love me and whom  
I love.*

**AYACHE OUSSAMA**

## *Dedications*

*This is my graduation note to my beloved parents; thank you for your endless support and great confidence in my abilities. I owe you every success and look forward to a bright future under your patronage.*

*To my sister, siblings, family, and friends, you are my companions on this incredible challenge. Thank you for the beautiful moments and the constant support you have given me.*

*I also dedicate it to my excellent professors, who have guided me throughout this academic cycle.*

***BOUZIDI SALAHEDDINE***

# General Introduction

Energy is a fundamental necessity; in this modern era, pursuing a comfortable lifestyle is universal; it powers our lights, heats our homes, cooks our food, and fuels our entertainment and communication. However, the 20th century's heavy reliance on hydrocarbon-based fuels and energy sources has led to a significant environmental crisis, producing large quantities of greenhouse gases, particularly carbon dioxide. Atmospheric pollution, climatic upheavals, the dangers of nuclear power, the limits of traditional energy reserves (natural gas, uranium, and oil), which are exhaustible and unequally distributed on the planet, as well as the increase in pollution and the increase in energy needs, have led to the need to resort to other means of energy production respectful of the planet where we live.

The solution consists in using renewable energies that make it possible to generate electricity that meets ecological requirements. Unfortunately, this solution has economic limitations; it has a high cost and a low yield. Solar (PV) is one of these energies.

Amidst the fossil fuel crisis, solar energy emerges as a promising alternative. The photovoltaic effect, a direct conversion of solar radiation into electricity, is at the heart of this renewable energy source. Its growth is exponential, driven by its durability, cleanliness, and environmental friendliness, making it a clear winner over fossil fuels.

The main objective of this work is to develop a system to measure and monitor the parameters of solar panels using Internet of Things technology. In the current era of transitioning to renewable energies, the role of IoT technology in monitoring solar panels for efficiency and longevity is paramount. This revolutionary solution allows for remote, real-time monitoring of these crucial installations, sparking curiosity and engagement in the potential of IoT in the renewable energy sector.

By using the power of sensors and Internet of Things devices, we can ensure constant monitoring of solar panels. This proactive system allows the rapid detection and resolution of malfunctions, performance problems or other anomalies. This reassures us about the efficiency of the system, as it improves the production of solar energy by adjusting the parameters in real time according to weather and environmental conditions.

## General Introduction

---

This work comprises three sections. The first chapter introduces photovoltaic systems, starting with the definition and history of solar panels. It then covers the different types of solar panels and explains how solar cells produce electricity. Points to consider when choosing a solar station and the advantages and disadvantages of solar panels are also discussed. The second chapter presents the Internet of Things (IoT), explaining its functionality and the architecture of IoT devices. It also explores benefits of using an IoT-based solar power monitoring system. The third chapter focuses on hardware and software design tools, detailing the electronic components used in the system's electronic board with the solar panel, and describing the design and implementation of the system. The chapter concludes by presenting the examination findings

# **Part 1: Background and State-of-the-Art**

# Chapter I

# Photovoltaic

### Introduction:

Solar power is the process of converting solar radiation into either electrical power or thermal energy. The world is home to some of the most abundant solar resources, making solar energy the most prevalent and eco-friendly renewable energy source today. Solar technology can harness this energy for various purposes, including generating power, illuminating spaces, maintaining a comfortable indoor environment, and heating water for industrial, commercial, or residential applications.

### I.1.Solar power panels:

An apparatus that transforms sunlight, made up of power particles called "photons," into electricity that may be used to power electrical charges is also known as a "PHOTOVOLTAÏC".

In addition to producing electricity for homes and businesses, solar panels can be used for various other purposes, such as remote power systems for cabins, telecommunications equipment, and remote sensing [1].

The sun is the most significant resource of energy in the world that can support life on Earth and give all its residents access to clean energy. Our planet receives more power from the sun in an hour than the entire global population uses in a year. Photovoltaic (PV) solar modules allow the conversion of solar energy into electrical power (photo = light, voltaic = electricity) [2].

A solar panel is a part of a photovoltaic system constructed from many photovoltaic cells organized in a certain way to produce energy from sunshine.



**Figure 1:Solar power panels**



### I.2. History of photovoltaic:

**1839:** Antoine Becquerel publishes a thesis on the electrical effects produced under the influence of solar rays relating to an experiment conducted by his son Edmond with a battery of platinum and oxidized copper electrodes immersed in an acid electrolytic solution. This battery is capable of supplying an electric current.

**1877:** W. G. Adams and R. E. Day discovered the photovoltaic effect of selenium, and C. Fritts developed the first photovoltaic panel based on selenium cells.

**1905:** Albert Einstein published an article on the photoelectric effect, which earned him the Nobel Prize in physics in 1921.

**1954:** D. M. Chapin, C. S. Fuller, and G. L. Pearson, two engineers from Bell Telephone Laboratories (USA), announce the development of a cell whose energy conversion efficiency reaches 6%, thus truly marking the birth of photovoltaic electricity.

**1959:** the United States is launching Vanguard, the first satellite powered by photovoltaic cells, into orbit.

**1970:** the oil crises reinforced the interest and the credits granted to photovoltaic energy.

**1978:** the first installed peak megawatt was reached in 1978.

**From 2010 to 2016,** the installed capacity of the global photovoltaic park multiplied by six between the end of 2010 (50 GW) and the end of 2016 (305 GW) [3].

### I.3. The different types of solar panels:

Solar projects primarily employ one of three types of solar panels: thin-film, polycrystalline, or monocrystalline. Because each type of solar panel has unique qualities, some are better suited for certain conditions than others. There are more than these solar panels, but due to their cost, these three are more commonly used in renewable energy.

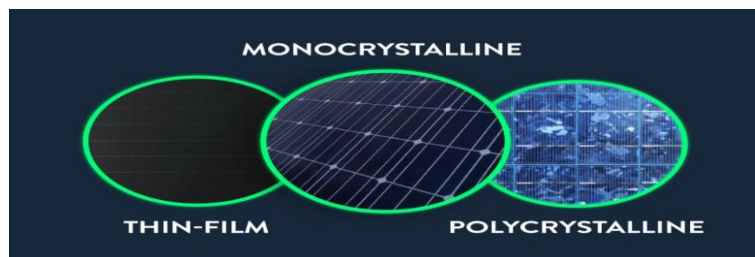


Figure 2 : Different types of solar panels

### I.3.1. Monocrystalline:

Monocrystalline solar panels are the most common type used in rooftop installations. The "seed" silicon crystal is placed in a high-temperature, molten vat of pure silicon to create monocrystalline silicon solar cells using the so-called Czochralski process. This procedure creates an ingot, or single silicon crystal, sliced into thin silicon wafers for use in solar modules.



Figure 3: Monocrystalline

### I.3.2. Polycrystalline:

Homeowners wishing to install solar panels on a budget are fond of polycrystalline panels, often known as "multicrystalline" panels. Polycrystalline solar panels are composed of silicon solar cells, just like monocrystalline solar panels. However, a distinct cooling process produces many crystals rather than one. Residential polycrystalline solar panels typically have 60 solar cells per panel.

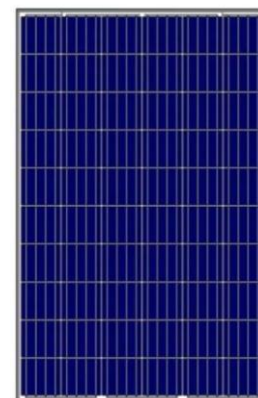


Figure 4: Polycrystalline

Because of their lower efficiency, thin-film solar cells are primarily used in large-scale industrial and utility solar installations.

### I.3.3. Thin-film:

Creating thin-film solar panels involves covering a solid surface, such as glass, with a thin coating of a photovoltaic material. Amorphous silicon (a-Si), copper, indium, gallium selenide (CIGS), and cadmium telluride (CdTe) are a few of these photovoltaic materials. Though they all fall under the general category of thin-film solar cells, each produces a distinct "type" of solar panel.



Figure 5: Thin-film

The photovoltaic material is formed during production into a thin, light sheet that can be flexible in certain situations [4].

### I.3.4. Advantages and disadvantages of each type of solar panel:

| Solar Panel Type | Advantages                      | Disadvantages                    |
|------------------|---------------------------------|----------------------------------|
| Monocrystalline  | High efficiency and performance | Higher costs                     |
| Polycrystalline  | Lower costs                     | Lower efficiency and performance |
| Thin-film        | Portable and flexible           | Lower efficiency and performance |

**Table 1: Advantages and disadvantages of types of solar panels**

### I.3.5. Which Solar Panel is the best?

As a result, the project and the budget are the two main factors in selecting the best solar panel. Although polycrystalline solar panels are more cost-effective for domestic use, monocrystalline solar panels still have a role. For instance, monocrystalline cells are the ideal option due to their higher efficiency if the property has a smaller roof. Even though thin-film solar panels are hardly ever utilized on residential premises, their small weight makes them suitable for large-scale projects like commercial or listed structures.

## I.4. The solar panels are made of:

### I.4.1. Glass:

The top layer of glass shields the panel's most fragile layers from harm. Although it may sound absurd, glass is the ideal barrier material.

Solar panel glass is incredibly sturdy and made to withstand heavy blows. Many solar panels are designed to survive hailstones up to one inch in size that fall at 50 miles per hour. Hence, even though this glass isn't unbreakable, it can withstand a blow.

### I.4.2. Encapsulant:

A layer of encapsulant sits behind the glass, connecting it to the solar cell layer underneath. This encapsulant has been mainly developed to resist exposure to UV light and high temperatures. For sunlight to reach the layers below, it must stay crystal clear. EVA (ethyl vinyl acetate) encapsulants are the most widely used type in solar panel manufacturing.

### I.4.3.Solar Cells:

The solar cells, the main attraction, and the "meat" of the solar sandwich are the following. When you look at a solar panel's front face, you see these. They resemble many tiny octagonal squares (monocrystalline panels) or multiple small rectangles (polycrystalline panels). They are usually blue or black. Many of these cells make up each solar panel.

Silicon crystals are used as semiconductors to make up these solar cells. To continue with our comparison of "cheese" sandwiches, Polycrystalline cells are comparable to bologna, while monocrystalline cells are like a freshly roasted turkey breast. Each solar cell in a monocrystalline panel comprises a single silicon crystal. On the other hand, many silicon crystals are fused during manufacturing to create polycrystalline panels. Polycrystalline panels are less expensive, while monocrystalline cells are usually more efficient.

A solar sandwich, however, has "double meat." Usually, the silicon cells are layered one on top of the other.

### I.4.4.Back-sheet:

A back sheet is located beneath still another layer of the encapsulant. This is what gives a solar panel its black or white lines. Every solar cell is separated, revealing the back sheet underneath.



Figure 6: Structure of solar panel

The back sheet keeps everything secure and intact, like perfectly toasted sandwich bread. It is impervious to moisture and other undesirable things because it comprises a polymer or a blend of polymers.

### I.4.5. Aluminum Frame:

After that, an aluminum frame encircled the whole solar panel. This maintains the safety and security of every layer [5].

## I. 5. How do solar cells produce electricity?

Direct current (DC) power is produced from sunlight using solar photovoltaic (PV) cells. Photons, or light particles, are emitted by the sun and travel through the anti-reflective layer on the cell's surface. A semiconductor layer and two layers of conductors—one positive and one

negative—are beneath the anti-reflective covering. The semiconductor material most frequently utilized in photovoltaic cells is crystalline silicon. Negatively charged electrons in semiconductor atoms are "knocked" free by photons of light, leaving behind free electrons and positively charged semiconductor ions. Ions are drawn to the positive layer, and free electrons are drawn to the negative conductor. Energy is produced by the movement of electrons, which can be used to power appliances, lights, and nearly anything else that requires energy.

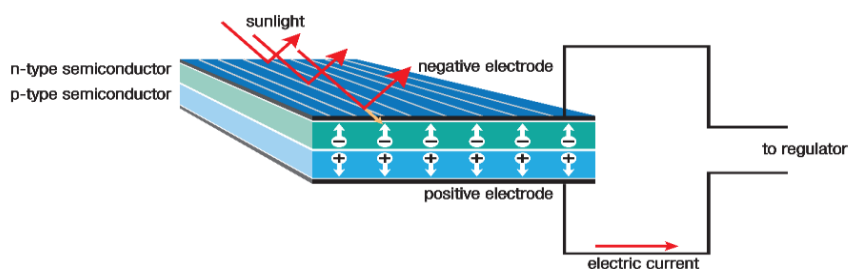


Figure 7: the work of PV

The classic solar panels are made up of arrays of solar PV cells. Storing the electrical current generated by the cells is inefficient for later use. As a result, solar PV installations are typically linked to the regional power system. Energy for PV systems in homes and businesses travels to an inverter, which converts DC electricity to AC power (alternating current). The energy that is utilized in homes and businesses is AC energy. Unused energy is sent to the electrical grid for use in other ways [6].

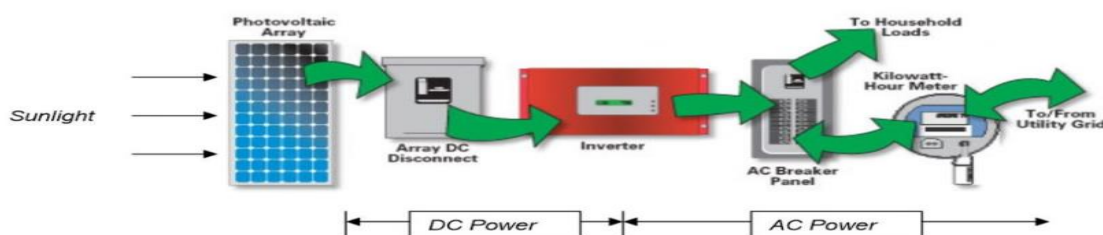
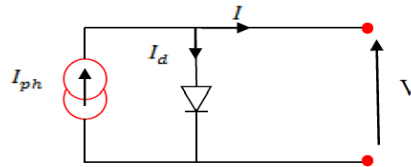


Figure 8 : converts DC electricity to AC power

## I.6. Equivalent Circuit of a photovoltaic cell:

### I.6.1. Ideal photovoltaic cells (Real model):

The photocell is a semiconductor component that delivers a current by exciting this last by photons, so as a first approximation, we have a short-circuited current source by a diode (because the photocell is a P-N junction)



**Figure 9: Model of an ideal photovoltaic cell**

The current delivered by the photovoltaic cell illuminated on a load  $R_s$  writes:

According to the law of knots:  $I = I_{ph} - I_d$

**$I$** : Current supplied by the cell

**$I_{ph}$** : The photonic current which  $I_{cc}$  estimates. (Photocurrent generated.)

**$I_d$** : The parallel current through the diode (Current passing through the diode.)

For an ideal PV generator, the voltage across the load resistor is equal to the voltage across the diode:

$$V = V_d$$

$$I = I_0(\exp(V_d/V_t) - 1)$$

**$I_0$** : The reverse saturation current of the diode [A].

**$V_d$** : The voltage at the terminals of the diode D.

**$V_t$** : Thermal potential.

According to the replacement of  $I_d$ , in finds:  $I = I_{ph} - I_0(\exp(V_d/V_t) - 1)$

### **I.6.2.Real photovoltaic cell (Real model):**

The previous photovoltaic model did not consider all the phenomena present during the conversion of light energy. Indeed, in reality, we observe a loss of output voltage and leakage currents. Therefore, we model the loss voltage by a resistor in series  $R_s$  and the leakage currents by a resistor in parallel  $R_p$ .

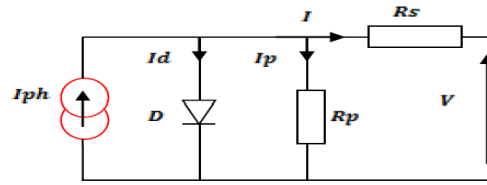


Figure 10: Model of the actual photovoltaic cell

Taking these resistances into account, the expression of the current intensity becomes:

$$I = I_{ph} - I_d - I_p$$

$$I_p = \frac{V_d}{R_{sh}} = \frac{V + LR_s}{R_{sh}}$$

$$I = I_{ph} - I_s \left[ \exp\left(\frac{V + LR_s}{A \cdot V_t}\right) - 1 \right] - \frac{V + LR_s}{R_{sh}}$$

***Rs***: Series resistance related to the volume resistivity and the impedance of the electrodes and the materials.

***Rsh***: Shunt resistance related to edge effects and volume recombinations.

***A***: Quality factor[7].

## I.7. Photovoltaic solar systems are composed of:

A solar station is a ready-to-plug equipment consisting of:

- A photovoltaic solar panel can produce direct current from solar energy.
- An onboard micro inverter that changes the direct electricity from the panels into alternating current by connecting it to the module. The micro-inverter is located on the rear of the panel.
- An AC (alternating) connection cable that serves as a bridge connecting the inverter to the housing electrical socket.
- A solar energy meter, if desired.
- An AC interconnect cable for connecting several kits.

### I.8. Choosing a solar panels:

Selecting from several solar station brands might be challenging. To decide which model is best for your project:

- Rated power (in Wc).
- Product warranty and performance.
- Mounting options.
- Integrated production monitoring.
- Installation time.
- Place of manufacture.
- Price [8].

### I.9.The future of photovoltaic power stations:

Photovoltaic power plants are a significant component of the renewable energy industry. Due to ongoing research, technology, and policy backing progress, future development prospects for photovoltaic power plants are up and coming. The International Energy Agency predicts that the installed capacity of solar power generation worldwide will reach 3.3TW by 2030 and is projected to reach 11.6TW by 2050. In the future, photovoltaic power plants will progressively replace conventional fossil fuel power generation as the primary energy supply technique. Several elements must be considered when building solar power plants, including site conditions, climate, location, technological requirements, etc. The successful growth of photovoltaic power plants also depends on social acceptance and policy backing from the government. In the future, solar power plants should be used in more domains and contribute more to sustainable development due to ongoing technological advancements and legislative assistance [9].



**Figure 11: Construction steps of photovoltaic**



### I.10. Advantages & Disadvantages of Solar Panels:

#### I.10.1. Advantages:

- Solar power is pollution-free and causes no greenhouse gases to be emitted after installation.
- Reduced dependence on foreign oil and fossil fuels.
- Renewable clean power is available every day of the year; even cloudy days produce some power.
- Virtually no maintenance, as solar panels last over 30 years.
- Creates jobs by employing solar panel manufacturers, solar installers, etc., which, in turn, helps the economy.
- Ability to live grid-free if all power generated provides enough for the home/building.
- Can be installed virtually anywhere, in a field or a building.
- Use batteries to store extra power for use at night.
- Solar can heat water, power homes, and buildings, and even power cars.

#### I.10.2. Disadvantages:

There are high initial costs for material and installation and a long ROI (however, with the price of solar decreasing over the last ten years, solar is becoming more cost-feasible every day). It needs lots of space as efficiency is not 100% yet.

- No solar power at night, so there is a need for a large battery bank.
- Some people think they are ugly.
- Devices that run on DC power directly are more expensive.
- Depending on geographical location, the size of the solar panels varies for the same power generation.
- Cloudy days do not produce as much energy.
- Solar panels are not being mass-produced due to a lack of materials and technology to lower their cost enough to make them more affordable (this is starting to change).
- Solar-powered cars do not have the same speeds and power as typical gas-powered cars (this, too, is starting to change).
- Lower solar production in the winter months [10].

### Conclusion:

Solar panels represent a key technology in the transition towards renewable energy, offering a sustainable solution for power generation with various applications from residential to commercial and industrial scales. In the first chapter of this document, we presented general information about photovoltaic systems. We started with a brief history of solar panels, followed by the different types of solar panels. Then, we focused on what solar panels are made of and how solar cells produce electricity. We presented the equivalent diagram of a photovoltaic cell and the points for choosing a solar station. This chapter ends with the future of photovoltaic power and the advantages and disadvantages of solar panels.

# Chapter II

# The internet of things (IoT)

### Introduction:

The IoT promises to revolutionize our lives by making objects more intelligent and autonomous. For example, connected homes can automatically adjust the temperature according to the occupants' preferences, autonomous vehicles can drive safely on the roads, and connected medical devices can monitor patients' health in real time.

### II.1. The internet of things (IoT):

The Internet of Things, or IoT, is a network of connected objects communicating with the cloud and other IoT devices to share data. IoT devices, including consumer goods and digital and mechanical machinery, are often incorporated with technology such as sensors and software.

Businesses across many industries use IoT to boost productivity, provide better customer service, make better decisions, and add value to their enterprises. IoT allows data to be transferred across a network without requiring communication between people or between people and computers.

An automobile with sensors built in to warn the driver when tire pressure is low, a person with an implanted heart monitor, a farm animal with a biochip transponder, or any other natural or artificial object that can be given an IP address and is capable of sending data over a network can all be considered "things" in the context of the internet of things.

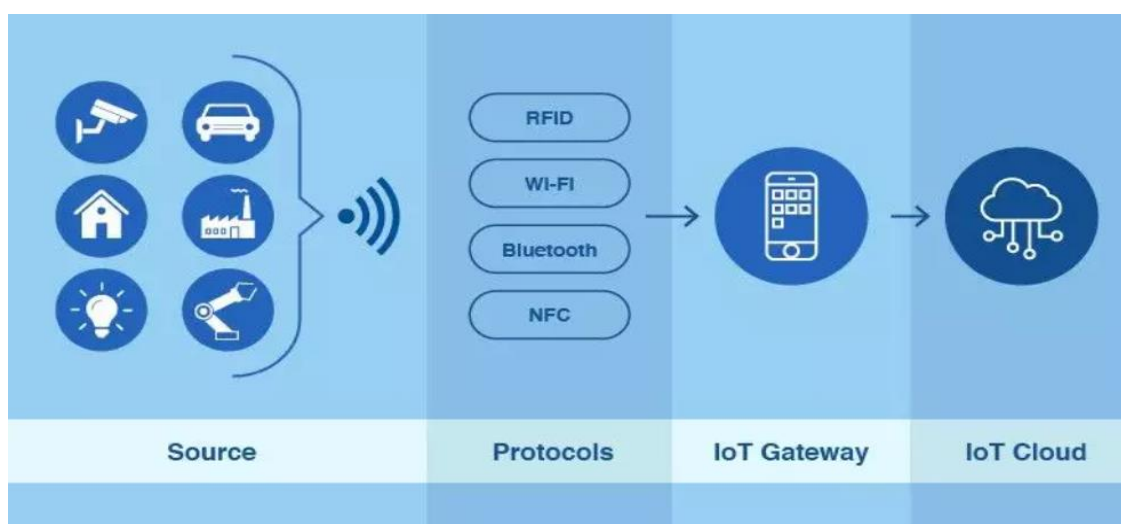


Figure 12: the internet of things

### II. 2. The functioning of the Internet of Things:

IoT terminals are our eyes and ears when we cannot be in person. They record every piece of information that is intended for them. This data can then be gathered and examined to direct and automate future decisions and actions. There are four steps to this process:

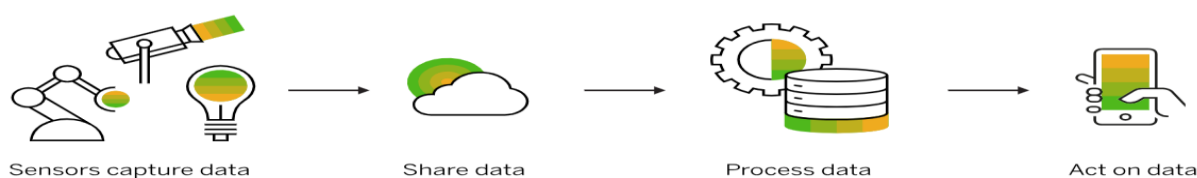


Figure 13: the work of IoT

#### The four key stages of the Internet of Things:

##### II.2.1. Data sensors:

Because of sensors, IoT terminals can gather data about their surroundings, a task that ranges from a straightforward temperature reading to a complicated live video stream.

##### II.2.2. Data sharing:

IoT terminals use network connections to convey this data to another terminal (terminal-to-terminal), a public or private cloud system, or to keep it locally for edge processing.

##### II.2.3. Data processing:

At this stage, the software is programmed to initiate an action, such as activating a fan or issuing a warning, in response to this data.

##### II. 2.4. Data exploitation:

The data acquired by an IoT network from each terminal is examined. As a result, you gain vital insights, enabling you to act confidently and make judgments [11].

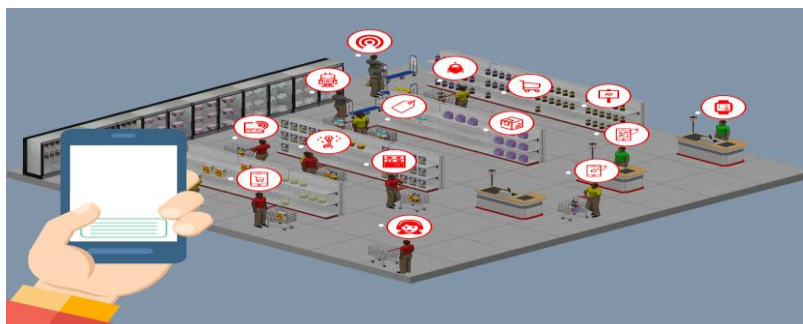


Figure 14: internet of things

### II.3. IoT's Seven-Layer Architecture:

Specific Internet of Things systems extend the conventional OSI model to seven levels, supplementing the basic five tiers with security and application layers. This all-inclusive strategy guarantees robust security protocols and improved application performance. The Internet of Things comprises several components that work together to build an elaborate web that facilitates the smooth flow of data and interactions within its ecosystem. These components include sensors, actuators, communication networks, data processing units, and user interfaces.

**Physical Layer:** The real hardware and sensors that gather environmental data are part of the Internet of Things' physical layer. Simple sensors to intricate IoT endpoints are examples of these devices.

**Data Link Layer:** The technologies and protocols used to connect devices to networks, such as Ethernet, Wi-Fi, and Low-Power Wide-Area Networks (LPWAN), are included in the data link layer of the Internet of Things.

**Network Layer:** In the Internet of Things, the network layer handles addressing and routing, ensuring that data packets reach their destinations accurately. Network protocols such as IPv6 are frequently utilized in this tier.

**Transport Layer:** This layer makes sure that all devices communicate with each other end-to-end. Internet of Things applications frequently use protocols like MQTT, CoAP, or HTTP to regulate data flow and dependability.

**Session Layer:** Because it deals with creating, preserving, and ending connections between devices or apps, the session layer is usually not specified in Internet of Things architectures. These operations are frequently controlled at the application or transport layers.

**Presentation Layer:** This layer handles compression, encryption, and data translation. Depending on the application's particular needs, these IoT capabilities are dispersed over several layers, including the middleware and application layers.

**Application Layer:** IoT services and applications are housed in the application layer of the network. It uses and analyzes sensor and device data to produce control features, user interfaces, and insightful information. The heart of IoT applications is this layer [12].

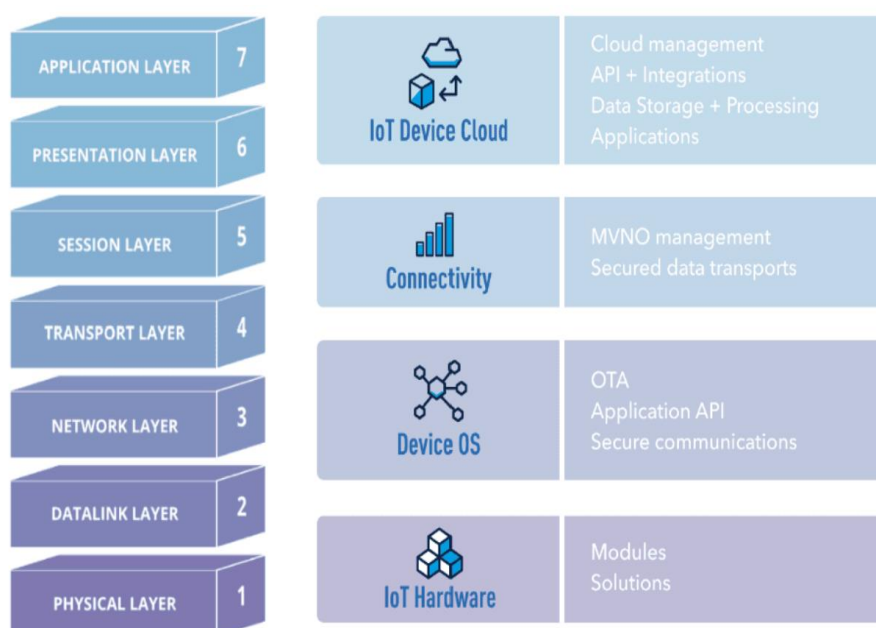


Figure 15: IoT Architecture Diagram

### II.4.IoT Technologies in Business:

IoT is essential for automating operations and offering insightful commercial data. Businesses may improve decision-making and better understand their operations by linking machines and

gadgets. Additionally, they can automate repetitive jobs, freeing up staff to concentrate on more strategic goals.



Figure 16: IoT in the industry

### II.4.1. Software Development:

Sensors and beacons are software development tools that may track and transform data into insightful information. Afterward, unique apps suited to a specific business's requirements may be developed with this data. Using IoT offers developers the following advantages:

- Tracking flaws and problems at a distance.
- Tracking the real-time performance of software.
- Automated testing and quality control of the code.

### II.4.2. Fintech:

The finance sector has progressively embraced IoT to streamline operations and enhance client satisfaction. Businesses in the industry can save expenses and streamline processes as a result. The following are a few ways companies might profit from the Internet of Things:

- Fraud detection through data collection from several sources.
- Use smart contracts to automate transactions and payments.
- Customers receive real-time warnings when any questionable behavior is found.



### II.4.3. Healthcare:

Healthcare practitioners may now deliver preemptive and individualized treatment because IoT devices like wearables and remote monitoring systems can track and analyze patient data. IoT may also be utilized to build "smart hospitals," where interconnected systems and gadgets boost patient safety in circumstances such as these, expedite procedures, and improve patient experiences.

- Real-time patient data collection for more accurate diagnosis.
- Using remote health monitoring systems to link patients with medical providers.
- By employing sensors, healthcare resources, like hospital beds,.
- Developing clever medication delivery systems that modify doses based on patient needs.

### II.4.4. E-commerce:

E-commerce companies may use IoT to enhance consumer experiences and boost operational effectiveness. By doing this, companies may save money while offering their clients better services. Among the ways e-commerce companies may use IoT are:

- Real-time tracking and analytics to improve customer support.
- Ordering and replenishment may be automated with inventory management systems.
- Technologies for automated user authentication to provide safe remote data access.
- Use ML and AI to provide clients with customized product suggestions.

### II.4.5. Manufacturing and Logistics:

The manufacturing sector leverages the Internet of Things to establish "smart factories," wherein networked devices maximize resource use, monitor and regulate production processes, and guarantee product quality. Another feature that industrial IoT may provide is predictive maintenance, which lowers downtime and maintenance costs by using sensor data to forecast

when equipment will need maintenance or repair. The use cases that pertain specifically to the manufacturing sector are:

- Real-time tracking and observation of the production process and supply chain.
- Examining information from several sources to improve decision-making.
- Constructing automated control systems with condition-adaptive capabilities.
- < UNK> Predictive maintenance can help find problems before they get out of hand

### **II.5. Adaptation of embedded memory solutions for various IOT applications:**

Because of Nexus's experience creating customized memory solutions, they can meet the specific needs of various Internet of Things applications by offering embarked memory solutions tailored to the needs of particular devices or industries.

#### **II.5.1.Intelligent buildings and home automation:**

The integrated memory solutions for this doevents application offer low power consumption, secure data storage, and seamless integration with other IoT devices. Nexus' customized solutions meet these requirements, ensuring that smart buildings and home automation systems can operate efficiently and safely.

#### **II.5.2.Industrial automation and monitoring:**

These applications require solid concepts, extreme temperature resistance, and high reliability, all of which Nexus' specialized embedded memory products meet.

#### **II.5.3.Connected health devices:**

**Nexus' integrated memory solutions for healthcare IoT devices ensure the highest performance, security, and reliability while protecting vital patient data and improving health outcomes [14].**



Figure 17: embedded memory solutions for IOT applications

## II.6. Benefits of Using an IoT-based Solar Power Monitoring System:

It is always a must-do task to track performance better and adjust accordingly, regardless of what you monitor. In particular, with solar plants, it is imperative to monitor! Utilizing the Internet of Things (IoT)--based solar power monitoring systems has several advantages that will help your company in various ways. Let's review a few of them:



Figure 18: FOUR Benefits of Using an IoT

### II.6.1. Enhanced Performance:

The better you monitor your power system's operations, the more you can work on the gaps and increase efficiency. An Internet of Things (IoT)- based monitoring system can detect and resolve problems that may be affecting the efficiency of the solar panels by collecting and evaluating data from sensors incorporated into the solar power system. This may result in higher energy output and better performance.

### II.6.2. Remote Monitoring and Control:

You can always diagnose problems and perform maintenance activities remotely without having physical access to your solar power system, even if it is far from your location.

### II.6.3. Cost-effectiveness:

An Internet of Things-based monitoring system lowers the cost of necessary maintenance and repairs by detecting problems before they become serious. Additionally, an IoT-based system can save money by extending the life of the solar power installation and reducing the need for additional energy sources by improving the solar power system's performance.

### II.6.4. Energy Optimization:

By modifying the power output of your solar power system in response to current conditions, you may maximize the use of solar energy by analyzing data from your system with the aid of an Internet of Things-based monitoring system. This may result in cost savings and improved energy efficiency [15].

Overall, if you want to control and maximize the efficiency of your solar power system, you must immediately choose bespoke corporate software development services.

### Conclusion:

The IoT is poised for significant growth driven by technological advancements, increased connectivity, cost reductions, and widespread adoption across various sectors, with advancements in technologies such as 5G, artificial intelligence, and edge computing further enhancing its capabilities. The future of IoT promises even greater connectivity, smarter automation, and a transformative impact on how we live and work.

This chapter provides a state-of-the-art overview of the Internet of Things (IoT), focusing on connecting devices to the Internet for data collection and exchange. It delves into the Seven-Layer Architecture framework for designing and implementing IoT systems. It discusses the advantages of using an IoT-based system, including real-time data collection and analysis, improved efficiency and maintenance, and better decision-making based on accurate and timely information. Overall, IoT can enhance the performance and reliability in our real life.

# **Part 2: Contribution**

# Chapter III

# Application &

# Contribution

### Introduction:

Solar energy is a popular renewable energy source for electrification, and photovoltaic (PV) systems convert sunlight into electricity. These systems can be installed anywhere with sufficient energy potential. However, performance studies are challenging due to varying parameters and system components. Real-time monitoring systems are needed to assess performance. This study discusses using the Internet of Things (IoT) in performance monitoring and real-time control of PV systems. IoT enhances understanding of real-time operating parameters, allowing for remote control, effective fault diagnosis, maintenance, generation recording, and performance data analysis. This study emphasizes the importance of IoT in PV systems.

### III.1. Architecture of IOT-based solar photovoltaic systems:

The primary components of Internet of Things-based solar PV monitoring systems are as follows:

#### Sensor nodes:

- Consists of the processing unit and the sensors.
- Protocol and communication technologies:
- Using a communication technique, the detected data is sent across the network. Wired and wireless communication technologies, such as WiFi, Bluetooth, GSM, Zigbee, or LoRA, are possible.

#### Base station:

- It might be a decentralized entity or a centralized one.

#### Overseeing the node:

- It presents the final user with a GUI. It may be a laptop or the host computer.

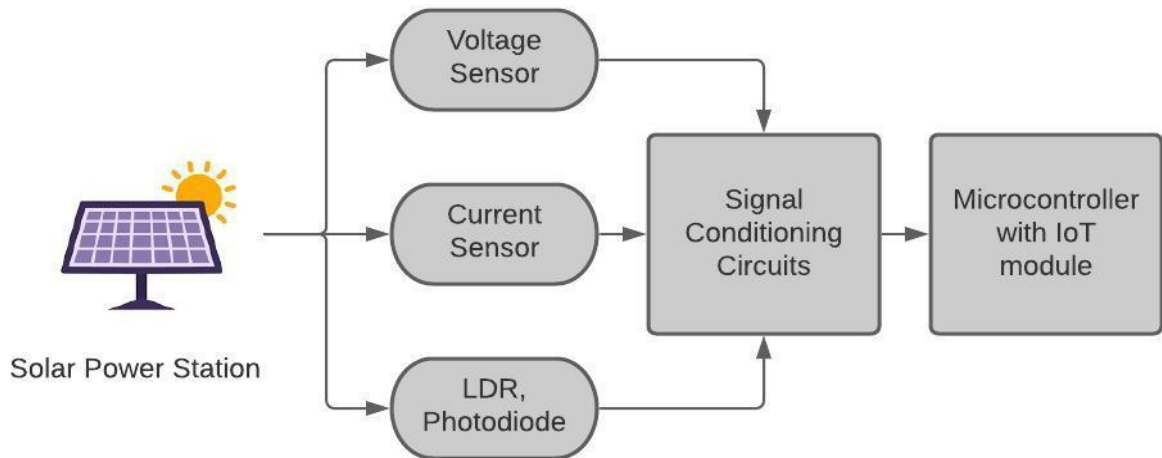


Figure 19: Connection between solar power station and IoT module

### III.2. Hardware and software design tools:

Figure 2 shows the wiring hardware of the main board of the proposed system.

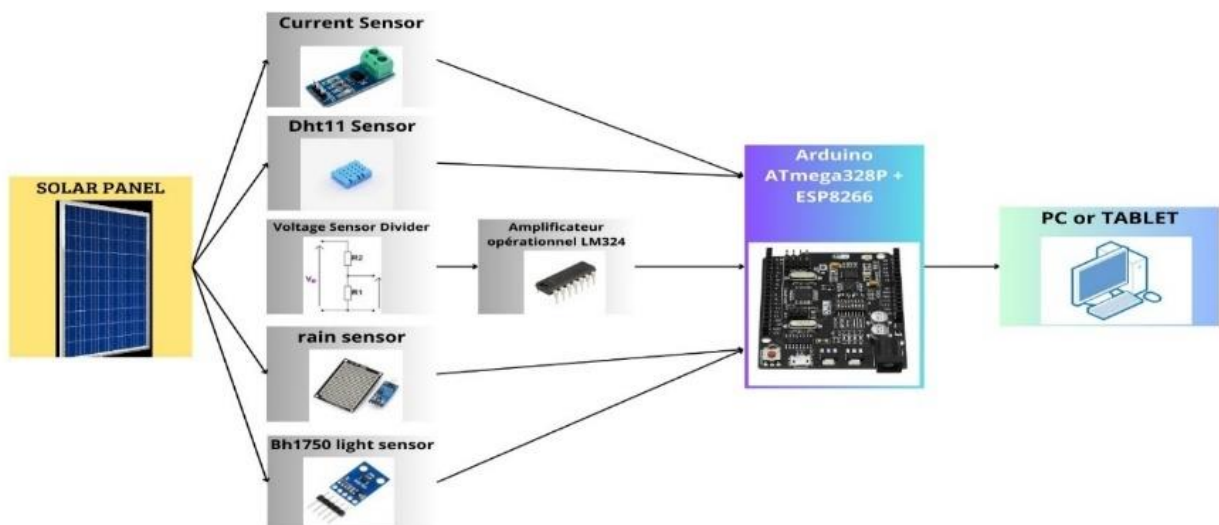


Figure 20: Schematic diagram of the proposed system



### III.2.1.Solar panel:

**Monocrystalline** silicon is generally created by one of several methods that involve melting high-purity, semiconductor-grade silicon (only a few parts per million of impurities) and using a seed to initiate the formation of a continuous single crystal.

Technical characteristics:

- **Maximum power:35W**
- Maximum power voltage:6V
- Maximum power current:5.83A
- Open circuit current:7A
- Open circuit voltage:7.2V
- Maximum system voltage size:1000VDC
- Dimension:350\_580\_1717mm



Figure 21:Solar panel

### III.2.2. ACS712 current sensor:

ACS712 is a current sensor that measures the intensity of the electric current using the technique of current-to-voltage conversion. It converts alternating or direct current into a voltage signal proportional to the current intensity. It is generally used to measure the current intensity in electronic systems, such as inverters, battery chargers, solar panels, energy consumption monitoring systems, etc. It is available in different current ranges, ranging from 5A to 30A [15].



Figure 22 :Acs712 current

#### Functional Block Diagram:

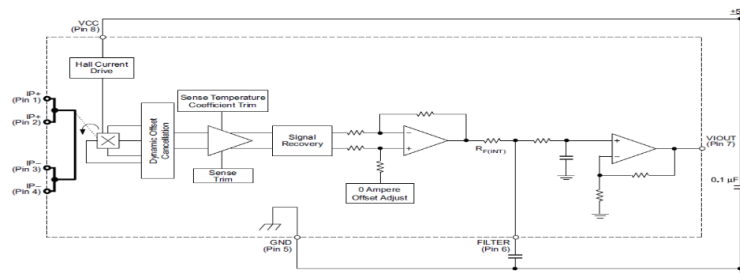


Figure 23: Functional Block Diagram

### Pinout Diagram:

| Number  | Name   | Description   |
|---------|--------|---|
| 1 and 2 | IP+    | Terminals for current being sampled; fused internally |
| 3 and 4 | IP-    | Terminals for current being sampled; fused internally |
| 5       | GND    | Signal ground terminal                                |
| 6       | FILTER | Terminal for external capacitor that sets bandwidth   |
| 7       | VIOOUT | Analog output signal                                  |
| 8       | VCC    | Device power supply terminal                          |

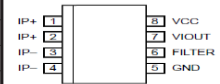


Table 2:ACS712 pinout Diagram

### Code of ACS712 current sensor with Arduino:

```

ACS712.ino
1  void setup() {
2  |   Serial.begin(9600); //Start Serial Monitor to display current
3  }
4
5  void loop() {
6  unsigned int x=0;
7  float AcsValue=0.0,Samples=0.0,AvgAcs=0.0,AcsValueF=0.0;
8
9  for (int x = 0; x < 150; x++){ //Get 150 samples
10  AcsValue = analogRead(A0);    //Read current sensor values
11  Samples = Samples + AcsValue; //Add samples together
12  delay (3); // let ADC settle before next sample 3ms
13  }
14  AvgAcs=Samples/150.0;//Taking Average of Samples
15
16  I = (2.5 - (AvgAcs * (5.0 / 1024.0)))/0.066;
17  Serial.println(I);//Print the read current on Serial monitor
18  delay(50);
19  }
20

```

Figure 24:code of ACS712

### ACS712 current sensor with Arduino:

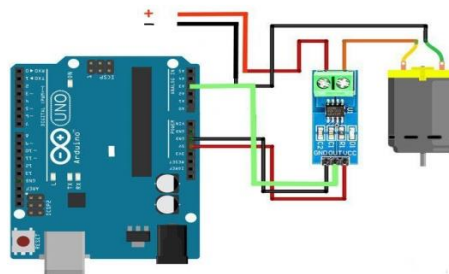


Figure 25:ACS712 current sensor with Arduino

### III.2.3. Voltage Divider Basics:

A linear circuit block that generates an output that is a fraction (real or complex) of its input voltage is called a voltage divider, often referred to as a potential divider. Making a known exact fraction of the output from a given input voltage is helpful, especially when making voltage references.

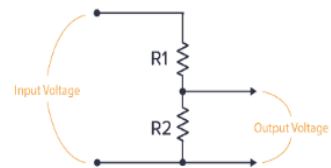


Figure 26 :Voltage Divider circuit

We'll discuss loading, which means that as you remove current from the voltage divider, the equivalent resistance changes and the voltage lowers.

#### Creating a Voltage Divider with Resistors:

At its most basic form, a voltage divider consists of two passive elements, with the output  $V_{OUT}$  taken from the node between them, as shown in the figure above.

When using resistors, the voltage drop  $V_{OUT}$  across a given resistor ( $R_A$ , for example) equals  $V_{OUT} = V_{IN} * R_A / R_{TOTAL}$ . In other words, for the figure above, the voltage drop across  $R_2$  is equal to  $V_{OUT}$  and is, therefore,  $V_{OUT} = V_{R2} = V_{IN} * R_2 / (R_1 + R_2)$ .

Like any passive linear circuit element, a voltage divider can be simplified into an equivalent Thevenin voltage and Thevenin resistance. This can be used as another method of visualizing how a voltage divider behaves and gives a clearer understanding of the effects of loading.

### III.2.3.DHT11–Temperature and Humidity Sensor:

The DHT11 is a commonly used Temperature and humidity sensor. It has a dedicated NTC to measure temperature and an 8-bit microcontroller to output the temperature and humidity values as serial data.

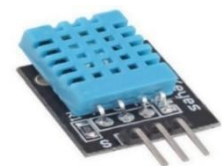


Figure 27 :DHT11

#### DHT11 Pinout Configuration:

|   |        |   |
|---|--------|---|
| 1 | Vcc    | Power supply 3.5V to 5.5V                                 |
| 2 | Data   | Outputs both Temperature and Humidity through serial Data |
| 3 | NC     | No Connection and hence not used                          |
| 4 | Ground | Connected to the ground of the circuit                    |

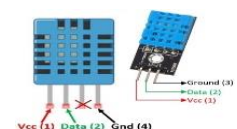


Table 3: DHT11 Pinout Config

### DHT11 Connection Diagram:

The DHT11 Sensor is factory-calibrated and outputs serial data; hence, it is straightforward to set it up. The connection diagram for this sensor is shown below. [16]

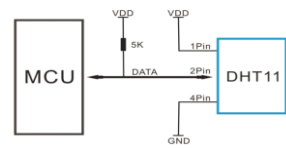


Figure 28 :DHT11 Connection

### Code of DHT11 with Arduino:

```
Code
Fichier Edition Croquis Outils Aide
DHT11_test
#include <DHT.h>
#define dht_1 A1
#define DHTTYPE DHT11

DHT dht (dht_1, DHTTYPE);

void setup() {
  Serial.begin(9600);
  Serial.println(F("Testing of DHT11 by Project Hub"));
  dht.begin();
}

void loop() {
  float humid=dht.readHumidity();
  float temp=dht.readTemperature();

  Serial.print("humidity= ");
  Serial.print(humid);
  Serial.println(" %");
  Serial.print("temperature= ");
  Serial.print(temp);
  Serial.println(" °C");

  delay(1000);
}
```

Figure 29:Code of DHT11 with Arduino

### DHT11 Temperature & Humidity Sensor with Arduino:

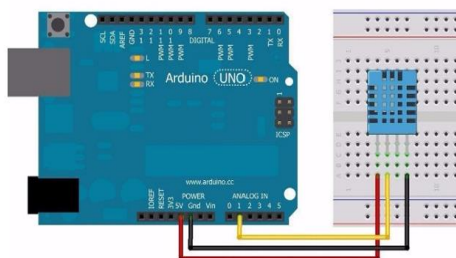
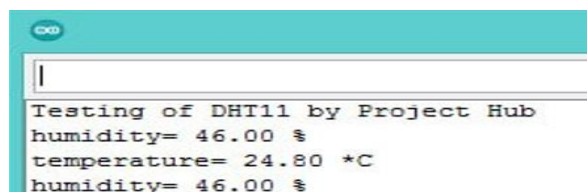


Figure 30 :DHT11 Temperature & Humidity sensor with Arduino

### Result of the test with Arduino:



```
Testing of DHT11 by Project Hub
humidity= 46.00 %
temperature= 24.80 *C
humidity= 46.00 %
```

Figure 31:Result of the test with Arduino

### III.2.4.YI-83 Rain Sensor Module:

The rain sensor module is an easy tool for rain detection. It can be used as a switch when a raindrop falls through the mainboard and for measuring rainfall intensity. The module features a drainboard and a separate control board for convenience, a power indicator LED, and adjustable sensitivity through a potentiometer.



The analog output is used to detect drops in the amount of rainfall. Connected to a 5V power supply, the LED will turn on when the induction board has no raindrop, and the DO output is high. When dropping a small amount of water, the DO output is low, and the switch indicator will turn on. Brush off the water droplets, and when restored to the initial state, outputs a high level. [17]

Figure 32 : .:YI-83 RAIN SENSOR

#### Pin Configuration:

1. VCC: 5V DC
2. GND: ground
3. DO: high/low output
4. AO: analog output



### Schematic Diagram:

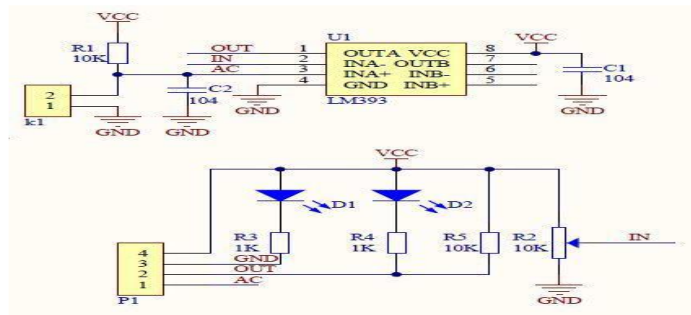


Figure 33: Schematic Diagram

### Code with Arduino:

```
Fichier Édition Croquis Outils Aide
YL-83

const int O = 2;

void setup() {
  Serial.begin(9600);
  pinMode(O, INPUT);
  Serial.println(F("Testing of YL-83 by Project Hub"));
}

void loop() {
  int test = digitalRead(O);

  if (test == 1)
  {
    Serial.println(" - Sunny day");
  }
  else {
    Serial.println(" - rainy day");
  }

  delay (1000);
}
```

Figure 34: code YL-83 with Arduino

**YL-83 Rain Sensor with Arduino:**

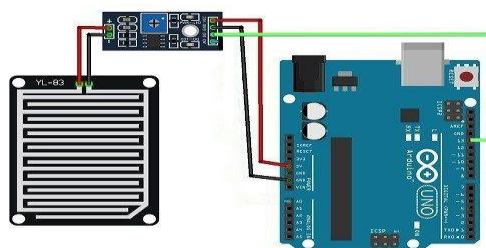


Figure 35: YL-83 Rain Sensor with Arduino

**Result of the test with Arduino:**

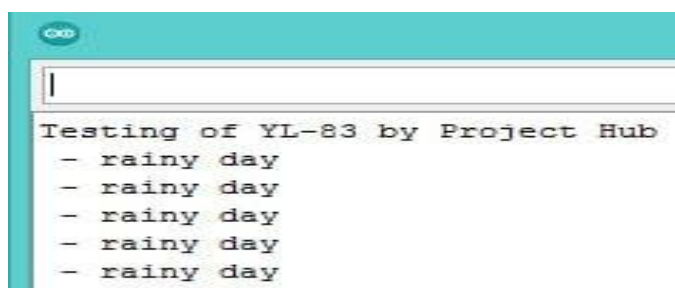


Figure 36: Result of the test with Arduino

**III.2.5.BH1750 – Ambient Light Sensor:**

BH1750 is a digital ambient light sensor commonly used in mobile phones to manipulate the screen brightness based on the environment's lighting. This sensor can accurately measure the LUX value of light up to 65535lx. [18]

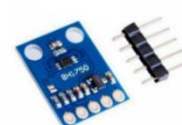


Figure 37 : BH1750 Sensor

**BH1750 Pin Configuration:**

| Pin Number | Pin Name | Description   |
|------------|----------|---|
| 1          | VCC      | Power supply for the module can be 2.4V to 3.6V, typically 3.0V is used                 |
| 2          | GND      | Ground of the module, connected to ground of the circuit                                |
| 3          | SCL      | Serial Clock Line, used to provide clock pulse for I2C communication                    |
| 4          | SDA      | Serial Data Address, used to transfer the data through I2C communication                |
| 5          | ADDR     | Device address pin, used to select the address when more than two modules are connected |

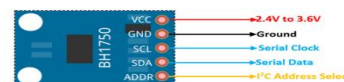


Table.III.2. BH1750 Pin Configuration





### BH1750 with Arduino:

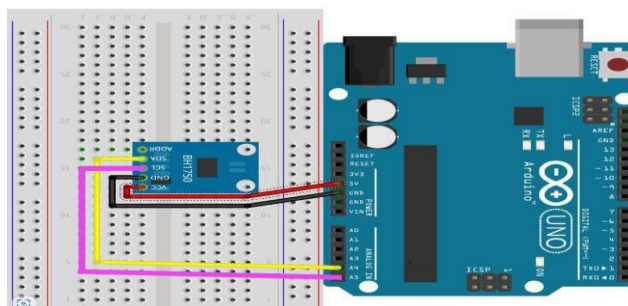


Figure 40: BH1750 with Arduino

### Result of the test with Arduino:

```
Testing of BH1750 by Project Hub
I2C Communication Started
Light Intensity Meter Started
Light Intensity: 0.00 lx
Light Intensity: 38.33 lx
Light Intensity: 38.33 lx
Light Intensity: 32.50 lx
Light Intensity: 5.00 lx
```

Figure 41: Result of the test with Arduino

### III.2.6. Arduino ATmega328P + ESP8266:

This is the new version of our **Uno+WiFi R3** board that is fully compatible with the **Arduino Uno+WiFi R3**. It is a customized version of the classic **ARDUINO UNO R3** board. Full integration of microcontroller **Atmel ATmega328** and IC, Wi-Fi **ESP8266** with 32 MB flash memory, and USB-TTL converter **CH340G** on one board. All modules can work together or independently.

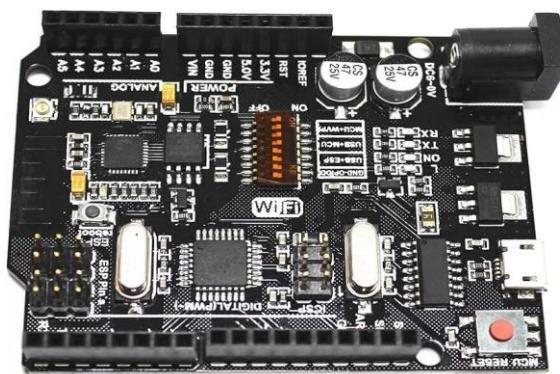


Figure 42: Arduino ATmega328P + ESP8266

### Mode Selection:

On the board where the switch of mode of operation with eight position Switch status and mode selection:

| Connection                                | DIP |     |     |     |     |     |     |
|---|-----|-----|-----|-----|-----|-----|-----|
|   | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
| ATmega328<->ESP8266                       | ON  | ON  | OFF | OFF | OFF | OFF | OFF |
| USB <->ATmega328                          | OFF | OFF | ON  | ON  | OFF | OFF | OFF |
| USB<->ESP8266 (Update firmware or sketch) | OFF | OFF | OFF | OFF | ON  | ON  | ON  |
| USB<->ESP8266 (communication)             | OFF | OFF | OFF | OFF | ON  | ON  | OFF |
| All independent                           | OFF | OFF | OFF | OFF | OFF | OFF | OFF |

**Table 4 : Arduino ATmega328P + ESP8266 mode Selection**

### Spécification:

- Microcontroller: ATmega328
- IC Wi-Fi: ESP8266
- USB-TTL converter: CH340G
- Power Out: 5V-800mA
- Power IN. USB: 5V (500mA max.)
- Power IN. VIN/DC Jack: 9-24V
- Power Consumption: 5V – 800mA
- Logic Level: 5V
- WIFI: Wi-Fi 802.11 b/g/n 2.4 GHz
- USB: Micro USB
- Clock Frequency: 16MHz
- Operating Supply Voltage: 5V
- Digital I/O: 14Pin
- Analog I/O: 6Pin
- Memory Size: 32Mb
- Interface Type: serialOTA
- Antenna: Built-in
- Dimensions: 53.34\_68.58mm
- Weight: 8Gm

### III.2.6. Operational Amplifier:

For adaptation and protection, We have installed a follower mounting as indicated in the Shema:

$$V_s = V_e, Z_e = \infty$$

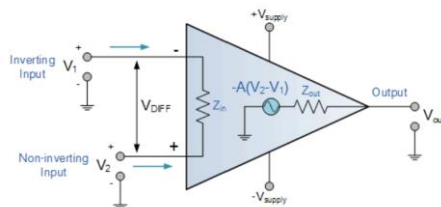


Figure 43: Operational Amplifier Basics

Often called the voltage buffer stage. Thanks to its very high input impedance and its low output impedance, it is intended to allow impedance matching between two successive stages of a circuit.

### III.2.6. Zener Diode:

We know the uses of the zener diode, which permits the current flow to be in a forward or reverse direction. A Zener diode is a semiconductor device consisting of a PN junction that conducts the current in reverse direction when a specified voltage is reached. It has a reverse breakdown voltage, meaning it can continuously operate in reverse-bias mode without damage.

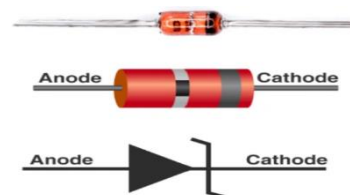


Figure 44 : Zener

## III.3.The simulation of the electronic card:

### III.3.1.The electronic card:

We have developed an electronic board based on Arduino ATmega328P and ESP8266 equipped with five inputs ensuring the measurement of the voltage and current of the photovoltaic panels, the intensity of the light projected on the solar panel, the temperature and humidity of the air, and a rain capture detecting the rain. All these capture the PC, which communicates with each other in real-time with Wi-Fi.

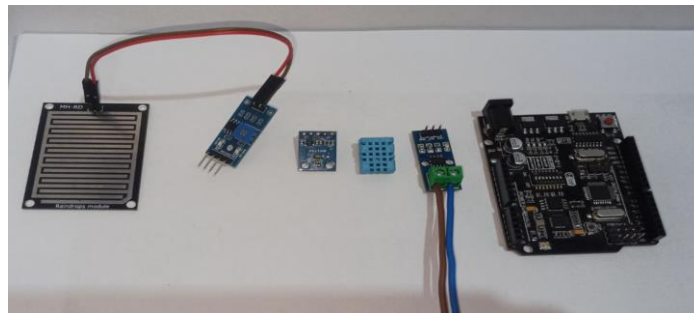


Figure 45: the sensors used in the electronic card

### III.3.2. The material used:

| Quantity | References                 | Value |
|----------|----------------------------|-------|
| 1        | R1                         | 1M    |
| 1        | R2                         | 110K  |
| 5        | Zener Diode                | 5V    |
| 1        | LM324                      |       |
| 1        | Current sensor             |       |
| 1        | Voltage Divider sensor     |       |
| 1        | Dht11 sensor               |       |
| 1        | BH1750                     |       |
| 1        | Rain sensor                |       |
| 1        | Arduino atmega328p+ESP8266 |       |

Table 5: The material used

### III.3.3. The simulation of the system by Proteus:

The Proteus Software allows us to simulate the behavior of circuits and the electronic card offers.

### III.3.3.1.Global schematic of the system by Proteus:

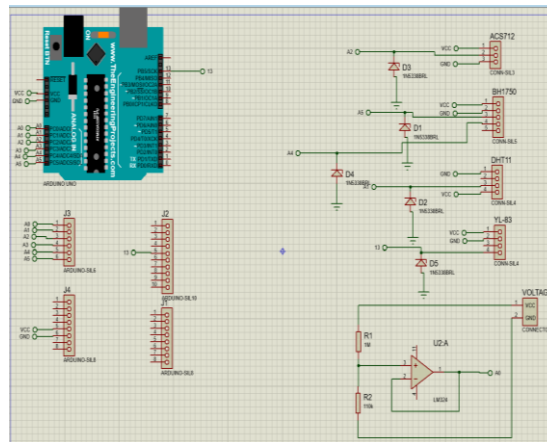


Figure 46: Global schematic of the system by Proteus

### III.3.3.2.PCB Layout of the system by Proteus:

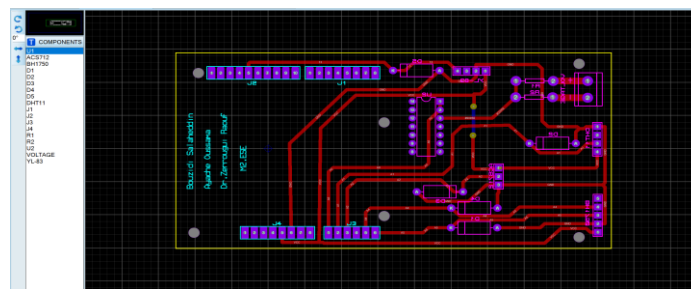


Figure 47: PCB Layout of the system by Proteus

### III.3.3.3. 3D Visualizer of the system by Proteus:

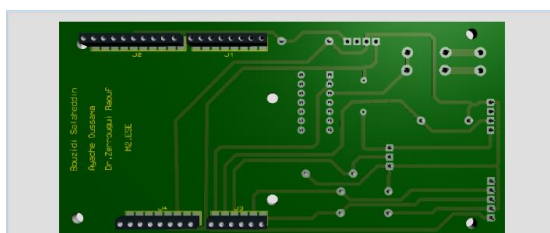


Figure 48 : 3D Visualizer of the system by Proteus

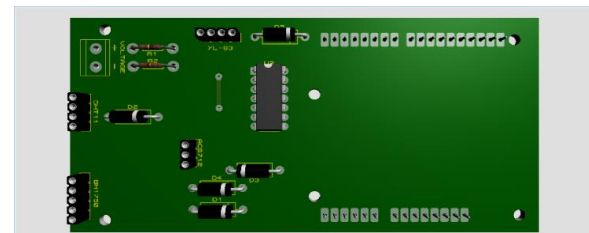


Figure 49 : 3D Visualizer of the system by Proteus1

## III.4.Realization of the electronic card:

### III.4.1. the Realization:

We have realized the electronic map of our system by these steps:

- 1st phase: Insolation

- 2nd phase: The revelation
- 3rd phase: The engraving
- 4th phase: Elimination
- 5th phase: Drilling
- 6th phase: Metallization of the holes

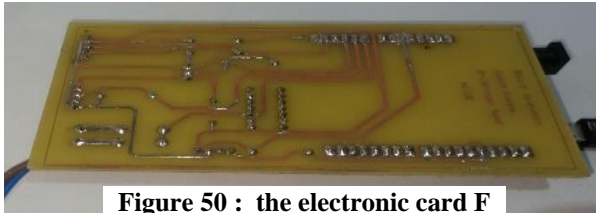


Figure 50 : the electronic card F

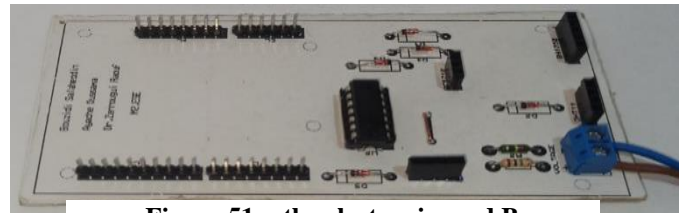


Figure 51 : the electronic card B

### III.4.2. Test with the card:

We install the components on the board and then do a test.

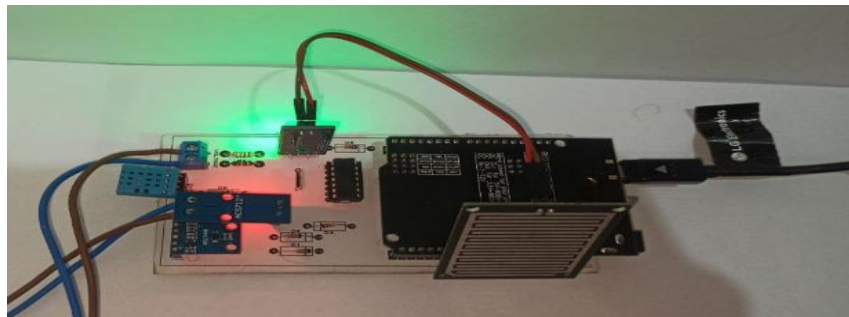


Figure 52: system testing

### III.4.3. the case of the electronic card:

We installed a case to fix and capture the cards as a finished product.

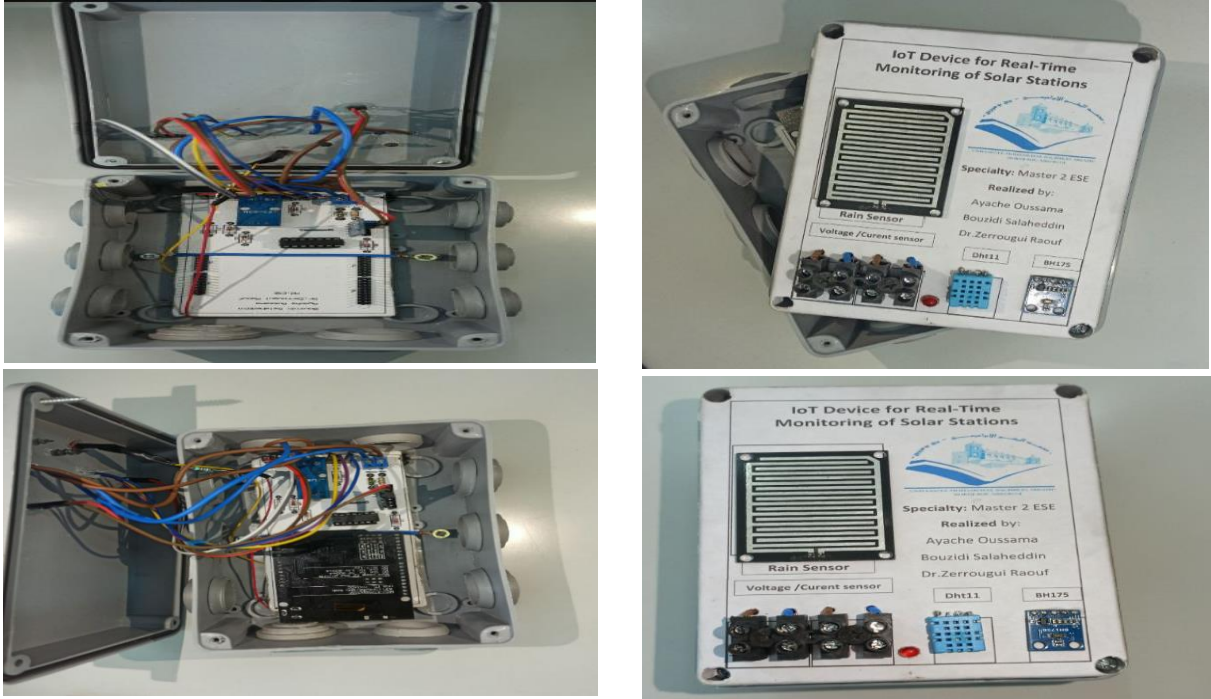


Figure 53 : the case of the electronic card

### III.5. The organization chart of the codes:

We used two programming software for our simulation:

- The first software is Arduino, which we use to write the Arduino and ESP8266 codes.
- The second software is Python, which we use to write the code that receives the data and draws the diagrams.

#### III.5.1. The structure for Arduino code:

This program measures the temperature, humidity, voltage, current, light intensity, and rain status, formats the values into character strings, and sends them via the serial link for possible use or external visualization.



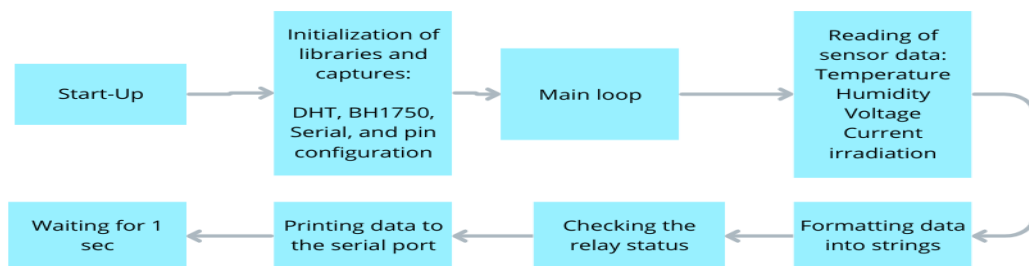
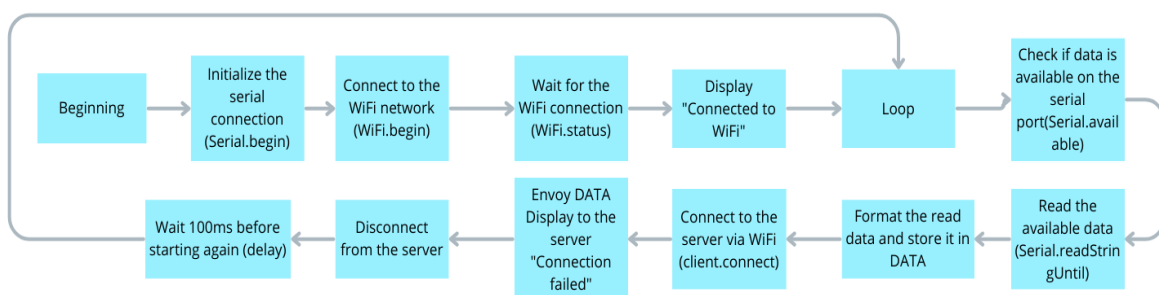


Figure 54: Diagram for Arduino code

### III.5.2. The structure for Esp code:

This program configures an ESP8266 module to connect to a Wi-Fi network, read the sensor data received over the serial link, and send this data to a remote server. The data is sent



whenever available, with a minimum delay between shipments to avoid overloads.

Figure 55:the structure for Esp code

### III.5.3. The structure for Python code:

This program creates a server that listens to the client's sensor data, updates the graphs in real-time, and allows you to save the graphs or exit the program via an interactive user interface.

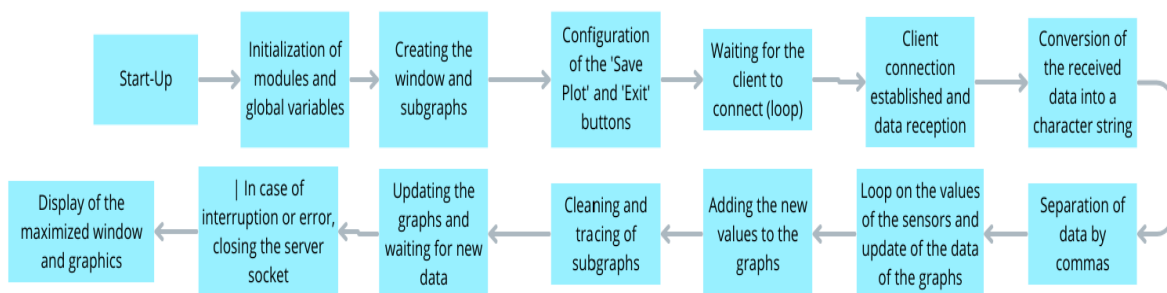


Figure 56:the Structure for Python code



### III.6. Test the system in real-time:

We conducted the tests in the electronics lab on May 16, 2024, at 10:00 PM. The atmosphere was a little cloudy, so the factors changed occasionally.

We used a 270-ohm resistor because we could not find a 5V regulator (MPPT or PWM) on the market.

#### III.6.1. Test the system in normal conditions:

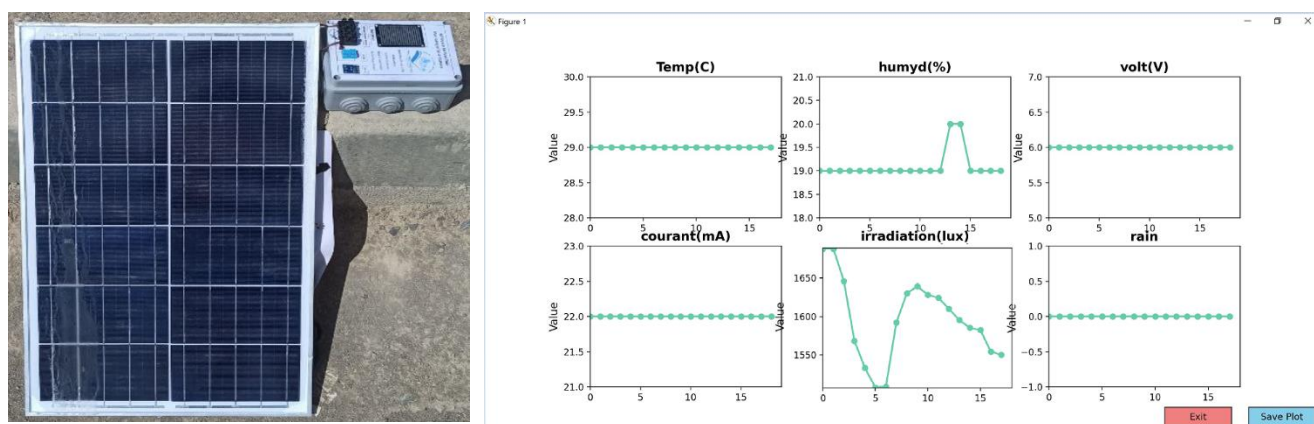


Figure 57: Test the system in normal condition

the system is under normal conditions, and we got these results:

| Temperature | Humidity | Current | Voltage | irradiation | rain |
|-------------|----------|---------|---------|-------------|------|
| 29(C)       | 19%      | 6V      | 22mA    | 1550 J/kg   | 0    |

Table 6: result in normal condition

The table below shows real-time measured data for our system under normal conditions.

- The ambient temperature is 29°C, and the relative humidity of the air is 19%.
- The current generated by the solar panel is 22 mA, with an output voltage of 6V.
- The solar irradiation, which measures the energy received per unit area, is 1550 J/m<sup>2</sup>.
- Finally, the absence of rain is indicated by a value of 0.

These parameters are essential to evaluate the performance and efficiency of the photovoltaic system under specific environmental conditions.

These results indicate that the PV system is functioning as expected under standard conditions, with moderate solar irradiation and stable electrical outputs.

### III.6.2. Test the system with the placement of a sheet on the panel:

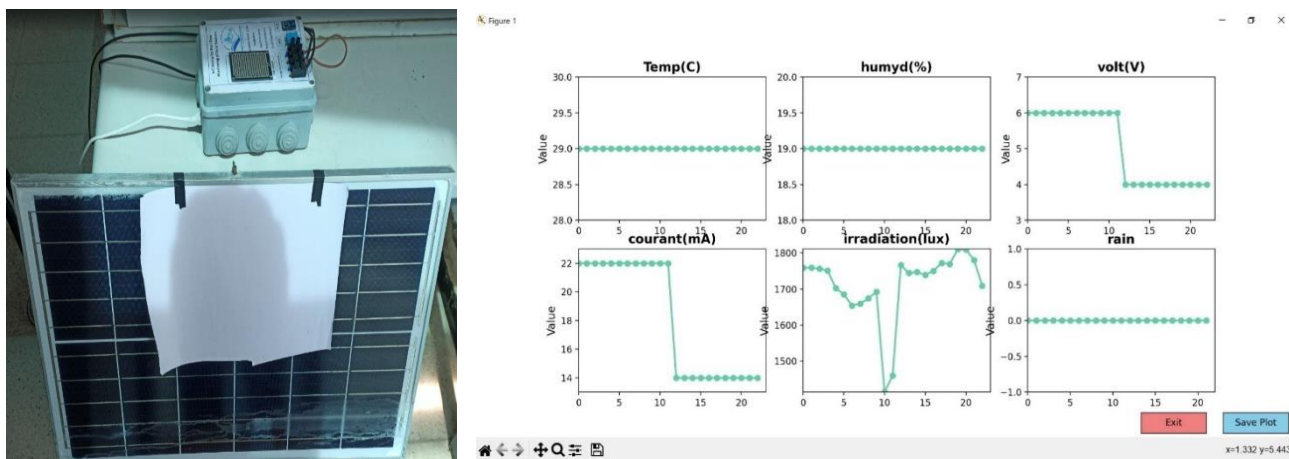


Figure 58: the system with the placement of a sheet on the panel

| Temperature | humidity | Current | Voltage | irradiation | rain |
|-------------|----------|---------|---------|-------------|------|
| 29(C)       | 19%      | 4V      | 14mA    | 1650 J/kg   | 0    |

Table 7: result with the placement of a sheet on the panel

We placed a blank sheet on the panel in this test, resulting in current efficiency and voltage changes.

- The ambient temperature was 29°C, and the relative humidity of the air was 19%.
- The current efficiency decreased to 14 mA, and the voltage efficiency decreased to 4 V.
- The solar irradiation was 1650 J/m<sup>2</sup>.
- Finally, the absence of rain was indicated by a value of 0.

The decrease in current and voltage is due to the obstruction caused by the sheet, which reduces the light hitting the panel. Interestingly, the solar irradiation increased slightly, which might be due to reflection or other environmental factors.

III.6.3. Test the system when it hides the BH1750 sensor:

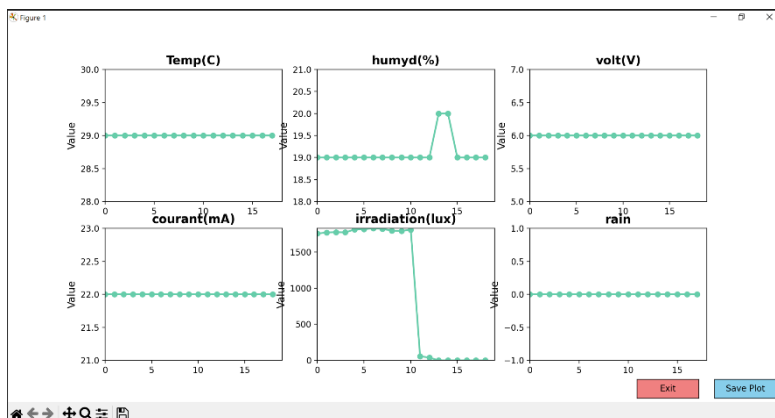


Figure 59: the system

when it hides the BH1750 sensor

| Temperature | Humidity | Current | voltage | irradiation | rain |
|-------------|----------|---------|---------|-------------|------|
| 29(C)       | 19%      | 6V      | 22mA    | 0 J/kg      | 0    |

Table 8: result when it hides the BH1750 sensor

In this test, we masked the light sensor on T=10s and obtained a change in the irradiation efficiency.

- The ambient temperature was 29°C, and the relative humidity of the air was 19%
- The current generated by the solar panel is 22 mA, with an output voltage of 6V.
- The solar irradiation decreased to 0 J/m<sup>2</sup>.
- Finally, the absence of rain was indicated by a value of 0.

As expected, the solar irradiation measurement dropped to zero because the sensor was covered, while other parameters remained unaffected.

III.6.4. Test the system when applying heat on the DHT11:

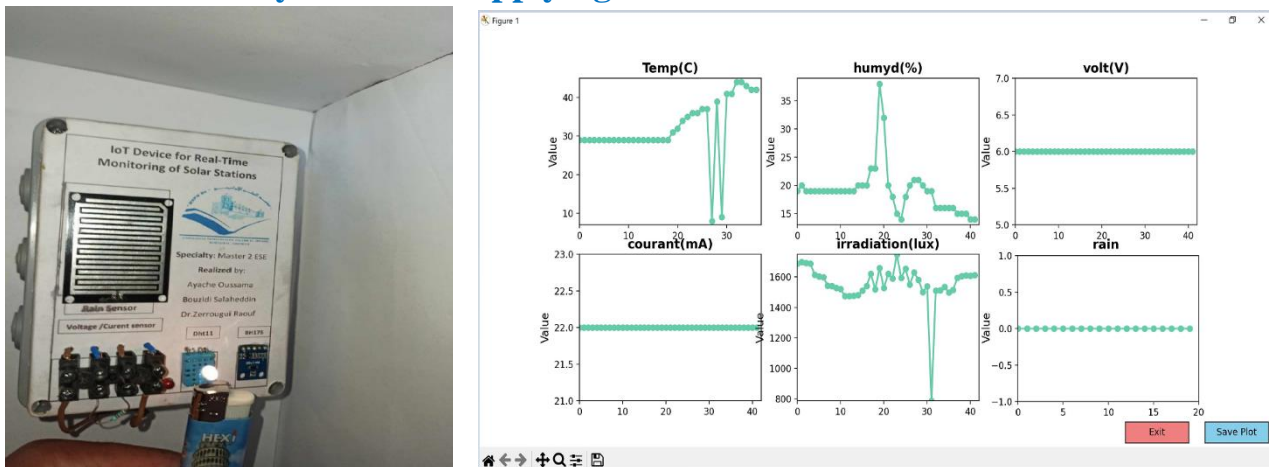


Figure 60: the system when applying heat on the DHT11

| Temperature | humidity | Current | voltage | irradiation | rain |
|-------------|----------|---------|---------|-------------|------|
| 40(C)       | 35%      | 6V      | 22mA    | 1500 J/kg   | 0    |

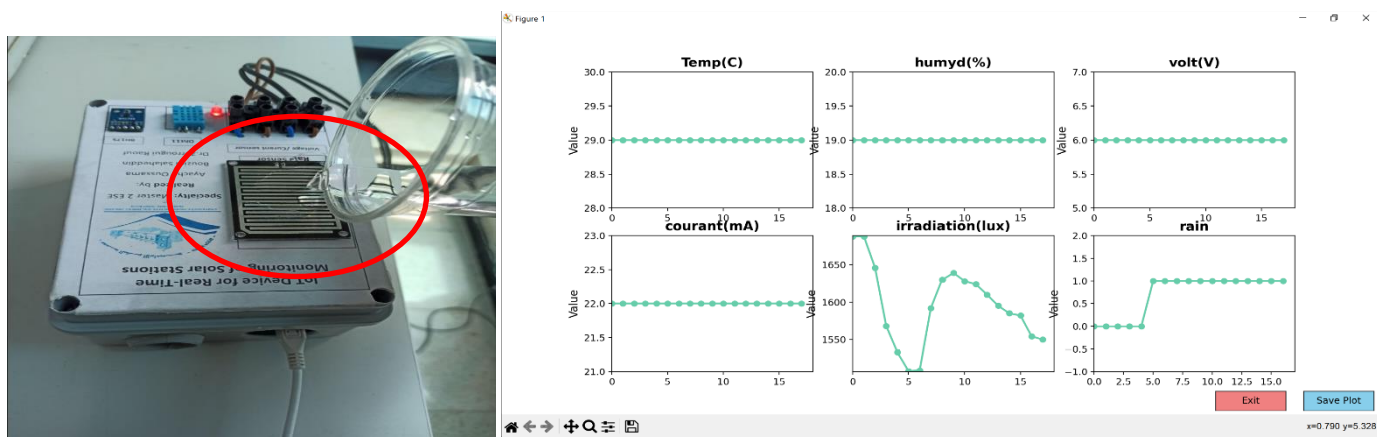
Table 9: result when applying heat on the DHT11

We applied heat to the temperature and humidity sensor at T=20s, and we got a change between these two conditions.

- The ambient temperature Increased to 40°C, and the relative humidity of the air Increased to 35%.
- The current generated by the solar panel is 22 mA, with an output voltage of 6V.
- The solar irradiation was 1500 J/m<sup>2</sup>.
- Finally, the absence of rain was indicated by a value of 0.

The increase in temperature and humidity demonstrates the sensor's responsiveness to environmental changes, while the electrical parameters and solar irradiation remain relatively stable.

III.6.5. Test the system when we make drops of water on the YI-83 Rain



sensor:

Figure 61: the system when we make drops of water on the YI-83 Rain sensor

| Temperature | humidity | Current | voltage | irradiation | Rain |
|-------------|----------|---------|---------|-------------|------|
| 28(C)       | 19%      | 6V      | 22mA    | 1600 J/kg   | 1    |

Table 10: result when we make drops of water on the YI-83 Rain sensor

We have made drops of water on the YI-83 Rain sensor, and we have seen a change in its conditions.

- The ambient temperature is 29°C, and the relative humidity of the air is 19%.
- The current generated by the solar panel is 22 mA, with an output voltage of 6V.
- The solar irradiation, which measures the energy received per unit area, is 1550 J/m<sup>2</sup>.
- Finally, the absence of rain is changing from 1.

The system accurately detected the presence of rain, indicated by the change in the rain value from 0 to 1, confirming the sensor's effectiveness. Other parameters showed minor variations, reflecting typical environmental fluctuations.

**Analysis of Results:**

The tests demonstrate that the developed electronic card can effectively monitor and report the environmental and electrical parameters of PV systems. The data collected under different conditions highlight the system's reliability and accuracy in detecting changes, such as

obstructions, environmental temperature variations, and rainfall. This real-time monitoring capability is crucial for optimizing the performance and maintenance of photovoltaic systems, contributing to more efficient and sustainable energy management.

### Conclusion:

Our system functions well, we can apply it in several fields such as solar stations, industrial plants, homes, and agriculture.

In the last chapter, we presented the architecture of IoT-based solar photovoltaic systems. We began with the hardware design tools, including the solar panel, the ACS712 current sensor, the basic principles of the voltage divider, the DHT11 temperature and humidity sensor, the YL-83 rain sensor module, the BH1750 ambient light sensor, and the Arduino ATmega328P + ESP8266 electronic board. Then, we simulated the electronic board and added components to optimize system performance. Subsequently, we explained the programs used in our system and conducted a real-time test, presenting the results obtained with plotter diagrams generated using Python software.

### Conclusion general:

The work presented in this thesis focuses on an embedded system for real-time monitoring of photovoltaic power panels using the Internet of Things device.

The first chapter presents a quick overview of solar panel history and discusses the many kinds of solar panels. Next, we concentrate on the components of solar panels and the process by which solar cells generate power. We demonstrate the photovoltaic cell equivalent circuit. The future of photovoltaic electricity and the benefits of solar panels round up this chapter.

The second chapter comprehensively explains the Internet of Things (IoT), focusing on connecting devices through the Internet to collect and share data. It then delves into the Seven-Layer Architecture framework, used to design and implement IoT systems. Additionally, the chapter discusses the advantages of using an IoT-based system, such as real-time data collection and analysis, improved maintenance and efficiency, and enhanced decision-making based on accurate information.

In the last chapter, we present our designed IoT-based solar photovoltaic system. First, we discussed the tools used in development. The circuit board simulation was the next step. After that, we described the software applications we used in our system, then performed a test in real-time, plotted the received data using Python software, and finally, discussed an analysis study.

This work allowed us to examine the knowledge acquired during our course and to do multidisciplinary work, combining instrumentation, electronics, mechanics, programming, and renewable energies.

This thesis aims to improve our system by adding additional sensors to measure parameters such as air pressure and wind speed and integrating the Maximum Power Point Tracking (MPPT) technique. These improvements could significantly increase the efficiency of this system and performance analysis.



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