Monitoring system of photovoltaic panels using 433 MHz radio frequency module

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Article Info	ABSTRACT
	In this article, we presented an innovative study that allows direct monitoring of the main parameters of photovoltaic panels. Our study focuses on the skills of radio frequency modules to send the main parameters of photovoltaic cells. In this paper, we used an Esp32 microcontroller in the radio frequency (RF) transmitter block and an Arduino Uno board in the receiver block, in addition, to measure current, we used a current sensor, and to measure voltage, we implemented a voltage divider. After that, we calculated the power and the energy. Note that the various measured and calculated values are stored and used via the ThingSpeak platform. In comparison with similar studies, our achievement presents an` effective and inexpensive solution because its operating principle is based on radio frequency transmission, so it works perfectly even in the absence of the internet. Finally, our study was very well tested without detecting any abnormalities, and the results obtained are a perfect witness to our success. *This is an open access article under the <u>CC BY-SA</u> license.*

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1. INTRODUCTION

Currently, renewable energy from the sun through the exploitation of photovoltaic panels is a key element in the development of countries. in fact, energy production becomes a source connected to the distribution network [1]. We have noted here that the relationship between electrical energy and photon energy, ie the power conversion efficiency of the PSCs exceeds 25% [2], [3]. During the operation of photovoltaic panels, various problems and distortions can occur, frequently leading to degradation of the performance of the photovoltaic system [4]-[7]. Effective management of these systems requires real-time monitoring to detect anomalies in a photovoltaic installation [8]-[10]. We will propose in this article a precise study of "design and construction", to supervise the main parameters of a photovoltaic panel, these parameters will be sent via connectivity based on radiofrequency technology. To increase the overlap space between the transmitter and the radiofrequency receiver in a monitoring context, it is necessary to use the RF433 MHz radio frequency modules with a 16 cm long antenna.

Our paper is systematized as follows: section 2 presents separate studies that have the same objectives, in section 3 we have presented the main characteristics of the Esp32 microcontroller, and Arduino Uno, as well as the sensor ACS712-30A, and finally, we have presented in a detailed way the transmitter radiofrequency 433MHz and the associated receiver, in the same section we presented the design and implementation of our study, in Section 4 we presented the experimental results and discussion via representative diagrams, we used the ThingSpeak platform which allows us to collect and store data from connected objects via the HTTP protocol, in section 5 we have a conclusion.

2.   RELATED WORK

In recent years, interesting research uses Arduino microcontrollers as the main processing element to measure characteristics of photovoltaic panels such as voltage and energy [11]-[14]. An interesting study determines the power characteristics of the photovoltaic panel, the design incorporates the ATMega2560 microprocessor of the Arduino mega board, and appropriate software routines, this study greatly reduces the hardware complexity [15]. Other studies have been based on the integration of the hall effect current sensor ACS712, to measure the value of the current intensity between the terminals of the photovoltaic panel [16]-[18]. In the same vision, other interesting studies have integrated the Raspberry pi as the main processing element and the Wi-Fi module to send the parameters of the photovoltaic panel and ensure its survival in real-time [19]-[21]. Other interesting research on the topic of solar panels used the Esp32 microcontroller for data processing, these studies have implemented a voltage sensor to determine the potential difference value of photovoltaic panels [22], [23].

3.   MATERIALS AND METHODS

3.1. Hardware part

The hardware part of our study consists of two microcontrollers, Esp32 and an Arduino Uno, on the other hand, to measure the current intensity we used the ACS712 30 A sensor, it is a very practical sensor and simple to integrate into IoT projects, note here that this sensor is based on the hall effect. The hardware part also has a voltage divider that will be used to reduce the voltage on the Esp32 microcontroller pins. For the data transmission part, in Figure 1 we used a radiofrequency module, Figure 1(a), and Figure 1(b) to designate the 433 MHz radio frequency transmitter and its receiver, and finally, we used two 16x02 LCD monitors in the RF transmitter/receiver assembly. Finally, we used two 16×02 LCD displays in the RF transmitter/receiver assembly.
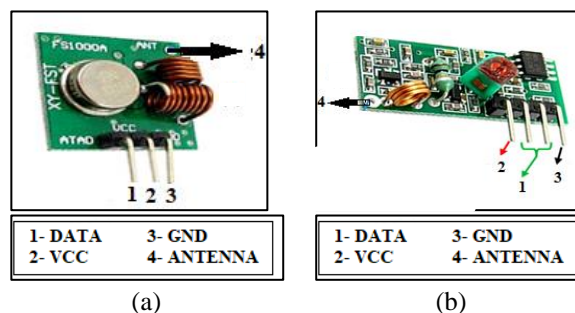

Figure 1. Radiofrequency module in, (a) the transmitter and (b) the receiver

3.1.1. Arduino Uno

The first element of this study is Arduino Uno, it is a microcontroller based on ATmega328, a power supply voltage in the order of 5 V, 2 KB of RAM, 32 KB of flash memory, 1Ko of EEPROM for parameter storage. Arduino Uno runs 300,000 lines of source code per second with a clock frequency of 16 MHz. Other Arduino Uno microcontroller features are grouped in the following table, see Table 1. The second element is the ESP32 microcontroller developed by the Espressif company, it is a development kit used in IoT projects, the main advantage of the Esp32 is that both Bluetooth and Wi-Fi modules are integrated. Other Esp32 microcontroller features are arranged in Table 2.

Table 1. Arduino Uno microcontroller characteristics

Function	Characteristic
Input voltage (recommended)	7-12 V
Input voltage (limits)	6-20V
Digital I/O pins	14 (PWM output)
Analog input pins	6
SRAM	2 KB
Length/ Width	68,6 mm/53,4 mm
Weight	25g

Table 2. Features of the esp32

Function	Characteristic
Number of cores	2
Supply voltage	2,7V-3,6V
GPIO pins	36
Wi-Fi	Wi-Fi: 802.11
Bluetooth	v5.0 et v 5.1
Dimension	48 26 x 11,5 mm

3.1.2. 433 MHz radiofrequency module

To transmit the main parameters of the photovoltaic panel such as power and energy as well as current and voltage to the terminal of the solar panel we used a 433 MHz radiofrequency module whose hardware description is as follows; the transmitter and receiver are unidirectional wireless (RF); the operating current of the transmitter is 9 mA to 40 mA, the operating frequency is equal to 433 MHz; and the transmission distance is in the order of 3 meters (without antenna) to 40 meters (practical), the modulation technique is amplitude shift keying (ASK) amplitude modulation [24]. Finally, the data transmission speed is equal to 10 Kbps, see Figure 1.

3.2. Wireless technology
3.2.1. Comparison

Wireless technology is widely used in several fields, such as the Internet of Things field. We will present in Table 3 a detailed comparison between Wi-Fi, RF 433 MHz, Bluetooth, and ZigBee, this comparison includes power consumption, throughput, bandwidth, and the association of standards [25]. In this part, we noted that the low energy consumption of the radio frequency link has a better advantage in comparison with other wireless modules such as Bluetooth and Wi-Fi. It is for this logic that we have chosen this type of communication in our study.

Table 3. Comparison of wireless technologies

Technologies	Standards Association	Energy consumption	Frequency	Debit
RF	IEEE 802.15. 4	Low	433 MHz	4-9 Kb/s
Wi-Fi	IEEE 802.11	High	2.4GHz	---
Bluetooth	IEEE 802.15.1	Low-High	2.4GHz	<24 Mbps
ZigBee	IEEE 802.15. 4	High	2.4GHz	<1Mb/s

3.2.2. Principle of proposal

In this part, we will propose the main design proposal of our study, our monitoring system is effective thanks to the following advantages: Easy maintenance, and installation, Remote Monitoring - Secure Communication and finally, sending data with 433 MHz radiofrequency modules is very useful in isolated places with "no internet". On the other hand, we have analyzed the propagation of the radio frequency signal so that the transmission is on an acceptable diffusion surface, we know that the various phenomena that limit the performance of our study are defined by (1), (2), and (3) in [26]. As shown in (1) defines the attenuation of the wave between the transmitter and the radio frequency receiver, Figure 2 represents the attenuation of the propagation of radio frequency waves.

$$PL_{dB} = 10 \, log_{10} \left(\frac{p_t}{p_r} \right) \tag{1}$$

- PL_{dB}: It is the attenuation of the wave in dB,
- p_t: It is the power transmitted,
- p_r: It is the power received

In the practical case, the free space noted above does not represent the ideal case in the field of transmission of wireless waves. The general model incorporates a coefficient n to denote the association between the separation distance and the received power. the propagation attenuation equation (in dB) can be expressed as (2) [27].

$$PL(d) = PL(d_0) + 10n \, log_{10} \left(\frac{d}{d_0} \right) + x_\delta \tag{2}$$

In this equation, n is the path factor (n=2 is the free space), Xδ Gaussian random variable of standard deviation δ. In free space, the relationship between antenna gain, the distance between transmitter/receiver, and power is given by the equation of Friis.

$$p_r = p_t \frac{G_t G_r \lambda^2}{(4\pi d)^2} \tag{3}$$

- Gr: The antenna gain of the RF transmitter,
- Gt: The antenna gain of the RF transmitter,
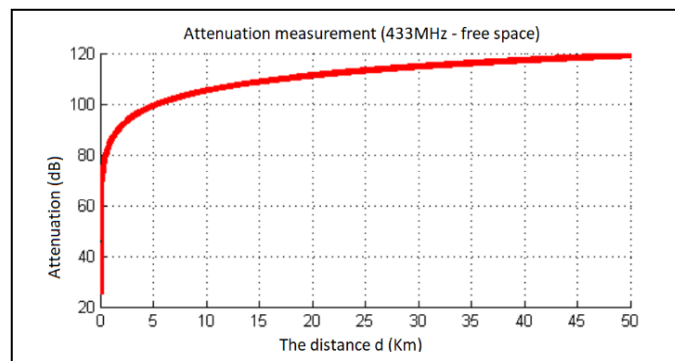- λ: The wavelength of the signal,
- d: The distance between the RF transmitter and the RF receiver.

Figure 2. Attenuation of radiofrequency wave propagation

3.3. Measure current and voltage

In this article, we have implemented the current sensor ACS712-30 to efficiently measure the current provided by the photovoltaic panel, the operating principle of this sensor is based on the hall effect to determine a direct current in the range 0 to 30 A, we have represented in Figure 3 the ACS712 current sensor, Figure 3(a) represents the input/output pins and Figure 3(b) represents the hall effect. We have noted here that the sensitivity of this sensor is equal to 66 mV per ampere [28]. The operating principle of this sensor is relatively simple, when a current runs through an internal copper conductor a magnetic field is generated, then this hall effect sensor transforms the magnetic field into adequate voltage [29]-[31].
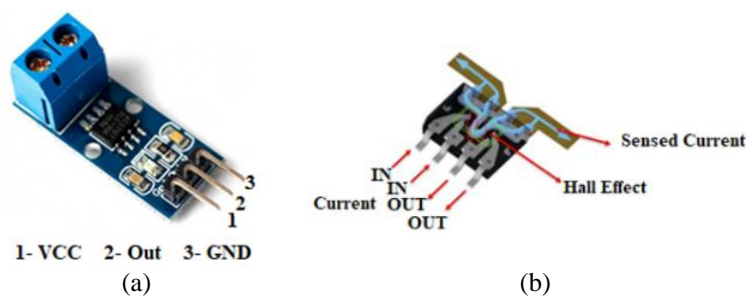

Figure 3. ACS712 current sensor in (a) pin out and (b) hall effect

To measure the potential difference delivered by the photovoltaic panel. We have noted here that the voltage at the level of the Esp32 pins must necessarily remain less than 5 v, for this we used and exploited the advantages of a voltage divider, in our project we used R1=1 KΩ and R2=12 KΩ, a photovoltaic panel voltage is applied as input to these two resistors, we measured the output voltage at resistance R2, see Figure 4. The measurement of the pin voltage 34 of the Esp32, allows us to deduce the voltage value of the photovoltaic panel. Finally, we used the two sizes measure current (I) and voltage(V) to calculate the other two values, power P and energy E.
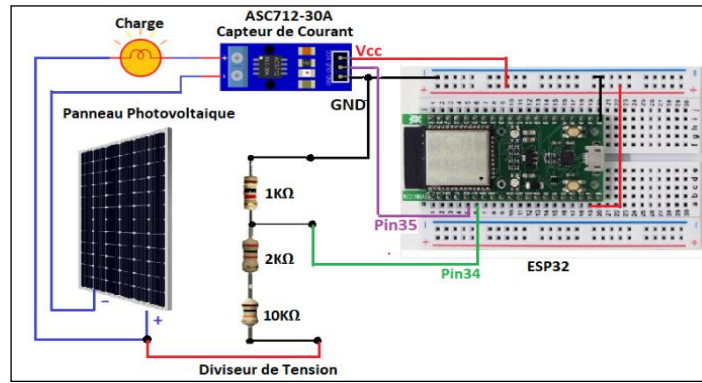
Figure 4. Main circuit diagram

To send the current value and the voltage as well as the energy and power, we created our radio frequency project using the 433 MHz modules, we implemented the Esp32 microcontroller and the FS1000 A RF module to build the transmitter block, on the other hand, the receiver block consists of an Arduino Uno board in which we operated a 433 MHz receiver module. The FS1000 A RF transmitter is characterized by the pins: GND, Vcc, and the data pin whose data will be sent and modulated using the ASK technique [32], [33]. The RF transmitter is characterized by a simple and very fundamental connection, the VCC is connected to 5 V, the GND is connected to the GND of the Esp32, and finally, the Esp32 pin number 12 is linked to the Data pin of the RF module. The connection of the RF receiver to the Arduino Uno microcontroller is very fundamental, the VCC pin is connected to 5 V, the GND pin is related to the ground of the microcontroller, and finally, one of the two data output pins (the center pins of the RF receiver) will be linked to pin number 11 of the Arduino Uno microcontroller. In the coding part, we started by installing the radio head library [34], this library provides fundamental data transfer between RF devices in a simple way. This is the basis of radio frequency communication via the 433 MHz RF module. The operating principle of this library is based on data encapsulation [35]. Before sending this package to another Arduino, a cyclic redundancy control will be added, the wrapping process adds a preamble and a header. If the data is received in accordance, the receiver Arduino starts decoding. After, we created an ASK object named "rf_driver", and in the main loop, we generated a buffer variable to record the size of the message transmitted with RF 433 MHz, note that spaces and punctuation marks are counted in the body of the message. We then checked to see if we had received a valid and acceptable package. We called the strtok() function to split the values received after a radio frequency communication, these quantities are power, energy, current and voltage. Figure 5 shows the various stages as well as the evolution of the main functioning of our study.
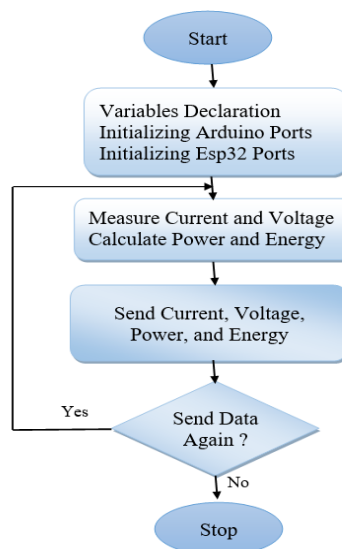

Figure 5. Main diagram

4.   RESULTS AND DISCUSSION

Our study has been implemented and tested; the results obtained provide a perfect testimony of the success of this study. Thus, the figures: Figure 7 which represents the RF transmitter FS1000 A and the associated receiver, shows in real-time, the received values of the parameters of the photovoltaic panel via radio frequency communication. In this study, to increase the coverage area of the transceiver, on the transmitter and receiver each, we have adjusted an antenna, with this help we greatly expanded the distance to approximately 100 m. On the other hand, to obtain relevant experimental results, we used a copper antenna with a diameter of 2.5 mm, and we noticed that the coverage space of the radio frequency module is related to the length of the antenna, several measurements are made, see Table 4. The RF433 MHz communication range in relation to the antenna length is represented in Figure 6.

Table 4. Range of the RF module relative to the length of the antenna

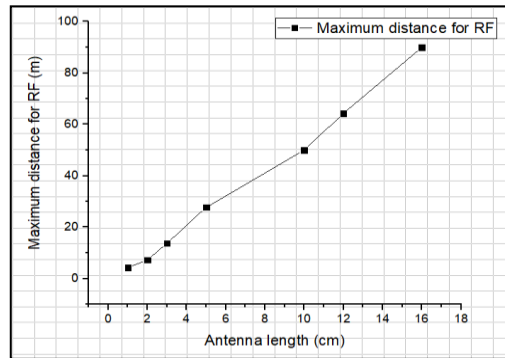| Number of measurements taken	Antenna length (cm)	Maximum distance for RF (m)
5	1	4,3
5	2	7,2
5	3	13,75
5	5	27,7
5	10	50
5	12	64,3
5	16	90

Figure 6. RF433MHz communication range/antenna length

Figure 7, represents the radio frequency module in Figure 7(a) we have the transmitter box. While Figure 7(b) represents the receiver box, noting clearly that the quantities present at the level of the transmitter are the same values received by the receiver after this RF link. In the first loop the transmitted data are: current: 2.5 A, voltage: 12.58 v, power: 31.43 W, energy:320.2 Ws.
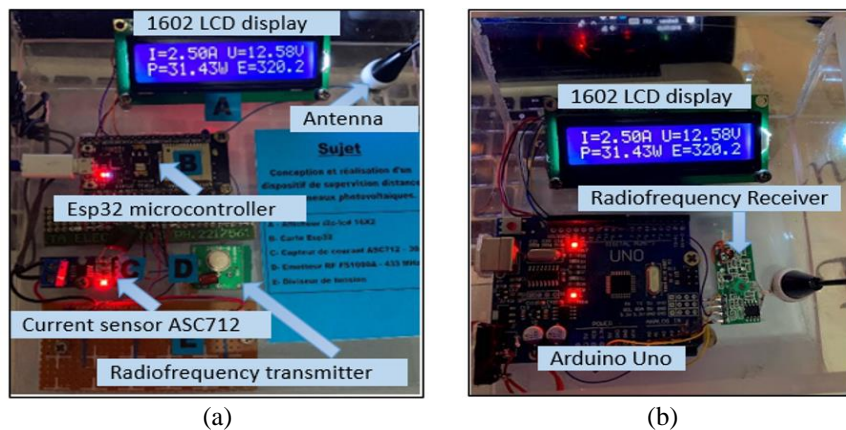

| (a) | (b) |

Figure 7. Radiofrequency module in (a) transmitter box and (b) receiver box

Finally, we exploited the ThingSpeak platform (open-source web application), this platform is intended for the internet of things projects, allowing us to collect and store data from connected objects via the HTTP protocol. Taking advantage of the different values collected over given periods, we represented the parameters of photovoltaic panels on graphs. It is therefore an easy scenario to properly detect malfunctions, Figure 8 shows a presentation of the data in the ThingSpeak platform, see Figure 8(a), to illustrate the energy changes per second, while Figure 8(b) describes the variations in total energy supplied by the photovoltaic panels. The quantities in question are displayed on the serial monitor of the Esp32, see Figure 9.

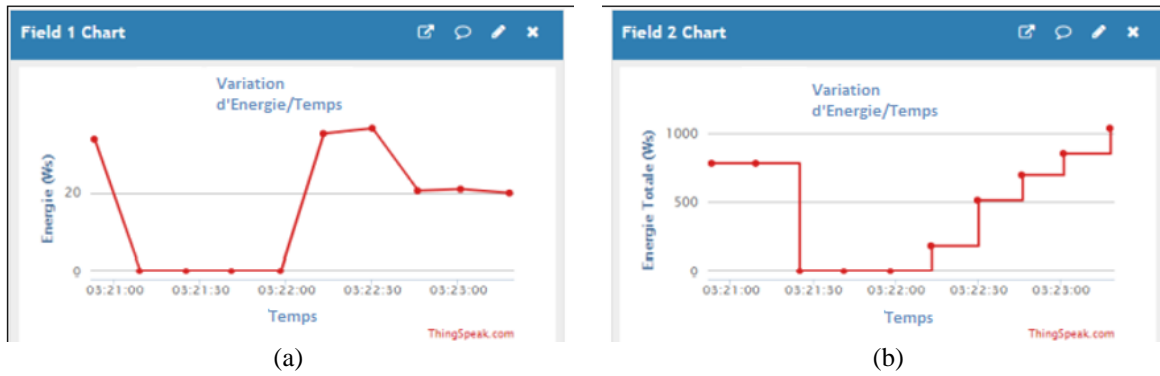(a)   (b)

Figure 8. Representation in the ThingSpeak platform, in (a) energy variations per second and (b) total energy variation
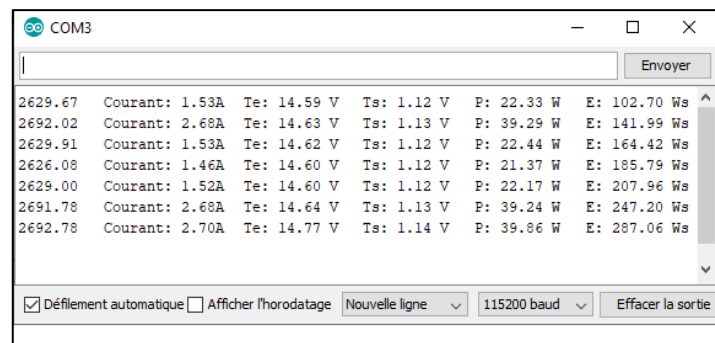

Figure 9. The result on the Arduino serial monitor

5.   CONCLUSION

Our study was implemented, and during its execution in different stages, we noticed high reliability. This shows that our study presents an acceptable solution for real-time data transmission in order to optimize remote supervision of photovoltaic panels, this monitoring system is necessary to identify failures and malfunctions before any unwanted surprises. Compared to other studies that target the same skills, our solution is based on radio frequency as the main element of transmission and remains always a better choice, especially in isolated places «with no internet». We have also noted that the integration of a wireless communication link via RF modules into IoT projects is perfectly simple. Unfortunately, the type of antenna used for omnidirectional propagation, so it is necessary to integrate other tools to direct the waves in a single direction since the presence of the information will be useless on the sides and in the opposite direction. Finally, the development of a photovoltaic monitoring system increases the credibility and reliability of the system and ensures its proper operation for acceptable time intervals.

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