Implementation of a low-cost intelligent street light system using internet of things

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ABSTRACT

In the contemporary world, science and technology are advancing swiftly to meet the growing human need for electricity. Within this framework, street lighting, serving as the most vital and ubiquitous element of urban lighting infrastructure, contributes significantly to public electricity consumption. Hence, enhancing the operational efficiency of street lamps becomes imperative to conserve energy. Nonetheless, traditional street lighting systems, being manually controlled, consuming excessive power, and entailing high installation expenses, present notable drawbacks and concerns. Leveraging the internet of things (IoT), advanced innovations automate various areas, including health monitoring, traffic management, agricultural irrigation, street lights, and classrooms. The current manual operation of street lights leads to substantial global energy waste. To address this, an integrated hardware and software solution is proposed. Practical implementation of the hardware devices employs a wireless sensor network, while the software focuses on developing an IoT application for data storage, analysis, and visualization. The proposed system enables effective monitoring of parameters such as ambient temperature, current, voltage, and energy consumption of photovoltaic street lights, which are used as an indicator of the lamp status. Using Xbee modules, a configuration by the X-CTU software is necessary to communicate between all street lights wirelessly. These Xbee modules are used as a leading technology for wireless sensor networks due to its low power and low cost. Experimental results demonstrate that the proposed system is energy-efficient and cost-effective, and further can be implemented in real street light systems.

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1. INTRODUCTION

The world's growing population, rapid urbanization, and the continuous development of technology require the implementation of an intelligent management system for street lighting to make cities smart according to the smart city model [1]. Furthermore, intelligent street light systems, also known as smart street lighting, are becoming increasingly relevant as cities around the world look for ways to reduce energy consumption and costs [2], [3]. Generally speaking, the research and investment in intelligent street light systems have come a long way in recent years [4]. Many current cities are now using advanced sensor technology, such as light-sensitive sensors, motion sensors, and cameras, to automatically adjust the brightness of street lights based on the level of ambient light and the presence of pedestrians or vehicles. This allows for energy savings and improved public safety. Additionally, some systems also include wireless communication capabilities, allowing for remote monitoring and control. However, there are also shortcomings to these systems. So, the main challenge is the cost of installation and maintenance, which can be significant. Another challenge is ensuring that the technology is reliable and able to withstand harsh outdoor conditions. Additionally, there is a need for standardization and interoperability among different systems to allow for seamless integration and data sharing. Lastly, the lack of widespread awareness and knowledge among municipalities and citizens, makes it hard to adopt these systems on a large scale [5]. Also, the integration of cameras and other sensors can provide valuable information for traffic management, public safety, and even air quality monitoring. The implementation of IoT-enabled intelligent street light systems can lead to improved efficiency, cost savings, and enhanced public services [6].

Numerous researchers have explored various techniques for monitoring public lighting, as documented in the literature. Mouaadh *et al.* [7] introduced an intelligent, adaptive control system enhancing public lighting performance, tested in the Bechar campus in Algeria with 9 LED lamps, achieving notable energy savings of up to 50%. Eriyadi *et al.* [8], a smart street lighting prototype, integrating IoT and fuzzy logic, automatically adjusts light intensity based on vehicle and pedestrian presence, resulting in an economic energy-saving system with up to 49.55% electricity consumption reduction. Hashim and Shakib [9] proposes an automatic control system for minimising electrical power waste on highways and urban roads, based on an Arduino circuit, effectively managing lights based on prevailing conditions. Outferdine *et al.* [10] present a technical and economic study of a solar-powered street lighting system in a Moroccan municipality's southern region, demonstrating substantial budget gains (about 70%) and notable energy savings compared to conventional public lighting.

This study focuses on treating the supervision of photovoltaic street lighting using the IoT with low-cost cards. The overall systems consist of street lights equipped with sensors, cameras, and wireless communication devices that allow for real-time monitoring and controlling of the lighting, by collecting data on light usage and patterns, cities can optimize the energy consumption of their street lights, reducing costs and carbon emissions. In brief, an intelligent management system for public lighting is studied. This system is equipped with INA219 current/voltage sensors installed in each solar street light, with LDR sensors to detect the beginning of the day and night, with Arduino boards, and with Xbee modules for data transmission between the different street lights using the ZigBee protocol. The system also consists of a Wifi module named ESP8266 for data transmission between the solar street lights and the monitoring application which is hosted in the Thingspeak platform [11], [12].

The current paper is organized as follows: after this introduction, Section 2 provides background information on the PV street lighting using IoT systems. Section 3 describes different components of the monitoring system of stand-alone PV streetlights. The results obtained will be presented and discussed in Section 4. Finally, the conclusion and future work of streetlights with IoT are provided.

2. BACKGROUND OF GLOBAL SYSTEMS

Typically, the supervision of PV street lighting using IoT systems involves the monitoring and management of various parameters of the lighting system. IoT devices collect data on energy production, battery status, lighting performance, and environmental conditions. This data enables real-time monitoring, predictive maintenance, energy optimization, and remote control of the street lighting system, enhancing its efficiency, reliability, and sustainability. Figure 1 displays the entire smart system using the Xbee module.

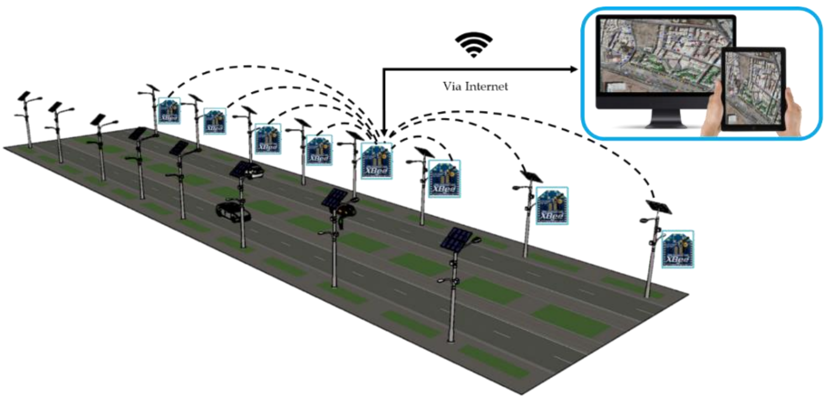


Figure 1. Photovoltaic street lighting using IoT systems

3. MATERIALS AND METHODS

3.1. Development tools

In this platform, many tools are used, that is:

- Things peak: is a platform providing various services exclusively intended for the creation of IoT applications. It offers real-time data collection capabilities, data visualization in graphical form.
- Arduino integrated development environment (IDE): is a software that brings together the tools needed to control the Arduino board. It includes a text editor, a debugger/compiler, an interface to manage COM ports and board type.
- X-CTU: is a free cross-platform application designed to allow developers to interact with Digi radio frequency (RF) modules through a graphical interface. It includes new tools for easy installation, setup and testing of Xbee modules.
- DHT22: (also named as AM2302) is an ambient temperature and humidity sensor, it uses a capacitive humidity sensor and a thermistor to measure air temperature and humidity and transmits it digitally on a serial bus.
- INA219: is a sensor module allowing the measurement of both voltage and direct current through an I2C bus.
- Xbee: is a wireless communication module, it uses the ZigBee radio communication protocol based on the IEEE 802.15.4 standard with an operating frequency of 2.4 GHz.
- ESP8266: is a microcontroller Wifi module developed by the manufacturer Espressif, it works with a frequency of 80 MHz with a Wifi interface.

3.2. Monitoring system of stand-alone PV street lights

In this section, smart street lighting is the main component of a smart city [13]. The major challenge is to achieve energy savings by integrating a system based on an intelligent sensors network in the public lighting [14]. This system is composed of several blocks, such as data processing block, wireless transmission block and sensor block [15]. Figure 2 shows the block diagram of the monitoring system of photovoltaic street lighting.

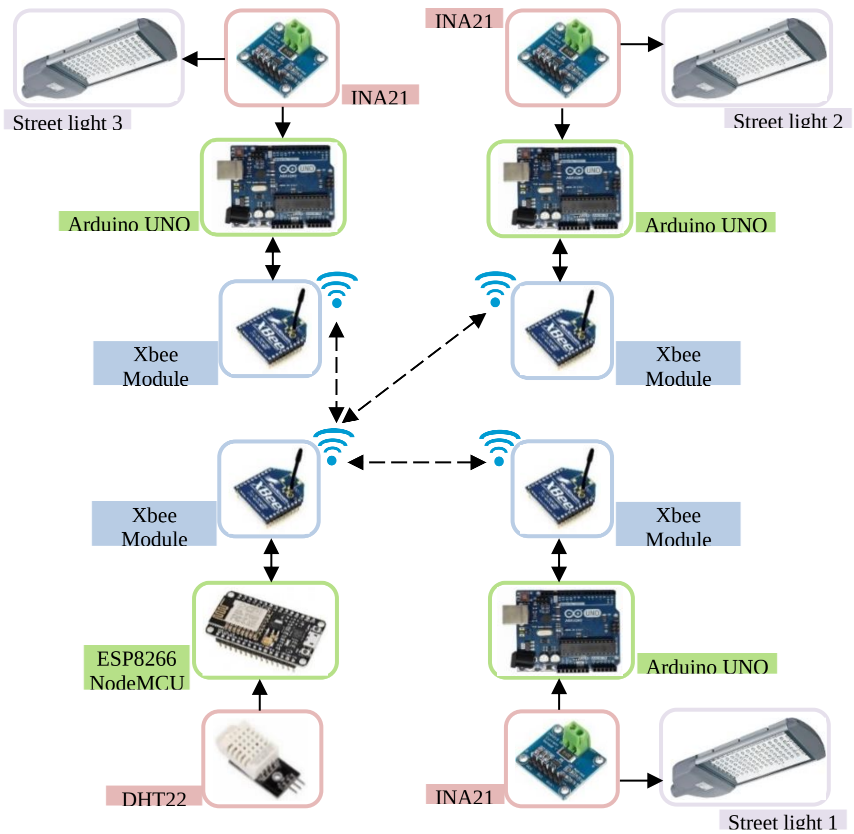


Figure 2. Block diagram of the monitoring system of stand-alone PV street lights

3.2.1. Algorithm developed in the monitoring system of stand-alone PV street lights

The monitoring system of PV public lighting allows the processing and analysis of the various parameters measured in real time. There are two types of parameters, the external ones are the intensity of the light and the degree of circulation [16]. While the internal parameters are the current, voltage, power and energy consumed by the Leds. All measurements from the sensors are processed by the microcontroller via algorithms, in addition to other algorithms for calculating power and energy. The results of these measurements are used to determine the state of the lamps (on or off) and whether the lamp is good or defective [17], [18].

All measured data are sent, wirelessly and via internet, to the server [19]. Then, the monitoring system displays the different data in the graphical interface. This system ensures two roles, monitor the state of the stand-alone PV streetlights, and at the same time remotely control these streetlights [20].

The system concerns the control of the lighting of three streetlights as shown in Figure 2. The three streetlights represent the slaves, each is equipped with an Arduino UNO microcontroller for data processing, an INA219 current/voltage sensor for the Led, an Xbee module for data transmission between slaves and master [21], [22]. The latter is equipped with a temperature/humidity sensor for measuring the ambient temperature, an Xbee module for data transmission to the slaves, an ESP8266 microcontroller Wifi module that ensures data processing and even communication between the streetlights and the monitoring application [23]. The INA219 current/voltage sensor used allows the measurement of current, voltage and power consumption of a device. It is also used to measure the power generated by the PV panel and the battery.

3.2.2. Configuration of the communication modules used

The Xbee modules allowing communication between the various stand-alone PV streetlights require the configuration of certain parameters, such as the operating mode either transparent (AT) or command (API), addressing that includes the network address (ATID), (ATMY) address and (ATDL) packet destination address. Finally, the network association either point-to-point or with coordinator. Figure 3 shows this configuration [24].

The Xbee module is configured using the X-CTU software that allows the management of Xbee modules connected to a computer as well as the transmission and reception of data [25]. As a prototype, we chose the Xbee series 1module with a star topology and whose configuration is illustrated in Figure 3 for the master and in Figure 4 for the slave.

Concerning the master (letter "C" in Figure 3), we have chosen the API 2 mode since the topology is a star. Then we chose 1111 as the PAN ID network address, 0 as the MY source address. Then, the value 0 for DL as destination address, because we have more than one recipient. Finally, the Xbee modules work in network mode with coordinator (CE=1) as shown in Figure 3.

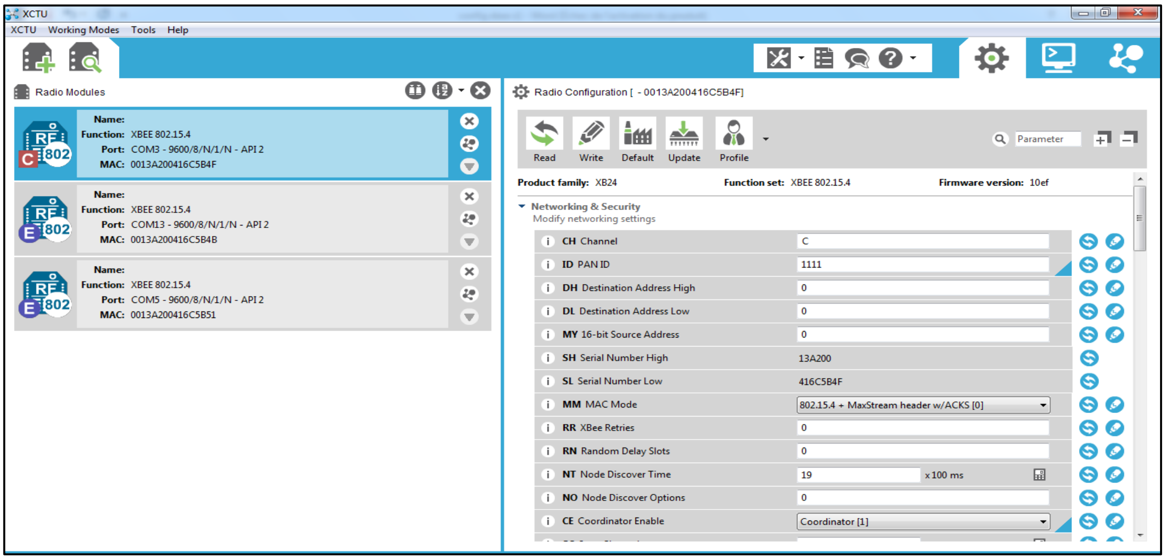


Figure 3. Configuration of Xbee module representing the master

For slave 1 (letter "E" in Figure 4), we have chosen the API 2 mode, then the same address 1111 of the PAN ID network, the value 2 for the MY source address. Then, the value 0 for DL. Finally, the Xbee modules work in the same network mode with coordinator (CE=0) as shown in Figure 4.

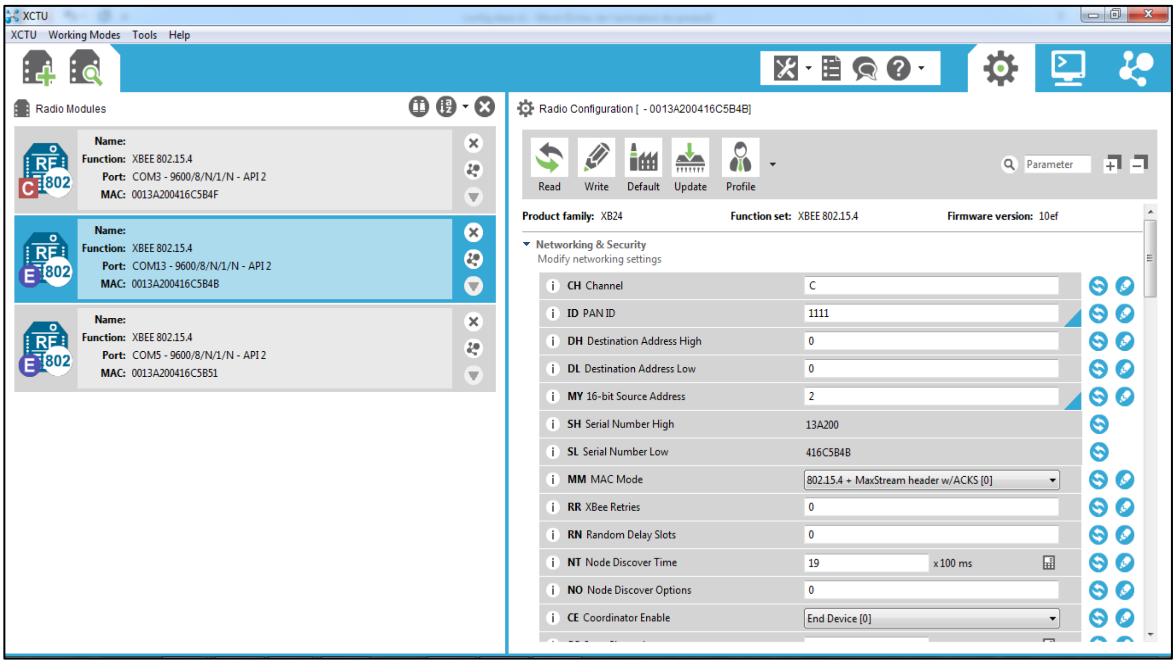


Figure 4. Configuration of Xbee module corresponding to the slave 1

3.2.3. Experimental platform

After the configuration of the various Xbee modules, the program developed and embedded in the Wifi module based on the ESP8266 microcontroller aims to send through the "Master" Xbee module, the on/off control of the different solar streetlights corresponding to "slaves 1, 2 and 3" as illustrated in Figure 5. The Wifi module also ensures the transmission of the state of the stand-alone PV streetlights, to the monitoring application developed under the Thingspeak platform. The latter allows the data reception through the HTTP protocol and, of course, the storage of this data. It also allows real-time display of several variables in the form of figures or curves.

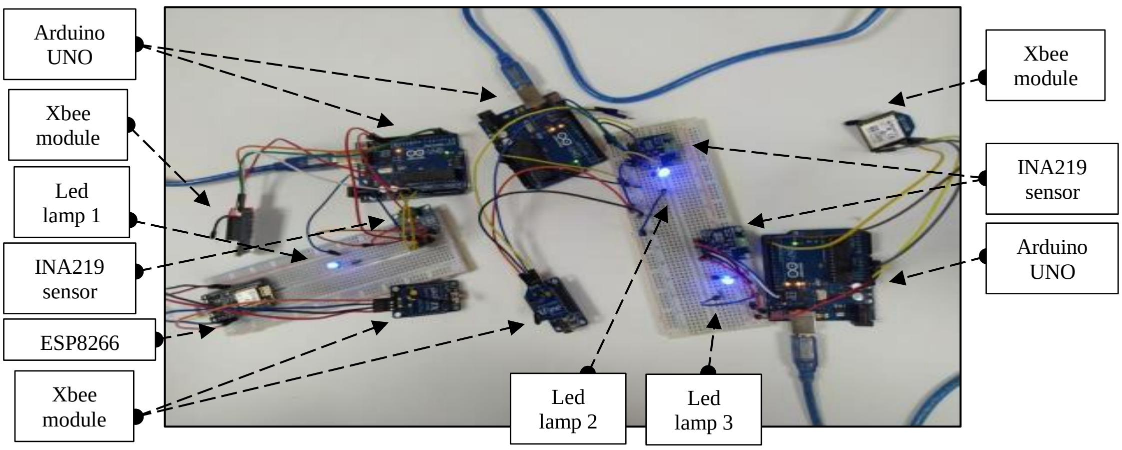


Figure 5. Remote control platform for three stand-alone PV streetlights

To control the lighting of LED lamps from the graphical interface, when the user presses the button of LED lighting control, the Thing speak server then interprets the request and sends it to the ESP8266 Wifi module via the HTTP protocol [26]. Then, this module processes and transmits this request over the serial port, to the Master Xbee module. Then, the latter sends the request by RF to the other Xbee modules. Finally, the corresponding module transmits this request via a UART serial link, to the Arduino UNO microcontroller for processing and thus control the lighting of the LED lamp [27], [28]. Figure 6 shows the synoptic of remote control of three stand-alone PV streetlights.

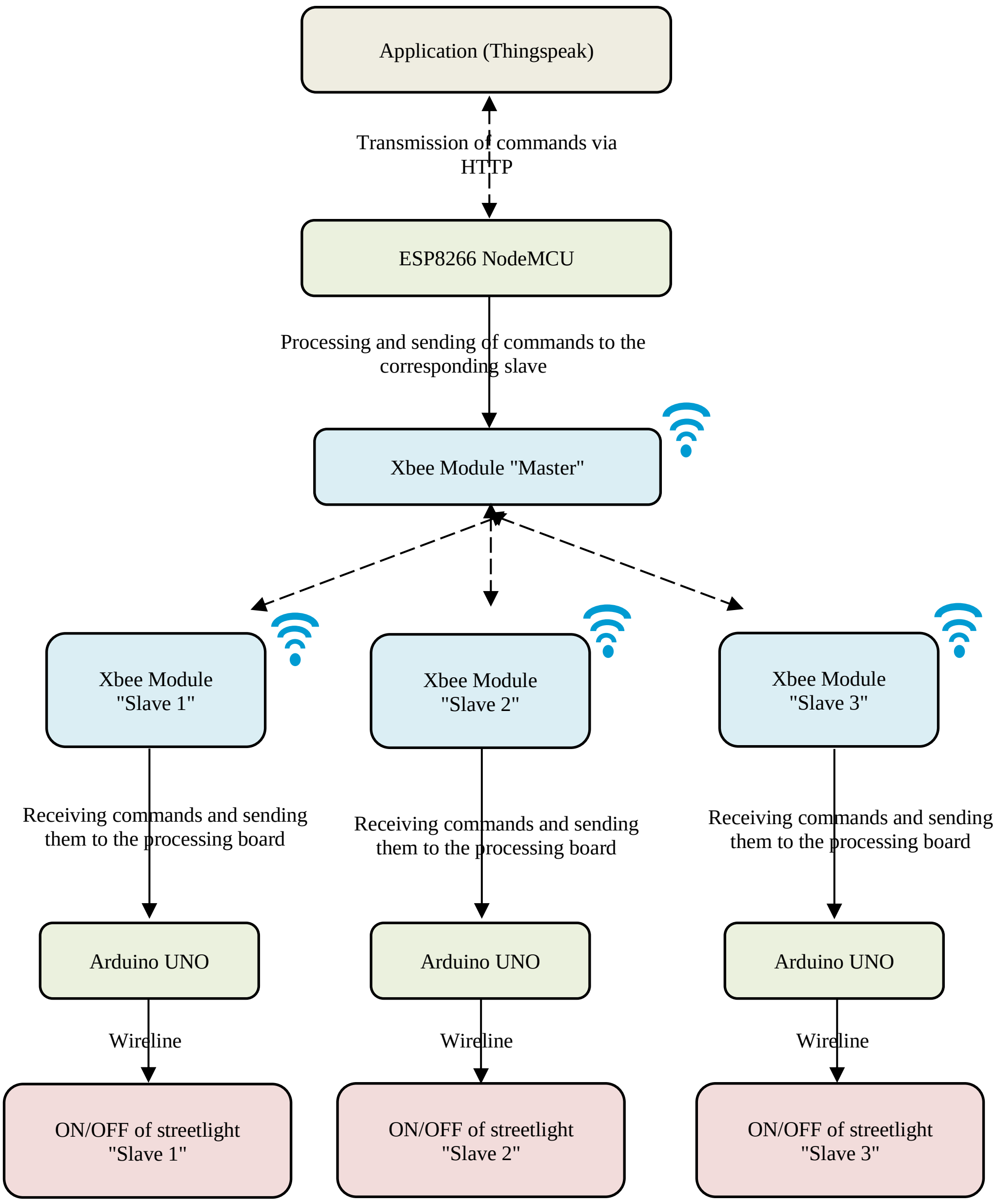
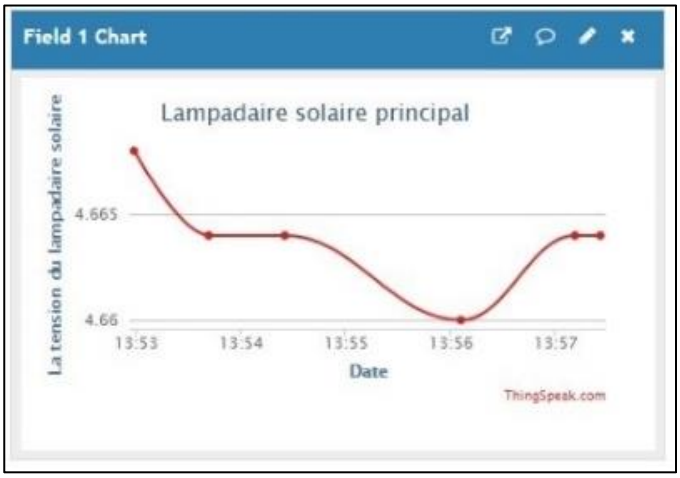


Figure 6. Synoptic of remote control of three stand-alone PV streetlights

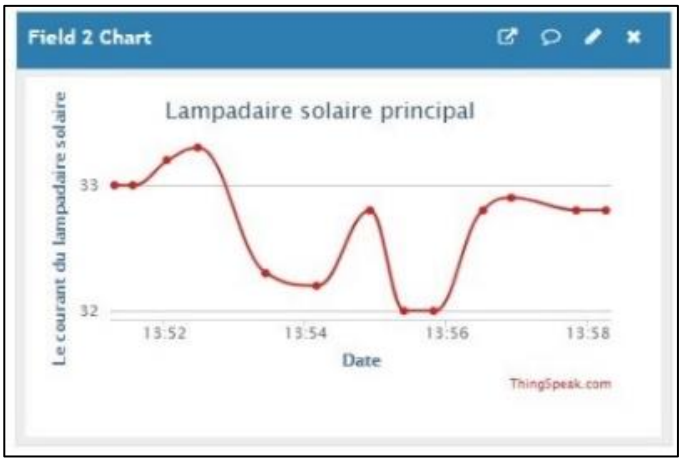
4. RESULTS AND DISCUSSION

After wiring and development of the various programs implemented in the processing boards (ESP8266 and Arduino), we have created under the Thingspeak platform, an interface to monitor the lighting of stand-alone PV streetlights [29]. First, we created a new chain named "Main PV streetlight". Then, we completed the fields corresponding to the measured variables, namely voltage at the terminals of the Led lamp, current through the Led lamp, ambient temperature. Then, we recorded the data entered.

Finally, we obtain the interface illustrated in Figures 7 is real time graph of Figure 7(a) voltage and Figure 7(b) current of a PV streetlight. From these figures, we deduce that the voltage measured at the terminals of the Led lamp is about 4.66 V, Figure 7(a). while the current absorbed by the Led lamp is 32.5 mA, Figure 7(b). The ambient temperature is displayed in Figure 8 which is equal to 29.4 °C.



(a)



(b)

Figure 7. Real time graph of (a) voltage and (b) current of a PV streetlight

Figure 7 shows two windows namely:
- Figure 7(a) shows the evolution, as a function of time, of the voltage of the Led lamp and equal to 4.66 V;
- Figure 7(b) corresponds to the evolution, as a function of time, of the current through the Led lamp whose value is 32.5 mA.

And Figure 8 illustrate two windows corresponding to:
- Figure 8(a) shows the evolution, as a function of time, of the ambient temperature whose value is 29.4°C.
- Figure 8(b) corresponds to the ambient temperature for a given moment.

The real-time information on state of the lamp help to detect and identify whether light is defective or not, then, to optimize and manage the maintenance via instantaneous maintenance. Consequently, it reduces the maintenance costs. In short, compared to other review papers on solar powered smart street lighting, our paper includes the configuration of the communication modules Xbee using the X-CTU software. In addition, the parameters that indicate the lamp status are continuously measured and displayed in the Thingspeak platform such as current and voltage of the lamp.

(a)

(b)

Figure 8. Representation in the Tingspeak platform in (a) ambient temperature variation and (b) instantaneous ambient temperature

5. CONCLUSION AND FUTURE WORK

In this paper, the experimental platform of the monitoring system of stand-alone PV streetlights described and elaborated- is composed of three parts such as the communication nodes, the manager and the monitoring software. We show that it allows the improvement of energy efficiency in the street lighting system, the remote management of lighting as well as the maintenance management of this system. And therefore, the reduction of maintenance costs. In this framework, the proposed platform is composed of a network of sensors, namely the INA219 current/voltage sensor and the ambient temperature sensor. They are linked to the Arduino UNO microcontrollers which are themselves linked to the Xbee modules. The latter has is responsible for the transmission of data between the main streetlight and the other streetlights, these modules allow a low power and low-cost smart streetlight system. Then, the ESP8266 Wifi module is installed in the main streetlight to communicate with the application developed in the Thingspeak platform. As consequence, this application allowed remote control of lighting of the PV streetlights, as well as real-time monitoring of several parameters such as the current flowing through the Led lamp, the voltage at the terminals of the Led lamp, the air temperature that influences the production of the PV generator. To conclude, the suggested smart system application will be adopted and applied in remote urban and rural locations with little/big traffic. In the future, this work could be improved upon by designing, simulating and comparing the conventional street lighting and solar LED street light which will confirm that the second system is much more economical, more inexhaustible and non-polluting.

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