Environment Monitoring Modules with Fire Detection Capability Based on IoT Methodology

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Abstract. Worldwide, forests have been devastated by fires in recent years. Whe- ther by human intervention or for other reasons, the history of burned areas is increasing year after year, degrading fauna and flora. For this reason, it is vital to detect an early ignition so that firefighters can act quickly, reducing the impacts caused by forest fires. The proposed system aims to improve the nature monitoring and to assist the existing surveillance systems through Wireless Sensor Network. The network formed by the set of sensors has the potential to identify forest ignitions and, consequently, alerts the authorities through LoRaWAN communication. This work presents a prototype based on low-cost technology, which can be used in areas that require a high density of modules. Tests with a Wireless Sensor Network made up of nine prototypes demonstrate its effectiveness and robustness in terms of data transmission and collection. In this way, it is possible to apply this approach in Portuguese forests with a high level of forest fire risk, transforming them into Forests 4.0 concept.

Keywords: WSN · IoT · Fire detection · Sensor Modules · Wildfires

1 Introduction

Portugal is the European country with the highest incidence of vegetation fires, not only in terms of number but also in the burnt area. This ecological disturbance occurs every year and causes dangerous social, economic and environmental damage [1,2]. The historical data indicates that in the last decades, there

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has been an increase in the occurrence and also in the severity of wildfires. In 2017, reports show that there were more than 15000 rural fires, corresponding to a burnt area close to 2400 km^2. The resulting devastation were directly responsible for the deaths of more than 100 people [3,4]. In the following year, in 2018, there were about 9700 rural wildfires, scoring a burnt area of approximately 380 km^2, with the Bragança region as the second district with the highest burnt area [3].

In this sense, monitoring the Portuguese forests is a fundamental action for our future, not only to observing flora and fauna but also to warn of possible fire ignition. By early warning of forest fire ignition, combat teams can act to minimize fire impacts. The project Forest Alert Monitoring System (SAFe) aims to contribute to the improvement of nature monitoring and to support the existing surveillance systems. The SAFe project implements a set of innovative operations that allow to identify a forest ignition and also will monitoring the fauna, such as sensors modules. The application of sensor modules for forest data acquisition will be implemented in the Bragança region, in the Serra da Nogueira territory. Due to the characteristics of this forest, spreading the modules across the whole would be chaotic and hard to understand the data [5]. Therefore, it is necessary to develop a strategy for fixing the modules regarding the vegetation type.

Some factors are deterministic for the choice of these points, such as forest type, history and estimation of areas at hazard of flame, areas that have been burned over the years, terrain elevation and forest density. Each of these maps provide essential data and finding the point that connects all of these maps is a possible solution for the insertion of each sensor modules. However, as a starting point for the SAFe project to find this point in common, it is necessary to obtain the operation of the fire detection modules in real situations. By attaching to each pair of modules in nearby regions, it is possible to determine the quality of communication and possible interference that the environment may cause in data collection.

This work will detail the modules' development that makes the detection of forest fires, as well as the small scale formation of the Wireless Sensor Networks (WSN) to obtain his behavior in real situations. In this way, the proposed sensor modules can provide the SAFe project with the necessary information from the developed modules to determine the optimal fixing points. Thus, the SAFe project could use the annual maps reported by the "Instituto da Conservação da Natureza e das Florestas" (ICNF) [6], and allocate the necessary number of sensors for each region with high fire risk.

This paper is organized as follows. After an introduction in Sect. 1, related work about fire detection techniques applied in Portuguese forests is presented in Sect. 2. In Sect. 3, SAFe system architecture is described. The sensor modules description is shown in Sect. 4, next is demonstrated in Sect. 5 the module assembled. The obtained results are presented in Sect. 6. Finally, Sect. 7 concludes the paper and points some future work direction.

2 Related Work

Wildfires are considered complex events in terms of causes, intensity, behavior, variability, hard to control, size and severity, their early detection is essential [7,8]. In this context, the maximum time interval, from ignition to the alert response of firefighters, should not exceed 6 min [9,10]. In addition to early detection capabilities, estimating the direction of propagation and the fire speed also crucial in extinguishing fires [11]. For these purposes, there are several methods: human observation towers [4]; systems that employ Charge-Coupled Device (CCD) [12,13] and Infrared detectors [14]; satellite systems and images [15] and WSN systems [16].

In the national plan, named "Plano Nacional de Defesa da Floresta Contra Incêndios" (PNDFCI) created by ICNF [6], it establishes myriad strategies to avoid wildfires. It is emphasizing on the existence of observation towers distributed throughout the national parks. However, the unreliability in the observation towers that are managed by human operators and their performance does not go beyond 10% in more unfavorable areas [7,17]. This reason pointed to use others technologies, as well as the use of surveillance cameras in the spectrum from the visible to the infrared. Even so, the accuracy of these systems depends on the type of topography, time of day, and other environmental conditions [18,19].

On the other hand, with the development of new technologies within the scope of Industry 4.0, the forestry sector can be digitized in terms of solving issues such as rural fires [20,21]. Integrating several systems, making them collaborative is a possible solution since there is still no type of operating system to alert wildfires based on these new approaches in Portuguese forests. For example, the service provided by [22], this company can provide forest ignitions in up to 4 min through modules that measure temperature, humidity, and CO_2 levels. In this sense, the literature does not present studies with developed techniques for forest fire alerts through the use of low-cost sensors that transmit information through long-range communication. This process would be possible with the implementation of sets of heterogeneous sensors that would work collaboratively, strategically located in forests with high fire risks. Therefore, the data can be analyzed by algorithms to predict regular situations based on forest history, and also identify abnormalities. Thus, an in-depth study is needed to integrate all these techniques that are available in the context of Industry 4.0 and apply in rural regions.

3 System Architecture

As already mentioned in the previous section, the SAFe project aims to install a set of innovative activities to be developed in regions with potential for ignition of fire in the district of Bragança. Therefore, SAFe is planned to follow an integration strategy with some tools that can work collaboratively. The union of these tools form the architecture of the system, illustrated in Fig. 1. Where a region with a greater risk of forest fire should be monitored according to its characteristics, such as identifying areas with greater or lesser irregularities in the soil. In this way, the forests in the Bragança region will benefit from these sets of components and applications proposed to identify forest ignitions.

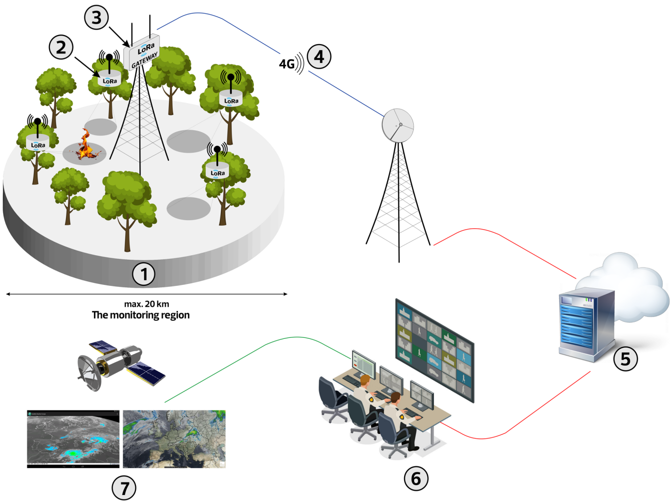


Fig. 1. Illustration of SAFe system architecture [23,24]. ① The monitoring region, ② Wireless sensor module, ③ LoRaWAN gateway, ④ 4G/LTE link, ⑤ Server, ⑥ Control center, and ⑦ Detection support system.

The proposed system can be divided into four essential elements: the monitoring region, the set of sensor modules, the communication system and the control center. The integration of these four elements together with a management system, based on artificial intelligence, will empower efficient and intelligent analysis of the data. This data analysis will generate the creation of forest ignition alerts, and consequently, should also alert the rescue and combat teams (such as firefighters, civil protection or city hall). These alerts must be parameterized and presented in a personalized way, according to each organization involved. It is still possible to fragment these four elements into smaller components, through categories. Therefore, it is possible to define eight categories that work collaboratively, identified by Fig. 1, they are:

– The monitoring region (represented by ①) is the region where the set of Wireless Sensor Modules will be placed to collect data. The choice of these regions should take into account the annual fire risk map provided by the ICNF [6].
– The WSN sets (represented by ②) are responsible for the data acquisition at the forest in real-time. The location of each Sensor Module is defined through an optimization procedure that considers the hazard fire in each coordinate,

and must also consider the forest characteristics, such as soil type, cover tree density, terrain relief, among others;
- The LoRaWAN Gateway (③) receives data from each sensor module by radio frequency communication, and then forward the data through a 4G/LTE link (or by Ethernet where available) to a server (represented by ④);
- The Control Center (represented by ⑥) receives all information, computes the data and sends alerts for hazardous situations or forest fire ignitions to the surveillance agent in the region. Therefore, this control center has a Server (represented by ⑤) that stores all collected data along over years, and perform artificial intelligence procedures to correlate data from sensor modules with external data (represented by ⑦); such as satellite image, local scale real-time fire hazard indexes, availability fuel content, weather data and moisture content of the vegetation.

Due to the complexity in the description and development of each of these items, this work will focus only on low-cost sensor modules. In this sense, the development stages of these modules are presented, with their respective considerations. The modules were designed to create a WSN, this network in turn will collect data from the region at risk of forest fires and inform the server. In order to form the WSN, many modules are necessary, and for that reason all the development was thought about the best cost benefit. In addition, it is also expected that these modules are easy to assemble and integrate with communication network, since the fixation sites are in the middle of dense forests. All these concepts is described, respectively, in the next section.

4 Wireless Sensor Modules

In the search to minimize the damage caused by forest fires, the PNDFCI plan determines what each region of Portugal must do [4]. These strategies have already shown that they are significant when compared to what has been implemented over the years. However, when comparing data from more recent years, it is noticeable that the areas affected by forest fires continue to grow. A possible justification is that the plan needs new approaches to complete the ones that are already being carried out. In this sense, considering that the plan only determines actions on a macro scale, it is necessary to take care of Portuguese forests with more attention to regional characteristics.

We are in a new technology paradigm, where digitization is revolutionizing industrial, medical and even educational sectors. Given this, it is possible to take advantage of and use the same technology to combat the fire. The Internet of Things (IoT) arises in a friendly way since the "thing" could be installed in the forests to detect fire ignitions and warn the fire-fighting teams. Therefore, each device needs to have unique characteristics to meet the most diverse scenarios found in Portuguese forests.

The development of these devices needs to consider a series of restrictions, such as size, battery autonomy, low cost (both in implementation and communication), being flexible for the addition of new sensors. Thus, the Fig. 2 illustrates in a simplified way the device proposed in this work. Each module components will be detailed in the next subsections.

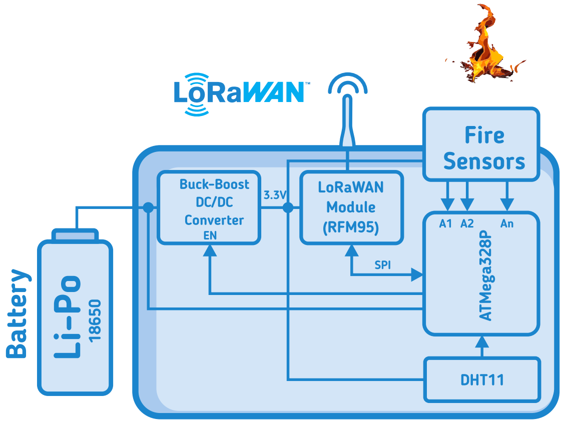


Fig. 2. The main architecture illustration of the proposed device [23].

4.1 The Core

This module was developed considering the characteristics that make it useful for forest situations, such as the ease installation and integration with WSN, and also low-cost for the use with WSN's high density. Besides, it can be placed in places where theft or vandalism may occur, such as the forest's edge regions. This module is also prepared to perform several measurements, in the case, to change or add more sensors for future approaches.

The central element of the module is the ATmega328p [26] microcontroller, hardware widely used by developers who want cost-benefit in their projects. It can be configured through the Arduino platform, either through the USB port or using the pin-outs RX and TX [25]; the latter is the means used in this work for the firmware update or configurations. Besides it is a well-known microcontroller, ATmega328p was chosen to be used in the modules because it has enough I/O analog and digital ports to support the sensors and the desired interfaces such as SPI to the LoRa module and it can be powered between 2.7 V and 5.5 V which is compatible with the Li-Po battery voltages.

4.2 Power Supply

Based on this, this module is powered by a 18650 lithium-ion cell battery that will power the entire system. The battery can supply a voltage of up to 4.1 V, so it can affect the operation of other components that operate in the 3.3 V region. To maintain the operating range of all sensors and transceivers used in

3.3 V, a buck-boost converter is applied. Therefore, this converter will ensure that no sensor changes its acquisition values during battery discharge and will also not damage the RFM95 transceiver. In this way, the 18650 battery is directly connected to the converter and the ATmega328p, and everything else is powered by the output of the DC-DC converter. Figure 3 presents the block diagram of the power supply system. Therefore, before entering the energy-saving mode, it is necessary to disable the converter through this digital pin. When it is necessary to collect and send data, it is required to activate this pin.

On the other hand, when the battery voltage reaches levels below 3.0 V, the converter stops working. In this case, the sensors and the transceiver will not work either, but the ATmega328p will continue to function because it is still in the operating voltage range. To avoid this case, one of the ATmega328p's analog ports is used to measure battery levels before performing the data collection and sending process. If the battery voltage is below 3.1 V, the sensor module sends a signal to the control center that the battery level is critical, then the microcontroller turns off the converter and the `Power Down` mode is triggered. The microcontroller will remain in `Power Down` mode and will no longer measure the sensors' values.

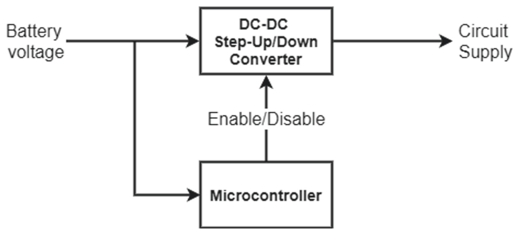


Fig. 3. DC-DC converter diagram used in each module.

4.3 Sensors

As already mentioned, the sensor modules are designed to be flexible in terms of sensor replacement or addition. It is possible to insert sensors with SPI and I2C interface (digital and analog), as long as it respects the limits of the ATmega328p. For this work, flame sensors and a device that acquires the temperature and relative humidity of the air were chosen.

These sensor modules read the ambient temperature and humidity through the DHT11 component [27]. Other temperature and humidity sensors could be used, but DHT11 was chosen to be implemented in the prototype due to the low cost, digital output, low installation complexity and also because it has a relatively small measurement tolerance (±5% humidity and ±2° temperature). In addition to the temperature and humidity measurement, there are five analog inputs that are used to acquire the commercial flame sensors values. Several flame sensors are being evaluated and will be addressed in future work. These values, both for flame and temperature and humidity, are measured over a sampling period of about 60 s. Then, they are transmitted to the control center to process these data.

4.4 LoRa Communication

The communication method to transmit the data collected from the forest must be based in low consumption (to enhance the sensor modules autonomy), long-range (due to the extensions of Portuguese forest reserves) and low-cost of implementation and operation (to maintain a good cost-benefit). Therefore, the LoRaWAN protocol emerges as a communication solution that satisfies all the listed requirements.

Among the available devices found on the market, RFM95 is the one used to approach this work, as presented in Fig. 4 a typical LoRa TM transmit sequence. This transceiver has a Long Range (LoRa) based modem, with interference immunity (which minimizes current consumption during transmission). Developed by Hope RF, this device makes it possible to achieve a sensitivity above 148 dBm, making it suitable for use in various industrial and agricultural sectors [28].

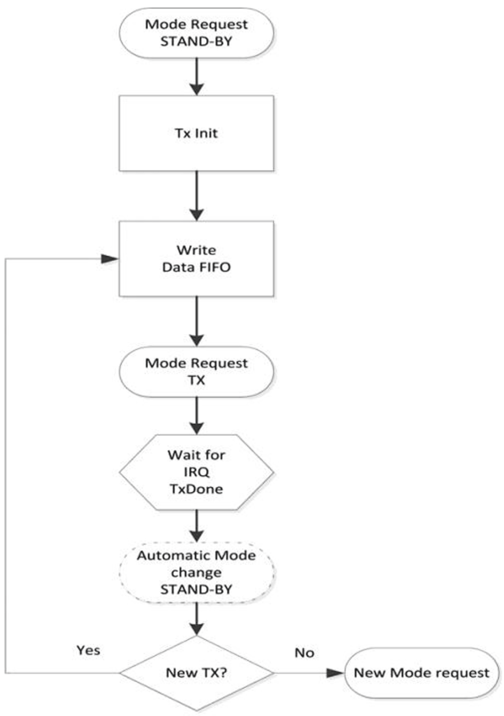


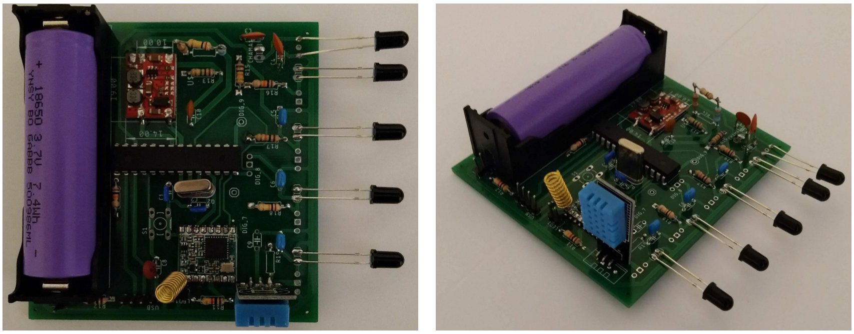
Fig. 4. RFM95/RFM96 applied in each module [28].

The RFM95 is powered by 3.3 V supplied by the DC-DC converter, so it will only be turned on after the ATmega328p microcontroller exits energy-saving mode. In this sense, the RFM95 is connected via SPI to receive from the microcontroller the data that the sensors have collected, and consequently, send to the LoRaWAN Gateway.

5 Sensor Module Assembled

Taking advantage of the tools mentioned in the previous section, a Printed Circuit Board (PCB) was created to aggregate all the tools in order to compose the sensor module. This PCB can be seen from different angles in Fig. 5, with ATMega328p used as the core, the DC-DC converter, the 18650 battery, the RFM95, the electronic components and the sensors. In which Fig. 5a indicates through a top view, the sectors distributed within the PCB, where the DC-DC converter is placed as close as possible to the battery and the microcontroller.

With an isometric view in Fig. 5b, there is a demonstration of the peripherals that need to be arranged on the edge of the board, such as serial communication for the firmware configuration, the DHT11 sensor needs to have contact with the ambient air to perform the measurement, RFM95 communication antenna to avoid signal blockages, and flame sensors cannot be blocked by other components.



(a) Developed PCB assembled with the components (Top view).

(b) Developed PCB assembled with the components (Side view).

Fig. 5. Developed sensor module assembled in PCB.

The Fig. 6 shows the proposed low-cost prototype module finalized and deposited in a 3D printed box, with dimensions: 100 mm × 40 mm × 90 mm. There was a necessity to reorganize some peripherals, such as the arrangement of flame sensors. These were removed from the PCB and connected by wires, then they were fixed to all sides of the box, except the top and back of the sensor module.

There was no fixation on these faces because the idea is to attach these low-cost modules to the tree trunks (rear face), and also because it is not necessary to point to the sky (upper face). Another peripheral that demanded to be moved is DHT11, as it could not be inside the box. Therefore, a grid was created at the box bottom so that DHT11 could adequately measure the temperature and relative humidity air. As it is a prototype, the modules developed in this work do not yet consider the Ingress Protection (IP) standards. This standard indicates a protection scale for solids from 1 to 6 and liquids from 1 to 8. In this sense, it is necessary to dedicate a study only to determine the module structures' IP code, and therefore it will not be detailed in this work and will be further addressed.

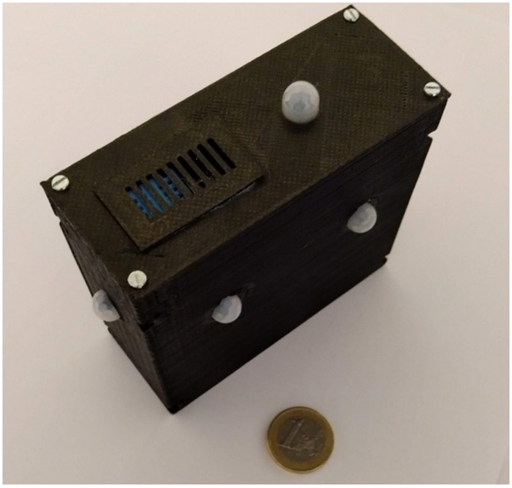


Fig. 6. Developed sensor module in the 3D printed case.

6 Results

This section will present the results of the module developed by performing a WSN, regarding acquisition, transmission and registration. First, nine modules were assembled equal to the one described in the previous section. In this way, all modules have a DHT11 sensor and also five flame sensors aimed at each box side (except the rear and upper face). Then, the nine modules were separated in pairs, forming four sets of 2. And a module was chosen to be fixed alone. Thus, in total, five points are selected on the map to create the WSN shown in Fig. 7.

Fig. 7. Map with the sensor modules distribution forming the WSN.

The five fixation points were chosen according to the soil type and tree around the Polytechnic Institute of Bragança (IPB) campus. In this sense, the pair formed by modules 1 and 2 are joined to trees close to buildings. Module 3 and 4 are attached to tree trunks in a small orchard, and modules 5 and 6 are positioned to medium-sized trees around the Fervenza River that crosses the campus. On the other hand, modules 7 and 8 were fixed off-campus, in reserve with a high level of tree cover density. And the last module 9 is set on a tree that is planted on a yard; that is, it does not share other elements around it.

As the objective is to analyze the WSN's behavior, it was not considered the modules' positioning concerning the sun or other factors that are around the trees chosen to receive them. Just as it was not regarded as climatic events, like rainy days. However, as shown in Fig. 8, the modules were fixed on branches considered to be free, that is, branches that have their smooth surface and that would not interfere with leaves or other branches. The following subsection shows the data collected from DHT11 sensors and also from flame sensors.

(a) Sensor module 1. (b) Sensor module 5. (c) Sensor module 9.

Fig. 8. Some examples of fixing the sensor modules on tree trunks.

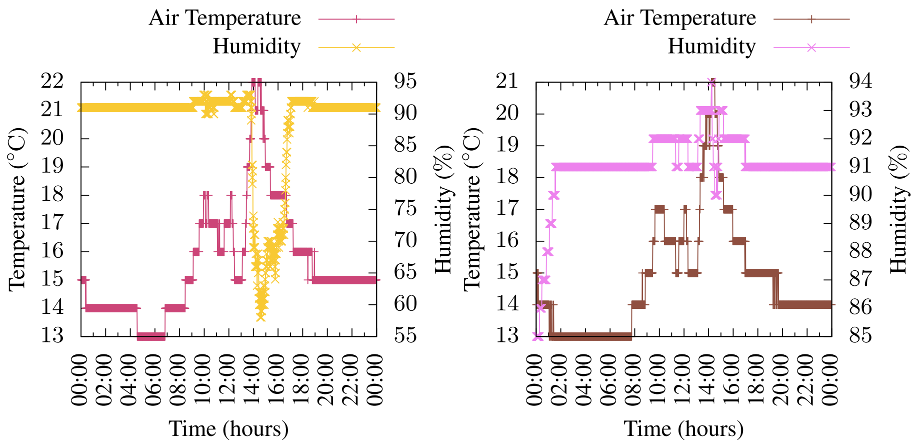
6.1 WSN Data

In order to verify the functioning of the WSN, the time interval of 60 s was configured in the firmware of each module. That is, at each time interval, the module checks the battery level, collects the environment data through the sensors and sends them to the LoRaWAN Gateway. Next, it goes into a power-saving state until the next time interval starts. The value configured for the time interval is the limit allowed according to the Things Network (TTN) server usage policies. In this way, all data is copied from the TTN to a local server and stored according to each ID, created individually for each module. The results are divided in temperature and humidity values at the beginning and for flame sensor values at the end of this subsection.

Temperature and Humidity. In Fig. 9, is shown the data collected during 24 h from the pair of sensors located at Point 1 (Module 1 and Module 2). Similarly, the graph in Fig. 10 exposes the data collected from Module 3 and Module 4 (Point 2).

As already mentioned, Point 3 and Point 4 are monitored, respectively by pairs Modules 5 and 6, and Module 7 and 8. The humidity and temperature data of these two points can be viewed through the graphs in Figs. 11 and 12.

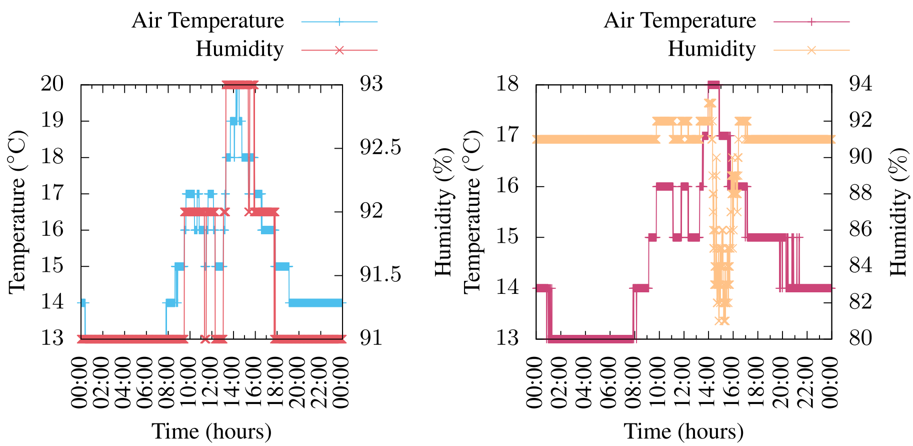
The data reported from Module 9, inserted in Point 5, can be seen in Fig. 13. The amount of data collected during the 24 h was the same for all graphs displayed, that is, each graph has 1440 samples. This means that all WSN modules were able to carry out the monitoring procedure without losing information.



(a) Sensor Module 1.

(b) Sensor Module 2.

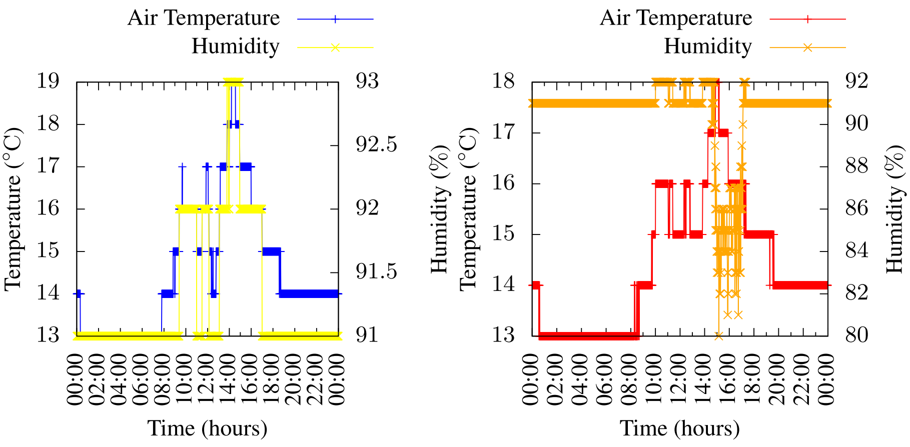
Fig. 9. Data collected from Point 1.



(a) Sensor Module 3.

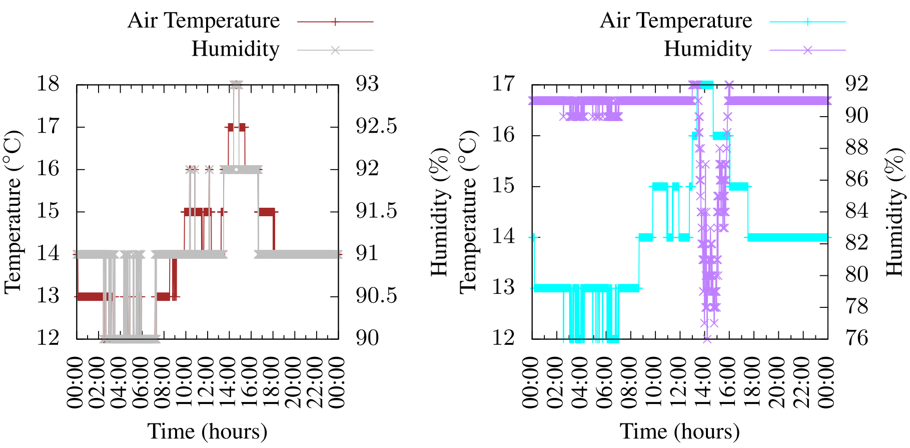
(b) Sensor Module 4.

Fig. 10. Data collected from Point 2.



(a) Sensor Module 5. (b) Sensor Module 6.

Fig. 11. Data collected from Point 3.



(a) Sensor Module 7. (b) Sensor Module 8.

Fig. 12. Data collected from Point 4.

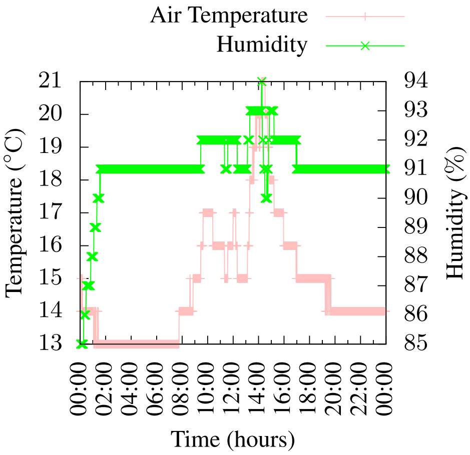
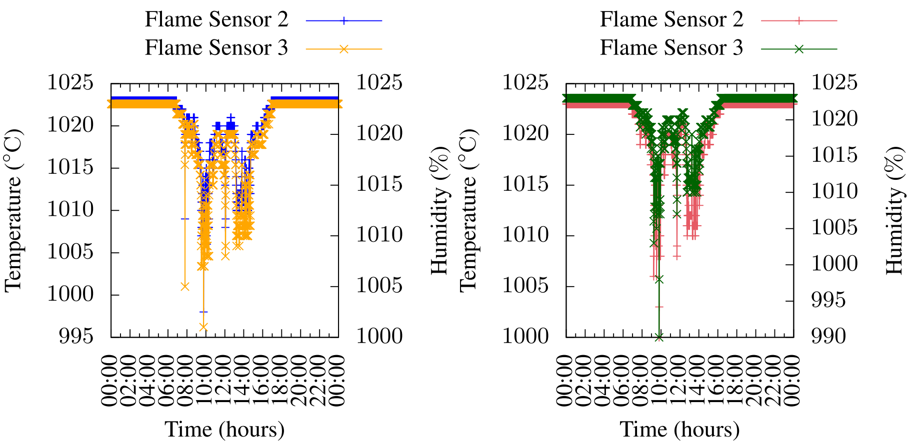


Fig. 13. Sensor Module 9, in Point 5.

Flame Sensor. As previously addressed, the developed module is equipped with five flame sensors. The results of the acquisition for modules 7 and 8, as example, are presented in Figs. 14. During the night period, the measured values are constant 1023. During the day, the acquired value decreases by an average of 1000. In fact it is true that the sunlight affects a little bit the flame sensor, but a fire ignition will be detected with lower values (around 400). It can be concluded that the modules should be placed in shadow places covered by the trees.



(a) Sensor Module 7.

(b) Sensor Module 8.

Fig. 14. Data collected from Point 4, Flame sensors in shadow area.

7 Conclusions and Future Work

The Forest Alert Monitoring System (SAFe) project proposes the development of innovative operations to minimize the alert time for forest fire ignitions. This project will contribute to real surveillance systems, improving firefighters and civil protection with more details and real-time information. As a basis for this project, the acquisition and communication modules, which will be spread across the forest, will gather information on various data relevant to the efficient characterization of existing forest conditions. This work addressed the developed modules that acquire and transmit the date through LoRaWAN. The hardware for these modules are presented and validated in real scenario. As future work, a new firmware will be developed to decrease the transmission rate while ensuring rapid fire detection and a battery consumption reduction. Furthermore, different flame sensors will be evaluated.

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