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A Novel Application in Overhead Power Lines of Wireless Self-Powered Monitoring System for Early Detection of Forest Fires.

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Abstract

Forest fires have burned a record 700,000 hectares in the EU in 2022. In this context, additional efforts are required to prevent hazards for humans, property and preserve wildlife. This paper presents a wireless self-powered and distributed sensor system to monitoring forest for the early detection of fire. The approach discusses the preliminary design to take advantage of overhead power lines to deploy a low-cost mesh network around them. A gateway node powered by an energy harvester on a power cable enables the deployment of a mesh network of nodes over a kilometer-long area.

Keywords: Forest fire; wireless sensor network; WSN; energy harvesting.

1 Introduction

According to forest fires in Europe, Middle East and North Africa report from European Commission, in 2020 fires of great than 30 ha were observed in 39 countries and a total area of 1075 145 ha was mapped, around 35% more than in 2019 [1]. To protect forest from fires, early detection is of the essence. Detection technologies are classified according to the sensors employed: optronic systems, satellite cameras and sensor networks. These methods are based on collecting data from sensors located in the area or through satellites passing over it, and its processing with specific algorithms.

Optronic systems consist of optical devices, which may operate in different spectrums, as infrared and visible range. Usually, cameras are set in a fixed location and placed on a high structure that can rotate to inspect the widest possible area. Infrared cameras operate in almost any circumstance (night, rain, fog…), while visible cameras are limited by sunlight and weather conditions.

In contrast, satellite cameras are orbiting the Earth capturing its surface data. This technology uses one satellite or a constellation, to capture infrared, visible, ultraviolet spectrum ranges and sometimes spectroradiometer. Typically, satellites used are in orbit, then the investment cost is relatively low. The satellites are able to capture large areas, but because of their low spatial resolution, cannot detect small forest fires. Furthermore, the information refresh may be low due to the image is captured when satellites pass over the area of interest.

Lastly, sensor networks measure, analyze and send environment variables and fire warnings to a management system to apply fire detection algorithms. Usually, each sensor harvest energy to be self-powered and works independently. These detection systems can detect fire at an early stage after it has started. On the other hand, they can fail in extreme environmental conditions and are more susceptible to damage or theft.

To address this issue an early warning tool based on sensors to monitor temperature, humidity and detect gases and cameras, could lessen the wildfire severity by detecting fire in the early stage and sending alerts. Wireless Sensor Networks (WSNs) consist of tiny, economical and low-power sensor devices to measure the environment variables, being one of the most reliable tools for early detection of forest fires [2].

Deploying a sensor network in remote areas brings challenges in power consumption, range, and connectivity. Some proposals use open source Arduino hardware to monitor environmental variables, such as a low-cost Bluetooth temperature sensor at [3], and a LoRa shield with a temperature, humidity, and air quality sensor at [4] or smoke detector in [5]. In order to provide LoRaWAN connectivity Raspberry Pi 3 and Pycom LoPy modules were used in [6] to monitor temperature, humidity, atmospheric pressure and gases. Also, low power ZigBee sensor nodes is used to extend life as battery powered node in [7].

In addition to those already mentioned, diverse sensors are proposed in the literature for the early detection of fires. A Raspberry Pi 3 with Arduino and flame sensor was proposed in [8] to detect flames with a wavelength between 760 nm - 1100 nm. Some approaches extend the node functionality with IR, ultrasonic, gas and soil moisture sensor using wifi communications [9]. Others analyze specific noises of different forest fires [2] or potential illegal deforestation via 3G/4G mobile network [10].

To improve energy efficiency in communication process, previous works present appropriate routing protocol such as MRA, LEACH, APTEEN, ADMS-MAC and NFOM [11] to be deployed for forest fire monitoring and analysis. The APTEEN reduces number of proactive transmissions and uses threshold parameters for reactive transmission when required, being the best suitable as concluded in [12]. Other routing protocol approach in [13] is based on flooding, therefore each intermediate node verifies if it has already treated this alert or not using a unique sequence number.

On the other hand, data mining is used to collect the important information for algorithms to analyze temperature, wind, relative humidity... patterns [14]. The scientific community is working on the improvement of the algorithms, including techniques as linear regression and deep learning. Neural networks have been shown to be effective in managing uncertainty and imprecision, so by combining WSN with NN, wildfire detection can be enhanced [15]–[17]. Also a fuzzy logic was proposed to determine the probability of fire and detect faulty nodes [18], and mist computing is introduce to reduce bandwidth and latency [19].

In wildfire detection, real time images are also used to make predictions and detect wildfires using deep learning [14]. Moreover, systems based on IoT and image provides a continuous live data of the forest environmental conditions to detect fire intensity [20]. In fact, advances in camera-equipped Unmanned Aerial Vehicles (UAVs) have made it possible to develop drones to observe forest fires, such as in [6], where a fixed-wing to provide an overall overview in difficult terrain and rotary-wing drones for confirm the fire detection was proposed.

Wireless sensors are efficient tools for collecting data because of quick deployment and low cost. However, cameras and gateway are power demanding devices, which makes it difficult to use in the forest. Magnetic energy harvesting form power lines is a promising technology for self-powered devices [21], [22] because it no depends on the weather condition. Some approaches use energy harvesters to scavenger energy from the power line to deploy wireless monitoring technologies [23]–[25] to obtain data of the energy transmission line [26]. So, energy harvesting has enough potential to be used for not only smart grid applications.

This paper proposes a novel approach, the use of grid infrastructure to power an advanced gateway and supervisor node, to deploy a mesh network of sensor around it. The gateway uses an overhead line harvester to power the gateway communication module and the advanced features. Therefore, the power module does not require an expensive infrastructure in the forest for its operation and requires low maintenance. Association of the Mediterranean Transmission System Operators (Med-TSO) and European network of operators of electrical transmission systems (ENTSO-E) operates more than 400,000 km of transmission lines and taking into account the huge grid distribution network, there is potential for the deployment of early fire detection approach, ensuring a wide coverage of the European territory.

This paper is organized as follows: Section 1 introduce the interest of WSN for early detection of forest fires and provide a literature review of previous works. Section 2 describes the proposed solution in detail. Relevant environment laboratory test is explained in Section 3. An installation example for forest fire detection system is presented in Section 4 and finally Section 5 concludes the paper.

2 Proposed solution

The solution shown in Fig. 1 is intended to be implemented in forest areas, where the distance between the measurement point and the receiver is in the range of kilometers. The goal is to measure environmental variables to provide information for early detection of fires. The acquired measurements are sent to the mesh gateway, to connect the sensor network with Internet through mobile or ad-hoc network.

The gateway node is equipped with a visible and infrared range camera to provide visual information and detect the intensity of the fire. This information and weather forecast can be combined by fire detection software to extract seasonal warning patterns.

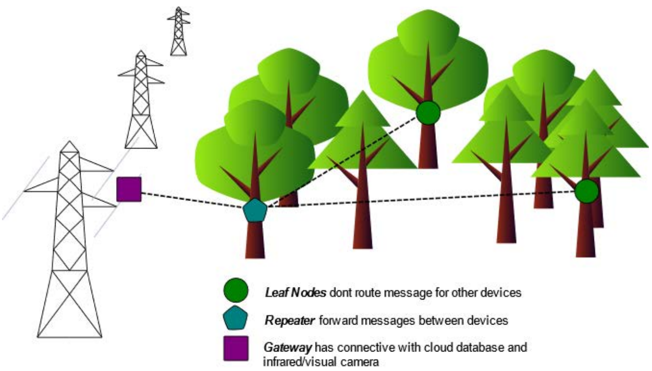

Fig. 1 Early detection of forest fires system diagram.

2.1 Sensor node

Wireless Sensor Networks (WSN) used in industrial applications are proposed as a key ingredient to implement an industrial wireless IP mesh network IIoT. The sensor network uses a RIIM (Radiocrafts Industrial IP Mesh) RF module, based on the IEEE802.15.4g/e standard, which was designed for robust long-range network with large node counts (1000 nodes), short transmit pulses and support for time synchronized channel hopping (TSCH).

Parameter	RC1882	RC1892	Unit
Frequency band	865-870	902-928	**MHz**
Data Rate	50		**kbps**
Max output power	27		**dBm**
Sensitivity (BER 1%) @50kb/s	-111		**dBm**
Supply voltage	2.3 - 3.6		**V**
Consumption, RX/TX	12.5 / 350		**mA**
Consumption, Deep sleep	3.5		**uA**
User application flash memory	32		**kB**
User application RAM	8		**kB**
Internal SPI Flash	1024		**kB**
Operating Temperature	-30 to +85		**ºC**

Table 1 RC18x2HP-IPM series reference data for RIIM (Radiocrafts Industrial IP Mesh) (typical at 3.6V, 868 MHz, 50 kb/s)

2.1.1 Sensor technologies

Wireless sensors collect environmental data and could be arranged according to the variables measured: flames, heat, humidity, smoke, and gas, among others.

Flames emit radiation which may include infrared, visible and ultraviolet wavelengths. Optical technologies measure the flame radiation with quick responses. However, these sensors require a direct view of the flames, which increases the number of sensors needed to monitor an area, making it unsuitable for the application.

Heat sensors answer to increases in temperature, which can be caused by convective heat transfer from the fire. These sensors are known as thermostatic detectors when they perceive a temperature value above a threshold during an interval of time and, in the case of measuring temperature rates instead of values, they are known as thermovelocimetrics. The latter provide faster detection and can be integrated into the same device as a combined detector. These heat detectors are maintenance free and resistant to dust and dirt, making them especially suitable for outdoor sensing.

The results of combustion processes, such as smoke, is also used for fire detection. Ionized smoke detector supervises electrical current changes in their ionization chamber to detect it. As well, the scattering of the light beam by a medium containing tiny suspended particles (Tyndall effect) is used for photoelectric smoke detection. These types of detectors provide quick responses, but are not a very practical solution, as they are prone to false alarms in dusty areas.

In contrast, gas sensing offers different measuring options, such as hydrocarbons, toxic components, or CO and CO2, for example. Most commercial devices remove the need for calibration, some have high IP protection to ensure reliable operation in harsh environments, making them suitable for detecting and analyzing wildfire gases.

2.1.2 Node definition

The RC1882-IPM module was selected for IIoT fire detection application because is an all-inclusive and cost-effective RF module for long-range applications. This device makes it possible to directly interface temperature, humidity and CO2 sensor through ADC, SPI or I2C. It supports mist computing to reduce bandwidth requirements and for fast responses to local events.

Also, this node uses 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Networks). It is a low power wireless mesh network where every node has its own IPv6 address. This allows the node to connect directly with the Internet using open standards.

Each node is configured with a unique IPv6 address to allow its identification. A timer triggers the measurement of temperature, humidity, and CO2 sensors every 30 s. The firmware algorithm performs the following calculations to detect the fire alarm:

- current temp. > threshold temp. alarm
- current temp. - last temp. > threshold rate temp. alarm
- current C02 > threshold CO2. alarm

If any of these assumptions is true, an alarm message is sent. This is an asynchronous message and can be produced by any node at any time. A synchronous message is also sent to update the environmental variables in the database. This allows additional cloud computing to detect warnings and patterns. To minimize power consumption and bandwidth, synchronous messages are sent one every 10 to 120 minute timestamp.

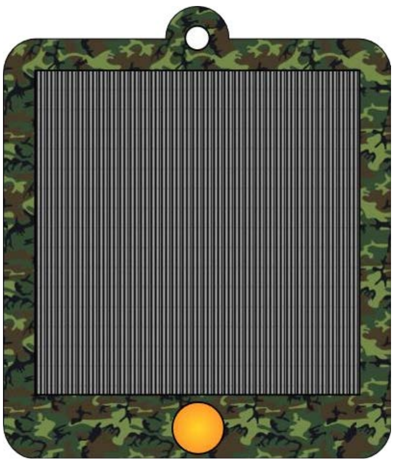

Fig. 2 Sensor node proposal to install in the trunk of a tree.

The data is collected wirelessly then moved from the network via a gateway to a fire detection software. RIIM high power nodes support long range with very low power for battery operation and up to 28 mesh hops. This makes it possible to cover an area of up to 40 by 40 km squared in an urban environment and double that in a rural environment.

Ultra-low power modules have a battery and a photovoltaic cell, as shown in Fig. 2, that collects energy to maintain the SOC. Mesh nodes implement a sleep state to prevent battery drain under adverse conditions. When battery SOC < SOC threshold, only asynchronous messages are repeated or sent. When the battery recovers power and the battery SOC > SOC hysteresis, normal function is restored in the mesh node.

2.2 Advanced Gateway node

The selected approach shown in Fig. 3, uses a current transformer to harvest energy from the magnetic field generated by the current Fig. 4. Moreover, a converter capable of adjusting the voltage of the energy captured from the conductor has been designed to be attached to it. To optimize energy harvesting, the system uses a MPPT control, adjusting the value of the load impedance depending on the current flowing through the line. Then, surplus power is stored in a battery, allowing the device to operate with low line current or blackout.

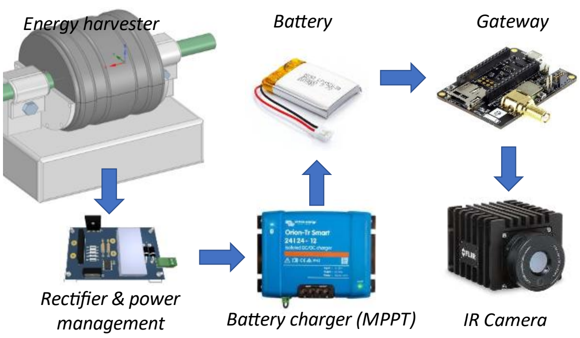

Fig. 3 Block diagram of the gateway node with power and control electronics.

Fig. 4 Gateway prototype with magnetic energy harvester on a test power line at the Circe Electronics Laboratory.

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The gateway is a network node that connects IIoT network with mobile network, where available, or ad-hoc network. The software's intelligence then makes decisions based on the data, either from single data points, or from trends and statistics derived from large data sets. This node is equipped with a motorized infrared camera to provide additional information for fire alert. The visual and thermal imaging camera rotates to detect warnings and also performs sweeps to detect any abnormalities around the overhead power line. An easy hook device was designed to be installed manually or by a robotic drone, without voltage discharge of the transmission or distribution line.

3 Relevant environment laboratory test

A relevant environment test for the gateway node was performed in the High Voltage Laboratory at LCOE-HV, as shown in Fig. 5, to validate the use on overhead power lines. A prototype node was exposed to 200 kV and 600 A to test the energy harvester, system operation, and wireless communication on the high-voltage line. The relevant environment tests were successful, and no operating problems were noticed due to exposure to the electric and magnetic field of 50 Hz.

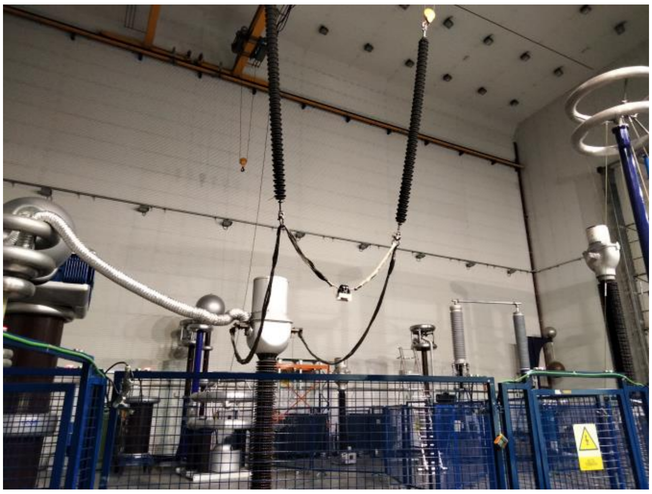

Fig. 5 Test carried out in the LCOE-HV High Voltage Laboratory for the gateway node

4 Installation example

This approach is suitable for detecting fires in a mountain range. Figure 3 shows an installation example in Sierra de Algairen (Spain), taking advantage of a 400kV line that crosses it. The Sierra de Algairen is part of the Iberian system mountain range and includes a wooded area of about 10k hectares. To preserve it, it is proposed to place the gateway at the upper edge of the overhead power line near the Valdemadera mountain peak, taking into account the mobile network coverage and strategic view as show in Fig. 6 and Fig. 8.

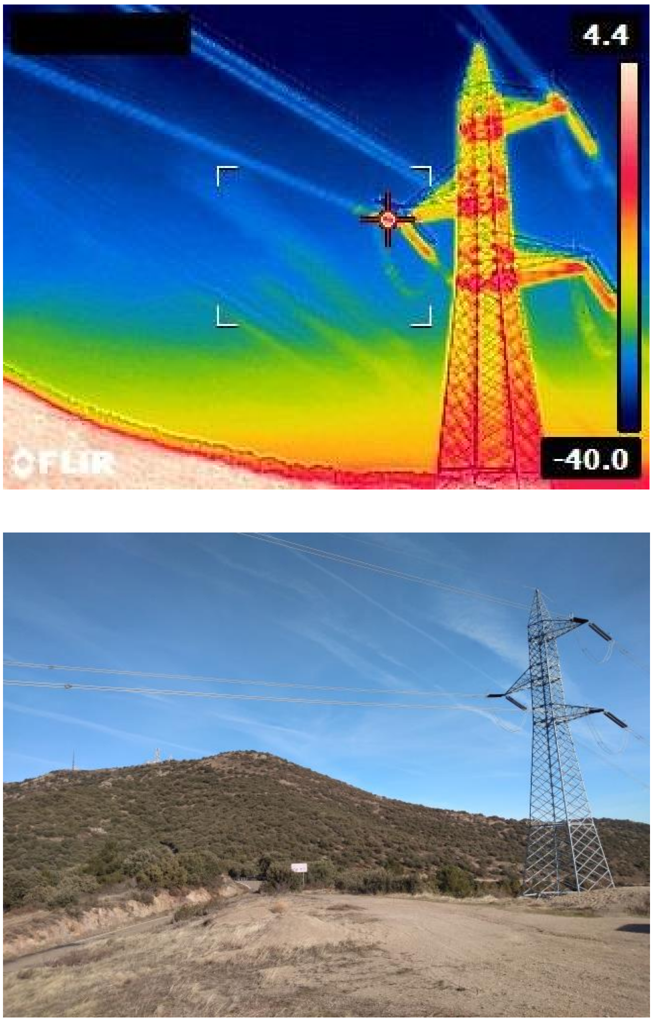

Fig. 6 Infrared and visual image of the 400kV overhead line proposed as the gateway location in the Sierra de Algairen.

Sensor nodes are located one every km^2, then about 100 sensors are required to cover the wooded area as shown in Fig. 7. The selection of the location of each sensor requires consideration of:

- a healthy tree tall enough to install the device to minimize damage or theft,
- well oriented position to receive enough insolation,
- accessible zone without communication shadow zone

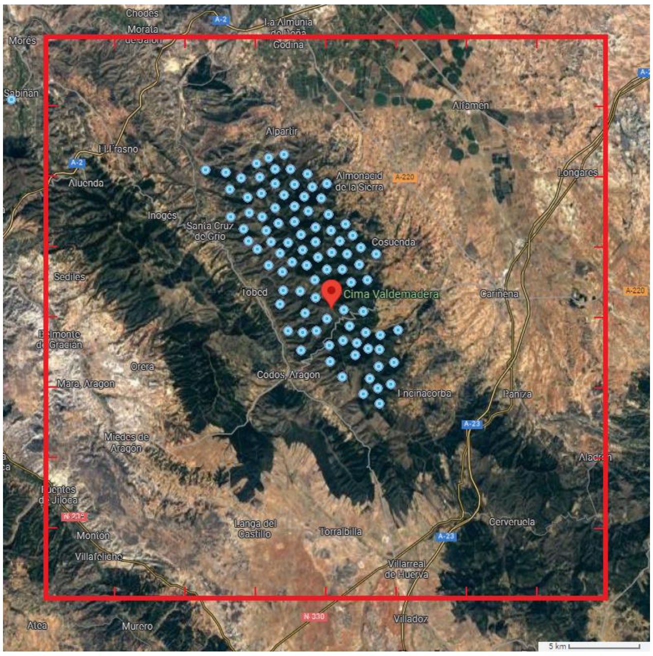

Fig. 7 40x40km area with sensor nodes proposal. Google maps. Imagery 2022 TerraMetrics, Map data 2022 Inst. Geogr. Nacional.

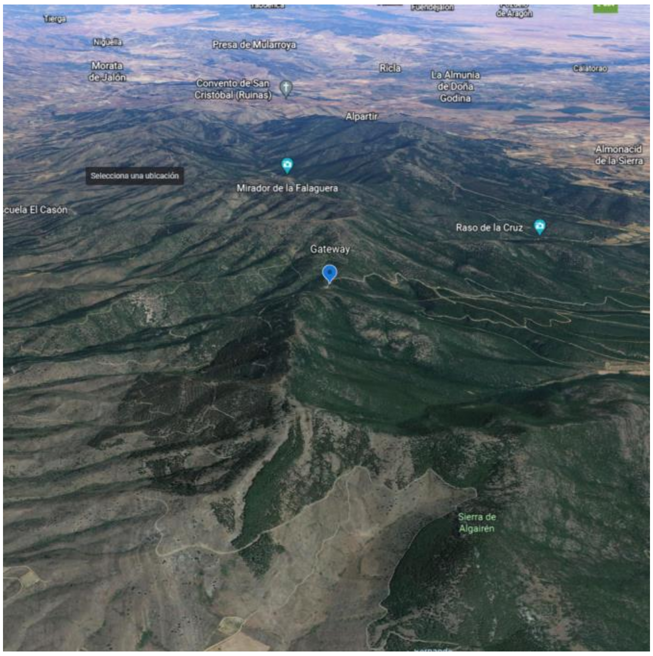

Fig. 8 3D view of Sierra Algairen and proposed location of the Gateway node . Google 2022 Inst. Geogr. Nacional Landsat/Copernicus Data SIO, NOAA, U.S. Navy, NGA, GEBCO.

In the installation process, each sensor node will be registered in a database with:

- the unique identifier based on IPv6 Internet addressing,
- GPS position, to identify the location of the sensor node,
- a picture of the installed place for later maintenance.

This information will be used by the fire detection algorithm to determine the specific pattern of the orography of the forest.

5 Conclusion

Fires are getting worse in number and magnitude due to climate change in Europe. Therefore, looking for new fast detecting techniques contributes to minimize their impact and hazards. Thanks to an energy harvesting system for overhead power lines, a new low-cost tool for fire detection in remote locations has been introduced. Besides, a real prototype has been manufactured and the energy harvesting feature has been successfully validated. Forest sensor nodes are also presented and an installation proposal is explained.

Further research is required, particularly on the application of the proposal for testing its long-lasting performance in forest. Some aspects such as the initial data collection and computational effort for training detection algorithm will be of special interest.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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