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Using Artificial Intelligence and IoT Solution for Forest Fire Prevention

Giovanni Pettorru*, Mauro Fadda†, Roberto Girau‡, Mariella Sole*, Matteo Anedda*, and Daniele Giusto*
*DIEE Department of Electrical and Electronic Engineering, University of Cagliari - UdR CNIT Cagliari
e-mail: {giovanni.pettorru, mariella.sole, matteo.anedda, ddgiusto}@unica.it
†University of Sassari, Sassari, Italy
e-mail: mfadda1@uniss.it
‡University of Bologna, Bologna, Italy
e-mail: roberto.girau@unibo.it

***Abstract*—Natural ecosystem conservation is a topical issue that is receiving increasing attention from different branches of the scientific community. Forests and woodlands are major contributors to climate change mitigation, able to absorb significant amounts of carbon dioxide. The conservation of tree areas has been addressed through the adoption of different solutions. This paper proposes a new monitoring system and the use of artificial intelligence (AI) for real-time fire detection. The system is based on intelligent Digital Mobile Radio (DMR) nodes and a Social Internet of Things (SIoT) platform on which AI algorithms have been implemented. The results obtained show the ability to detect the slightest change in observed environmental parameters, determining the direction and speed of fire propagation.**

***Index Terms*—Sensors and Actuator Systems, Internet of Things, Internet of Everywhere, and Edge Computing, Machine Learning, Deep Learning and AI in CE**

I. Introduction

Recent years are characterized by climatic changes with obvious alternations of abundant winter rainfall concentrated in a few hours/days, with periods of prolonged drought especially in summer periods. Furthermore, more and more policies are becoming available to solve global pollution problems using two approaches: a preventive and a reactive one. In the former case, in the literature there are numerous examples of Internet of Things (IoT) in many configurations such as in the industry [1], smart cities [2] and mobility [3]. Abrupt climate change and the use of intensive pesticides undermine the balance of biodiversity with impacts on flora and the spread of tree diseases that can incentives the spread of forest fires. The use of artificial intelligence (AI)-based systems enable the identification of the occurrence of plant diseases, providing crowd-sourcing tools to inexperienced people for early determination of tree diseases [4].

Therefore, in the short and medium term, it is necessary to work according to a reactive approach, monitoring forests in order to be able to prevent and intervene in a timely manner. Under the European Copernicus project, the European Forest Fire Information System (EFFIS) [5] collects and analyzes satellite images. According to data collected since the beginning of 2022, more than 600.000 hectares of forests are burned simply considering the territory of the European Union. Arson fires are one of the greatest threats to the ecosystem, animal kind and human life, as well as a source of enormous economic and social damage. Moreover, because of fires, the previous balance is undermined with additional risks from other natural events such as landslides and avalanches.

Overall, fire risk prevention and mitigation practices are marginal and insufficient. Therefore, early detection plays a very important role. Currently, this task is entrusted to operators deployed in the area of interest and appropriately placed at strategic locations. Obviously, the use of a system based on land coverage through human presence over large areas entails several limitations that can be appropriately supplemented through the use of modern Information an Communication Technology (ICT) type technologies. For example, in recent years the monitoring systems have been supplemented with the installation of video cameras placed at strategic locations, and remotely controlled within monitoring centers.

Although the introduction of cameras can facilitate human monitoring and control activities, the presence of an operator remains essential for the correct interpretation of the sensed data [6]. More recently, hybrid monitoring techniques have been introduced through the use of cameras and artificial intelligence (AI) tools that partially replace the human operator. Technically, the development of high-performance digital cameras, increasingly technologically advanced image processing techniques, and the use of machine learning (ML) algorithms have made it possible to create firefighting systems based entirely on image processing. The principle of operation consists of evaluating changes in pixel values of images acquired at different instants of time. The use of ML techniques enables the determination of a situation of potential risk [7]. Furthermore, ML-based models require additional considerations that affect the accuracy of the system and the generation of false alarms, as well as requiring high computational capabilities from the devices involved.

Moreover, several works on urban air quality monitoring [8], [9], and the creation of low-cost prototypes [10] have inspired the proposed work on monitoring large areas in rural environments. In this work, a fire monitoring system is proposed through multi-sensor nodes that acquire real-time data: temperature, humidity, atmospheric pressure, CO_2, CO, ethanol, ammonia and other gases that can complement the sensing system. In the proposed system, environmental information is forwarded from the nodes to the social IoT platform named Lysis via Digital Mobile Radio (DMR), where it will be analyzed and correlated through a Recurrent Neural Network (RNN) with the purpose of early detection of fire outbreaks.

In recent years, smart applications have been studied extensively to support sustainable environments and improve human living conditions. In this context, a smart solution based on the Social Internet of Things paradigm for real-time monitoring and detection of potential forest fires is presented.

The rest of the paper is organized as follows: in section II, an overview of state of the art is presented. The system architecture and design of the proposed fire-fighting system are described in section III. The system implementation, scenario and results are discussed in section IV. Finally, conclusions are drown in section V.

II. Related Works

There are several solutions to detect and manage forest fires. In particular, the analyzed works can be divided into two broad categories: those using ML and image processing and those using sensors to analyze environmental parameters. In the category of ML and image processing, there are several methods of image acquisition used as input by the detection system. In [11], the authors propose work based on satellite images processed according to intensity levels in order to identify regions affected by fires (hot spots). Agglomerative hierarchical clustering algorithms are used to identify these regions and the directions of fire propagation. Fire identification by image analysis is based on the analysis of Red-Green-Blue (RGB) pixel values. In [12], the authors process multi-temporal satellite images acquired from Moderate Resolution Imaging Spectroradiometer (MODIS) sensors and employ artificial neural networks (ANNs) to identify areas of high forest fire risk. In this work, samples of areas where forest fires have been detected were selected to train, validate and test the ANNs, yielding promising results in terms of fire prediction speed and accuracy.

With recent developments in unmanned aerial vehicles (UAVs), real-time monitoring for military and civilian applications employing these devices is gaining in popularity. In [13], a forest fire monitoring and detection system has been designed using UAVs equipped with sensors and cameras. Algorithms based on image comparison, infrared detection, and correlation of acquired data (e.g., temperature) are used to monitor forest fires. In [14], an early fire detection system based on the use of drones is presented. The paper refers to networks of UAVs to acquire thermal images, RGB, and positioning and distance data, useful in the fire mitigation phase. To process data from multiple sources, both traditional and deep learning-based computer vision algorithms have been developed and employed.

Regarding analysis on image acquisitions, a system based on devices placed locally in the scenario of interest is proposed in [15]. The acquisition system essentially consists of two devices: a raspberry Pi Zero W and a Pi Camera V2 module. The acquired images are processed and analyzed using Matlab tools. In [16], an IoT platform and a Raspberry Pi microcontroller equipped with a smoke sensor and camera is proposed. The detection system relies on color and motion information to minimize false detections. This information is processed together with that of the smoke sensor. When a fire is detected, the device sends an SMS to the monitoring station via Global System Mobile (GSM).

In general, systems that rely on image processing have advantages in terms of fire detection accuracy, but at the same time they have several disadvantages, both hardware system implementation and maintenance costs, and high computational capacity requirements. For these reasons, several approaches are based on sensors that analyze environmental parameters. In [17], the authors propose a method that improve the accuracy of forest fire detection performance of evergreen and temperate forests by detecting temperature and atmospheric carbon dioxide level.

The automatic fire detection system proposed in [18] includes two sensors: smoke sensor MQ-2 with very high sensitivity toward propane, methane, liquefied petroleum gas (LPG), smoke, alcohol, carbon monoxide and hydrogen; fire sensor. The sensors are mounted on the slave nodes which acquire the environmental values of the area where they are located. Then, slave nodes send this information to the leader nodes via Radio Frequency (RF). Once received, the leader node analyzes the data and communicates the presence of fire towards the control station via GSM. In [19], a monitoring system based on a wireless sensor network (WSN) composed of multi-sensor devices, a solar charging mechanism and a wireless transmission module is proposed. The device acquires environmental information regarding temperature, humidity, smoke, and methane every 15 minutes and then transmits it to the base station where it is stored, processed, and analyzed and then, if necessary, contacts the Civil Defense.

III. System Architecture

A. The DMR hardware system

This section describes the components used to design DMR nodes and the DMR gateway. The DMR node consists of a board to which sensors, a charge controller, rechargeable batteries, and a small solar panel are connected, making the individual node totally energy autonomous. The transmission standard is DMR, according to the standard currently used by civil defense.

The **4FM YSF NXDN DSTAR P25 DMR module** is the heart of the fire detection node. The node manages the main smoke detection sensors and sends them in VHF/UHF to the DMR gateway. In addition, the node is powered through rechargeable batteries connected to a charge controller and a suitably sized solar panel. This node is based on a Raspberry Pi Zero 2W+ and a transmission module compatible with the DMR standard.

The **BME688** 4-in-1 Air Quality Breakout (Gas, Temperature, Pressure, Humidity) sensor has updated features as a gas scanner that can react to volatile organic compounds (VOCs), volatile sulfur compounds (VSCs) and the presence of carbon monoxide and hydrogen to give a general measure of indoor or outdoor air quality.

A **solar panel** (10W 6V 1700mA 260x140x2.5mm) with USB Charge for Outdoor Working support was appropriately sized to support the energy needs of the node throughout the day, charging the 3500mAh - 10A 18650 batteries.

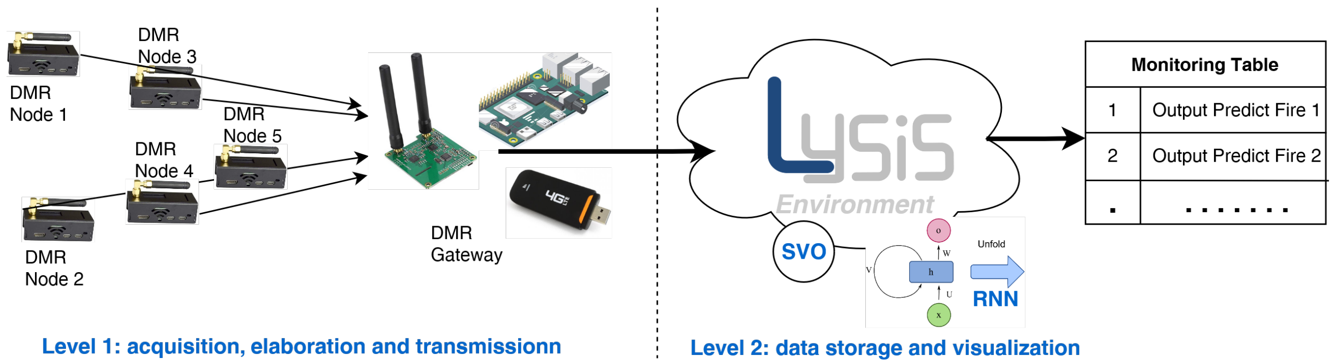

Fig. 1: General view of the DMR system with Lysis platform for real time monitoring and alert.

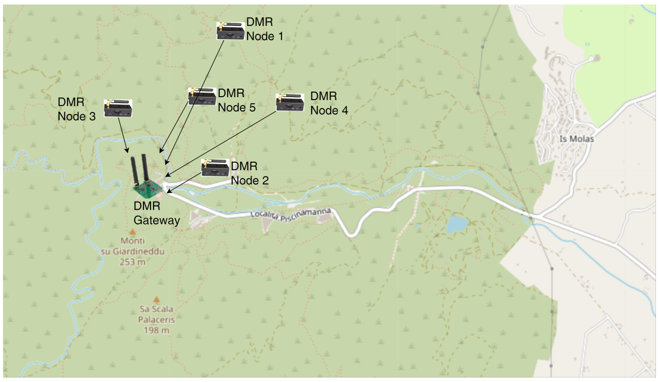

Fig. 2: The scenario employed for preliminary testing with 5 DMR nodes and DMR gateway within an area of 5 kmq.

The **DMR gateway** is based on a Bewinner Hotspot Duplex MMDVM module, 32 Bit High Performance Arm processor MMDVM Hotspot Module Supports DMR, P-25, D-Star and System Fusion for Raspberry Pi with SMA Antenna. This shield houses on a Raspberry Pi 4 connected to the cloud through 4G LTE network.

The system shown in Fig. 1 is designed to work completely autonomously without any special human intervention, restarting all processes in case of temporary power source failure.

B. *The software architecture*

The proposed system consists of 5 DMR nodes working independently of each other. Each node is equipped with sensors for detecting forest fire smoke in addition to other useful parameters for studying dynamics such as temperature, humidity, atmospheric pressure, UV index. The nodes are mainly in deep sleep mode to preserve batteries and limit power consumption. A wake-up is triggered every 5 minutes to acquire sensor data, perform a packet processing and, finally perform DMR wireless transmission of the acquired data. The DMR gateway collects information from all DMR nodes and transmits the data to a Social IoT (SIoT) platform called Lysis, using the 4G LTE network. Lysis is a SIoT platform carried out for distributed IoT applications involving socially connected objects [20]. Objects are capable of establishing social relationships in an autonomous way with respect to their owners with the benefits of improving the network scalability and information discovery efficiency [20].

The overall architecture of the Lysis platform through four functional levels:

1) the lower level is made up of the "things" in the real world;
2) the virtualization level, which interfaces directly with the real world and is made up of Social Virtual Objects (SVOs);
3) the level of aggregation is responsible for composing different SVOs to set up entities with augmented functionalities called micro engines (MEs);
4) the last level is the application level in which user-oriented macro services are deployed.

To take advantage of the Lysis architecture, the virtualization layer elements (SVOs) representing DMR nodes were designed and implemented. Each DMR node has its own SVO with which it communicates to send and record information relating to smoke levels and other useful parameters.

An artificial intelligence algorithm was developed within Lysis for fire case determination through training performed in the field through simulations of fire and smoke propagation, as explained in the next section. Lysis collects sensor data and processes it through continuous comparison with previously stored data. The nodes have social relationships to enable greater identification of hazardous situations. Outliers are processed to avoid false positives and create warning situations.

IV. System Implementation

A. *Scenario*

The scenario employed for the preliminary tests has been depicted in Fig. 2. The identified region is located in Sardinia (Italy) in the mountainous area "Pixina Manna" locality at 450 meters above sea level. The area has several elevation profiles typical of the region and is characterized by "maquis" type vegetation. The nodes were placed as in the figure, on tree trunks at a height of 5 meters above the ground. The arrangement of the nodes allows the detection of fire smoke from any direction. The tests were conducted on a "mistral" type wind day with west/northwest (WNW) direction. The smoke source was positioned WNW with respect to the

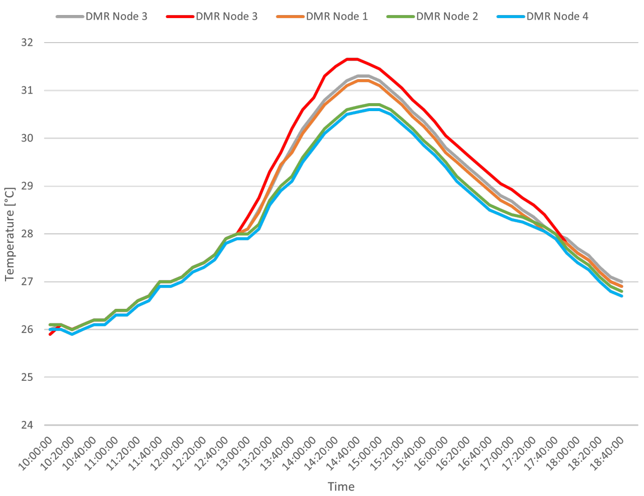

Fig. 3: Trend of temperatures detected by the various DMR nodes due to the presence of a fire with W-NW origin.

TABLE I: RNN confusion matrix

		Predicted Data	
Real Data		***Fire detection***	***Fire absence***
	Fire detection	97.72	1.15
	Fire absence	2.18	98.85
	Sum	100	100

proposed scenario so that nodes 3, 1 and 5 were the first to be involved in smoke reception. Then the detections were reported by nodes 2, and 4. The detection timeline plays a very important role in determining the direction of origin of the fire front. Typically, the first nodes to notice the smoke are also the ones closest to the fire, so they are critical for identifying the direction of the fire and implementing appropriate countermeasures.

B. Results

The hardware/software system was tested within a real-world scenario where DMR nodes periodically transmitted sensed data to the DMR gateway. The DMR gateway transmits the data in real-time to the cloud, where it is processed and represented graphically. Smoke propagation situations were artificially created from burning of organic material of the "brushwood" type. DMR nodes detected an increase in temperatures and a surge in CO values during brushwood burning. As we can appreciate in Fig. 3, the tampering trend of the 5 DMR nodes shows an overlap in the first part of the graph, in the time range from 10:00 a.m. to 1:10 p.m. The BME688 sensors [21] were tested in the laboratory in a controlled environment before being placed in an outdoor environment, showing no deviations other than those indicated by the manufacturer. At 1:00 p.m., the fire source positioned WNW relative to the system of the 5 DMR nodes positioned as in Fig. 2 was activated. The tests were conducted on a mistral wind day with the same direction in which the fire source was positioned. This aspect was crucial in assessing the worst-case scenario in which emergency responders would be faced with the emergency. The system promptly returned responses detecting not only an increase in temperatures due to the presence of hot air caused by the fire, but also appreciable temperature changes detected by DMR nodes. In fact, the nodes closest to the source (i.e., 3, 1 and 5) were the first to detect the temperature rise. Similarly, the remaining nodes farthest from the source "noticed" with delay an external heat source affecting the normal daily temperature trend. The greater the distance of the nodes, the lower the temperature rise, as shown for DMR nodes 2, and 4 compared to nodes 3, 1 and 5. The second aspect to be discussed concerns the peaks of the individual curves. The shorter the distance between the DMR node and the fire front, the shorter the time in which the curve reaches the maximum temperature peak. More distant nodes will arrive at the peak with some delay. Therefore, the greater the distance between the fire front and DMR node, the longer the response time and the smaller the modulus of the peak temperature detected by fire. At 2:30 p.m., the fire source was cut off, the trends decreased and overlapped asymptotically due to natural conditions and without an additional external source influencing the trends. The trend of CO detected by individual DMR sensors is shown in Fig. 4. The characterizing aspects from these curves mainly concern the modulus and the delay of detection of the change in CO concentration. An important consideration to make is that the greater the distance between the fire source and the DMR node, the lower the CO concentration detected by the DMR nodes due to the greater dispersion of the detected smoke. Because of the greater distance from the smoke source, nodes 2 and 4 measure lower concentrations than nodes 3, 1 and 5. Similarly, due to low wind intensity, nodes farther away from the smoke source detect concentrations with a delay compared to the nearest ones. In the Fig. 4, can be observed the rightward shift of the trends of the node values moving away from the fire source. Along with the temperature readings, CO data were processed to make an early detection of the criticality of the fire by determining its propagation speed, direction, and heading. These aspects save a lot of time for the survey station to launch the rescue equipment and all the necessary policies to fight and extinguish forest fires in the shortest possible time. Finally, Table I summarizes the confusion matrix of the collected data, which highlights the high accuracy (i.e., almost 98%) of the RNN in correctly detecting forest fire with very low values of false positives and false negatives. Moreover, RNN correctly detects the fire absence with a percentage almost 99%. The recursive structure of the RNN jointly with the work done by the DMR-SVOs allow limiting the cases of uncertainty by applying oversampling of the acquired data through queries made by the SIoT Lysis platform to the DMR nodes. The RNN developed in the Lysys environment is concerned with detecting:

1) the development of a fire based on the input temperature and CO values. When multiple nodes show a variance of values beyond a certain threshold determined on the training of the neural network, the system communicates the fire starting through alerts sent to law enforcement, civil and environmental protection;

2) the direction of propagation and speed of the fire front based on the order of detection of DMR nodes. Since DMR nodes are geolocated, it is possible to reconstruct the

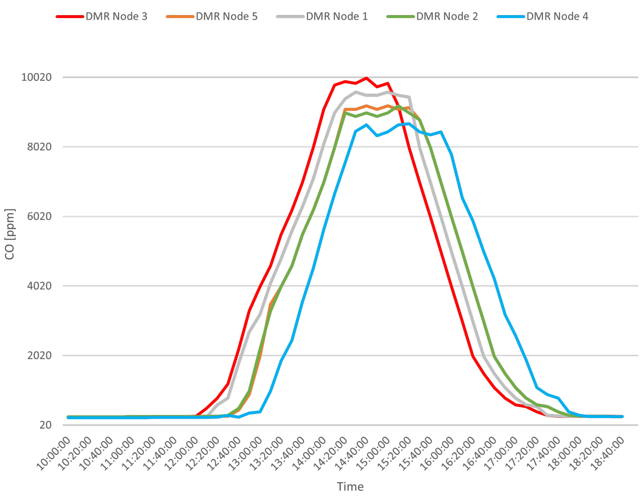

Fig. 4: Trend of CO detected by the various DMR nodes due to the presence of a fire with W-NW origin.

positioning and distance between DMR nodes. The variation and rate of change of the air quality parameters of the various DMR nodes makes it possible to determine the order of events in the scenario of interest, thus the fire starting point, direction(s), and propagation velocities. The system responds correctly by identifying the four main directions (i.e., N-S-W-E), the four intermediate directions (NE-NW-SE-SW), and the mixed combinations (ENE-WNW-ESE-WSW-NNW-NNE-SSW-SSE). Tests in the real scenario were conducted according to one of the main winds of the affected region (i.e., WNW) and verifying the correct response of the RNN.

V. Conclusions

In this work, geolocated electronic noses were developed based on innovative sensors that detect the variation of air components that lead back to the presence and development of forest fires. The telecommunication system is based on the DMR standard, integrating the functionality of the proposed system with the DMR standard in civil defense. Tests conducted showed faster detection of forest fires in comparison with studies in the literature. The values detected by the various DMR nodes are interpreted within the SIoT Lysis platform through artificial intelligence algorithms, eliminating cases of false positives. The system is able to calculate the direction and speed of fire front propagation. The system has been tested and trained in a real outdoor scenario, demonstrating its effectiveness, by up to a correct fire detection rate of 98%.

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