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# IoT Based Forest Fire Monitoring System

**Radosveta Sokullu**[1]
[1] *Corresponding author: Ege University, Department of Electrical and Electronics Engineering, 35100, Bornova/Izmır, Turkey. radosveta.sokullu@ege.edu.tr*

## Abstract

This paper describes a prototype system for monitoring forest fire using IoT and drones. Sensors placed in the forest area continuously measure parameters, which can provide early warning about arising fire situations such as temperature, humidity, carbon monoxide and simultaneously transfer the data for processing to a control unit. The control unit aggregates and maps the collected information separately for each parameter and then creates fire mapping based on the FFDI index including all parameters. The severity of the situation is reflected on the map using a special coloring scheme. When a certain color level is exceeded, a drone (possibly carrying water supplies) is sent to the transmitted coordinates to provide visual data and help extinguish the fire at as early stage as possible. The wireless sensor network consists of small size sensors, cheap off-the-shelf nodes placed in the environment to interact with the physical world. These nodes autonomously cooperate in the physical area and provide information about the current surrounding environment over LAN and WAN. Since these devices can easily be damaged and need to be replaced, they are intentionally selected to be very cheap with little processing ability. The functions of integrating and evaluating the collected data are embedded in the control unit, which is located at a safe distance within communication range. The communication between the control unit and the drone is over WAN. The drone would normally be waiting ready in a monitoring station or fire fighter location. Upon receiving critical information the drone can be dispatched to collect visual data of the area and/or if possible to help with extinguishing the fire.

## Key words

Internet of Things, smart devices, forest fire detection, FDDI index

## 1. INTRODUCTION

One of the first areas where wireless sensor networks and Internet of Things have found application is environment monitoring. In the early stages WSN were custom-designed to provide early warning about possible forest fires. With the development of infrastructure and the standardization of new low cost wireless connectivity protocols, the Internet of Things (IoT) established itself as the main technology in many applications, like environmental monitoring, agriculture, industry etc. From smart homes, smart appliances, smart traffic, and smart agriculture to smart vital signs collecting systems and industrial applications IoT has become a ubiquitous technology. The paper describes the design of a system for monitoring forest fire using IoT and drones. Sensors placed in the forest area continuously measure parameters, which can provide early warning about arising fire situations such as temperature, humidity, carbon monoxide and simultaneously transfer the data for processing to a control unit. The control unit aggregates and maps the collected information separately for each parameter and then creates fire mapping based on the FFDI index including all parameters. When a certain color level is exceeded, a drone (possibly carrying water supplies) is sent to the transmitted coordinates to provide visual data and help extinguish the fire at as early stage as possible. From here on the paper is organized as follows: in the next section a short overview of some related work is presented. In section 3 the theoretical background on forest fire indices and fire danger calculations is provided. Section 4 presents the system architecture and main components followed by user interface design, evaluation and conclusion.

## 2. RELATED WORK

In the last decade, together with rising temperatures and unstable weather conditions causing draughts and excessive flooding the number of forest fires all over the world has increased considerable. Incurred forestation destruction, wildlife loss and environmental calamities are becoming more sizeable every year. Studies show that the fires contribute to the rise of global temperatures and negatively affect climate change. [3,4]. That is why there are a lot of work focusing on monitoring, preventing and detecting forest fires. Depending on the adopted approach research can roughly be divided into 3 groups: based on WSN; using images and image processing techniques; using unmanned aerial vehicles (UAVs).

An interesting study covering the use of WSN and a small satellite to provide early warning about forest fire is presented [1]. The authors describe a WSN for collecting data about temperature, smoke and CO2 which is transmitted over wireless medium to the small satellite which re-transmits the data to a ground station where they are analyzed. The proposed prototype comprises a set of sensors, a transmission module, a microcontroller with an LCD and a remote control unit. The authors in [2] address the problem faced by wildlife and forest departments due to the reduced forest areas and the increased movement of wild animals into residential areas. The work proposes a system for tracking animals and alarming the responsible authorities to protect both animals and forests against forest fires. A fire detector using Arduino UNO is designed which is interfaced with a temperature sensor, a smoke sensor and a buzzer. Whenever a fire occurs, the system automatically senses and alerts the user by sending an alert to an app installed a mobile or webpage accessible through the internet. A detailed overview of using artificial neural networks to help in early forest fire warning systems is provided in [3]. The authors define three phases in the development of forest fires: pre-fire when action for controlling the occurrence of fire control can be taken; during arising fire, when early detection and appropriate action is required; post-fire when damage assessment and mitigation planning is done. In many countries satellite-based surveillance system are used to detect forest fire but this approach is usually used when fire has already spread over a large area. The authors propose a model for early fire detection and prediction. Besides Raspberry Pi microcontroller and required sensors the system comprises a centralized server, used for storing the data and analyzing that data. Feed-forward fully connected NN is used for prediction purpose. In [4] the authors present two solutions for early fire detection systems based on emerging new technologies: unmanned aerial vehicles (UAVs) with specialized cameras and LoRaWAN sensor networks. Different scenarios for the possible use of the drones in such cases are presented and analyzed. An interesting angle to detecting forest fire at an early stage using image processing and color schemes is proposed in [5]. The work classifies the characteristic color of the forest fire using image processing techniques. The authors argue that especially during the late spring and summer when the fire is easily distinguished from the color of trees and foliage and suggest a new method which combines several predetermined and fuzzy criteria for image segmentation. Another approach that has emerged in recent years is based on incorporating drones. Such options provide lower operational costs and allow UAVs to reach areas that are inaccessible or considered too dangerous for firefighters. The work in [6] describes the application of a real-time forest fire detection algorithm using aerial images captured by a video camera onboard an UAV. The forest fire detection algorithm consists of a rule-based color model that uses both RGB and YCbCr colour spaces to identify fire pixels. A fire geolocation algorithm is proposed to estimate the location of the fire and transmit the location in terms of latitude (φ), longitude (λ) and altitude (h).

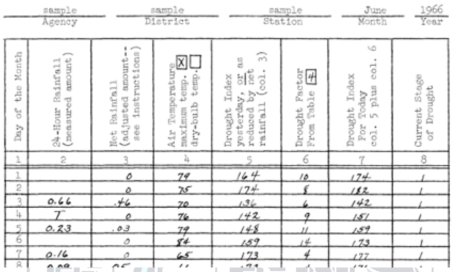
Different than the research presented above, in this work the fire detection is done based on a combination of sensing data, color-scale map using the FDDI index and coordinate determination for drone dispatch. A large number of sensors are used to collect data which is then aggregated and processed by a remote control unit to produce a map of the area with colors depending on the possibility of fire occurrence. Location information is also extracted and a UAV can be sent to the endangered area.

## 3. FOREST FIRE DANGER ESTIMATION AND DETECTION

Forest fires all over the world cause a lot of damage to the wildlife habitat and human population. During the years various methods have been developed for detecting forest fires at an early stage and also evaluating the danger of their occurrence. Scientists have proposed various indices which take into consideration parameters from the surrounding environment to evaluate the possibility of fire ignition.

One of the most popular indices is the McArthur Fire Danger Index (FDI), which was proposed by McArthur in 1966. [7] [8] The FDI is a measure of fire initiation, spreading speed and also evaluates how difficult it is to contain it at the source. Later on it has been extended it to include other environmental parameters like temperature, relative humidity, wind direction, vegetation type and terrain characteristics. Noble in 1980 proposed a detailed equation form of the index. [9] Besides this index, which has been operational in Australia since 1967, the number 1 country in danger of forest and bushfires, other indices are also used. Examples include the Canadian Fire Weather Index (FWI) [10], the American National Fire Danger Rating System (NFDRS) [11], Nesterov index [12], Angstro¨m index [13].

Today many countries use the FFDI (Forest Fire Danger Index) and GFDI (Grasland Fire Danger Index) which also include the draught factor (DF). The DF, provides an estimation of the vegetation fuel available for burning and has values in the range 1-10, where a DF = 10 indicates maximum possible fuel available for combustion. In their centennial paper [14] John J. Keetch and George M. Byram formulated the Drought index (DI) drought index, which expresses moisture deficiency in hundredths of an inch and the index is based on 8.00 inches of water available for transpiration, so the index ranges from 0 to 800. It can be computed for a given level of mean annual rainfall. Since there were no computers at that time, the authors developed detailed tables and recording examples (Fig. 1) for deriving the correct value of DI.


sample Agency | sample District | sample Station | June Month | 1966 Year

| Day of the Month | 24-Hour Rainfall (measured amount) | Net Rainfall (adjusted amount--see instructions) | Air Temperature maximum temp. dry-bulb temp. | Drought Index yesterday, or as reduced by net rainfall (col. 3) | Drought Factor From Table 4 | Drought Index For Today col. 5 plus col. 6 | Current Stage of Drought |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | | 0 | 79 | 164 | 10 | 174 | 1 |
| 2 | | 0 | 75 | 174 | 8 | 182 | 1 |
| 3 | 0.66 | .46 | 70 | 136 | 6 | 142 | 1 |
| 4 | T | 0 | 76 | 142 | 9 | 151 | 1 |
| 5 | 0.23 | .03 | 79 | 148 | 11 | 159 | 1 |
| 6 | | 0 | 84 | 159 | 14 | 173 | 1 |
| 7 | 0.16 | 0 | 65 | 173 | 4 | 177 | 1 |

*Figure 1 – Drought Index Sample Record (1968)*

An ongoing EU funded project, the **H**igh-**E**nd c**L**imate **I**mpacts and e**X**tremes (HELIX) project, which started in 2014, is a collaborative research work of 16 organizations worldwide assessing the potential impacts of climate change. [15] Scientists work together to develop future scenarios of the natural and human world as a consequence of global warming. Using the McArthur and Keetch-Byram indices as well as the Noble equations they have summarized the following fire index calculations and values for the FFDI:

$$FFDI = 1.25 * D * \exp[(T - H)/30.0 + 0.0234 * V] \quad (1)$$

where D is the drought factor, T is the temperature (ºC), H is the humidity (%), and V is the wind speed (km/h). The DF is calculated using Eq. 2:

$$D = (0.191 * ( I + 104) * (N + 1)^{1.5}) / (3.52 * (N+1)^{1.5} + P -1) \quad (2)$$

where P is the precipitation in mm/day, N is the number of days since last rain, and I is the Keetch-Byram drought index.

## 4. PROPOSED SYSTEM AND MAJOR COMPONENTS

### *4.1. System Architecture*

In this study a fire warning and detection system is presented incorporating three major modules. The first is the WSN, which provides sensor data from the environment; the second is the FFDI calculation and color mapping; the third is coordinate determination and drone dispatch (if required). The general system architecture is presented in Fig.2 below. Sensor nodes transmit through a gateway (also serving as an aggregating and control unit) over a TCP connection to a server where users can login to view and download the information.

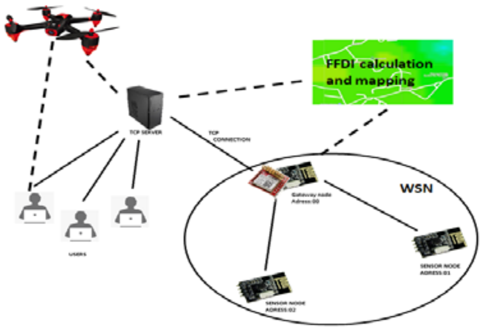



*Figure 1. System Architecture*

Data collected from the sensor nodes is used in the calculation of the FFDI. Based on the specific temperature, humidity etc. values a mapping is done to a color-scale map. The collected data is also used for determining the local coordinates.

### *4.2. Major Components*

In this section the main components of the proposed system are discussed.

#### *4.2.1. The sensor node*

The wireless node and its components are shown in Figure 2. The DHT-11 is the temperature and humidity sensor, MQ-7 is CO2 sensor, connected to an Arduino Nano processor, nrf24l01 wireless module transmission module and the power supply.

The DHT-11 is a common temperature and humidity sensor used in embedded projects. The temperature range is from 0 to 50 degrees Celsius with an accuracy of + -2 degrees. The humidity range is between 20 and 80 percent with an accuracy of 5 percent. DHT11 operates with extremely reliable technology and thus ensures high stability. It is small, inexpensive and easy to use. This sensor is also used in weather stations to measure atmospheric temperature and humidity.

The sensitive material of the MQ-7 gas sensor is $SnO_2$ with lower conductivity in fresh air. It adjusts by high and low temperature cycle method and detects CO at low temperature (heated by 1.5V). The conductivity of the sensor becomes higher with increasing gas concentration. MQ-7 gas sensor has high sensitivity to Carbon Monoxide. The sensor can also be used to detect different gases containing CO, it is low cost and suitable for different application.

The NRF24L01 is a single chip radio transceiver for the worldwide 2.4-2.5 GHz ISM band. The transceiver frequency filter consists of a power amplifier, a crystal oscillator, a demodulator, modulator and protocol engine. Output power, frequency channels and protocol settings can be easily programmed through a SPI interface. The current consumption is very low, only 9 mA at -6dBm output power and 12.3mA in RX mode. It can easily save power with its built-in Power Off and Standby modes. When the NRF24L01 is powered off, it must always stand by 1.5 ms before entering either TX or RX mode. Supports up to 100 meters range in low band open area.

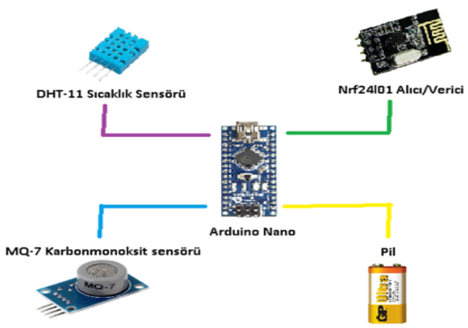


*Figure 3. Components of a sensor node*

*4.2.2. The GSM/GPRS Module*

SIM800L GSM / GPRS module is a miniature GSM modem that can be integrated into many IoT projects. This module can do almost anything a normal cell phone can do. It can be connected to the internet via GPRS or TCP/IP. Moreover, the module supports the quad-band GSM / GPRS network, which means it can work almost anywhere in the world. The Sim800L GSM/GPRS module plays the role of a gateway.

### *4.3. System software*

*3.3.1. The NRF24 library*

In order to manage the NRF24 sensor network as required, nrf24 network open source library is used. When a transmission occurs from one radio module to another, the receiving radio communicates with an acknowledgment (ACK) packet with the sender to indicate success. If the transmitter does not receive an ACK, the radio automatically switches to a series of timed retries at regular intervals. Radios in this network are connected with the addresses assigned to the channels. Each radio can listen to 6 addresses on 6 lines, so each radio has a main line and 5 sublines used to create a tree structure. Nodes communicate directly with their parents and child nodes. All other traffic to or from the node must be routed across the network.

*3.3.2. Phyton Based Interface*

Python is an object oriented, interpretive, unitary and interactive high-level programming language. Today it has started to replace the C series programming languages, and it has a wide area of use especially related to IoT applications and interfaces. With Phyton one can easily access the open source codes of many libraries from graphics engines to artificial intelligence. It has been selected as the basis of the interface system designed in this application. The functional interface includes many systems from mapping system to drone command application.

*3.3.3. Phyton Based TCP Server*

The project uses TCP/IP based communication. In order for TCP messages to be transmitted, the recipient must be specified. However, if the recipient is a WiFi user, every time WiFi connection is turned on and off, the port addresses of the users on the WiFi change, even if the IP address remains the same. Therefore, in this system a server with fixed IP and port addresses is used to deliver data to the recipient. While the sender transfers data to the server, the receiver receives that data from the server. Thus, there is no need for a fixed port, the receiver and the transmitter can exchange messages over the desired IP address and port.

### *4.4. Forest Fire Detection Index Calculation*

The novelty in this work, different from other similar system is in the use of FFDI and color-scale map. For defining the value of the FFDI the procedures determined by the HELIX project are used. The diagram for the calculation process is given in Figure 4. The number of sensors is independent of the map, so the number of nodes can be increased to obtain highly successful predictions in high risk areas. The FFDI index is calculated using the temperature and humidity values received from sensor readings while the wind speed is derived from a regional external source. The value obtained for the FFDI determines the degree of fire hazard. (Figure 5) Values from neighboring sensors are aggregated and averaged to provide easier color mapping. The color scale and an example map are provided in Figure 5.

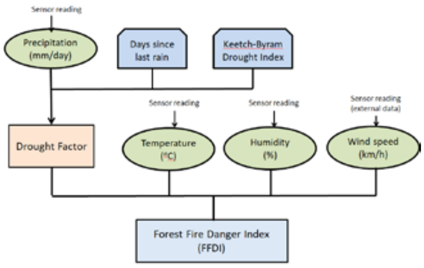



Figure 4. FFDI calculation

| Category | Fire Danger Index | |
|---|---|---|
| | Forest | Grassland |
| Catastrophic (Code Red) | 100 + | 150 + |
| Extreme | 75–99 | 100–149 |
| Severe | 50–74 | 50–99 |
| Very High | 25–49 | 25–49 |
| High | 12–24 | 12–24 |
| Low–Moderate | 0–11 | 0–11 |

Figure 5. FFDI and color mapping

## 5. USER INTERFACE AND SYSTEM EVALUATION

The user interface is designed using Phyton and compatible libraries. Two types of user maps are provided: sensor map, which gives the positions, names and coordinates of the deployed sensors and a color-scale map,

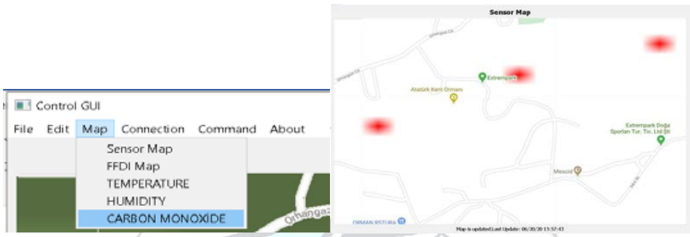



Figure 6. The Sensor map and readings selection

which reflects the degree of fire danger. Figure 6 gives an example of a sensor map. The sensor map provides a selection of different readings, temperature, humidity, CO. The designed interface allows the user to add and delete sensors, to display sensor readings in a table format (Excel) or to edit descriptions of the sensors (Figure 7).

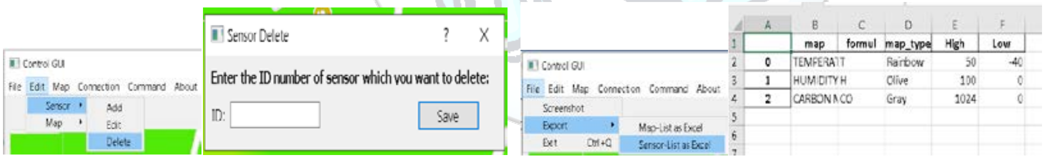
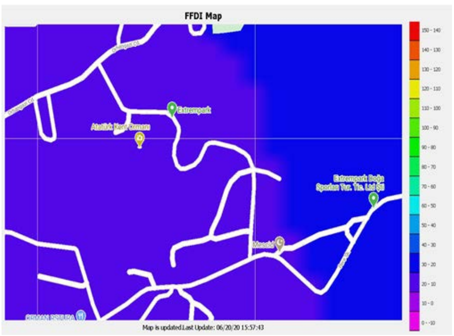



Figure 7. User interface editing and viewing options

Furthermore after the FFDI is calculated, the user is provided with a color-scale map depicting the degree of fire danger. (Figure 8).




| Category | FFDI range |
|---|---|
| Low-Moderate | 0-11 |
| High | 12-23 (12-31 in Western Australia) |
| Very High | 24-49 (32-49 in Western Australia) |
| Severe | 50-74 |
| Extreme | 75-99 |
| Catastrophic | >100 |

Figure 8. FFDI map with color scale; fire danger level-FFDI range table

Besides the visual features the software allows to calculate the absolute coordinates of the sensors using positioning information. The sensor positions can be mapped on Google maps. Also the coordinates can be calculated in latitude/longitude format to be fed to a drone. Drone can be sent to the coordinates determined to take visual aerial images of the area and/or provide help in extinguishing the fire. This part depends on the actual implementation.

The operation of the hardware and software was tested under various environmental conditions in the city of Bursa, Turkey. Sensor operation, control unit operation, FFDI calculations and TCP server connections all proved to be going smoothly without extensive connection delays. System was tested under varying weather conditions (high temperature, low humidity, high humidity etc.) but no real life fire situations were tested.

## 6. CONCLUSION

This paper discussed a system for an IoT based Fire Danger Detection. Several different approaches in monitoring and detecting fire danger conditions were incorporated in this work. First of all environmental data is collected using a WSN. A central unit, playing the role of a gateway as well is used for aggregating and evaluating the collected data. Using the FFDI calculation procedures suggested by the international HELIX project and using the McArthur and Noble Forest Fire danger Index a color map is provided depicting the degree of fire occurrence. An user interface, designed with Phyton provides options to add and delete sensors, to switch between different map options and to export the sensor data information into external (excel) file format. Furthermore, the software allows to calculate the absolute coordinates of the area involved and to direct an UAV if required for aerial imaging or to help extinguish the fire.

## ACKNOWLEDGMENTS

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