

A New Approach based on Wireless Sensor Network and Fuzzy Logic for Forest Fire Detection

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ABSTRACT

Undoubtedly, great environmental damage especially in forests due to wild fire expansion has been occurred lately which has for result the deterioration of the human quality of life. For this reason an urgent need for environmental protection and preservation has been raised in the last years. This paper, presents a new approach dedicated to forest fire detection and based on wireless sensor network and fuzzy logic that performs a real-time monitoring system in order to detect forest fires and avoid considerable damages. Wireless sensor networks are used in many fields and have been deployed in a variety of applications ranging from monitoring a small room to large forests. The use of wireless sensor networks in forest fire detection applications becomes an efficient approach to early detect fires in order to minimize damages and save human life. The proposed system consists of several sensor nodes having the architecture of the System-on-Chip (SoC), CC2430. Each sensor node acquires the appropriate information and sends it to the base station node connected to a personal computer. All the nodes in the monitoring area are alimented by a PV cell, collect the information of temperature, humidity and wind speed. The collected information is the input variables of the fuzzy logic of the system applied to detect forest fires. So, it will send real-time alarm messages and deliver the forest fire risk level to the monitoring authorities in order to undertake immediate actions.

General Terms

Wireless Sensor Network, Wind speed, Forest, Humidity, Fire, Temperature.

Keywords

Forest fire, ZigBee, SoC, CC2430, Wireless Sensor Network, fuzzy logic.

1. INTRODUCTION

Recently, due to the availability of low cost and low power WSNs, many goals set by researchers have been achieved in the field of environmental protection by the aid of WSNs [1]. In fact, several industrials, researchers and engineers work on this new technology that requires the use of many nodes, even hundreds or thousands. Moreover, these nodes must be capable of sensing, processing and communicating physical parameters like temperature, humidity and wind speed through the global wireless sensor network. This paper proposes a new approach for forest fire detection based on wireless sensor network technology and using the fuzzy logic technique as a way of supervision and monitoring to detect the forest fires in a beginning step. To acquire the necessary information like temperature, humidity and wind speed, several sensor autonomous nodes have been used at a dense

spatial distribution. As an indication, 400-800 sensors may be required to cover one square kilometer by deploying a sensor every 30-50 meters [1]. In our system, we have used the nodes of the type CC2430 having the characteristic to send and emit according to the protocol IEEE 802.15.4 and with the frequency of 2.4 GHz. After receiving all the necessary information, we apply the fuzzy logic technique to detect the fire risk level. So, this paper presents the followed detection strategy based on one wireless sensor node and one fuzzy detection algorithm (FDA) to detect the forest fire risk level. The organization of this paper is as follows: The section 2 presents the system architecture. The section 3 describes the wireless sensor network nodes architecture. In the section 4, we illustrate the IEEE 802.15.4 standard that defines the physical layer in all ZigBee devices; this standard is used by the sensor nodes to communicate with each others. The fuzzy control algorithm is presented in section 5. The Fuzzy Detection Algorithm is presented in section 6. The software architecture is exposed in section 7. In section 8, we present the results and discussion. Finally, a conclusion is given to the whole work in section 9.

2. SYSTEM ARCHITECTURE

The designed system is principally based on two parts: a wireless sensor network (WSN) with one remote control and monitoring center. Several sensor nodes with temperature sensors, humidity sensors and wind speed sensors are scattered through different regions in the forest. The framework of the smart system is shown in Fig.1. The ZigBee protocol is adopted in tree topology network to ensure the information communication between different nodes until the PAN coordinator node. Most of the sensor nodes act as terminal devices, can only collect data and send it to the near node until they reach the base station or the coordinator node. Then, the real time acquisition data can be then used by a fuzzy logic algorithm to prevent and detect forest fire risk level in order to avoid their spread and to limit the damage.

WSN is composed of sensor nodes, routing nodes and PAN coordinator node, distributed in the forest of monitoring area. All nodes were powered by a PV cell (Fig.2). The temperature, humidity and wind speed sensors collect temperature, humidity and wind speed information; routing nodes are responsible for routing communication and forwarding data; the PAN coordinator node after receiving data from routing node sent it to the host computer monitor center through RS232 serial port. The monitoring center one basing itself on the collected data and with adopting the fuzzy logic will try to detect the occurrence of forest fires and computed the fire risk level.

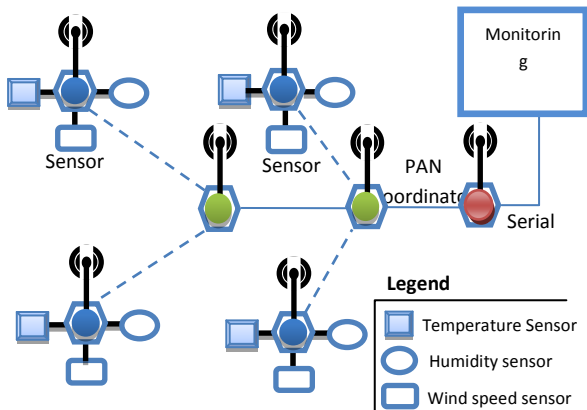


Fig 1: System framework.

3. WIRELESS SENSOR NETWORK NODES

As shown in Fig.2, our system consists of several nodes and one monitoring center. An end device is a sensor node composed by one SoC CC2430 and is responsible for sensing environment parameters such as temperature, humidity and wind speed, then sending the sensed data through the routing node until it reach the PAN coordinator node. The coordinator node or the base station contains also one SoC, CC2430 connected to the personal computer through the serial port. The PAN coordinator node is responsible for collecting data from the end devices. After that, it sends this information joined with the address of the appropriate sensor node to the personal computer through the serial port. The monitoring center presents one interface developed to visualizing the received information, it has also the capacity to make further analysis, interpretation and apply the fuzzy logic algorithm to detect forest fire risk level.

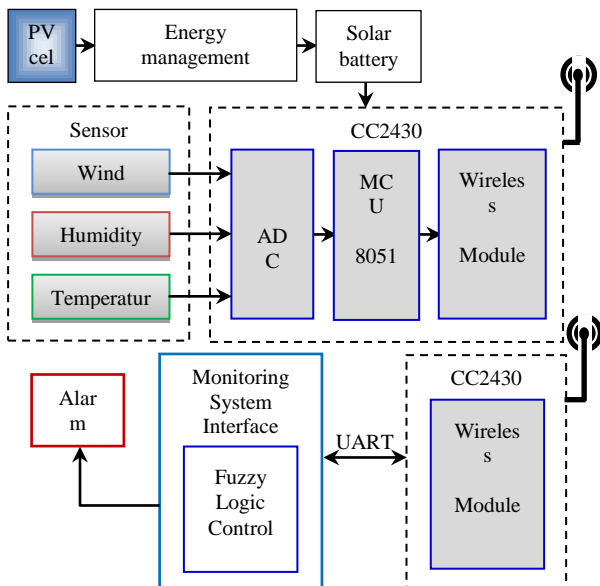


Fig. 2: Sensor node components.

3.1 A. System-on-Chip CC2430

The CC2430 comes in three different versions: CC2430-F32/64/128, with 32/64/128 KB of flash memory respectively. The CC2430 is a true System-on-Chip (SoC) solution specifically tailored for IEEE 802.15.4 and ZigBee™ applications. The CC2430 combines the excellent

performance of the leading CC2420 RF transceiver with an industry-standard enhanced 8051 MCU, 32/64/128 KB flash memory, 8 KB RAM and many other powerful features. The CC2430 is highly suited for systems where ultra-low power consumption is required. This is ensured by various operating modes. Short transition times between operating modes further ensure low power consumption.

3.2 B. BB-Battery Board

The main function for this board is to power the CC2430EM (Evaluation Module) or CC2431EM with the use of two AA batteries. It can also be powered by a lab powered connected directly to GND and VDD on the board. As presented in Fig.3, it has one LED, one push switch, one power switch and I/O connector A and B gives access to all I/O on the SoC and to some additional pins. It can deploy a SoC network [2]. On this Battery Board, we can find the Evaluation Module, which contains the minimum components for a RF part to function.

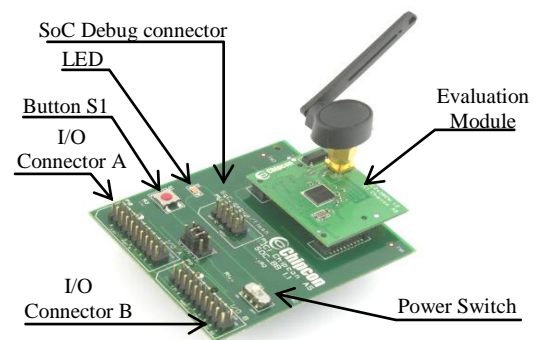


Fig. 3: SoC Battery Board with CC2430EM.

3.3 C. Power Supply

Solar energy is an attractive source for powering sensor nodes especially when the network is steady deployed. The power provided by a photovoltaic (PV) cell is heavily dependent on the environmental conditions and on the operating power point (V_{PV} , I_{PV}) of the PV module [3]. Energy scavengers using small PV modules have been recently proposed to enable perpetual operation of WSNs [4] and a new class of methods to track Maximum Power Point (MPP) has been designed. Each sensor node can be powered by a small PV module. The capacitors must be added in order to store the necessary energy needed by the sensor node [5][6].

4. ZIGBEE STANDARD

Based on the IEEE 802.15.4, the ZigBee standard [7] defines the higher layer namely: the network layer and the application layer (Fig.4). The network layer is responsible for joining/leaving a network, security, routing, discovering 1-hop neighbors and storing neighbor information. The ZigBee network layer supports three topologies: the star topology where end devices (RFD) are attached to a central point playing the role of PAN coordinator (FFD), the tree topology where end devices can be attached also to FFD nodes with routing capabilities playing the role of ZigBee routers in a hierarchical manner (with parent-child relationship), the mesh topology where ZigBee routers can be fully connected.

As shown in Fig.4, the application layer includes the Application Framework, the ZigBee Device Objects (ZDO), and the Application Sub Layer (APS). The Application Framework can have up to 240 Application Objects, that is, user defined application modules which are part of a ZigBee

application [8]. The ZDO defines the role of the device, initiates and responds to binding requests and establishes a secure relationship between devices. The APS offers an interface to data and security services to the APOs and ZDO.

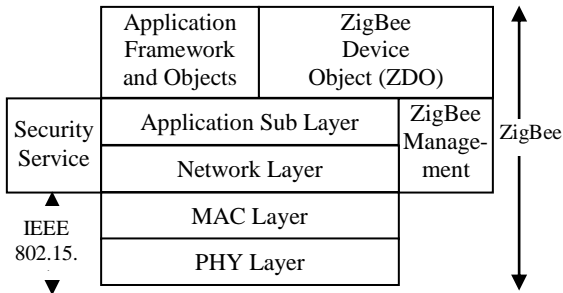


Fig. 4: The communication stack.

5. FUZZY CONTROL ALGORITHM

The soil environment is a large inertia, nonlinear and time delay system, it is very difficult to establish a precise mathematical model, and because of the unified, variability and complexity in the greenhouse field conditions, it is also difficult to achieve precise control if we use the traditional control method [9][10]. We select fuzzy control theory of intelligent control method. Fuzzy control theory does not need to establish accurate mathematical model of controlled object, robust, it is suitable for the lag, nonlinear and time-varying system, so it is suitable for using fuzzy control strategy to realize the controlling of the monitoring system [11].

Whether to construct fuzzy controller reasonably is related to the precision of fuzzy control system, the structure of fuzzy controller is shown in Fig.5.

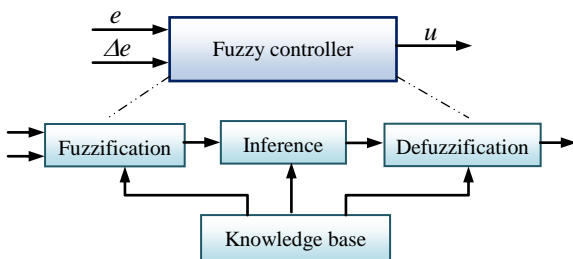


Fig. 5: Block diagram of the fuzzy logic controller.

The fuzzy controller includes three steps: Fuzzification with trapezoidal and triangular functions, the inference diagram where the fuzzified variables are compared to preset (Fig.5) [12][13][14]. During fuzzification, numerical variables are converted into linguistic variables to take the five following values: VL for Very Low, L for Low, N or M for Normal or Medium, H for High, VH for Very High.

6. THE FUZZY DETECTION ALGORITHM (FDA)

6.1 Detection strategy

In each node, the suitable treatment consists in successively acquiring the information corresponding to the current values of humidity, temperature and that of the wind speed. The combination of these different values joined with the node number will be sent inside one package to the neighbor node until reaching the base station where they will be transmitted through the serial port to the monitoring detection center. The

analyzing of the information existing in the received packed will indicate the state of the zone inside the forest and gives the risk fire level inside the forest.

6.2 The knowledge base of the expert

The fuzzy algorithm, giving the fire risk level inside the forest, is based on two parts: a WSN and one remote control and monitoring center. Four partitions are necessary to the innovative approach, which are:

- For the temperature: the fuzzy partition is defined by five fuzzy sets nominated $A_i = (VL, L, N, H, VH) = (Very\ Low, Low, Normal, High, Very\ High)$ is the i^{th} fuzzy subset, $i = \{1, 2, 3, 4, 5\}$. These subsets cover the fuzzy domain $x = [0, 50\ ^\circ C]$ and verify (Fig.6):

$$\forall x_i \in x, \sum_{i=1}^5 \mu_{A_i}(x_i) = 1, \quad (1)$$

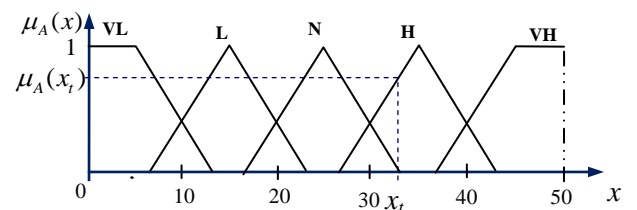


Fig. 6: Fuzzy set of Temperature.

Where $\mu_{A_i}(x_i)$ the membership function corresponding to A_i evaluated at x_i .

- For the relative Humidity: the fuzzy partition is composed of five fuzzy subsets, which are $B_j = (VL, L, M, H, VH) = (Very\ Low, Low, Medium, High, Very\ High)$ is the j^{th} fuzzy subset, $j = \{1, 2, 3, 4, 5\}$. These subsets cover the interval $y = [0, 100\%]$ and verify (Fig.7):

$$\forall y_j \in y, \sum_{j=1}^5 \mu_{B_j}(y_j) = 1, \quad (2)$$

Where $\mu_{B_j}(y_j)$ the membership function corresponding to B_j evaluated at y_j .

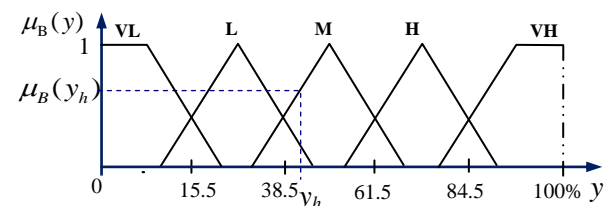


Fig. 7: Fuzzy set of relative Humidity.

- For the Wind Speed: the fuzzy partition is designed by five fuzzy sets $C_k = (VL, L, N, H, VH) = (Very\ Low, Normal, Medium, High, Very\ High)$ is the k^{th} fuzzy subset, $k = \{1, 2, 3, 4, 5\}$. These subsets cover the interval $z = [0, 100\ km/h]$ and verify (Fig.8):

$$\forall z_k \in z, \sum_{k=1}^5 \mu_{C_k}(z_k) = 1, \quad (3)$$

Where $\mu_{C_k}(z_k)$ the membership function corresponding to C_k evaluated at z_k .

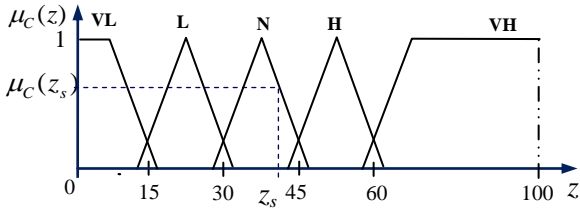


Fig. 8: Fuzzy set of Wind Speed.

- For the Output state: This partition is composed of five fuzzy sets, which are $D_h = (VLR, LR, MR, HR, VHR) = (Very\ Low\ Risk, Low\ Risk, Medium\ Risk, High\ Risk, Very\ High\ Risk)$ is the w^{th} fuzzy subset, $w = \{1, 2, 3, 4, 5\}$. The interval $l = [0, 1]$ must be covered by these five fuzzy and verify (Fig.9):

$$\forall l_n \in l, \sum_{n=1}^5 \mu_{D_n}(l_n) = 1, \quad (4)$$

Where $\mu_{D_n}(l_n)$ the membership function corresponding to D_n evaluated at l_n .

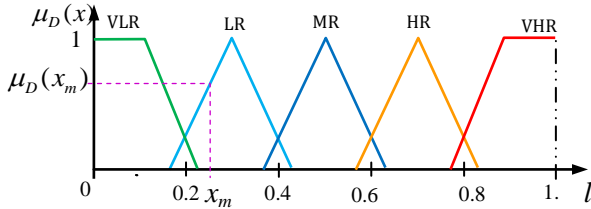


Fig. 9: Fuzzy set of the fire risk level.

6.3 The fuzzification

These fuzzy partitions lead to the computed of the membership functions $\mu_{A_i}(x_{0i})$, $\mu_{B_j}(y_{0j})$, $\mu_{C_k}(z_{0k})$ and $\mu_{D_n}(l_{0n})$, considering the symmetric triangular functions using the symmetric triangular type. These expressions of membership functions are as follows:

$$\mu_{A_i}(x_i) = \begin{cases} 1 - \frac{|x_i - x_{0i}|}{\varepsilon_{x_{0i}}} & \text{if } |x_i - x_{0i}| \leq \varepsilon_{x_{0i}} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Designed for the temperature T of the forest.

$$\mu_{B_j}(y_j) = \begin{cases} 1 - \frac{|y_j - y_{0j}|}{\varepsilon_{y_{0j}}} & \text{if } |y_j - y_{0j}| \leq \varepsilon_{y_{0j}} \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

Designed for the relative Humidity H at the forest.

$$\mu_{C_k}(z_k) = \begin{cases} 1 - \frac{|z_k - z_{0k}|}{\varepsilon_{z_{0k}}} & \text{if } |z_k - z_{0k}| \leq \varepsilon_{z_{0k}} \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

Designed for the wind speed level, WS at the forest.

$$\mu_{D_n}(l_n) = \begin{cases} 1 - \frac{|l_n - l_{0n}|}{\varepsilon_{l_{0n}}} & \text{if } |l_n - l_{0n}| \leq \varepsilon_{l_{0n}} \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

Considered for the forest fire risk level FRL.

Where x_{0i} , y_{0j} , z_{0k} , l_{0n} are respectively the values of the variables x_i , y_j , z_k , l_n in their membership intervals and $\varepsilon_{x_{0i}}$, $\varepsilon_{y_{0j}}$, $\varepsilon_{z_{0k}}$, $\varepsilon_{l_{0n}}$, are the range values of x_{0i} , y_{0j} , z_{0k} , l_{0n} , respectively.

6.4 The inference diagram

Since the rules are aggregated, the defuzzification consists of calculating the real value z_{0n} , of the fire risk level using the centroid method (z_{0n} is the centre of μ_{D_i}) [15]:

$$z_{0n} = \frac{\int_0^1 z_i \mu_{D_i} dz_i}{\int_0^1 \mu_{D_i} dz_i} \quad (10)$$

7. SOFTWARE ARCHITECTURE

The software design is based on a layered architecture:

- Application layer: This Software offers the way to access to the Basic RF and the Hardware Abstraction Layer.
- Basic RF: This layer offers a simple protocol for transmission and reception on two-way RF link.
- Hardware Abstraction Layer: This layer Contains functionality for access to the radio and on-board peripherals modules like LCD, UART, joysticks, and timers [16]

7.1 Acquisitions climatic parameters

7.1.1 Software Diagram

The main task of sensor node is data acquisition and transferring, after completing the initialization of the protocol stack and hardware, the terminal node starts scanning channel, it then sends the information of joining the network. If confirmed, it began to collect data through the sensors, it then sends it to the coordinator node through the wireless transmission[9].

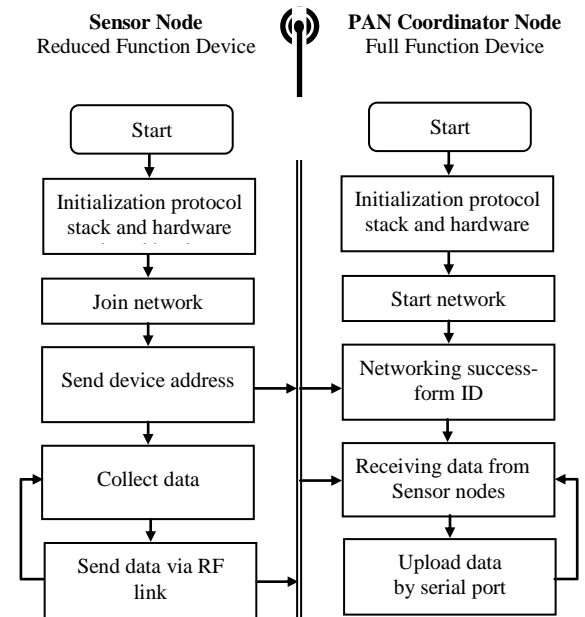


Fig. 10: Flow chart of the node program.

7.1.2 Temperature

Inside each node, one periodical temperature acquisition function is executed, having for objective the acquisition of the temperature value.

7.1.3 Humidity

The soil temperature and humidity sensor TDR-3A used, can measure the humidity with the characteristics of waterproof and seal adaptable to the soil environment. The range of humidity measurement is 0~100%, the accuracy in the range of 0 to 50% is $\pm 2\%$ and the output current is 4~20 mA. The output of sensor can be directly connected to port P0 of the SoC, CC2430 [17].

7.1.4 Wind Speed

Among them, the wind speed sensor would use three cup structures. When the cups would make the effect of horizontal direction it would be rotated by the rotor shaft through the slit activity of the rotary optical coupler and the output frequency signal through the built-in signal unit processes the output voltage signal [18].

7.2 Basic RF layer

The Basic RF protocol offers the service for packet transmission and reception. It can also offer a secure communication by the use of CCM-64 authentication and encryption/decryption of packets [19]. The protocol uses IEEE 802.15.4 MAC compliant data and acknowledgment packets. Basic RF contains only a small subset of the 802.15.4 standard.

7.3 Basic RF instructions

- (i) `halBoardInit()` : called first to make sure that the board peripherals and radio interface is initialized.
- (ii) `basicRfInit()` : called to initialize the packet protocol.
- (iii) `basicRfSendPacket()` : called to create a buffer with the payload to send. Maximum payload size for Basic RF is 103 Bytes. Check the return value.
- (iv) `basicRfPacketIsReady()` : to perform polling to check if a new packet is ready to be received.
- (v) `basicRfReceive()` : to receive the packet by higher layer. The caller is responsible for allocating a buffer large enough for the packet and 2 Bytes buffer space for the RSSI value [19].

7.4 Nodes acquisition programs

(1) Node temperature acquisition program

```
include <adc.h>
ifndef hal_temp_h
define hal_temp_h
define adc_ref_1_25_v 0x00
define adc_12_bit 0x30
define adc_temp_sens 0x0E
define const 0.61065
define offset_datasheet 743
define offset_measured_at_25_degrees_celcius 29.75
define offset (offset_datasheet +
offset_measured_at_25_degrees_celcius)
define temp_coeff 2.45
unsigned char getTemp(void)
{
unsigned int adcValue;
float outputVoltage;
adcValue=adcSampleSingle(adc_ref_1_25_v,a
dc_12_bit,adc_temp_sens);
adcValue >>= 4;
outputVoltage = adcValue * const;
return ((outputVoltage - offset) / temp_coeff);
}
define pan_id 0x2007
define client_addr 0x2524
define serveur_addr 0xBEEF
define app_payload_length 3
```

```
static uint8 pTxData[app_payload_length];
define a 0
define b 1

static void Node()
{
pTxData[a] = client_addr;
basicRfConfig.myAddr = serveur_addr;
if (basicRfInit(&basicRfConfig) == FAILED) {
HAL_ASSERT(FALSE); }
while (TRUE) {
halLedToggle(1);
pTxData[b] = getTemp();
basicRfSendPacket
(serveur_addr,pTxData,app_payload_length);
halIntOff();
halMcuSetLowPowerMode(hal_mcu_lpm_3);
halIntOn();
}}
```

(2) Base Node acquisition program

```

define app_payload_length 3
define a 0
define b 1
static uint8 pRxData[app_payload_length];
static void Basenode()
{
    while (TRUE) {
        while(!basicRfPacketIsReady());
        basicRfReceive(pRxData, app_payload_length, null);
        long temp=pRxData[b];
        PODIR=0xFF;
        PO=pRxData[a];
        halMcuWaitMs(100);
        PO=pRxData[b];
    }
}
    
```

8. RESULTS AND DISCUSSION

The results are based on the climatic database relative to Tunis-Carthage region of the year 2013. In Summer, we find an important increase of the temperature values. Otherwise, we notice an important decrease of the humidity values. For the wind speed, it is variable, sometimes we can see a big increase, sometimes the values are very small (Fig.11). So, the fire risk level is very high (Fig.12).

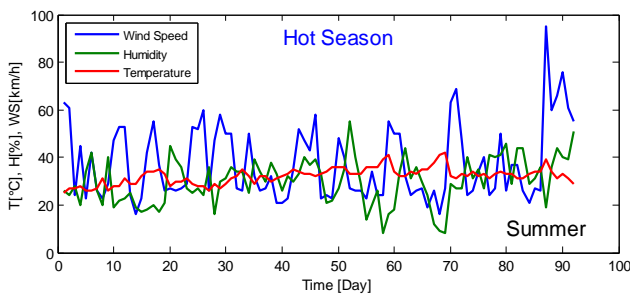


Fig. 11: Summer climatic parameter curves.

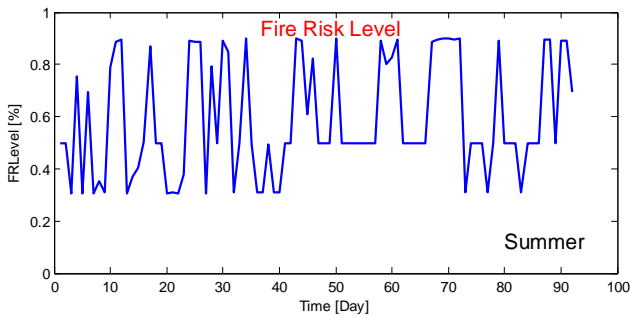


Fig. 12: Summer fire risk level estimated.

In Winter, we find a decrease of the temperature values. On the other side, we notice an increase of humidity values and the wind speed too (Fig.13). So the fire risk level is low (Fig.14).

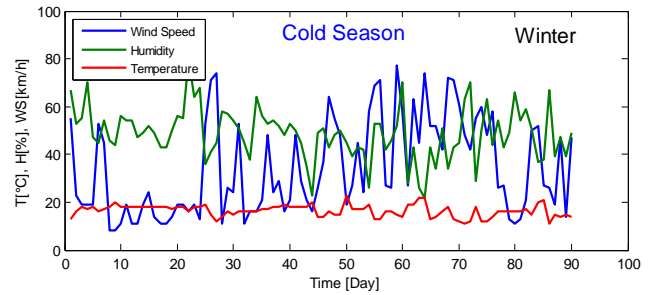


Fig. 13: Winter climatic parameter curves.

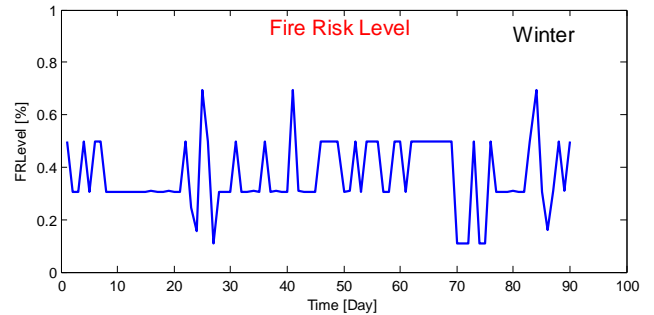


Fig. 14: Winter fire risk level estimated.

In Autumn, we find a medium temperature values. On the other side, we notice an increase of humidity values. The wind speed is sometimes high (Fig.15). So, the fire risk level is usually low but sometimes it can be high (Fig.16).

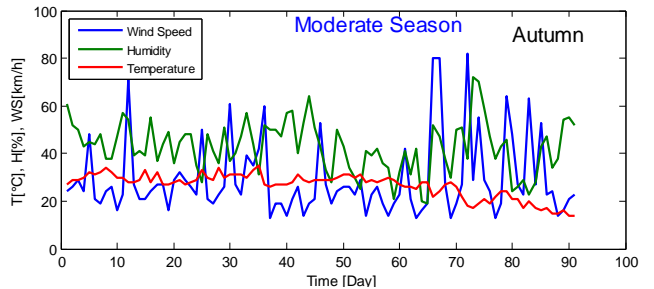


Fig. 15: Autumn climatic parameter curves.

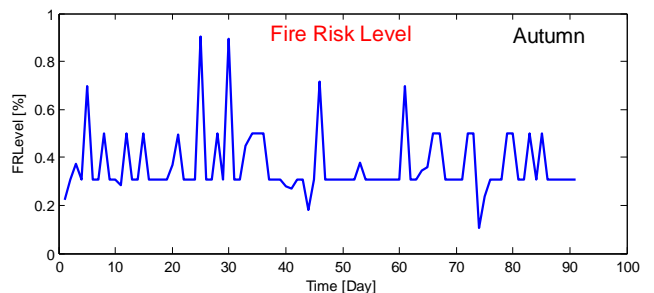


Fig. 16: Autumn fire risk level estimated.

In Spring, we find a low temperature values. Otherwise, we notice an important increase of the humidity values as well as for the wind speed (Fig.17). So, the fire risk level is high mainly in the end of the season (Fig.18).

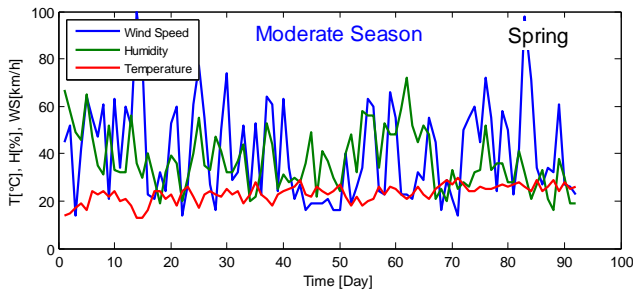


Fig. 17: Spring climatic parameter curves.

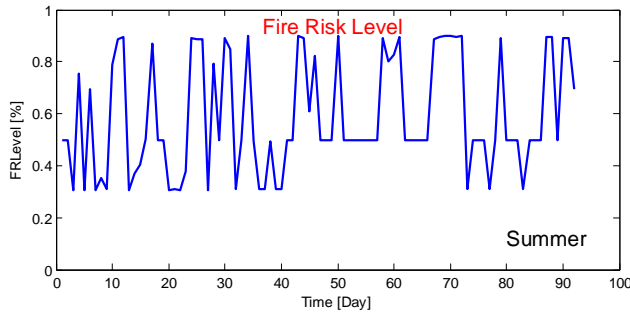


Fig. 18: Spring fire risk level estimated.

The monthly and seasonal average values of fire risk level are computed by the following equation:

$$\forall x \in \xi, \bar{X} = \frac{1}{N_j} \sum_{j=1}^{N_j} (x_j), \quad (11)$$

Where $\xi \in \{VLR, LR, MR, HR, VHR\}$ and N_j is the day number of the interval.

Table 1. Monthly percentage fire risk level values

Month	Fire Risk Level (%)				
	VLR	LR	MR	HR	VHR
January	0.00	25.65	9.67	0.00	0.00
February	2.56	20.57	14.29	0.00	0.00
March	0.00	16.01	24.70	0.00	0.00
April	0.48	20.39	12.07	6.13	0.00
May	10.2	17.53	19.62	7.73	0.00
June	0.00	14.33	29.60	0.00	0.00
July	0.00	15.44	33.82	14.63	9.30
August	0.00	4.20	33.84	30.0	21.20
September	0.00	24.47	11.64	0.00	0.00
October	1.27	24.74	14.70	0.00	0.00
November	0.82	22.58	6.25	15.45	0.00
December	0.98	22.30	11.54	0.00	0.00

Table 2. Seasonal percentage fire risk level values.

Month	Fire Risk Level (%)				
	VLR	LR	MR	HR	VHR
Winter	1.13	16.50	17.22	2.48	0.00
Spring	0.34	13.89	20.68	11.68	2.54
Summer	0.00	7.63	21.22	34.70	27.18
Autumn	0.38	22.68	9.93	8.45	5.99

The system simulation is computed by bloc diagrams with Matlab/Simulink [20][21][22].

9. CONCLUSION

The development of wireless sensors networks arises new challenges to engineers in several fields. Our system includes

two aspects hardware and software. The hard-ware is composed of one PAN coordinator node CC2430 and several sensor nodes CC2430. Each component contains a System-On-Chip CC2430 that contains the processor which executes the necessary program on each node. The software aspect is mainly consisted of one monitoring center that can supervise all the forest, through the information given by all the nodes inside the whole network. The results provided can indicate the fire risk level inside the forest. The results, obtained by the application of the fuzzy logic algorithm, justify an important fire risk level in hot season. Otherwise, the fire risk level varies between low and medium in relation to the wind speed. This new approach gives a reliable solution that can permit to detect forest fires risks, in order to avoid severe damage of this disaster, when it happens

10. REFERENCES

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