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A smart wireless sensor network node for fire detection

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Abstract: Fires generally occur due to human carelessness and the change in environmental conditions. The uncontrolled fire results in death incidents of humans and animals as well as severe threats to the ecosystem. The preservation of the natural environment is important. The wireless sensor networks, widely used in different monitoring applications, is used in this work. For fire detection, we use flame, smoke, temperature, humidity, and light intensity sensors in our proposed network node which is low-cost, reduced-size, and power-efficient. The experiments are performed in a well-controlled real-time environment. The proposed node transmits the sensed data to the central node. The central node then transfers the data gathered from all the nodes to the control station using an air interface. To decide whether there is an incident of fire or not, and to have an idea on fire intensity, we combine multiple attributes sensed from a single node using Bayesian approach due to its simplicity and resemblance with human reasoning. In the experimental setup, the conditions for fire with different intensity are generated and the results confirm the validity of the proposed approach in terms of accuracy and less false alarms.

Key words: Wireless sensor networks, microcontrollers, fires, classification algorithms, gas detectors

1. Introduction

Human negligence or drastic environmental changes may lead to hazardous fires. Accidental fire is a major threat in various environments, and may lead to potential loss of human lives and economic damage. The preservation of the natural surroundings is really essential. A lot of work has been carried out for preventive and corrective measures to handle the fire-related problems. If fire can be detected at a proper time and necessary corrective measures are taken, then the fire disasters can be efficiently avoided. Fire accidents can take place in two different environments, such as indoor and outdoor environments. Indoor accidents include the buildings where fire occurs due to gas leakages, unattended equipment, heat source close to the combustibles, poor handling of sensitive materials, etc., whereas outdoor fire accidents involve forest fire, agricultural operations, natural factors, or deliberately setting fire in enmity, etc. Among these two, outdoor accidents are considered the most devastating accidents. A comparison between fires occurring in indoor and outdoor environments is provided in Table 1. From Table 1, we observe that risk factor is high for wildlife and environment in outdoor environments whereas it is high for human life, assets, and infrastructure in indoor environments. Forest fire detection is an important task which has to be handled at early stages to avoid a huge loss. It is also very difficult to prevent fire in outdoor environments.

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Table 1. A comparison between indoor and outdoor losses due to fire.

Risks	Risk factor	
	Indoor	Outdoor
Human life	High	Low
Wild life	Low	High
Assets	High	Low
Environment	Low	High
Infrastructure	High	Low

In the past, manual procedures were being used to detect forest fire. A watchman was appointed to monitor a specific area for fire accidents. His duties were to look around the surroundings and to observe the environment to foresee any incoming fire. The manual method was simple; however, it required manpower, had limited range, and prone to human errors. Another method was patrolling which was faster than the former. In patrolling, the guard moves on the vehicle to monitor the area for any fire accidents. The advantage of this method was that it was fast and required less manpower. However, the transportation cost was very high. The wireless sensor network (WSN) has attracted a lot of interest from the research community working on automated fire detection. Using WSN nodes is an efficient way to determine the fire accidents well in time. To reduce fire hazards, there is a need to make such a node which can be implanted in different areas which will send data from various sensors attached to the WSN node. The WSN is a suitable and low-cost solution for fire detection. It is a reliable solution for different monitoring problems and used in various fields such as forests [1–3], wild lands [4, 5], residential areas [6], buildings [7, 8], rural areas [9]. Fire detection is important for the above mentioned areas for the protection of land, infrastructure, and human and animal life. The WSN node is implemented using different set of sensors. In [8, 10, 11] fire detection is carried out using multiple combinations of the sensors and cameras such as infrared, internet protocol (IP), and thermal cameras. It gives us the visualization and 3D image of the area of implementation. However, it is expensive and requires manpower continuously for its monitoring.

Alkhatib in [12] proposed a WSN model for fire detection using only temperature sensors. The model provided high accuracy and used cheap temperature sensors. The authors in [13] extended the work in [12] by increasing the types of sensors such as temperature, humidity, pressure and position sensor etc. In [14], Antonio et al. proposed a hierarchy of WSN which is used for early fire detection. It includes the sensor nodes (SNs) to sense air temperature, relative humidity, wind speed and direction, CO and CO2 levels and provided the data to central nodes which transmit the data to the control center. However, the designed WSN lacked intelligence and provided less efficiency.

Hakilo et al. in [15] described a WSN node based on wildfire hazard prediction (WFHP) system. The WSN-WFHP system model used 2-tiered WSN architecture and consists of 16 weather sensor nodes. This makes the WSN more efficient and precise. However, due to the limited types of sensors used, these algorithms yield ineffective results and may not detect fire on time. In [16, 17], the author used fuzzy logic with multiple sets of sensors such as temperature, humidity, light intensity, and distance sensor for intelligent fire detection. However, it increased the exponential growth of rule-based decision making. The authors in [18–20] made improvement in fuzzy logic by using multiple approaches such as fuzzy logic II, tree classifier, and neighbor-based fuzzy logic algorithms for fire detection. These approaches reduced the rules for correct decision making. However, fuzzy logic is unsupervised, so it may give errors while detecting the fire. Therefore, we used supervised intelligent system in the proposed fire detection WSN node. It is based on the Bayesian optimization machine learning algorithm with less chances of false fire detection. The WSN will be trained for most of the sets of values that may cause fire, eventually detecting the fire incident. In this work, we present the wireless sensor node with different sensors such as flame detection sensor, gas sensor (smoke) [21], temperature sensor, humidity sensor, and light sensor. These sensors will monitor the environmental parameters continuously and send the data collected from sensors to the base station, where it will be monitored to prevent any kind of hazardous fire. This application will be useful for almost every type of environment and it will be convenient as it is going to be wireless. The node used will be cheap and small so that it can be implemented anywhere.

The main contributions of the paper are: 1) To use optimal combination of sensors for fire detection. 2) To select hardware components for smart fire detection with low cost, compact size, and low-power WSN node. 3) To provide a hardware design of smart fire WSN node in terms of schematic model, PCB model, and final hardware assembly. 4) To provide cost analysis of the proposed hardware. 5) To test the hardware under different real-time environmental conditions. 6) To apply machine learning algorithm for intelligent and reliable decisions.

The paper is organized as follows: Section 1 includes the introduction for fire detection. In Section 2, we provide comprehensive discussion about the architecture of WSN node. The description of sensors used in the proposed work and fundamental parts of the WSN node along with voltage sensor circuit are explained in Section 3. Complete circuit design of smart fire node and their budget analysis is discussed in Section 4. Testing of the hardware and machine learning algorithms is discussed in Section 5 followed by discussion and conclusion in Section 6.

2. Wireless sensor network

Over the last ten years, the WSN has attracted a lot of attention from research community due to its various applications. The WSN is a wireless network composed of different devices used for monitoring and controlling applications. The main applications include health and environment monitoring, home and office automation and military-related applications. The block diagram of WSN is shown in Figure 1. The WSN consists of two major parts i.e. WSN node and base station.

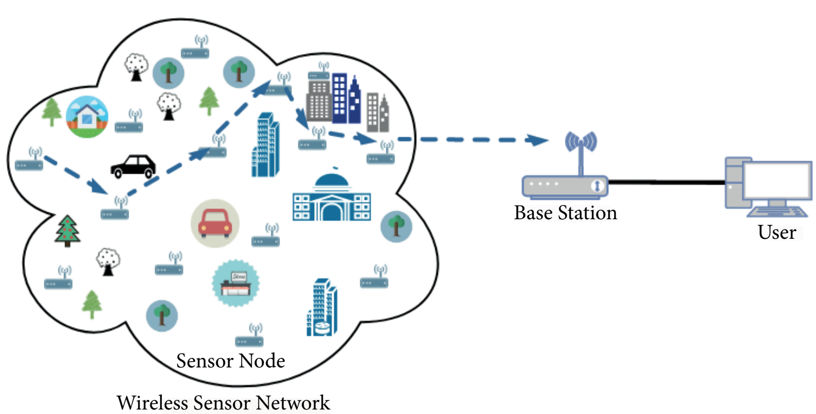


Figure 1. Block diagram of wireless sensor network.

2.1. WSN node

The sensor node is the main component of WSN which is responsible to sense the changing parameters of the environment and transmit the information to the base station. A WSN node consists of a transceiver, microcontroller, sensors, and power source. The components of the WSN node are illustrated in Figure 2a. The sensors are mounted on the node which is responsible for collecting information. The microcontroller receives the sensor data and transmits it towards the base unit through the transceiver. The battery source provides the necessary power for operations. The architecture of multiple sensor nodes is placed at different places and these nodes can communicate with each other by applying different networking algorithms. The nodes can be placed by using different network topologies such as star, mesh, and hybrid.

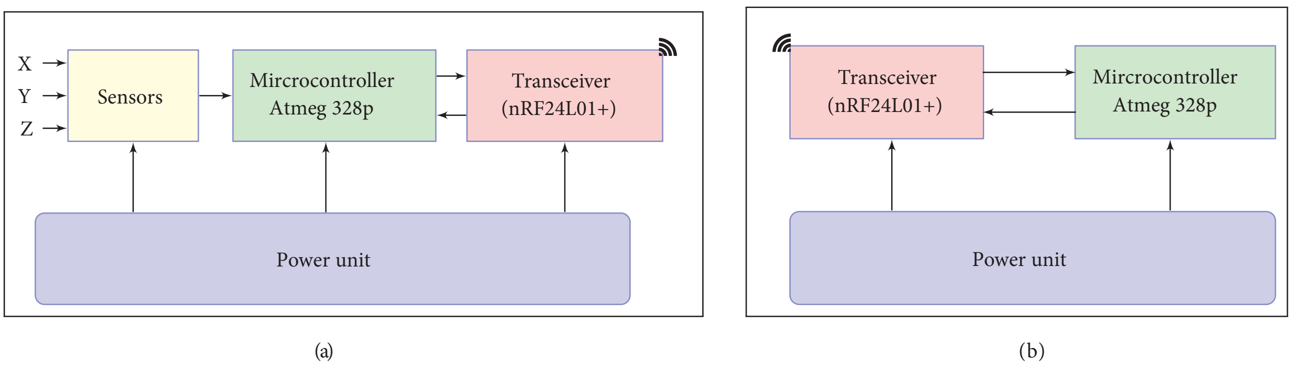


Figure 2. Components of WSN: a) WSN node b) base station.

2.2. Base station

The base station is responsible for receiving the information sent by the WSN node and delivers it to the end user. It operates as a bridge between the sensor node and the user. The base unit consists of a transceiver, microcontroller, and battery. A block diagram of a base station is shown in Figure 2b. The transceiver is used to receive the information from WSN node and microcontroller takes necessary decisions using the data received from sensors. Due to this control functionality, base station is also known as an administrative unit. The battery source provides the power to the microcontroller and transceiver.

3. Proposed wireless sensor network node

In this paper, we propose a WSN node which will be used to detect the fire using sensors including flame sensor, smoke sensor, light sensor, temperature, and humidity sensor. The smoke sensor is used to detect the smoke produced in the early stage of fire. The flame sensor detects the flame of the fire. The node also includes temperature and humidity sensor used to measure the temperature and humidity of the environment because the fire affects the temperature and humidity of the environment. The fire also produces light variations in the environment. The node measures the light intensity by using the light dependent resistor (LDR). The combination of the sensors used here provide accurate and early fire detection. These sensors will provide the data to a microcontroller. The microcontroller is connected to the radio frequency (RF) transceiver due to its large range and low cost. The transceiver will transmit the data to the base station. A lithium ion battery is used to supply the power to the node components. The battery status is monitored with the help of voltage-dependent resistor (VDR) circuit. Figure 3 shows the block diagram of the proposed fire detection WSN node and a brief discussion of various components is provided in the following sections.

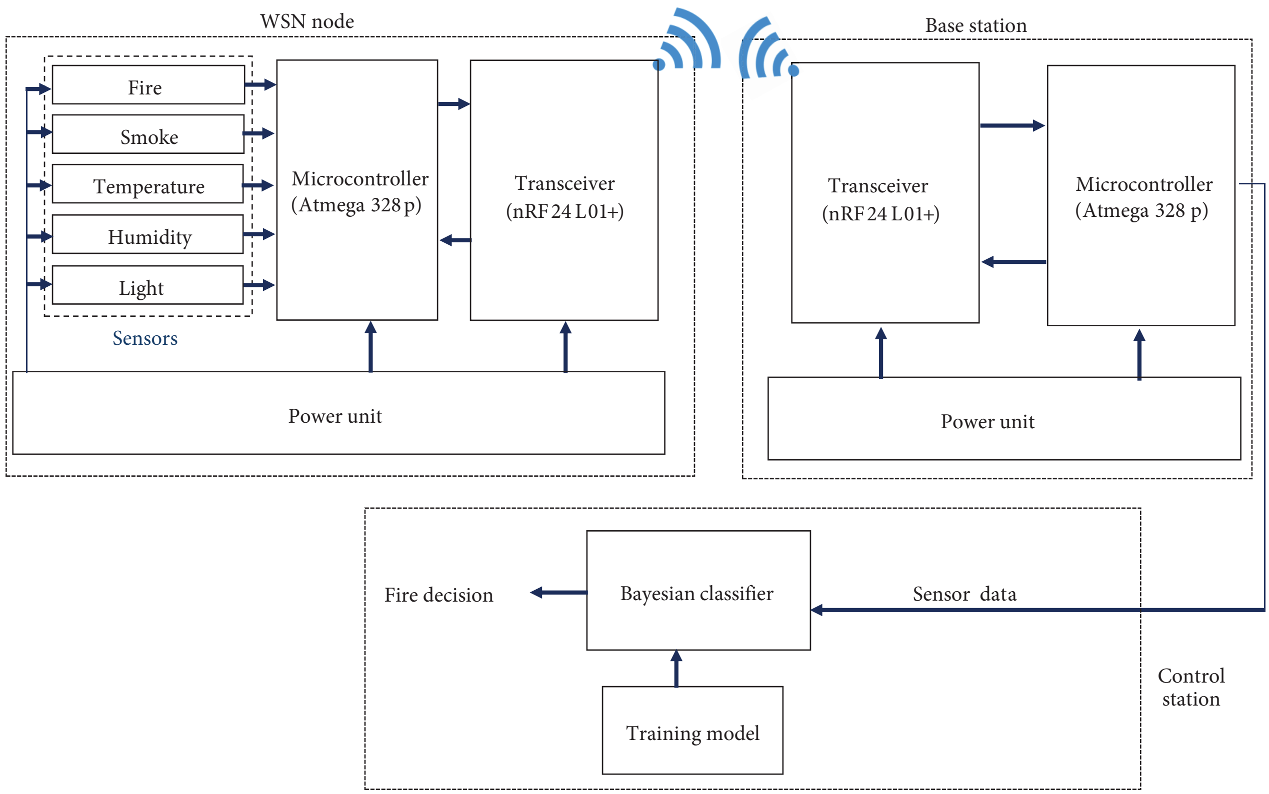


Figure 3. Framework of the proposed WSN-based fire detection.

3.1. Sensors

We used different sensors to detect the fire in our proposed WSN node. The technical details of each sensor used are provided as follows.

3.1.1. Flame sensor

The infrared (IR) flame detection sensor is used to detect the infrared wavelength ($760 - 1100$ nmλ) emitted from the flame of fire (see Figure 4a). It operates at low voltage (3.3 V to 5 V) and detects the flame up to 1 m. It gives both analog and digital output. The digital output is set with the help of adjustable sensitivity knob. It has comparator chip LM393 which keeps the output readings more stable.

3.1.2. Temperature and humidity sensor

The DHT22 digital temperature and humidity sensor is used due to its small size and low power consumption (see Figure 4b). It measures both temperature and humidity and provides digital output. It is more accurate and stable than other available sensors. Its operating voltage is $3.3 - 6$ V. The temperature measurement ranges from -40 to 125 $^\circ$C with ± 0.5 $^\circ$C accuracy. The humidity measurement is from $0 - 100\%$ with $\pm 2\%$ accuracy.

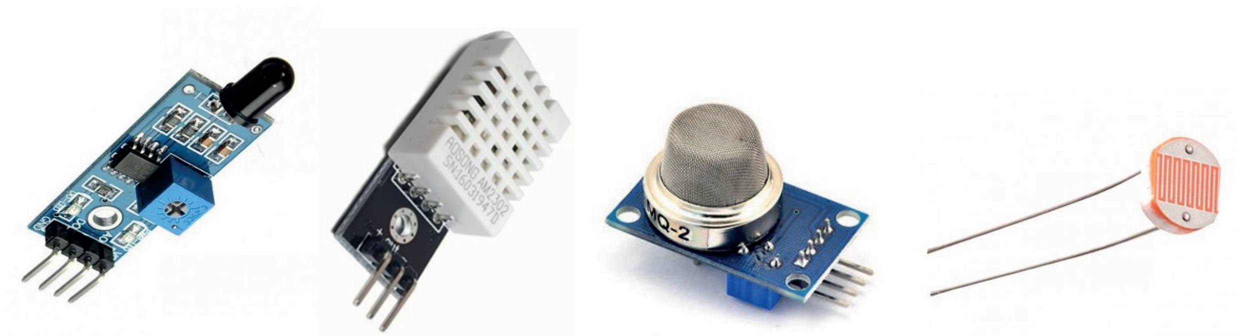
3.1.3. Smoke sensor

The MQ-2 smoke sensor with sensitive material SnO_2 is used to detect smoke (see Figure 4c). The SnO_2 has low conductivity in clean air and high conductivity for liquefied petroleum gas (LPG), Methane, Hydrogen, and

Propane gases in the environment. The sensor produces high output voltage in case of high conductivity. It is a low-cost sensor and operates at 5 V $\pm$0.1 V.

3.1.4. Light intensity sensor

A 5-mm LDR is used as a light intensity sensor due to its low cost (see Figure 4d). In case of increased brightness, its resistance reduces and produces low voltage drop across it, whereas in darkness it acts as a high-value resistor so the voltage drop is high. It is used in series with another resistor and voltage drop across that resistor is measured.



(a) (b) (c) (d)

Figure 4. Sensors: a) IR flame detection sensor, b) DHT22 temperature and humidity sensor, c) MQ-2 smoke sensor, d) light intensity sensor.

3.2. Microcontroller

Most of the WSN nodes use Arduino microcontroller development board due to ease in implementation and simplicity. In this work, we use ATmega328p microcontroller chip instead of the whole Arduino board due to three main reasons: (i) reduced cost, (ii) small size, and (iii) power efficiency. The dimension of the chip is 34.8×7.49 mm compared to the Arduino which is 68.6×53.3 mm. The Arduino consumes about 50 mA in active mode while the chip only consumes 16 mA. Therefore, power consumption is reduced 3 times less than the Arduino. The chip operates at 1.8–5 V voltage levels with 4–204 MHz clock speed.

3.3. Transceiver

In this paper, we use NRF24L01+, an RF transceiver with 2.4 GHz operating frequency. It has very low cost in comparison to other transceivers and consumes less power. The voltage operating range lies between 1.9 and 3.6 V. It has a small size (dimension: 12×18 mm) and transmission range is about 100 to 1000 m. The NRF24L01+ module can operate on three different data rates according to applications which are 250kbps, 1 Mbps, and 2 Mbps. The NRF24L01+, with channel frequency band of 2400−2525 MHz, provides 125 independent channels for multiuser communication. One transceiver can communicate with 5 transceivers at a time. Therefore, by using different end devices and coordinate routers we can make a complete network of different topologies. The power consumption is about 12 mA during transmission. The NRF24L01+ has 4 power modes which can be selected according to the power of the amplifier and the distance travelled by the transceiver. The modes are named as minimum power, low power, high power, and maximum power. The hardware chips of RF, Zigbee, Bluetooth, and RF tranceivers are shown in Figures 5a–5d respectively while a detailed comparison is provided in Table 2.

Table 2. A comparison of different transceivers used in wireless sensor networks.

Transceiver	Cost	Range	Data rate	Power
Bluetooth	$7.69	10 m	2.1 Mbps	Moderate
Wi-Fi	$4.5	400 m	54 Mbps	High
Zigbee	$19.99	100 m	250 kbps	Low
RF module	$2	250 m	2 Mbps	Moderate

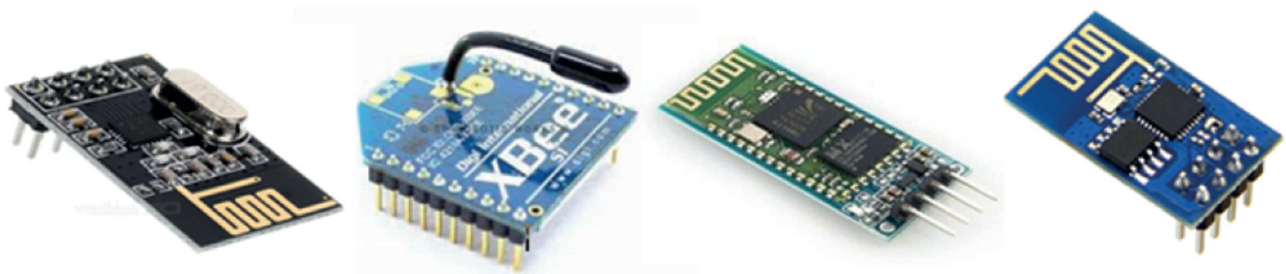


Figure 5. Transceiver modules: a) NRF24L01+ RF module, b) Zigbee S1 module, c) HM-10 Bluetooth module, d) ESP8266 Wi-Fi module.

3.4. Power source

The power source is the key component in WSN node. It is important to design the battery that provides high storage capacity, low self-discharge rate, and must be environment friendly. In order to reduce the cost and improve battery life, lithium ion cells (2 cells in series) are used. Each 18650 lithium ion cell provides 3.7 V with 2600 mAh capacity. It can be used in open environment without reducing its efficiency. A voltage sensor circuit is used to monitor the power utilization during the working of node.

3.4.1. Voltage sensor circuit

The battery power is very important for the wireless sensor node and therefore the battery status has to be monitored properly. For this purpose, voltage sensor circuit is used in this node. A voltage sensor circuit is based on voltage-dependent resistor (VDR) which consists of two series resistors connected parallel to the battery input to monitor the battery status. The low resistance consumes large power ($P = I^2R$). Therefore, to avoid power loss, we choose resistor with high resistance ($R_1 = 220$ KΩ and $R_2 = 100$ KΩ). The circuit for measuring the voltage is shown in Figure 6.

In this work, a battery source provides normal input voltage, $V_{in} = 7.4$ V, across the WSN node. The

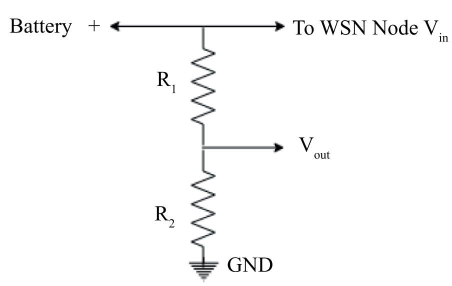


Figure 6. A schematic of voltage sensor circuit.

V_{out} is the analog input of microcontroller and it is the voltage across R_2 resistor. According to the voltage divider rule,

$$V_{out} = \frac{R_2}{(R_1 + R_2)} \times V_{in} = \frac{100}{(220 + 100)} \times 7.4 = 2.3125 \text{ V}. \quad (1)$$

The analog pin of Atmega328p microcontroller has built-in 10-bit analog to digital converter (ADC) which converts analog signal into 10-bit digital signal. The ADC maps the analog voltage (0–5 V) to digital signal V_{ADC} $(0 - 1024)$ e.g., in case of $V_{out} = 2.3125$ V,

$$V_{ADC} = \frac{1023 \times V_{out}}{5} = \frac{1023 \times V_{out}}{5} = 473 \text{ V}. \quad (2)$$

In microcontroller program, we remap the digital signal VADC to analog voltage $\{V_{out} = \frac{5 \times V_{ADC}}{1023}\}$ and multiply the inverse factor of VDR $R_f = R_1 + R_2 R_2$ from which the actual battery voltage $V - bat$ is calculated.

$$V_{bat} = R_f \times \frac{5 \times V_{ADC}}{1023} \text{ V} = 1/\left(\frac{100}{100 + 220}\right) \times \left(\frac{5 \times 473}{1023}\right) = 7.4 \text{ V}. \quad (3)$$

The battery is constructed using 2 lithium ion cells where the operating voltage of each lithium ion cell is 2.9–4.2 V and the operating voltage of battery is 6-8.4 V. When the voltage range crosses that limit, it strongly damages the lithium ion cell. The battery limit is mapped in percentage for monitoring the battery status.

$$V_{bat}\ \% = \left(\frac{V_{bat} - 6}{8.4 - 6} \times 100\right) \%. \quad (4)$$

4. Hardware design

4.1. Schematic circuit design

The schematic circuit design is mostly used to give a visual display of the electrical circuit design which is helpful for representing the circuit design. The benefit of using the schematic circuit is that it displays all the components and where they are connected. Thus, by just looking at the diagram we know the connections. The schematic diagram of smart fire detection node is shown in Figure 7. The optimal design for the smart fire node is efficient and has low jumper costs.

This WSN fire detection node can be operated using DC power supply or battery. The 1N4007 diode is used for reverse voltage protection. The red LED is used with 1 K resistor for power indication. The mini Buck converter is used for down voltage regulation to convert 7.4 V into 5 V. It is more power-efficient than linear voltage regulator. The NRF24L01+ is best operated at 3.3 V. For this purpose, we select AMS1117 (3.3 V) low-dropout regulator and also add 10 μF capacitor between VCC and GND pin to avoid power fluctuations. The 16 MHz crystal oscillator is used between pin-9 and pin-10 with two 22 pF capacitors. A push button is also used with the reset pin to reset the Atmega328p microcontroller.

4.2. Printed circuit board design

The printed circuit board (PCB) models are very important to make the circuits more effective. These circuits help us provide the suitable connections for the configuration of the node. We designed two-layer PCB for fire

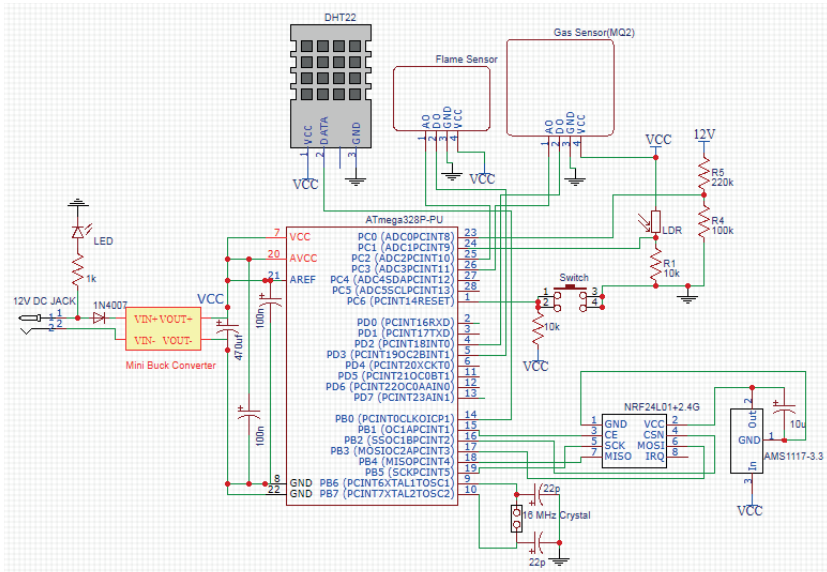
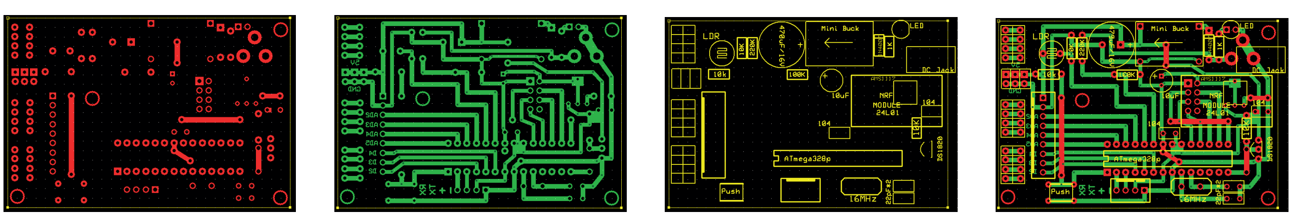


Figure 7. Schematic diagram of WSN fire detection node.

detection WSN node to reduce the size of the node. The dimension of our PCB circuit design is 71.12×50.80 mm. In this PCB design, we create custom components for sensors such as nRF24L01+, DHT22, fire sensor, smoke sensor, mini buck convertor, and FTDI. Then, we connect other components, such as Atmega328p, resistors, capacitors, and crystal oscillator, according to the schematic diagram. The FTDI, a 4-pin program header which connects to TX, RX, VCC, and GND pin of Atmega328p, is used to program the microcontroller from Arduino software. The 1.21 mm trace is used for connections between the circuits given in Figures 8a, 8b, and 8c respectively whereas all the three components are collectively shown in of node for mounting. The top copper layer, bottom copper layer, and silk screen layer are shown in Figures 8a–8c, respectively, whereas all the three layers are collectively shown in Figure 8d.

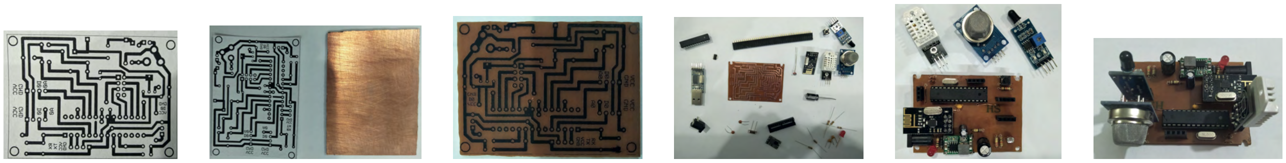
4.3. Etching and assembling

The PCB circuit design is further printed on a photo paper (Figure 9a). A copper sheet (Figure 9b) of same dimension is then cleaned and the designed circuit is imprinted and ironed for 8–10 min. The copper sheet is then separated from the photo paper resulting in the printed image on the PCB sheet. The PCB sheet is then placed in a Ferric Chloride ($FeCl_3$) solution to get the exact circuit design (Figure 9c). Finally, we drill the sheet and solder the components (Figures 9d and 9e). The final built circuit is shown in Figure 9f. In Figure 10, we have also shown the final fire detection node working in real environment.



(a) (b) (c) (d)

Figure 8. PCB circuit design: a) top copper layer, b) bottom copper layer, c) silkscreen layer, d) all layers.



(a) (b) (c) (d) (e) (f)

Figure 9. Different phases of hardware design: a) printed circuit on photo sheet, b) PCB copper sheet, c) ironed PCB, (d) hardware components. e) components soldered on PCB, f) final WSN fire detection node.

Figure 10. Final fire detection WSN node in working environment.

4.4. Hardware components

The list of hardware components used in the proposed fire detection WSN node is as follows.

- Atmega328p microcontroller, nRF24L01+ transceiver module
- DHT22 temperature and humidity sensor, IR flame detection sensor, MQ-2 Smoke sensor
- 5 mm LDR (light dependent resistor)
- Mini-360 DC-DC buck converter, AMS1117 3.3 V voltage regulator
- 3 mm LED, 1N4007 diode, 16 MHz crystal oscillator
- Capacitors: 1×470 μF, 1×10 μF, 2×100 nF, 2×22 pF
- Resistors: 1×1 K, 2×10 K, 1×100 K, 1×220 $K\Omega$
- 2.54 mm female header, 2.54 mm male header
- 28 Pin IC Socket, push button switch, 2.1 mm DC jack

4.5. Budget

The prices of each component used in the fire detection WSN node are separately given in Table 3. The battery used is rechargeable, so there is very little maintenance required. From Table 3, we observe that the node is very low-priced and therefore suitable for wide range of applications.

5. Experimental results

5.1. Data collection

After completing the hardware circuit, we tested the WSN node in different environmental conditions and time such as in open area at midnight, in room at midnight, in open area in smog at late night, in sunlight in the

Table 3. Details of budget for the proposed wireless sensor network node.

Sr. No.	Items	Price (USD)
1	Atmega328p microcontroller	2.46
2	nRF24L01+ transceiver module	2
3	DHT22 temperature and humidity sensor	4.7
4	IR flame detection sensor	2.97
5	MQ-2 Smoke sensor	1.98
6	Mini-360 DC-DC buck converter	1.2
7	Batteries	7
8	Miscellaneous parts	3
	Total	$ 25.31

afternoon, in bonfire in the afternoon, and in smoke in the afternoon. The values of 5 sensors are taken in the winter and are discussed in the following subsections.

5.1.1. Temperature

Six different conditions of temperature were measured. Figure 11a shows the plot of temperature readings at different time intervals. From the plot, we observed that at midnight, temperature was constant for several hours. Then, the temperature decreased further due to smog but remained constant. In sunlight the temperature rose. Later, we initiated a fire which resulted in an abrupt increase in the temperature. This would be the peak temperature. Lastly, after the fire was extinguished, the temperature decreased gradually.

5.1.2. Humidity

Figure 11b shows the plot of humidity readings at different time intervals. From the plot, we observed that humidity at midnight was slightly higher than that in the closed room. The peak level was achieved in the open environment where humidity was high due to smog. In sunlight, humidity decreased and dropped to the lowest level under the fire ignition due to heat and smoke.

5.1.3. Light intensity

Figure 11c shows the plot of light intensity readings at different time intervals. From the plot, we observed that light intensity was zero at midnight and late at night in the open area. Intensity was measured low due to the presence of light in the room. The light intensity in the sunlight was at its peak. Later, the fire was started resulting in increased light intensity which gradually decreased to its normal level.

5.1.4. Flame status

Figure 11d shows the plot of flame status readings at different time intervals. The results show high voltage in the no-fire condition and low voltage in the fire condition. In the fire condition, the graph shows very low voltage due to high intensity of flame in fire but at night it shows high voltage due to no fire. We observed that IR flame detection sensor is not an effective sensor for open environments because it detects infrared from sunlight as well.

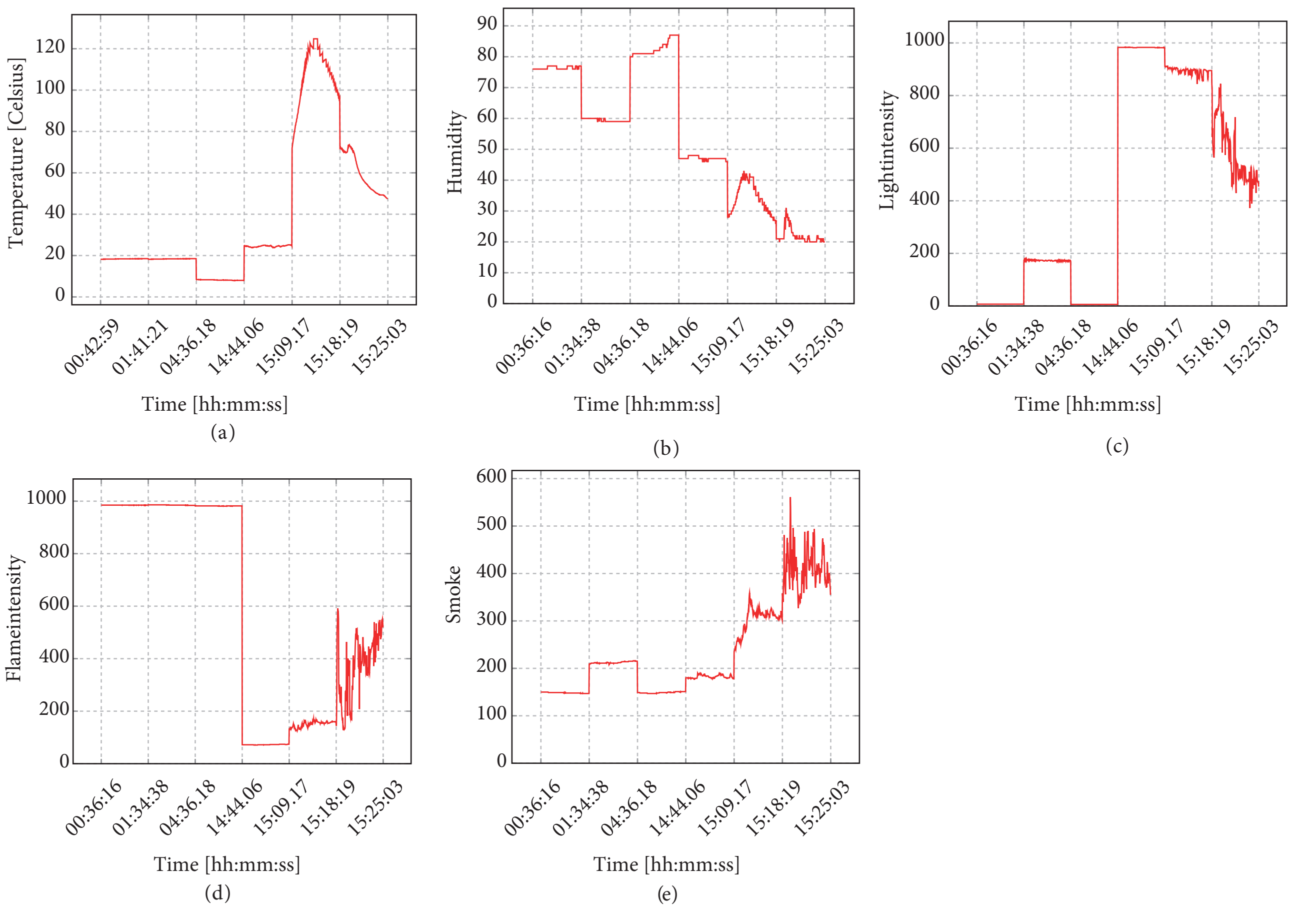


Figure 11. Plot of (a) temperature, (b) humidity, (c) light intensity, (d) flame intensity, and (e) smoke readings at different time intervals.

5.1.5. Smoke status

MQ-2 smoke sensor is sensitive in measuring multiple gases but shows high sensitivity in measuring CO, smoke, etc. We observed that in open areas, smoke sensor gives low value without any fluctuations, whereas in fire and smoke condition it gives maximum level. Figure 11e shows the plot of smoke readings at different time intervals.

5.2. Fire detection using machine learning

In our work, for fire detection, we have used the Bayesian classifier. The Bayes classification model, commonly used in data and image processing, is a machine learning approach that provides excellent results for classification and detection problems. Here, we use real data collected from our experiments (as discussed in previous section) with the Bayesian classifier. The dataset used for training and testing is collected from real environments under different conditions. We divide our data into two categories: i) fire, which includes the data collected in bonfire, ii) no-fire, which includes the data collected in an open area at noon, midnight and in smog condition, in closed room environment, and in smoke conditions. In total, we have 300 samples for fire and 900 for no-fire event where each sample contains sensor values collected from five sensors i.e. temperature sensor, humidity sensor, flame detection sensor, light sensor, and smoke sensor. The normalized sensor values are used as features for training and testing. For our experiments we have used five features i.e. one feature from each sensor for fire and no-fire events. From this data, we use 60% for training of Bayesian classifier and 40% for testing and validating the results of the proposed model.

5.2.1. Bayesian classification framework for fire detection

For fire detection, we used a supervised Bayesian classification framework with a multivariate normal distribution. For a test feature vector y, the probability density function (PDF) is given by:

$$P(y/m) = \frac{1}{(2\pi)^{N/2}\sqrt{det(\sum_m)}} \left\lfloor \exp \left\lfloor -\frac{1}{2}(x-\mu_m)^T \sum_m {}^{-1}(x-\mu_m) \right\rfloor \right\rfloor \tag{5}$$

where N is the number of features, m represents the number of classes, and μ_m and $\sum_m$ are the class mean vectors and covariance matrices. For a given test vector y containing the sensor values, the decision rule on whether y represents a Fire event or a No Fire event is based on the following framework: Decide class i ($i = 0$ for No Fire, $i = 1$ for Fire) if

$$P(c_i/y) > P(c_j/y) \;\; j = 0,1 \;\; i \neq j \tag{6}$$

The above a posteriori probabilities can be expressed in terms of the a priori probability and the class conditional PDFs using the Bayes theorem:

$$P(c_j/y) = \frac{P(y/c_j)P(c_j)}{P(y)}. \tag{7}$$

5.2.2. Objective evaluation of the proposed framework

To evaluate the performance of our proposed Bayesian classification framework for fire event detection, we use precision, recall, accuracy, and F-measure which are commonly used as objective evaluation metrics in detection and classification problems. To calculate these metrics, we compute the true positive (TP), the false positive (FP), the true negative (TN), and the false negative (FN) values using the trained classifier and the test data.

TP: Fire events detected correctly, TN: no-fire events detected correctly, FP: no-fire events detected as Fire, FN: fire events detected as no-fire.

$$\text{Precision} = \frac{\text{TP}}{\text{TP}+\text{FP}}, \tag{8}$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP}+\text{FN}}, \tag{9}$$

$$\text{Accuracy} = \frac{\text{TP}+\text{FP}}{\text{TP}+\text{TN}+\text{FP}+\text{FN}}, \tag{10}$$

$$\text{F-measure} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision}+\text{Recall}}. \tag{11}$$

In Table 4, we show the results for our model using the data collected from experiments. Precision gives the percentage of correctly detected fire events out of total detected fire events. The proposed model gives excellent precision values which prove its excellent detection performance. Recall gives the percentage of correctly detected fire events out of total fire events. Our model gives a recall value of 0.97 which suggests that the model is able to detect almost all the fire events correctly. To evaluate the overall performance of the WSN-based fire detection framework, we use two state-of-the-art metrics; accuracy and F-Measure. For our model, we get 97.2% accuracy and 0.95 F-measure values, which shows that the WSN-based model detects fire and no-fire events correctly with much less confusion.

Table 4. Fire detection results using the proposed wireless sensor network node.

Sr. No.	Measure	Value	Sr. No.	Measure	Value
1	TP	291	5	Precision	0.924
2	TN	876	6	Recall	0.97
3	FP	24	7	Accuracy	97.2%
4	FN	9	8	F-Measure	0.95

6. Conclusion and future recommendations

In this work, a smart WSN node is presented for early fire detection. The proposed node is efficient in terms of cost, size, and power. The hardware for the node is prepared using the PCB design of the circuit and the sensors. The fire event is detected using five sensors; flame detection sensor, temperature sensor, humidity sensor, smoke sensor, and light sensor. The cost of our final standalone node is 25$ which is lowest compared to other available nodes. In addition, the node utilizes less power compared to other state-of-the-art models. The experiments are performed in a well-controlled real-time environment. The data collected from real experiments is used to train a Bayesian classification model and test the validity of the proposed fire detection workflow. The smart node-based fire detection model achieved an excellent accuracy thus outperforming other state-of-the-art fire detection algorithms. The results showed that the proposed WSN node can efficiently detect fire events with fewer false alarms.

In the next phase, we are progressing in developing IoT-enabled fire detection node. The RF transceiver on the current node will be replaced by the Wi-Fi module. The fire detection nodes, base station, and client user will be connected to the Internet. The Internet will be used as the platform to transmit real-time sensor values and other data. The data received from the sensor will be secured using a cryptographic approach before transmission. A web interface will be used to analyze real-time results. This will enable the fire department to monitor live updates and take quick action in case of fire. The work is in progress and expected to be completed within few months.

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Contributions of authors

In this work, idea was provided by M Ali Qureshi, Wajahat Khalid developed the hardware, Asma Sattar wrote the paper, Asjad Amin developed the matlab code for Baysian classifier, Mobeen tested the hardware and provided real-time environments and Kashif Hussain proofread the whole paper.

References

[1] Yu L, Wang N, Meng X. Real-time forest fire detection with wireless sensor networks. In: IEEE 2005 International Conference on Wireless Communications, Networking and Mobile Computing; Wuhan, China; 2005. pp. 1214-1217.

[2] Hefeeda M, Bagheri M. Wireless sensor networks for early detection of forest fires. In: IEEE 2007 International Conference on Mobile Adhoc and Sensor Systems; Pisa, Italy; 2007. pp. 1-6.

[3] Cantuña JG, Bastidas D, Solórzano S, Clairand JM. Design and implementation of a wireless sensor network to detect forest fires. In: IEEE 2017 Fourth International Conference on eDemocracy & eGovernment (ICEDEG); Quito, Ecuado; 2017. pp. 15-21.

[4] Lutakamale AS, Kaijage S. Wildfire monitoring and detection system using wireless sensor network: A case study of Tanzania. Wireless Sensor Network 2017; 9 (8): 274-289. doi: 10.4236/wsn.2017.98015

[5] Sahin YG. Animals as mobile biological sensors for forest fire detection. Sensors 2007; 7 (12): 3084-3099. doi: 10.3390/s7123084

[6] Derbel F. Reliable wireless communication for fire detection systems in commercial and residential areas. In: IEEE 2003 Wireless Communications and Networking; New Orleans, LA, USA; 2003. pp. 654-659.

[7] Huang Q, Cox RF, Shaurette M, Wang J. Intelligent building hazard detection using wireless sensor network and machine learning techniques. In: International Conference on Computing in Civil Engineering; Clearwater Beach, Florida, USA; 2012. pp. 485-492.

[8] Zeng Y, Sreenan CJ, Sitanayah L. A real-time and robust routing protocol for building fire emergency applications using wireless sensor networks. In: IEEE 2010 8th International Conference on Pervasive Computing and Communications Workshops; Mannheim, Germany; 2010. pp. 358-363.

[9] Lloret J, Garcia M, Bri D, Sendra S. A wireless sensor network deployment for rural and forest fire detection and verification. Sensors 2009; 9 (11): 8722-8747. doi: 10.3390/s91108722

[10] Martinez-de Dios JR, Arrue BC, Ollero A, Merino L, Gómez-Rodríguez F. Computer vision techniques for forest fire perception. Image and Vision Computing 2008; 26 (4): 550-562. doi: 10.1016/j.imavis.2007.07.002

[11] Ko A, Lee N, Sham R, So C, Kwok S. Intelligent wireless sensor network for wildfire detection. WIT Transactions on Ecology and the Environment 2012; 158: 137-148. doi: 10.2495/FIVA120121

[12] Alkhatib AA. Smart and low cost technique for forest fire detection using wireless sensor network. International Journal of Computer Applications 2013; 81 (11): 12-18. doi: 10.5120/14055-2044

[13] Bouabdellah K, Noureddine H, Larbi S. Using wireless sensor networks for reliable forest fires detection. Procedia Computer Science 2013; 19: 794-801. doi: 10.1016/j.procs.2013.06.104

[14] Molina-Pico A, Cuesta-Frau D, Araujo A, Alejandre J, Rozas A. Forest monitoring and wildland early fire detection by a hierarchical wireless sensor network. Journal of Sensors 2016; 2016: 1-8. doi: 10.1155/2016/8325845

[15] Sabit H, Al-Anbuky A, GholamHosseini H. Wireless sensor network based wildfire hazard prediction system modeling. Procedia Computer Science 2011; 5: 106-114. doi: 10.1016/j.procs.2011.07.016

[16] Bolourchi P, Uysal S. Forest fire detection in wireless sensor network using fuzzy logic. In: IEEE 2013 Fifth International Conference on Computational Intelligence, Communication Systems and Networks (CICSyN); Madrid, Spain; 2013. pp. 83-87.

[17] Ammar MB, Souissi R. A new approach based on wireless sensor network and fuzzy logic for forest fire detection. International Journal of Computer Applications 2014; 89 (2): 48-55. doi: 10.5120/15477-4169

[18] Maksimović M, Vujović V, Perišić B, Milošević V. Developing a fuzzy logic based system for monitoring and early detection of residential fire based on thermistor sensors. Computer Science and Information Systems 2015; 12 (1): 63-89. doi: 10.2298/csis140330090m

[19] Kapitanova K, Son SH, Kang KD. Event detection in wireless sensor networks – Can fuzzy values be accurate? In: International Conference on Ad Hoc Networks (ADHOCNETS); Victoria, BC, Canada; 2010. pp. 168-184.

[20] Wang B, Zhuang A, Sun H, Li T, Sun X. An improved spatial-based fuzzy logic event detecting algorithm for wireless sensor networks. International Journal of u- and e-Service, Science and Technology 2015; 8 (4): 265-278. doi: 10.14257/ijunesst.2015.8.4.24

[21] Abdullah ET, Mesut GN. Design of a methane monitoring system based on wireless sensor networks. Scientific Research and Essays 2010; 5 (8): 799-805.