EAI Endorsed Transactions
on Smart Cities
Research Article EAI.EU

Intelligent Aircraft Hangar Fire Detection and Location System Based on Wireless Sensor Network in A Smart City

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Abstract

Fire detection systems in aircraft hangars are vital for safeguarding both the facility's assets and the aircraft within. When it comes to anticipating potential fire incidents in the context of a smart city, Intelligent Aircraft Hangar Fire Detection systems emerge as high-performance solutions. These systems are meticulously designed around the core concept of a wireless sensor network (WSN). They operate by deploying three sensor nodes strategically within the aircraft hangar, each tasked with measuring gas concentrations in the ambient air. These measurements are then relayed to a central base station (BS) and subsequently transmitted to a central server for real-time analysis and risk assessment. The server harnesses the power of Machine Learning (ML) techniques to scrutinize the incoming data, combining it with reference gas data. This amalgamation is processed and translated into a dynamic report, which is instantly displayed on a user-friendly Graphic User Interface (GUI). In situations where smoke or gas concentrations reach critical levels, the server's predictive capabilities come into play. It proactively identifies high concentration zones on the GUI, serving as an early warning system. Simultaneously, it pinpoints the potential source and location of the fire outbreak, thus expediting emergency response procedures. In the broader context of a smart city, the integration of such Intelligent Aircraft Hangar Fire Detection systems extends their utility beyond hangar-specific safety. Data generated by these systems can be seamlessly integrated into the city's overarching safety infrastructure, facilitating swifter and more coordinated responses to fire emergencies across the urban landscape. By doing so, these systems contribute significantly to enhancing urban safety, protecting critical assets, and, most importantly, preserving human lives within the smart city framework.

Keywords: Smart City, Aircraft Hangar, Fire Protection, Safety, WSN, Data Visualization, Machine Learning, GUI

Received on 17 August 2023, accepted on 04 October 2023, published on 05 October 2023

doi: 10.4108/eetsc.3742

1. Introduction

The research work is titled 'Intelligent Aircraft Hangar Fire Detection and Location System Based on Wireless Sensor Network (WSN) in a Smart City.' As our cities evolve into smart, interconnected hubs of human civilization, the importance of fire safety takes center stage. Fires, with their lethal potential and destructive aftermath, pose threats not only to aircraft hangars but also to warehouses, businesses, residential areas, and, most importantly, the lives of city residents. In the context of a smart city, where technology and data-driven solutions are pivotal, addressing fire safety becomes an integral part of urban planning. The interconnectedness of smart city infrastructure allows us to rethink and enhance traditional

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fire safety measures. Smart cities leverage digital and communication technology, as well as data analytics, to create an efficient and effective service environment that improves urban quality of life and supports sustainability. [1] The development of smart applications (see Figure 1) in recent years has altered the way we live and work. [2] Emerging technologies such as the Wireless Sensor Network (WSN), the Internet of Things (IoT), artificial intelligence (AI), and big data power these applications. They have been used to address complex challenges and improve the quality of life for individuals and communities in a variety of fields, including safety and security, healthcare, governance, the environment, transportation, energy, infrastructure, and education.

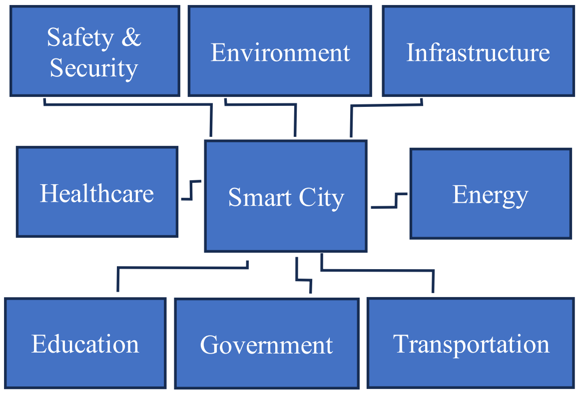


Figure 1 Applications of Smart City

Our study goal is to develop fire safety protection-type smart city application in aircraft hangars and their societal impact. This study has the potential to have a substantial impact on the development of smart city initiatives related to safety in our society. This research delves into the development of an Intelligent Aircraft Hangar Fire Detection and Location System using Wireless Sensor Networks (WSN) that harnesses the power of smart city to protect critical assets within environment.

As the smart city concept continues to evolve, the preservation of life and property through advanced fire detection and location systems becomes an imperative. [3] This research seeks to contribute to the safety and resilience of smart cities by exploring innovative solutions [4] that not only protect aircraft hangars but also extend their reach to safeguard various urban structures and, most importantly, the well-being of urban inhabitants. The use of an intelligent system for monitoring the level of gas concentrations in the air and an alert system is the greatest strategy to reduce the risk of a fire. [5] The system is equipped with a gas sensor, embedded computer and transceiver to measure gas concentration in the air. This can help in detecting unfavourable accidental circumstances like smoke, when the concentrations measured and identified in the sample gas data illustrated in Figure 3. With the aid of a transceiver unit, the signal can then be transmitted wirelessly via radio frequency to the Based Station (BS) which identifies each node by a unique address assigned to it. It processes the collected information and send it to the server for visualization and notification.

In any fatal situation, a quick detection and alert will minimize loss of life and property. By using the concept of WSN, star network topology illustrated in Figure 2, the system can monitor and analyse the information from the various sensor nodes. Wireless sensor networks are a collection of sensor nodes that run on batteries and have little radio, computation, and storage capabilities [6].

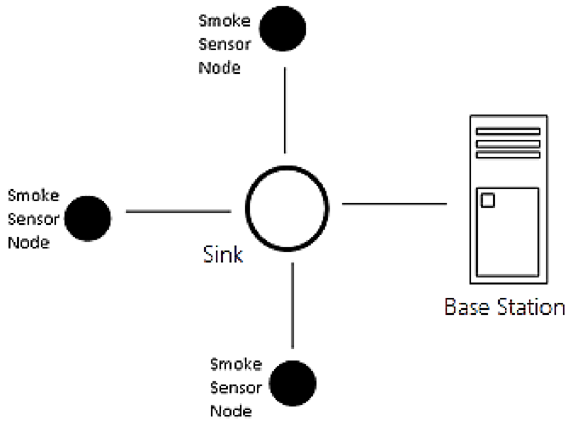


Figure 2 Star network topology based on WSN

Nodes operate by sensing and relaying their findings to a processing facility called a "sink." And since the replacement of the embedded batteries is a highly challenging task, once these nodes have been deployed, the design of protocols and applications for such networks must be energy-aware in order to increase the lifetime of the network. Traditional methods, such as direct transmission and minimal transmission energy [7], do not provide an even distribution of the energy load across the sensor network nodes. Sensor nodes that use direct transmission send data directly to the sink, which causes nodes that are farthest from the sink to go offline first. The intelligent system is designed to predict a fire outbreak at its early stage by visualizing every level of the concentration of gases in the air and trigger an alarm when it reaches a predetermined threshold [8]. The system stores the node's information as well as the time in the database continuously in real-time and it is a technique intended to prevent fire disaster. It typically displays a warning to the control station and to show the degree of forecast on a computer graphic user interface (GUI), along with the precise location of such an incident anywhere the aircraft hangar. (See Figure 3)

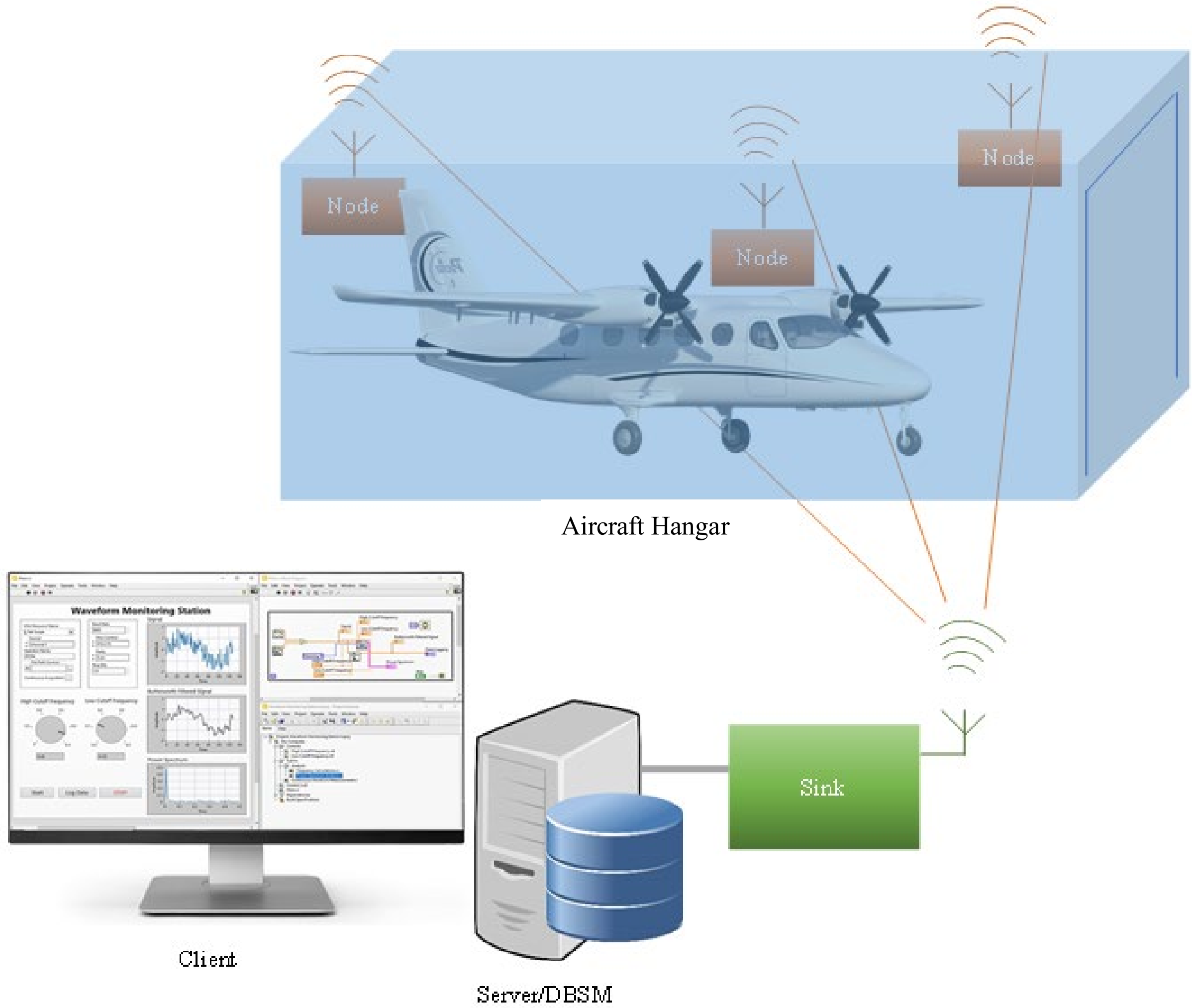


Figure 3 Star network topology based on WSN

2. Literature Review

Several monitoring systems have been proposed as a result of the growing need of having an accurate fire detection system.

2.1 Fire Detection Method in Smart City Environments Using a Deep-Learning-Based Approach

[9] In the construction of new smart cities, traditional fire-detection systems can be replaced with vision-based systems to establish fire safety in society using emerging technologies, such as digital cameras, computer vision, artificial intelligence, and deep learning. In this study, we developed a fire detector that accurately detects even small sparks and sounds an alarm within 8 s of a fire outbreak. A novel convolutional neural network was developed to detect fire regions using an enhanced You Only Look Once (YOLO) v4network. Based on the improved YOLOv4 algorithm, we adapted the network to operate on the Banana Pi M3 board using only three layers. Initially, we examined the originalYOLOv4 approach to determine the accuracy of predictions of candidate fire regions. However, the anticipated results were not observed after several experiments involving this approach to detect fire accidents. We improved the traditional YOLOv4 network by increasing the size of the training dataset based on data augmentation techniques for the real-time monitoring of fire disasters. By modifying the network structure through automatic color augmentation, reducing parameters, etc., the proposed method successfully detected and notified the incidence of disastrous fires with a high speed and accuracy in different weather environments—sunny or cloudy, day or night. Experimental results revealed that the proposed method can be used successfully for the protection of smart cities and in monitoring fires in urban areas. Finally, we compared the performance of our method with that of recently reported fire-detection approaches employing widely used performance matrices to test the fire classification results achieved.

The authors developed vision-based systems using camera for the fire safety. However, the use of a vision-based using camera for fire protection type does not predict the early stage of fire by detecting the concentrations in air, therefore, cannot guarantee fire protection.

2.2 Hangar fire detection alarm with algorithm for extinguisher

[10] A fire alarm system with a high-performance that detects smoke, heat or flames, for the protection of lives and property. It is employed in aircraft hangars for the protection of aircraft, personnel as well as the hangar structure. The need for a fire alarm in a hangar with algorithm for extinguishers cannot be overemphasized. The structure of the hangar building, type of aircraft housed in the hangar and activities carried out at the hangar such as inspections, overhauls and modifications of aircraft, determine the type of fire alarm to be used, whether it should be automatic or manual. The detection employed, be it smoke detection, heat sensing or both and the process of extinguishing in the face of a fire threat or hazard is equally important. The effectiveness of the alarm is dependent on genuine alerts and not false alarm triggers, hence in this research paper, the employment of intelligent detection using comparators in programmed IC, the Micro-controller, was interfaced with a 555 Timer, a multi-vibrator for generating aural sound for alarm, LCD Display for indicated readings as well as algorithm for extinguishing using water or foam via sprinklers. The basic work started with a block diagram representation, thereafter, individual subsystems, which form the building blocks were analyzed and the components parts identified.

The author employed the use of a single sensor-type device rather than a network of multiple connected sensors for wider coverage in the aircraft hangar, fire location-based indication, and the use of modern technology to make the system more intelligent and accurate in fire protection. Such a system does not guarantee accurate fire protection in a smart environment.

The proposed method employed an interconnected system using WSN, machine learning, and data analytics and visualization which can be deploy in a smart city environment to monitor fire scenarios and fire prediction in real-time.

3. Design and Implementation of the System

The system is designed on the WSN basis with three networked sensor nodes for the detection which are deployed in three locations with each having an identification (ID) for sharing the sensor data with the BS and the server. The server is designed to visualize the data and notify the Hangar.

3.1 Methodology

Sensor Nodes Module:
Design sensor node modules that incorporate gas sensors to measure changes in gas concentrations in the air. This will use specialized gas sensor technology sensitive to relevant gases and wireless communication protocols for data transmission to enable data exchange between sensor nodes and base stations using industry-standard wireless protocols for reliable and secure communication. The sensor node will have an on-board computing subsystem.

Base Station Modules:
Design of base station modules to receive data from sensor nodes. Aggregate and preprocess data locally using on-board computer subsystem for data processing and wireless communication. The base station enables data transmission to the central server for data analytics and visualization.

Machine Learning (ML) Algorithms:
Develop and deploy ML algorithms to train predictive models on the central server, to analyze gas concentration data for fire prediction.

Graphic User Interface (GUI):
Develop a user-friendly GUI on the central server to display real-time data, fire predictions, and alerts by utilizing software development tools.

Database:
Design a database to store and manage data to store historical data, dataset, system logs, and fire incident records using relational databases for data storage and retrieval.

Data Analytics and Visualization:
Integrate an algorithm for data analytics and visualization into the central server to process data, generate reports, and visualize risk levels.

Real-time Alerting:
Implement real-time alerting mechanisms within the GUI and server, to notify relevant personnel and authorities in case of a fire scenario. Employ sound alarm notification and SMS.

Wireless Sensor Network (WSN):
Deploy sensor nodes strategically within the aircraft hangar to collect real-time data on gas concentrations, utilize wireless communication protocols to transmit data to base stations.

Successful implementation of these key technologies ensures the Intelligent Aircraft Hangar Fire Detection and Location System's effectiveness in early fire detection and protection of assets, hangar facilities, and human lives within a smart city context. The system leverages advanced sensor technology, data analysis, and real-time communication to enhance safety and mitigate fire risks.

3.2 System Design

1. Sensor Node Modules:

Sensor node modules are the frontline components of the system placed at different strategic locations within the aircraft hangar. They are responsible for continuously monitoring gas concentrations in the hangar's air, specifically targeting potential indicators of a fire outbreak. These nodes use specialized gas sensors to detect changes in gas levels. When significant changes are detected, they transmit this data wirelessly to the base station module for analysis. Low power consumption, wireless communication capabilities, and gas sensing technology.

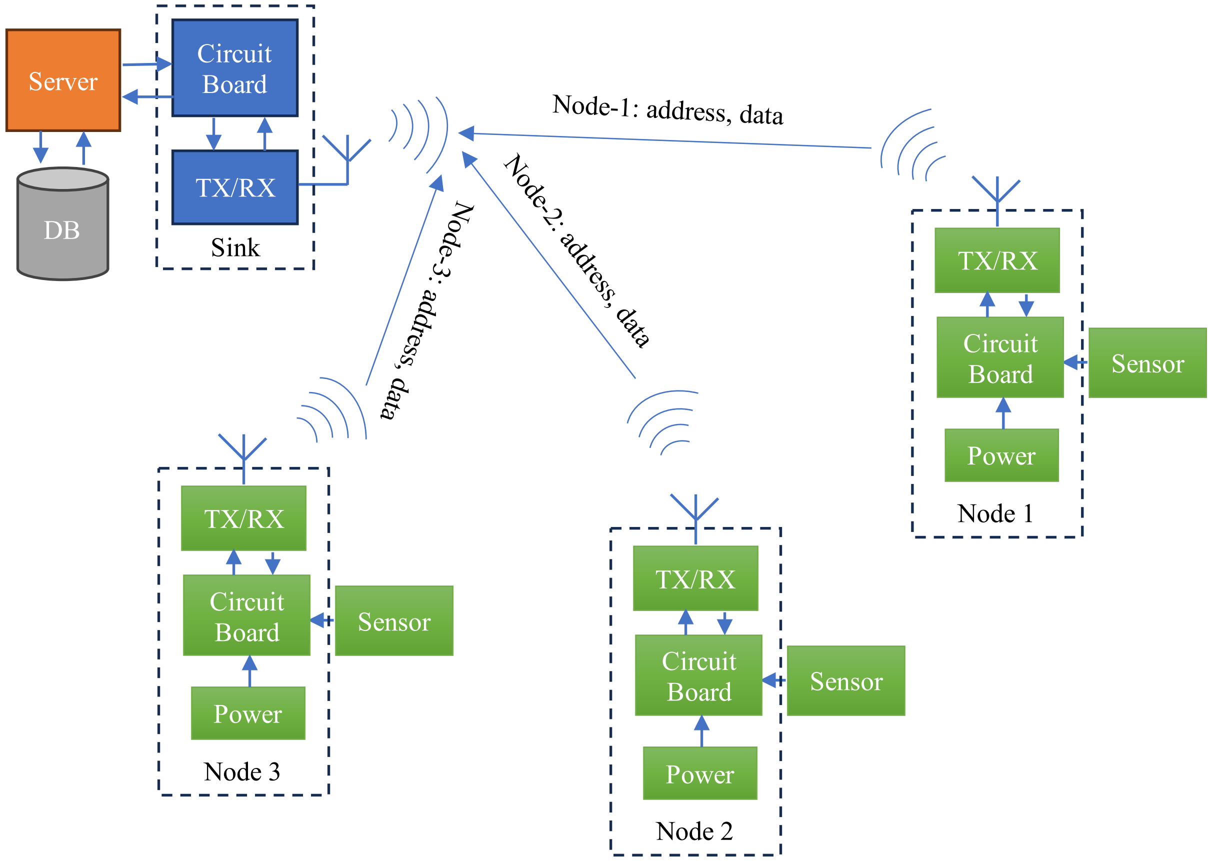


Figure 4 shows the system architecture

A. System Architecture

To solve the shortcomings of other methods, Machine Learning (ML) and Wireless Sensor Network (WSN) techniques were deployed to make the system more intelligent and ability to cover wide range of environment using a start topology for sensor data transmission from the sensor network to the base station as a sink and to the server (Computer) as illustrated in Figure 2 which consists of the sensor nodes, the BS and the sever for assessing and reporting the predicted fire scenario [11]. Figure 2 shows the system architecture, which includes the sensor node modules, base station modules, and the computer system as the server which visualizes the situation and sends an alert in case of a fire scenario.

2. Base Station Modules:

Base station modules act as the intermediary between the sensor nodes and the central server. They receive the gas concentration data from the sensor nodes and serve as a local processing hub. Data received from sensor nodes is aggregated, and preliminary analysis may be performed at this level to assess the immediate situation. If necessary, data is forwarded to the central server for further analysis. Data aggregation, local analysis, and wireless communication with the sensor nodes.

3. Computer System as the Server:

The server is the core component responsible for data analysis, visualization, and decision-making. It processes incoming data from sensor nodes and base stations, applies Machine Learning (ML) techniques, and generates real-time reports. ML algorithms assess the gas concentration data in conjunction with reference data to identify potential fire scenarios. The server displays this information on a Graphic User Interface (GUI) in real-time. High processing power, ML capabilities, GUI for real-time visualization, and alert generation.

4. Database:
The database stores and manages critical data related to fire detection and historical records. It serves as a repository for gas concentration data, historical fire incidents, and system logs. The database stores incoming data for future reference, enabling long-term analysis, trend identification, and system maintenance. Data storage, retrieval, and management capabilities.

Collectively, this system architecture enables the Intelligent Aircraft Hangar Fire Detection and Location System to continuously monitor the hangar environment for potential fire hazards. The sensor nodes detect changes in gas concentrations, while the base stations assist in local analysis and data relay. The central server processes data, predicts fire scenarios, and provides real-time alerts through the GUI. The database ensures data preservation for historical analysis and system optimization. This architecture enhances fire safety and contributes to the protection of aircraft assets, hangar facilities, and human lives within a smart city context.

B. Implementation of Key Technologies

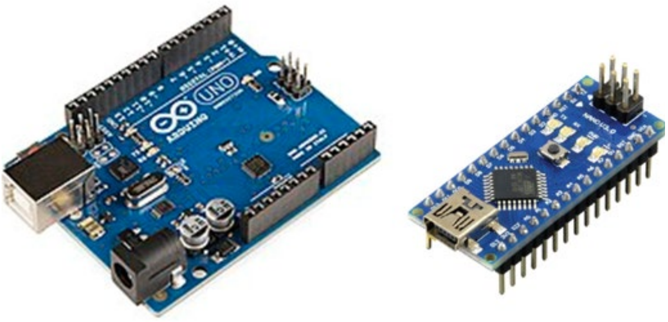
The implementation of key technologies within the Intelligent Aircraft Hangar Fire Detection and Location System Base on WSN in a Smart City involves the integration of various components and software tools to create a cohesive and effective fire detection system (see Table 1).

Table 1

Hardware Components	
Devices	Module
On-Board Computer 1	Arduino Nano
On-Board Computer 2	Arduino Uno
Wireless Communication Module	nRF240L
Gas Concentration Sensor Module	MQ-2
GSM Communication Module	SIM800L

1. On-Board Computer Subsystem

This subsystem is based on the Arduino single board on the Atmega 328P microcontroller as the core dedicated system in charge of processing the data obtained by the sensors to transmit the information the information using communication module.



(a) (b)

Figure 5 (a) Arduino Uno (b) Arduino Nano

2. Communication Protocol

The system used the nRF240L transceiver module for wireless communication, which was interfaced with Arduino in order to communicate effectively between the nodes and the sink (see Figure 2). The nRF24L01 module is designed to operate in the 2.4GHz worldwide Industrial, Scientific, and Medical (ISM) frequency band and transmit data using GFSK modulation. [12] The data transfer rate can be configured to 250kbps, 1Mbps, or 2Mbps. The 2.4 GHz band is one of the ISM frequencies reserved for unlicensed low power equipment around the world. [13] ISM frequencies are used by devices such as cordless phones, Bluetooth devices, Near Field Communication (NFC) devices, and wireless computer networks (WiFi). The working voltage of the module ranges from 1.9 to 3.9V.

Figure 6 nRF240L transceiver module

The nRF24L01 communicates with a maximum data rate of 10Mbps using a 4-pin SPI (Serial Peripheral Interface). The SPI interface allows you to adjust all characteristics such as frequency channel (125 selectable channels), output power (0 dBm, -6 dBm, -12 dBm, or -18 dBm), and data rate (250kbps, 1Mbps, or 2Mbps). The SPI bus employs the master and slave concept. Table 2 listed the pin configuration of the module.

Table 2

MQ-2 Gas Sensor Pin Configuration		
Number	Pin	Descriptions
1	GND	Ground
2	VCC	3.3 V Supply
3	CE	Chip Enable
4	CSN	Chip Select Not
5	SCK	Serial Clock
6	MOSI	Master Out Slave In
7	MISO	Master In Slave Out
8	IRQ	Interrupt Request

The transceiver module architecture is made up of several concurrent data pipelines with unique addresses. A data pipe is a logical channel in the physical RF (radio frequency) channel which uses ShockBurst Technology [14].

The transceiver module decodes the physical address (also known as the data pipe address) of each data pipe. The technology of ShockBurst employs First-In, First-Out (FIFO) on a chip to clock in data at a low rate and transmit it at a high rate which in turn allows for significant power savings.

The Transceiver module can be utilized in ShockBurst mode to make use of the 2.4 GHz band high data rates (1 Mbps) without the requirement for an expensive, high-speed microcontroller (MCU) for data processing [15].
The Transceiver module also offers the following benefits by housing all high-speed signal processing that is related to the RF protocol on-chip.

- Highly reduced current consumption
- Reduced system cost (allows for the use of a less expensive microcontroller)
- A much lower probability of on-air collisions due to short transmission periods.

3. Gas Concentration Sensor Module

The MQ-2 Gas Sensor Module was used in the design of the system. MQ-2 is a flammable gas semiconductor sensor. The MQ-2 gas sensor's sensitive substance is SnO_2, which has a reduced conductivity in clean air. When the target flammable gas is present, the sensor's conductivity increases, as does the gas concentration. The MQ-2 gas sensor detects LPG, propane, smoke, and hydrogen with excellent sensitivity; it might also detect methane and other combustible steam. It is inexpensive and useful for a variety of uses. Combustible gas concentrations present in the air are monitored and detected using the MQ-2 gas sensor which has a straightforward drive circuit and a wide operating range with 4pins configuration (see Table 3). The MQ-2 sensor module showed in Figure 3.

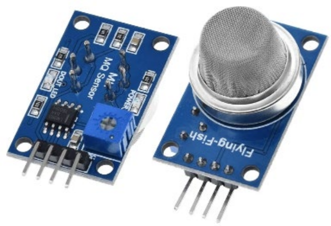


Figure 7 MQ2 Gas Sensor Module

Table 3

MQ-2 Gas Sensor Pin Configuration		
Number	Pin	Descriptions
1	VCC	5V Supply
2	GND	Ground
3	D0	Digital Out
4	A0	Analog Out

It is also steady, long-lasting, responsive and rapid. Due to its great sensitivity to smoke, hydrogen, LPG (liquid petroleum gas), methane, carbon dioxide, alcohol, and propane, the gas sensor has long been used to assist in detecting gas leaks in a variety of domestic and commercial settings.

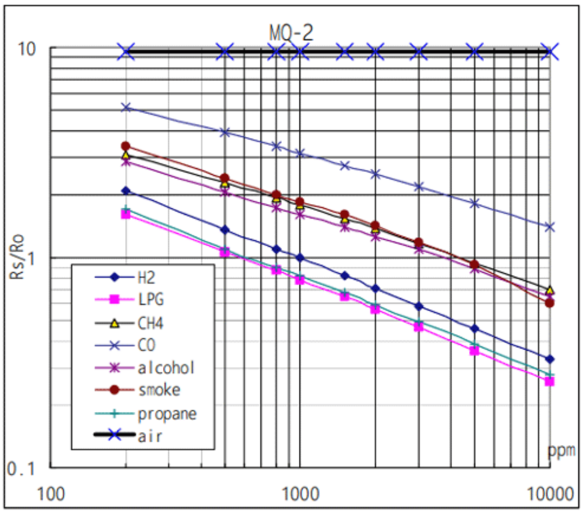


Figure 8 Sensitivity characteristic curve

The concentration of gases measured in parts per million (ppm) is estimated by using a resistance ratio (RS/R0). Where R0 is the stable sensor resistance in fresh air or without gas presence, and RS is the recorded change in resistance when the sensing device detects any gas leak. Using Ohm's law and the sensor schematic as a guide.

$$R = \frac{VC-RL}{Vout} - Rl. \quad (1)$$

VC is the voltage current, Output Voltage (Vout) is the output voltage (measured analog/digital values), and RL is the load resistance (set up is at 10K). R0 was then calculated using this equation, R0 = RS/Fresh air ratio value from the datasheet. In order to convert the digital signal to concentration units, a nonlinear expression in Equation 2 was used for implementing a simple calibration line for the MQ-2 gas sensor

$$y = mx + b \quad (2)$$

Since it follows a log-log scale, a bit more advanced calculation was needed and equation (2) was converted to

$$\log(y) = m * \log(x) + b \quad (3)$$

By using a chart, the slope and intercept were calculated in which

$$m = \frac{log\left(^{y}/_{y0}\right)}{log\left(^{x}/_{x0}\right)} \text{ and b} = \log(y) - m * \log(x) \quad (4)$$

Once these values were obtained, the concentration of gases was now be calculated as

$$x(ppm) = 10^{[\log(y)-b]/m} \quad (5)$$

Where y is equal to RS/R0.

4. GSM Communication Module

The base station used SIM800L GSM/GPRS module to offers a compact and versatile solution for SMS notification. The SIM800L GSM/GPRS module designed for various applications, which included Internet of Things (IoT) and alert notification. It offers a wide range of functionalities like a standard cell phone. The core component of this module is the SIM800L GSM cellular chip manufactured by Simcom. Operate at low voltage range of 3.4V to 4.4V, which makes it well-suited for battery-powered applications. Table 5 showed the Pin configurations of the module.

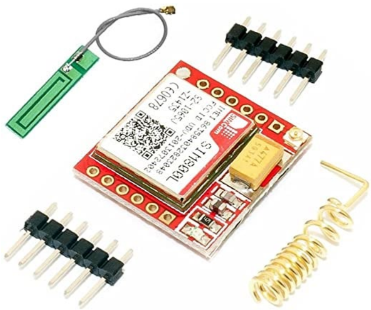


Figure 9 SIM800L GSM/GPRS module

Features:

- Supports Quad-band: GSM850, EGSM900, DCS1800 and PCS1900
- Use all GSM network SIM
- Voice calls using speaker and microphone
- Transmit and receive SMS
- Transmit and receive data (TCP/IP, HTTP, etc.)
- FM radio broadcasts

Table 4

SIM800L GSM/GPRS Module Pin Configuration		
Number	Pin	Descriptions
1	NET	Network antenna
2	VCC	3.7V – 4.4V supply
3	RST	Reset
4	RXD	Data Receiver
5	TXD	Data Transmitter
6	GND	Ground
7	SPK-	Speaker negative pin
8	SPK+	Speaker positive pin
9	MIC-	Microphone negative
10	MIC+	Microphone positive

11	DTR	Control sleep mode
12	RING	Ringing indicator

C. Hardware Circuitry

One of the primary objectives of the research was to showcase an advanced fire protection solution for aircraft hangars within the framework of a smart city concept. This solution leverages a sensor network, communication technologies, and Machine Learning (ML) as its core components. The system has been successfully implemented, and its schematic is depicted in Figures 8 and 9.

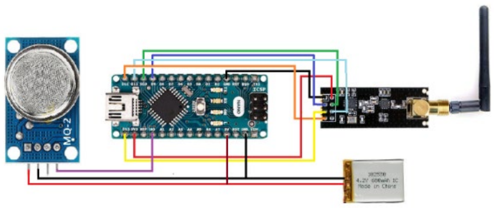


Figure 10 Sensor node module schematic diagram with all the components

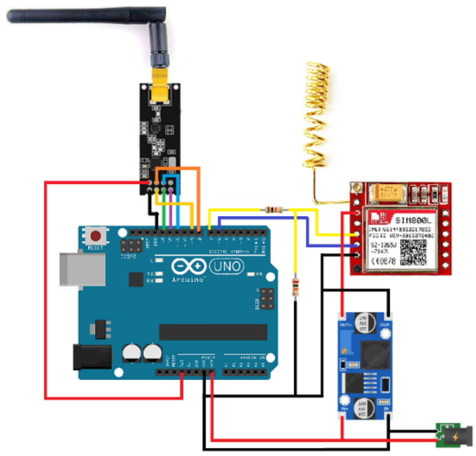


Figure 11 Base Station (Sink) module schematic diagram with all the components

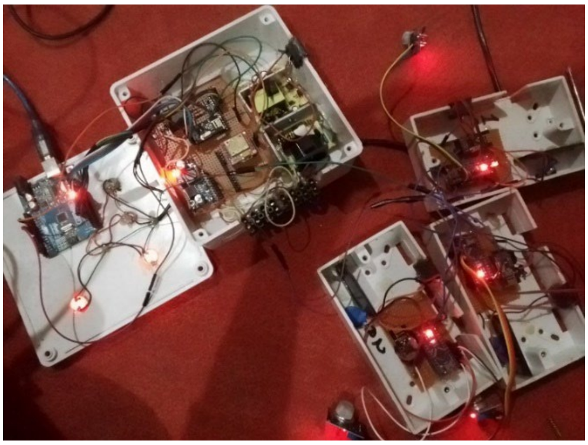


Figure 12 Sensor nodes and base station hardware.

The project's overarching idea is to provide useful safety equipment for monitoring an aircraft Hangar in case of a fire outbreak. Three nodes and to present the state of the condition under three different scenarios which represent the normal smoke concentration state, warning gas concentration state and the fire predicted concentration state, as illustrated in Figure 5. It is a concept that can be successfully implemented in a real-world situation.

4. Experimental Analysis

The system is made up of three fundamental components which include detecting sensor nodes, a base station unit that serves as the sink and a computer system which serves as the server for real-time data analysis and display. To carry out the experiment, datasets from a Mendeley Data repository were examined [16] [17]. During the experiment however, both the high fire prediction state and other conditions were recorded in the database and several thresholds were used in the research to activate notification and fire alarm systems as well as fire locations when the threshold reached its limit.

The environment for the prototype was designed for the integration of prediction algorithm and data visualization of the system. This was developed in C# .Net programming language using the Visual Studio IDE 2022. Once the program executed, the user is shown the main window. The window is shown in the following captured image (see Figure 20).

Thus, the main window of the program has the following sections:

1. The right side of the window displays the data received from the base station in real-time
2. The left side of the window displays the nodes gas concentration level includes; percentage, and notification.

3. Below, are the data logs in stored in the database

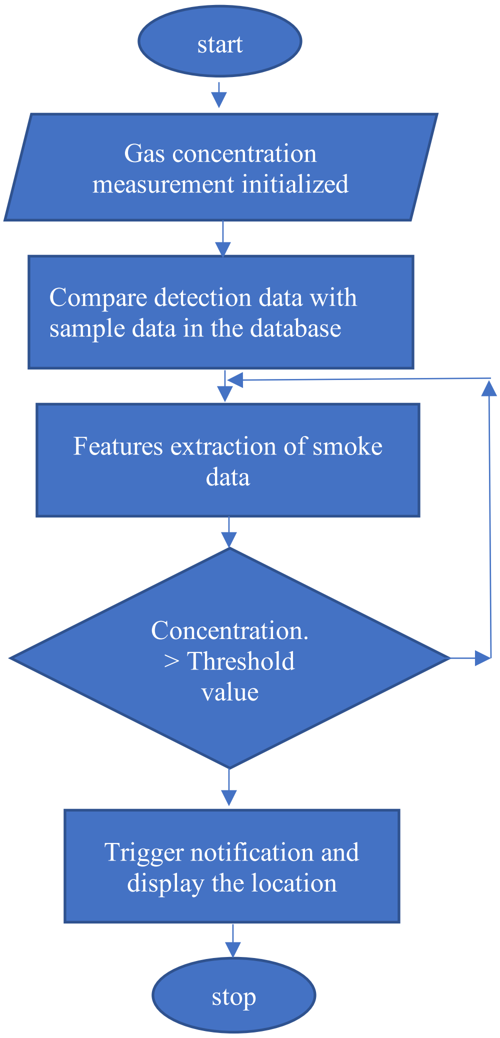


Figure 13 Algorithmic Flowchart.

The system used a threshold of 400 and the detection rate of the gas concentrations in the air to display its various levels but this work is focused mainly on the emitted smoke to determine the normal scenario, the warning and high alert levels. Table 1 displays the simulation results that were obtained.

Table 5. Simulation Result

T	N1 *ppm*	Node1 State	N2 *ppm*	Node2 State	N3 *ppm*	Node3 State
7:30	800	Warning	302	Normal	632	Warning
7:35	1560	Fire	302	Normal	532	Warning
7:40	2000	Fire	320	Normal	432	Warning
7:45	2500	Fire	320	Normal	532	Warning
7:50	3000	Fire	302	Normal	430	Warning
7:55	3500	Fire	154	Normal	434	Warning
7:60	3530	Fire	202	Normal	440	Warning

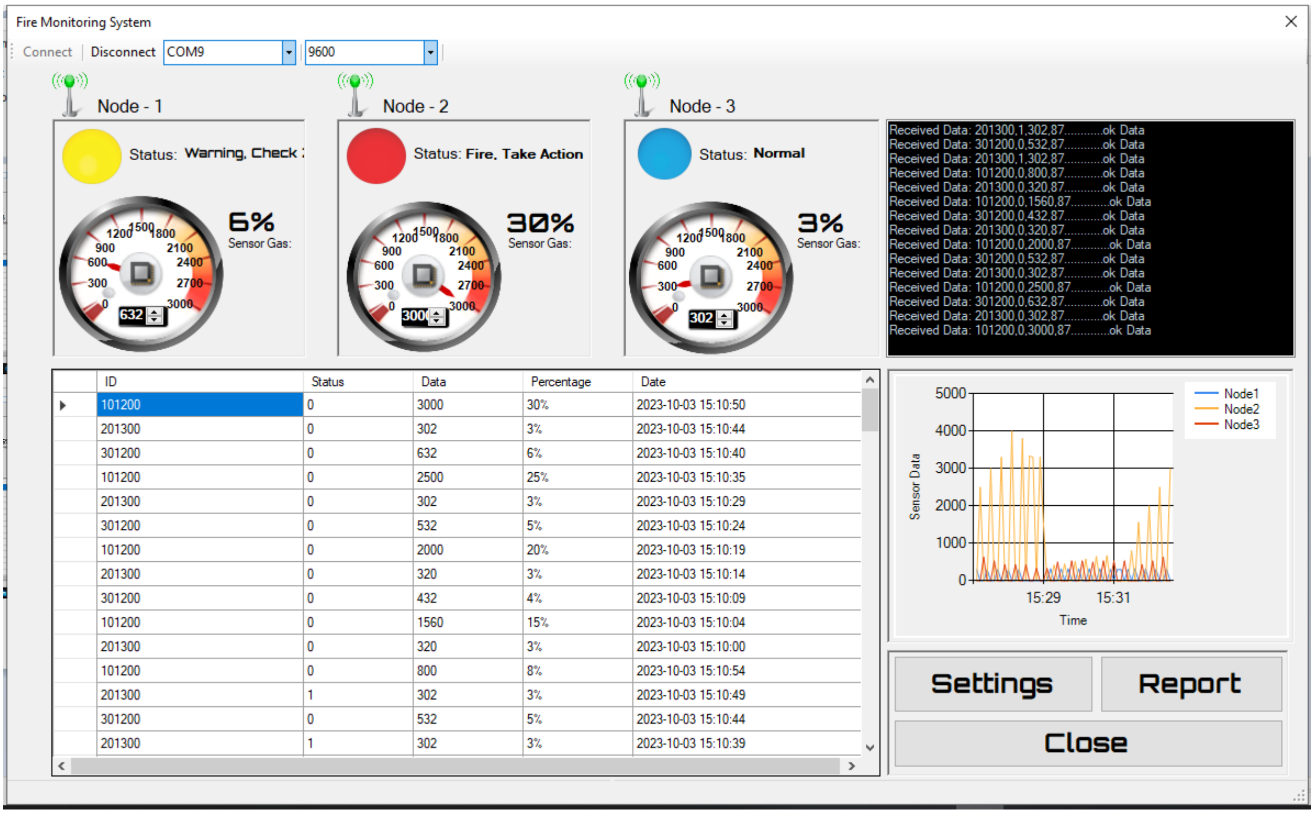


Figure 14 Graphical User Interface visualization data

Conclusion

The major objective of this project is to install several smoke sensor detector circuits in an aircraft Hangar using the WSN concept in order to evaluate sensor data and predict the chances of a fire outbreak using an algorithm established on a real-time basis in a smart city environment. Additionally, the system has the ability to locate and visualize different gas concentrations in the air from the computer GUI and trigger a warning system throughout the Hangar. This research proposes a solution to the problem of possible fire outbreaks through an early warning system capable of minimizing the risk of such dangers at Aircraft Hangars. On a computer system, the user can examine the status of each sensor node to reduce false alarms. This information would be very helpful for the firefighting effort as well as the evacuation procedure. The system can be used in both residential and commercial projects.

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