

A Smart IoT Framework for Real-Time Air Quality Monitoring in Healthcare Environments

Yogesh S. Kale¹, Prachi D. Gawande², Amol Dhenge³, Shweta Bondre⁴, Minal Keote⁵, Sujata Chiwande⁶, Rashmi Keote⁷

¹Yeshwantrao Chavan College of Engineering, Electronics and Telecommunication, Nagpur
Email: ycceetyogesh@gmail.com

²Yeshwantrao Chavan College of Engineering, Computer Technology, Nagpur
Email: gawandeprachi7@gmail.com

³Symbiosis Institute of Computer Studies and Research
Email: amol.dhenge.phd2026@sitpune.edu.in

⁴School of Computer Science and Engineering, Ramdeobaba University, Nagpur
Email: bondresv@rbunagpur.in

⁵Yeshwantrao Chavan College of Engineering, Electronics and Telecommunication, Nagpur
Email: klminal@rediffmail.com

⁶Yeshwantrao Chavan College of Engineering, Electronics and Telecommunication, Nagpur
Email: sujata_chiwande28@yahoo.co.in

⁷Yeshwantrao Chavan College of Engineering, Electronics and Telecommunication, Nagpur
Email: 9212@ycce.in

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Abstract— Air quality is a critical concern in healthcare environments, particularly In Vitro Fertilization (IVF) laboratories, where volatile organic compounds (VOCs) can adversely influence environmental conditions and treatment outcomes. This study aims to develop a low-cost, scalable, real-time IoT framework for continuous monitoring and control of indoor air quality. The proposed system integrates an SGP40 sensor for VOC detection, a DHT11 sensor for temperature and humidity measurement, an Arduino Nano for data processing, and a D1 Mini (ESP8266) for Wi-Fi-enabled communication. A TFT display provides local visualization, while ThingsBoard and Google Sheets support cloud-based data storage, visualization, and remote monitoring. An automated buzzer and fan mechanism is incorporated to respond when VOC levels exceed prescribed limits. Experimental monitoring recorded a VOC index of 13, temperature of 28°C, and relative humidity of 55%, indicating low VOC contamination and favorable indoor air conditions. Additional observations demonstrated a VOC index of 79, illustrating the system's capability to identify moderate VOC concentrations and support time-series assessment. The novelty lies in combining sensing, cloud connectivity, real-time visualization, and automatic environmental response within an affordable integrated architecture. The framework contributes a practical solution for IVF clinics, hospitals, smart rooms, and industrial environments. Overall, the developed system demonstrates effective real-time environmental monitoring and provides a foundation for safer, data-driven indoor air-quality management with potential for broader healthcare deployment.

Keywords— Internet of Things (IoT), Air Quality Monitoring, Volatile Organic Compounds (VOCs), Healthcare Environments, SGP40 Sensor, Real-Time Monitoring

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Introduction

Volatile organic compounds (VOCs) are pollutants that affect human health and environmental quality. In this paper, a VOC sensor-based monitoring system integrated with Arduino Nano and D1 Mini is presented, which uses an SGP40 sensor for VOC detection and a DHT11 sensor for temperature and humidity measurement. The system provides real-time monitoring and provides useful information for improving air quality in industrial areas. Previous related studies are reviewed and examined in detail below. The creation of a prototype system to track

several air quality metrics, such as indoor air quality (IAQ), CO₂, temperature, and humidity, is covered in Paper 1. The BME680 sensor, a NodeMCU ESP-12 microcontroller, and the ThingSpeak cloud platform are used in this system to visualize data. The study highlights how cloud platforms may be used for remote monitoring and real-time data storage, both of which are essential for upholding safe air quality requirements in commercial and industrial settings. The system's potential for scaling up, which would make it an effective solution for a variety of

applications, is also described in the paper. In order to ensure both air quality monitoring and fire safety in industrial environments, Paper 2 offers an Internet of Things device that integrates multiple sensors, including the DHT11 temperature and humidity sensor, the MQ135 gas sensor, and a flame sensor. The gadget offers both preventive and remedial actions by providing real-time data on fire hazards and air quality. This study emphasizes how critical it is to integrate several sensors in order to address multiple environmental safety concerns at once, which is especially important in hazardous and industrial work situations. In Paper 3, the use of inexpensive sensors to detect health-harming pollutants such as ammonia, carbon monoxide (CO), and particulate matter (PM_{2.5} and PM₁₀) is examined. The possibility of real-time cloud notifications to notify users when pollution levels surpass safe thresholds is also highlighted in the paper. The use of affordable sensors to track environmental health hazards is the main emphasis of this work, providing a method that can be extensively implemented in places with little funding for air quality control [1]-[3]. In Paper 4, VOCKit, a small Internet of Things kit, is shown. It uses machine learning algorithms and fluorometric sensors to detect and categorize volatile organic compounds. This study emphasizes the creative fusion of software and hardware to produce an intelligent system that can identify and evaluate volatile organic compounds. In industrial settings where VOC exposure changes according to chemical processes, the research focuses on integrating machine learning for the classification of various VOC types, making it a crucial tool for applications.

The creation of a transportable robotic system intended to identify volatile organic compounds (VOCs) leakage in agricultural environments is examined in Paper 5. To monitor VOCs and guarantee worker and environmental safety, the system makes use of air quality sensors and a battery management system. This study highlights the value of mobility in environmental monitoring, especially in expansive and dynamic industrial settings like farms, where exposure to volatile organic compounds (VOCs) might change depending on the circumstances. In order to monitor pollutants like CO and NO₂, Paper 6 investigates the creation of inexpensive sensor nodes that use electrochemical and infrared sensors. Because these nodes may communicate over Wi-Fi and LoRaWAN networks, real-time, scalable air quality monitoring is made possible. For large-scale environmental monitoring projects, where multiple nodes must be placed over huge areas to gather data simultaneously, the study emphasizes the significance of affordable, scalable sensor nodes.[4]-[6]. Paper 7 describes an Internet of Things (IoT)-based sensor

system for home automation that monitors temperature, humidity, and air quality to guarantee thermal, visual, and sanitary comfort. This study shows how real-time air quality data may be utilized to automate tasks like triggering air purifiers or modifying ventilation systems in response to elevated volatile organic compounds (VOCs) by combining air quality monitoring with home automation systems. By giving residents a more pleasant and healthy living space, this integration improves the quality of life [7]. The detrimental effects of volatile organic compounds (VOCs) on groundwater are reviewed in Paper 8, which also emphasizes the significance of keeping an eye on VOC levels in both residential and industrial regions. The environmental effects of VOC emissions are discussed in this research, which emphasizes the necessity of more extensive monitoring to avoid contaminating essential natural resources like water. In order to prevent VOCs from getting into nearby water supplies, it is necessary for industrial sites to integrate monitoring systems. The impact of VOCs on certain settings, such as IVF labs, where their presence can have an impact on patient health and treatment success rates, is examined in Paper 9. The necessity of VOC monitoring in extremely sensitive settings, where even trace amounts of contaminants can have a big impact on results, is shown by this study. In order to guarantee that air quality regulations are fulfilled, the study promotes the deployment of trustworthy sensors in crucial environments. The testing of gas sensors for determining indoor VOC and Indoor Air Quality Index (IAQ) levels is the main topic of Paper 10. This study assesses the precision and dependability of several gas sensors, offering important information on sensor selection for a range of settings, including workplaces, medical facilities, and educational institutions, where air quality can have a direct influence on occupant productivity and health.[8]- [10].

I. Related work

Volatile organic compounds (VOCs) have emerged as important environmental contaminants because their presence can influence indoor air quality and create health and operational risks in sensitive environments. Yadav and Pandey [8] reviewed the environmental occurrence, fate, distribution, and adverse implications of VOC pollutants, emphasizing the necessity of systematic monitoring to limit exposure. Khoudja et al. [9] examined air-quality improvement in IVF laboratories and demonstrated the importance of maintaining cleaner laboratory environments for improving assisted-reproduction outcomes. These observations are particularly relevant because IVF laboratories require tightly controlled environmental conditions, where even relatively small variations in airborne contaminants may affect sensitive biological

procedures. Consequently, continuous VOC monitoring represents an important component of environmental quality management in healthcare facilities.

Al-Okby et al. [10] evaluated indoor air-quality indices and total volatile organic compounds as measurement parameters for IoT-enabled hazardous-gas detection and alarming systems. Their work demonstrated the practical importance of selecting reliable sensing parameters for detecting changes in environmental conditions. The U.S. Environmental Protection Agency [11] further emphasized that indoor air quality is influenced by pollutant sources, ventilation, and environmental conditions, establishing the broader motivation for continuous indoor monitoring. TVOC-based assessment approaches [12] provide an aggregated indication of volatile chemical contamination and can therefore support rapid evaluation of environmental quality. Similarly, indoor-air-quality research [13] recognizes temperature, humidity, ventilation, particulate matter, and gaseous pollutants as interconnected parameters requiring systematic observation. These studies collectively indicate that single-parameter measurement is insufficient for comprehensive environmental assessment and motivate integrated sensing architectures combining VOC, temperature, and humidity measurements.

Al-Okby et al. [14] developed mobile detection and alarming approaches for hazardous gases and volatile chemicals in laboratory and industrial environments, demonstrating the value of automatic warning mechanisms for improving environmental safety. Neubert et al. [15] introduced a flexible IoT gas-sensor node suitable for automated life-science environments and stationary or mobile robotic platforms, highlighting the benefits of network-connected environmental sensing. Xing et al. [16] presented the FireNose mobile robotic sensing approach for harsh environments, illustrating how distributed and mobile sensing can extend hazardous-gas monitoring beyond fixed installations. Similarly, Kaliszewski et al. [17] developed and tested a multi-gas sensing system for remote unmanned aerial and ground vehicle missions, demonstrating the growing relevance of remotely accessible environmental sensing. However, these approaches primarily emphasize laboratory, industrial, robotic, or generalized hazardous-environment applications rather than an integrated, healthcare-oriented real-time VOC management architecture. The present framework addresses this gap by integrating SGP40-based VOC sensing, DHT11 environmental measurement, Arduino Nano processing, ESP8266 connectivity, TFT visualization, ThingsBoard/Google Sheets cloud monitoring, and automated buzzer and fan responses into an affordable system specifically

applicable to healthcare and IVF environments.

Table 1 demonstrates the progression from conventional VOC and indoor-air-quality assessment toward IoT-enabled, mobile, and remotely accessible sensing systems. Existing studies establish the importance of VOC detection and environmental monitoring but provide limited healthcare-specific automation, motivating an integrated framework combining continuous sensing, cloud visualization, alerts, and automatic ventilation control.

Table 1: Summary of Related Work on IoT-Based Air Quality and VOC Monitoring

P a p e r	Stu dy Foc us	Envir onmen t	Mai n Tec hno logy	Par am eter s	Key Cont ribut ion	Iden tified Limi tation
[8]	VOC environmental pollution	General environment	VOC assessment	VOCs	Examined VOC fate and distribution	No real-time IoT monitoring
[9]	Air quality and IVF outcomes	IVF laboratory	Air-quality improvement	VOCs/Air quality	Connected improved air quality with IVF outcomes	Limited IoT automation
[10]	Hazardous-gas detection	Indoor environments	IoT gas sensing	IAQ, TVOC	Evaluated IAQ and TVOC measurement parameters	Limited healthcare-specific control
[11]	Indoor air quality	Indoor buildings	Environmental assessment	Indoor pollutants	Established importance of indoor	No dedicated IoT framework

			ssment		r pollut ion mana geme nt	ewor k
[1 2]	TV OC asse ssm ent	Indoor enviro nment	TV OC mea sure ment	TV OC	Supp orts aggre gate VOC asses sment	Limi ted multi - para mete r integ ratio n
[1 3]	Indo or air-qual ity asse ssm ent	Indoor enviro nment	IAQ mon itori ng	Mul tipl e poll uta nts	Provi des broad er IAQ persp ective	Lack s auto mate d resp onse
[1 4]	Haz ardo us che mica l dete ctio n	Labora tory/in dustria l	Mo bile sensi ng and alar min g	Haz ard ous gas es, VO Cs	Enabl ed dete ction and alar ms	Not healt hear e-speci fic
[1 5]	Aut oma ted gas mon itori ng	Life-scienc e enviro nments	Flex ible IoT gas sens or node	Gas es	Supp orts statio nary/ mobil e sensi ng	Limi ted IVF-focu sed impl ementati on
[1 6]	Gas dete ctio n in hars h cond ition s	Harsh enviro nments	Fire Nos e mobil e robo t	Gas es	Exten ded sensi ng throu gh mobil e platfo rms	Grea ter syste m com plexi ty
[1 7]	Rem ote mult i-gas	UAV/ UGV enviro nments	Mult i-gas sens or	Mul tipl e	Supp orts remot e	Not desig ned for

	dete ctio n			gas es	envir onme ntal missi ons	healt hear e room s
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II. Methodology

The proposed methodology develops an IoT-based framework for continuous air-quality monitoring in healthcare environments. The SGP40 sensor measures volatile organic compound levels, while the DHT11 sensor simultaneously records temperature and relative humidity. These sensing units are interfaced with an Arduino Nano, which collects and processes environmental measurements. A D1 Mini ESP8266 module provides Wi-Fi connectivity for transmitting processed information to the ThingsBoard cloud platform and Google Sheets for remote visualization, storage, and subsequent analysis. A TFT display presents current VOC, temperature, and humidity measurements locally. When VOC concentrations exceed the prescribed safe threshold, the Arduino activates a buzzer to generate an immediate warning and controls a fan to increase ventilation. This integrated sensing, communication, visualization, and control mechanism enables continuous and responsive healthcare environmental management.

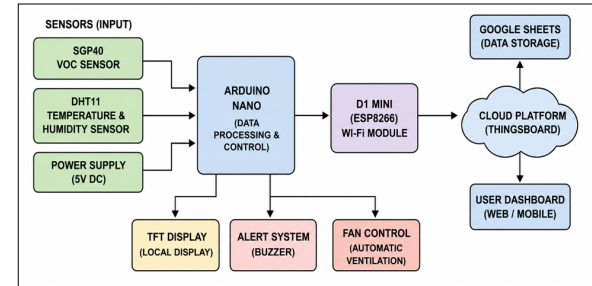


Fig. 1. IoT Framework for Real-Time Air Quality Monitoring in Healthcare Environments

The figure 1 illustrates the proposed IoT framework integrating SGP40 and DHT11 sensors with Arduino Nano for environmental data processing. ESP8266 enables cloud communication through ThingsBoard, while Google Sheets supports storage. The TFT display, buzzer alerts, and automatic fan control provide continuous monitoring and responsive air-quality management.

A. Components used-

The proposed IoT-based air-quality monitoring framework integrates multiple sensing, processing, communication, visualization, and control components to enable continuous monitoring of environmental conditions. The major hardware components include the **SGP40 VOC sensor**, **DHT11 temperature and humidity sensor**, **Arduino Nano**, **D1 Mini (ESP8266)**, **TFT display**, **buzzer**, **fan**, and **regulated power supply**. Each component performs a

specific function, ranging from environmental data acquisition and processing to wireless transmission, local visualization, alert generation, and automatic ventilation control. Their coordinated operation enables both local and cloud-based monitoring of VOC, temperature, and humidity levels in healthcare environments.

i. D1 Mini

- Works with 2.4 GHz Wi-Fi with WPA/WPA2 security.

It has D0 to D7 Digital Pin and A0 - Analog Pin

- Integrated TCP/IP protocol stack
- uses SPI, I2C and USART interfaces

Fig. 2. Pin Diagram of D1 Mini

Figure 2 illustrates the connection between the Arduino Nano and D1 Mini (ESP8266). The D1 Mini provides Wi-Fi connectivity so that the environmental measurements processed by the Arduino can be transmitted to the cloud. The Arduino Nano Digital Pin 4 (TX) is connected to the D3 (RX) pin of the D1 Mini, while Digital Pin 5 (RX) is connected to D4 (TX), establishing serial communication between the two controllers. Their GND terminals are connected together, and the D1 Mini is supplied through the 5 V connection. The ESP8266 supports 2.4 GHz Wi-Fi and an integrated TCP/IP protocol stack, enabling the system to send the acquired VOC, temperature, and humidity measurements to ThingsBoard and Google Sheets for remote monitoring and storage.

ii. TFT Display

- It's has a resolution of 128×160 pixels .
- It uses SPI (Serial peripheral interface)
- full duplex communication
- Master out slave in - MOSI
- Master In slave out - MISO
- Slave select (SS) / chip select (CS)
- Serial clock (SCLK)- generated by microcontroller
- Data/command (DC)

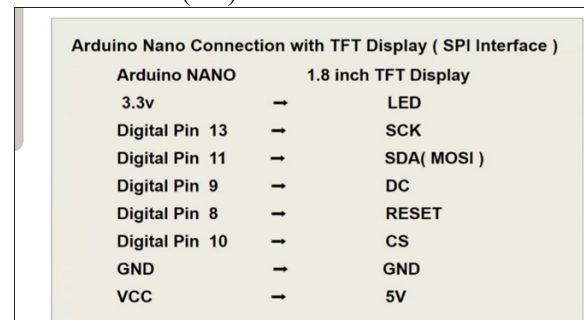


Fig. 3. Pin Diagram of TFT Display

Figure 3 presents the interfacing of the TFT display with the Arduino Nano using the SPI communication interface. The TFT display has a resolution of 128 × 160 pixels and provides local visualization of the monitored environmental parameters. As shown in the figure, Arduino digital pins are connected to the TFT's

SCK, SDA/MOSI, DC, RESET, and CS terminals, together with the required power and ground connections. Through this interface, the Arduino continuously updates the display with the measured VOC index, temperature, and humidity, allowing users to observe current environmental conditions without accessing the cloud dashboard.

iii. DHT 11

- 1 wire protocol
- Data format:- 40 bit
- Data collection in form of 8-8 bit packages.

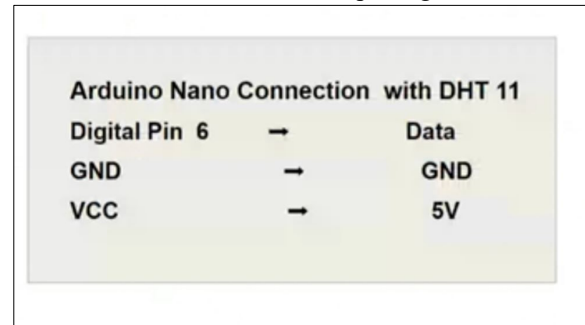


Fig. 4. Pin Diagram of DHT 11

Figure 4 shows the connection of the DHT11 temperature and humidity sensor to the Arduino Nano. The DHT11 uses a single-wire communication protocol and transfers measurements in a 40-bit data format consisting of 8-bit packages. In the presented connection, the sensor's Data pin is connected to Arduino Digital Pin 6, while its GND and VCC terminals are connected to the corresponding ground and 5 V supply. The DHT11 continuously measures the ambient temperature and relative humidity, which are used alongside VOC measurements to characterize indoor environmental conditions.

iv. SGP 40

It uses I2C communication protocol with the microcon- troller half duplex, serial data , serial clock

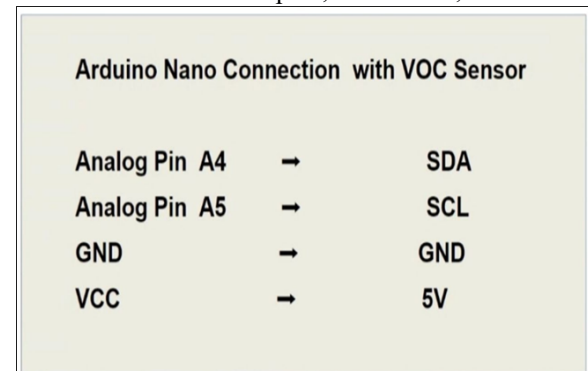


Fig. 5. Pin Diagram of SGP40

Figure 5 illustrates the connection between the SGP40 VOC sensor and Arduino Nano. The SGP40 is the primary sensing component used for detecting variations in volatile organic compounds (VOCs). It communicates with the Arduino through the I²C

communication protocol. As shown in the figure, Arduino Analog Pin A4 is connected to SDA for serial data transmission, while Analog Pin A5 is connected to SCL for the serial clock. The sensor's GND and VCC terminals are connected to ground and the 5 V supply, respectively. The VOC information obtained from the SGP40 is transmitted to the Arduino for processing and subsequently used for display, cloud monitoring, and activation of the alert and ventilation mechanisms when the predefined VOC threshold is exceeded.

The integration of these components establishes the hardware foundation of the proposed real-time air-quality monitoring system. The SGP40 and DHT11 acquire the required environmental parameters, while the Arduino Nano processes the sensor measurements. The TFT display provides immediate local visualization, and the D1 Mini (ESP8266) enables wireless transmission of the processed data for cloud-based monitoring and storage. In addition, the buzzer and fan provide alert and ventilation responses when VOC levels exceed the predefined threshold. Thus, the coordinated operation of sensing, processing, communication, visualization, and control components enables continuous and responsive monitoring of indoor air quality.

B. Working

The proposed IoT-based air-quality monitoring system operates through the coordinated functioning of the SGP40 VOC sensor, DHT11 temperature and humidity sensor, Arduino microcontroller, D1 Mini ESP8266, TFT display, buzzer, fan, and cloud platform. The SGP40 and DHT11 serve as primary sensing devices for continuously acquiring environmental information. These sensors are interfaced with the microcontroller through appropriate communication pins. The microcontroller reads and processes the acquired measurements and subsequently transfers the environmental data through the ESP8266 Wi-Fi module to the cloud platform. ThingsBoard supports IoT-based visualization and monitoring, while Google Sheets stores the recorded VOC, temperature, and humidity measurements for subsequent analysis. This arrangement enables both local and remote observation of environmental conditions.

The SGP40 sensor is employed for detecting variations in volatile organic compounds. According to the implemented working mechanism, interactions occurring at the sensor surface produce changes in its output signal, which is transmitted to the microcontroller for processing. Heating facilitates sensor operation and prepares the sensing surface for subsequent environmental samples. Simultaneously, the DHT11 sensor measures ambient temperature and relative humidity, providing supplementary

environmental parameters required for assessing indoor conditions. The system uses a regulated power arrangement to supply the required operating voltage to its electronic components. Together, the SGP40 and DHT11 provide digital environmental information for continuous processing and monitoring by the microcontroller.

After processing, current VOC, temperature, and humidity measurements are presented on the TFT display, enabling users to observe environmental conditions locally in real time. The system also compares VOC measurements against predefined acceptable levels. When the VOC level remains within the prescribed safe range, measurements are continuously displayed and uploaded without activating corrective mechanisms. Conversely, when the VOC level exceeds the predefined threshold, the buzzer is activated to provide an immediate warning, while the fan speed is increased to improve ventilation and reduce pollutant accumulation. Simultaneously, environmental measurements are updated through ThingsBoard and Google Sheets for remote monitoring and historical analysis. Thus, the framework combines sensing, processing, visualization, cloud connectivity, warning generation, and automatic ventilation control to provide continuous air-quality management for sensitive healthcare environments. In Accordance to the set levels if the VOC levels is in safe range, we will only get to see the current VOC, temperature and Humidity levels on the TFT display TFT stands for Thin Film Technology. It is an output device which will display the level of VOC, Temperature and Humidity and will also indicate whether the levels are safer or not. If VOC levels do not fall under the prescribed safer range, buzzer will get on and Fan speed will increase to maintain the VOC levels. VOC Level, Temperature and Humidity will get updated on Google Sheet through things board. Things board is an open source IoT platform.

The figure 6 illustrates the hardware architecture of the air-quality monitoring system centered on Arduino Nano. DHT11 and VOC sensors provide environmental inputs, while ESP8266 enables communication. The TFT displays measurements, whereas the buzzer and fan provide alert and ventilation responses. A regulated 5V supply powers components.

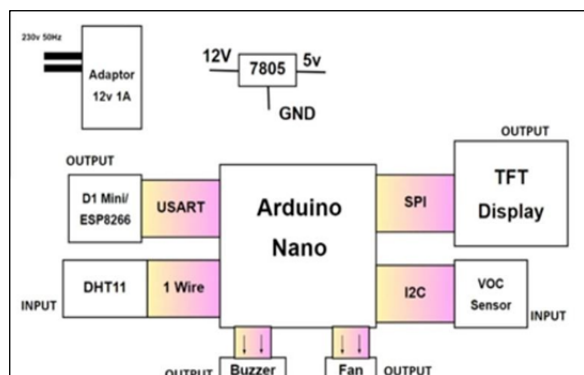


Fig. 6. Working Model of VOC Sensor

Existing IoT-based air-quality monitoring studies demonstrate several sensing, communication, and data-processing approaches for detecting VOCs and other environmental pollutants. An IoT air-quality monitoring system based on MQ-series gas sensors employed MQTT communication and cloud storage for real-time assessment of urban air quality. Another real-time IoT monitoring approach integrated Arduino and Wi-Fi communication to measure VOC-related air-quality parameters, emphasizing sensor accuracy and calibration. Smart-city monitoring systems have also adopted VOC sensors with LoRaWAN communication to provide low-power, long-range connectivity and improve scalability across large urban areas. Wireless sensor network approaches combine VOC sensing, communication protocols, and cloud-based analytics for environmental monitoring and smart-city applications. Low-cost indoor monitoring systems extend these concepts to homes and offices by integrating economical sensors with mobile applications, although calibration and interference remain important challenges.

Edge-computing-based IoT frameworks process environmental measurements locally to reduce communication latency and enable real-time analytics and machine-learning-based prediction. Industrial air-quality monitoring systems integrate VOC sensors with industrial control mechanisms and immediate alerts to support pollution management and workplace safety. Other wireless sensor network solutions employ Zigbee or LoRa communication for large-scale urban pollutant monitoring and public-health assessment. Smart IoT-based indoor monitoring frameworks use Wi-Fi or Bluetooth connectivity to integrate VOC sensors with home automation systems, thereby supporting occupant comfort and environmental management.

Cloud-based smart air-quality systems further combine IoT sensors with cloud analytics and visualization to provide continuous monitoring, data storage, and scalable deployment in urban environments. Overall, these studies demonstrate the transition from basic sensor-based monitoring toward

connected, cloud-enabled, and intelligent environmental management systems. However, greater emphasis is required on healthcare-specific environments where continuous VOC monitoring, immediate alerts, local visualization, cloud connectivity, and automated ventilation control must operate within a unified framework.

Flow Chat :

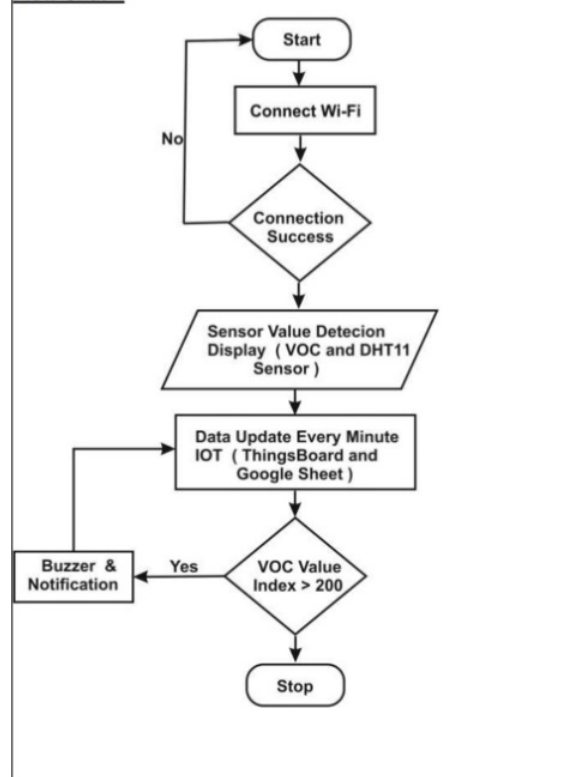


Fig. 7. Flow Chart of VOC Sensor

The flowchart illustrates in figure 7 real-time air-quality monitoring beginning with Wi-Fi connectivity and sensor-data acquisition. VOC and DHT11 measurements are displayed and uploaded every minute to ThingsBoard and Google Sheets. When the VOC index exceeds 200, the system activates buzzer notifications, enabling timely environmental intervention.

III. RESULT

The data obtained from the environmental monitoring performed on December 4, 2024, at 09:48:51 are as follows: 1. VOC Index: o The VOC index was measured as 13, indicating a relatively low level of volatile organic compounds in the environment, which implies good air quality at the point of measurement. Lower values for VOC indices signify better conditions since they reflect fewer concentrations of pollutants present in the air. 2. Temperature: Ambient temperature was 28° Celsius. Ambient temperature was within a range in which VOC emission rates and volatilities might be affected by such, since the organic

compound release from materials is also considerably increased due to higher temperatures. 3. Relative humidity o Relative humidity was at 55. The data reveals that, at the time of measurement, the environment was characterized by a low VOC index, moderate temperature, and balanced humidity. Such conditions favor maintaining good indoor air quality. A low VOC index implies the minimum amount of harmful organic compounds in the air, which is advantageous for human health and comfort. Temperature and humidity levels that are usually not in the exacerbating range of VOC emissions support the observed air quality.

This images of environmental conditions provide a basis for further analysis, especially in studies that look at the relationship between VOC levels, temperature, and humidity. Future research can investigate how these parameters vary over time and their impact on VOC concentrations, especially in different indoor or outdoor settings. The figure illustrates a graphical or visual representation of data collected by a VOC sensor along with accompanying environmental parameters of temperature and humidity.

The dashboard presents, in figure 8, real-time environmental monitoring through VOC, temperature, and humidity indicators. The recorded VOC index of 79 represents moderate contamination, while the temperature and relative humidity are 28°C and 55%, respectively. These measurements demonstrate effective visualization of indoor air-quality conditions for continuous healthcare monitoring.

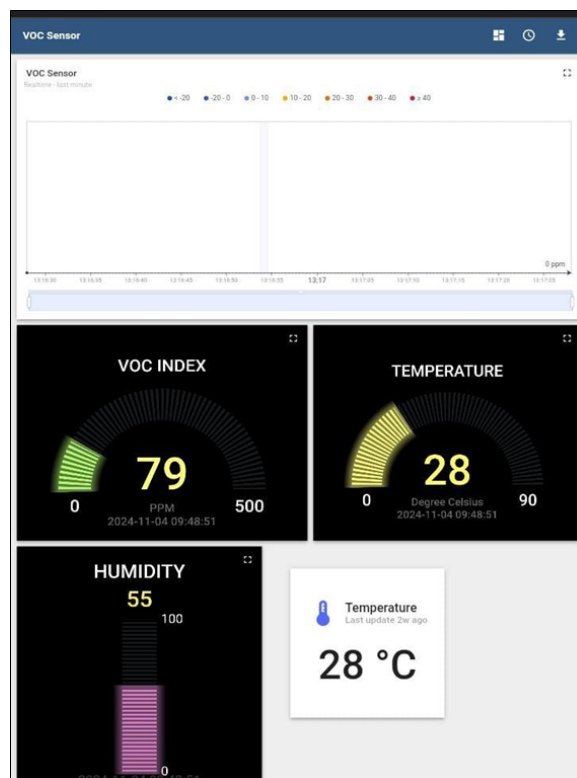


Fig. 8. Result image

1. VOC Sensor Reading: The picture shows reading from the VOC sensor, which tells the concentration of volatile organic compound in the environment. Time relative to the presentation of the concentration of the relative VOC is shown. Timestamps are assigned to each reading with a VOC index showing 79. It implies a moderate VOC concentration. The record "2024-11-04 09:48:51" indicates when this data was recorded.

2. Temperature and Humidity: The environment data also are included in the image, such as temperature set at 28 degrees Celsius, and humidity 55%.

3. Time Series Data: The timestamps indicate that the sensor records data at a high frequency, thus enabling a detailed time series of VOC levels. The high frequency helps to understand the short-term variation and trends of VOC concentrations.

4. Contextual Information The figure gives an overview of the environmental conditions and VOC levels at a particular time point. The data can be used to assess the relationship between VOC emissions and environmental factors, which is helpful for studies in air quality, indoor environmental monitoring, or health-related research.

Below is a comparison of how VOC sensors can be utilized in these environments, along with examples of different readings and potential graphical representations:

- Importance: In IVF laboratories, clean air is of significant significance to the proper success of

procedures. High VOC levels can even deteriorate embryo development and overall lab conditions.

- **Example Reading:** For an example, a VOC index of 79, as highlighted by the image, would be regarded as quite high for an IVF lab. Ideally, it would be within as low as possible, often below 50.
- **Graphical Representation:** A time-series graph showing VOC levels throughout the day can help identify peak times of contamination, allowing for targeted interventions like increased ventilation or air purification.
- **Smart Rooms**
- **Importance:** Smart rooms, often found in hotels or advanced office spaces, use VOC sensors to enhance occupant comfort and energy efficiency. Monitoring VOCs helps in adjusting HVAC systems dynamically.
- **Case Study Read:** A value of 13 of VOC should be ideal in intelligent rooms while keeping the fresh quality of the air. Ambient conditions of temperatures (28°C) and percent humidities 55
- **Graph:** Combination graph indicating trend of variations with time over these parameters (VOC concentrations, temperature and

5. **Hospitals Importance:** In hospitals, VOC sensors help ensure that the surrounding settings remain sterile, especially operating rooms and patient wards. High VOC readings may suggest hazardous chemicals or inadequately ventilated settings and storage. Future research will focus on expanding sensor compatibility to detect a wider spectrum of air contaminants and improving sensor calibration for increased accuracy. In IVF centers, where maintaining ideal air quality is essential for embryo development and successful fertilization outcomes, the suggested system exemplifies the potential of IoT-enabled air quality monitoring, supporting environmental safety, smart city applications, industrial hazard prevention, and air quality management. The figure 9 compares VOC conditions across IVF laboratories, smart rooms, and hospitals. IVF and hospital environments require VOC indices below 50, whereas smart rooms target below 20. Recorded temperature and humidity values support environmental assessment, while time-series, combined, and bar graphs enable comparative air-quality visualization and monitoring.

Standard	VOC Index	Reading Temperature	Humidity	Graphical Representation
IVF	< 50	79 28°C	55%	Time-series graph of VOC levels
Smart Rooms	<20	13 28°C	55%	Combined graph of VOC, temp, humidity
Hospitals	Less than 50	7928°	55%	Bar chart of VOC levels by zone

Fig. 9. Comparative Analysis of Voc Index,

Temperature and Humidity

A. Comparative analysis:

The comparative analysis evaluates VOC levels, temperature, and humidity across IVF laboratories, smart rooms, and hospitals to identify variations in indoor air-quality conditions. The bar chart compares the ideal VOC index with example sensor readings, highlighting environments where improved ventilation or pollutant control may be required. IVF laboratories and hospitals require particularly low VOC concentrations because maintaining controlled air quality is important in sensitive healthcare settings. Temperature and relative humidity are included to provide additional environmental context for interpreting VOC measurements. Similar temperature or humidity conditions may coexist with different VOC indices, indicating that these parameters alone cannot explain variations in VOC concentration. The graphical representation therefore enables straightforward comparison of environmental conditions among different settings and supports identification of areas requiring air-quality improvement, continuous monitoring, or appropriate corrective measures.

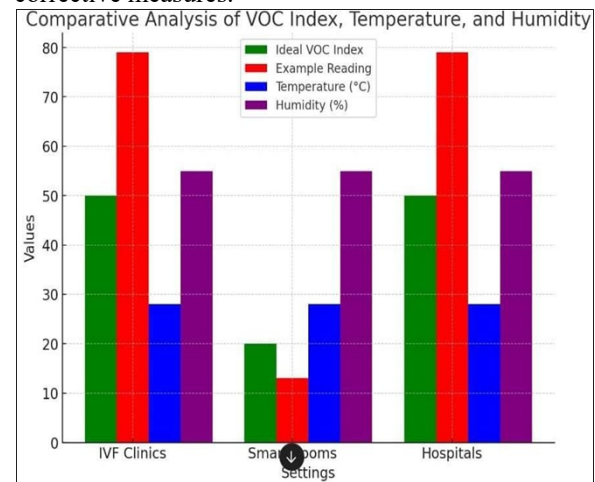


Fig. 10. Graphical representation of Voc Levels

IV. Conclusion

The proposed smart IoT framework provides an effective, affordable, and scalable solution for real-time air-quality monitoring in healthcare environments, particularly IVF laboratories, hospitals, and other contamination-sensitive spaces. The system integrates the SGP40 VOC sensor, DHT11 temperature and humidity sensor, Arduino Nano, and D1 Mini ESP8266 to enable continuous environmental sensing, processing, and wireless data transmission. ThingsBoard and Google Sheets facilitate cloud-based visualization, storage, and remote observation, while the TFT display provides immediate local information. Experimental observations demonstrated the practical capability of the framework, including measurements

of a VOC index of 13 under favorable conditions and 79 under moderate VOC conditions, with temperature and relative humidity values of 28°C and 55%, respectively. The incorporation of buzzer alerts and automatic fan control further strengthens the system by enabling rapid responses when VOC concentrations exceed predefined safety thresholds. Overall, the framework combines environmental sensing, IoT connectivity, cloud monitoring, visualization, and automated control within a unified architecture. The developed approach can support safer indoor environments and continuous environmental supervision. Future work can extend the framework through additional pollutant sensors, improved calibration, predictive analytics, and intelligent ventilation control for broader healthcare applications.

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