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An IoT Based System for Detection of Formaldehyde Using CH_2O Sensor in Ambient Air

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Abstract
Formaldehyde is one of the hazardous components found in the ambient air. Moreover, Formaldehyde is one of the key components of Volatile Organic Compound (VOC) that has significant health implications. This Formaldehyde is mainly released by industries and vehicles plying on the road. Continuous exposure to Formaldehyde results in a range of adverse effects, that includes respiratory irritation, eye and skin irritation, and even cancer also. For ensuring public health and safety, Monitoring of formaldehyde levels in ambient air is apparent. The framework presented is a comprehensive investigation for the detection of Formaldehyde in ambient air that utilizes the CH_2O sensor Module, an ESP32 microcontroller, and AWS cloud services. This study investigates how well this integrated system performs real-time monitoring, facilitates accurate Formaldehyde concentration measurements, and allows for effective data processing. The presented work explores the experimental setup, technique, results, and discussion, emphasizing the main takeaways and possible uses of this novel approach to air quality monitoring. The system has the ability to store, analyse, and visualize data on Formaldehyde concentrations by utilizing AWS cloud services. This allows researchers and environmental organizations to obtain important insights into trends in air quality and pinpoint possible sources of pollution. In addition to improving safety and health, this integrated system provides a viable option for Formaldehyde monitoring that is economical, effective, and scalable.

Keywords – Formaldehyde, Internet of Things (IoT), Volatile Organic Compound (VOC), Amazon Web Service (AWS),

I. INTRODUCTION

As per the World Health Organization (WHO) report, around 92% of human beings on Earth reside in regions where ambient air quality standards have exceeded. The report also claims that air pollution is the largest environmental health threat, accounting for one in nine fatalities annually. Furthermore, data indicate that 3 million deaths a year are directly related to outdoor air pollution [1].

Subsequent research has also shown that globally air pollution is one of the biggest threats to human health and environment. The World Health Organization estimates that air pollution puts 7 million people's health at risk [2].

One major source of Formaldehyde in the environment in urban areas is vehicular exhaust. Formaldehyde emissions are caused by burning fuels such as gasoline and diesel, as well as incomplete combustion of other fuels. Formaldehyde levels in the atmosphere are also increased by factories and other industrial facilities that use gas, oil, or coal as energy sources. Exposure to Formaldehyde from automobile exhaust and industrial pollutants, particularly in heavily industrialized or inhabited areas, can be harmful to one's health. Short-term exposure can cause skin responses, respiratory discomfort, and irritation of the throat, nose, and eyes. Prolonged exposure, especially at high concentrations, has been associated with asthma, long-term respiratory disorders, and an increased risk of cancer, including leukaemia and nasopharyngeal carcinoma. These negative health consequences can be lessened by employing cleaner fuel technology and lowering industrial pollutants.

The WHO developed air quality guidelines specifically addressing Volatile Organic Compounds to detail its health effects as a pollutant. These guidelines outline the risks associated with both short-term and prolonged exposure to Formaldehyde, providing thresholds to help limit its impact on respiratory health, irritation, and cancer risk [3].

Traditionally, Volatile Organic Compounds detection methods have often involved complex laboratory procedures and specialized equipment, making them expensive and time-consuming. These limitations have limited their widespread application, especially in real-time monitoring scenarios. However, recent developments, advancements in sensor technology and empowered cloud computing have paved the way for the development of Portable and economical air quality monitoring systems. The CH_2O Sensor Module, equipped with an electrochemical sensor, provides a sensitive and accurate means of measuring Formaldehyde – a key component of Volatile Organic Compounds concentrations.

The research paper outlines a comprehensive investigation into the Detection of Formaldehyde in ambient air utilizing the CH_2O Sensor Module, an ESP32 microcontroller, and AWS cloud services. The study explores the effectiveness of this integrated system in accurately measuring Formaldehyde concentrations, providing real-time monitoring capabilities, and enabling efficient data analysis. The aim is to address the limitations of traditional methods by developing a system that is: (1) economical, (2) portable, and (3) capable of collecting the real-time information and provision of analysis. The remaining part of the paper is structured as follows. Section 2 details the survey of available literature in order to identify the sensors, its integration in the system and utilization of Internet of Things (IoT) for

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cloud services. Section 3 details the methodology employed in development and implementation of the system. Section 4 describes the experimental setup, outlining the hardware and software components utilized, along with its working in details. Section 5 presents the experimental results and its analyses with respect to the system developed. Section 6 discusses the implications of the findings and explores potential applications of the system. it also concludes the presented work with a summary of the key contributions.

II. RELATED LITERATURE

The study of the existing literature is essential for exploring different types of sensors and techniques used for the detection of various harmful gaseous compounds. The following section outlies the details about the different literatures that is reviewed for the identification of sensors and exploring the simple, portable and cost-effective technique.

Changhai Peng et'al presented a work that involves the detection of CO, CO2, VOC and PM by employing ATmega16 processor and the RF230 ZigBee module, which is designed to manage communication data effectively while minimizing power usage and enhancing sensing efficiency. This is achieved by integrating various intelligent task management and power optimization protocols. [4].

In-depth analysis of the state-of-the-art in gas-sensing technologies is provided by João B. A. Gomes et'al, along with an examination of the advantages and key traits of transducers and how they fit into the Internet of Things (IoT) paradigm. The literature discusses about different sensors used for the detection of CO, CO2, PM, VOC and LPG. This study shall facilitate the processes of gathering and exchanging information, improving user experiences and preventing significant losses and costs [5].

A framework suggested by Dan Zhang et'al use both stationary and mobile Internet of Things sensor installed on patrolling vehicles—to predict the pattern of air quality in a particular area specifically CO_2. This method allows for the complete spectrum of variations in air quality in neighbouring locations to be examined. Using real-world data, we show that our technique can measure and predict air quality successfully using various machine learning algorithms [6].

The platform tracks real-time gas concentrations in Dhaka City, including nitrogen dioxide (NO2) and carbon monoxide (CO), to generate the air quality index (AQI). The purpose of sensors is to detect significant changes in gas conditions using an Arduino-based Node MCU. The data is transmitted to the server with the help of ESP-32 Wi-Fi module by enabling remote access [7].

Dylan Wall et al. suggested an Internet of Things (IoT) framework for indoor air quality monitoring that is based on low-cost air quality sensors and edge computing nodes. The relationship between temperature, humidity, and air quality is developed in the study. The Bosch BME680 sensors in the kitchen were employed in the proposed test setup to gather research samples [8].

An inexpensive metal oxide sensor-based air quality monitoring system that measures the concentrations of carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), and particulate matter (PM) was presented by Rady Purbakawaca et al. using laser diffraction, a microcontroller, and a general packet radio service module [9].

An IoT based indoor air quality monitoring was suggested by Ramik Rawal that is useful for remote areas. The system was based on the request and respond protocol with combination of address and data centric protocols. Though the system was economical and consumes less energy but it was only capable of addressing air quality and carbon monoxide [10].

Waheb A. Jabbar et'al suggested LoRaWAN based IoT System that consists of gateways and The Thing Network (TTN). The system was capable of addressing the common pollutants like NO_2, SO_2, CO_2, CO, $PM_{2.5}$, temperature, and humidity with the help of respective sensor [11].

To reduce the air pollution, Yu-Lin Zhao et al. proposed an Internet of Things (IoT)-based, intelligent, and multipurpose monitoring platform that compares and analyses sensor networks, M2M, and radio frequency identification (RFID). The study also demonstrates how complete network connectivity, cloud-based decision making, information tracking, and online administration may improve and increase the efficacy of air quality monitoring [12].

M. Anith et'al proposed an IoT based framework that is consisting of various sensors for air quality monitoring along with Raspberry Pi Module. The design is also responsible for measuring the concentration of CO, CO2, and NH4 purification of air with the help of multiple filters of particles from sizes 200 to 0.3 lm [13].

The goal of Rady Purbakawaca et al.'s proposed air quality monitoring system, which is based on a microcontroller and a general packet radio service module, is to create an inexpensive system that uses a variety of sensors to measure the concentrations of common pollutants such as carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), and particulate matter (PM) using the laser diffraction method [14].

After the through literature survey as mentioned above, it is evident that most of the literature is either addressing the common pollutants or Volatile Organic Compounds (VOC). But none of the study deals with a specific VOC. Since the specific VOC like formaldehyde is overlooked by many studies, this has laid the motivation to work in this domain. The system is expected to store, analyse, and visualize data on Formaldehyde concentrations by utilizing AWS cloud services. This makes it feasible for scientists and environmental groups to identify potential pollution sources and get crucial insights into changes in air quality. This integrated system offers a practical, cost-effective, scalable and easily deployable alternative not only for formaldehyde but also for other air pollutants for monitoring while ensuring safety and health.

III.METHODOLOGY

The methodology employed in this research follows a systematic approach to address the objective of detecting Formaldehyde in air. Exhaustive literature survey helps to identify the objective, hardware & software components required for the development of the system. The hardware is so chosen that it would make the system cost effective and portable. This will help to install the system everywhere unlike traditional systems which require large space and maintenance.

Figure-1 below depicts the flowchart that outlines the steps involved in developing an IoT based system for the detection of Formaldehyde in air. The overall approach employed in this study involves the following steps:

1. Identification of objective through literature survey
2. Hardware Identification & Setup
3. Software Development
4. Data Acquisition and Processing
5. Data Visualization and Analysis

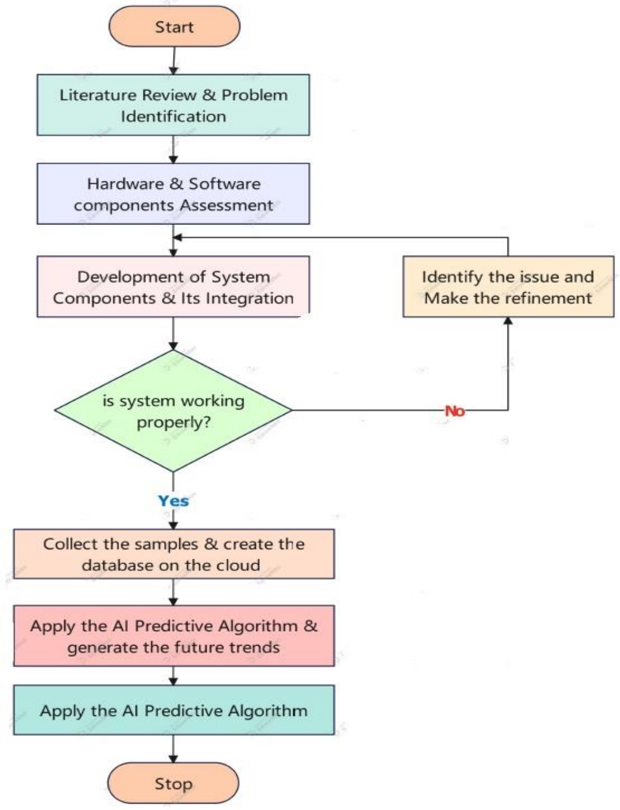


Fig-1: Flowchart showing the development process

The hardware components are identified and finalized after the thorough literature survey. The system is built upon the integration of the CH_2O Sensor Module, ESP32 microcontroller, and AWS cloud services, each playing a crucial role in the overall process. ESP32, an IoT controller system is the main hardware component that is used to with the sensor module and the cloud.

Figure-2 below show the block diagram for the detection of formaldehyde. It consists of Sensor for formaldehyde detection, Data Acquisition Analog to Digital Converter, Signal Conditioning, IoT Controller, AWS Cloud.

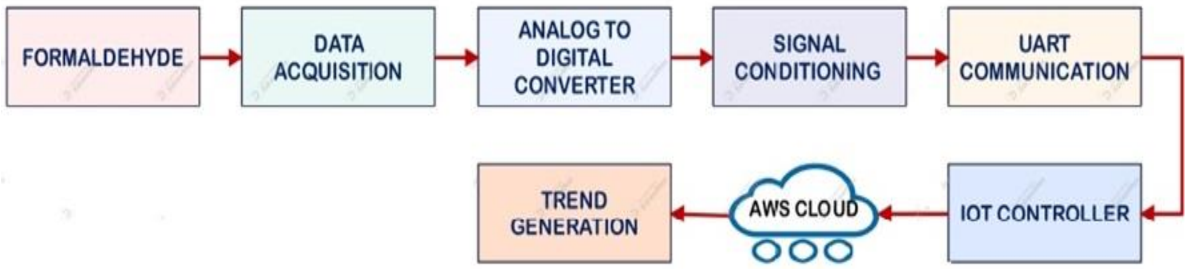


Fig-2: Block Diagram of IoT Based System for Detection of Formaldehyde

The block diagram depicts a system developed for monitoring formaldehyde levels and sending the data to an IoT controller through the AWS cloud. The system is especially valuable in environments where formaldehyde exposure is a worry, such as indoor spaces, vehicular exhaust or industrial settings. The process commences with a formaldehyde sensor that consistently tracks the surrounding formaldehyde concentration. Typically, the sensor produces an Analog signal, which is then transformed into a digital signal using inbuilt Analog-to-digital converter (ADC). This digital signal undergoes further processing through signal conditioning to guarantee its quality and compatibility with subsequent stages of the system. The digital signal is sent to a UART communication module once it has been conditioned. Data transfer between devices is made possible using the commonly used serial communication protocol known as UART (Universal Asynchronous Receiver-Transmitter). The baud rate used for the UART is 9600 with one stop bit.

Here, the data samples are sent to an IoT controller by the UART module after every 5 seconds. Collecting the samples at such rate will help in better analysis of the formaldehyde. The formaldehyde data is received by the IoT controller, which serves as the system's central processing unit. In accordance with predetermined thresholds, it can send alerts or notifications, store the data locally, process the data to find trends or anomalies. The AWS cloud platform can also be accessed by the IoT controller, enabling remote data access, analysis, and visualization.

The CH_2O Sensor Module is a key component of the system, responsible for detecting and measuring Formaldehyde levels in the surrounding air. This sensor is chosen for its sensitivity to Formaldehyde, enabling the detection of even low concentrations. The ESP32 microcontroller serves as the system's brain, collecting data from the CH_2O Sensor Module, processing it, and transmitting the data to the cloud server. The ESP32's low power consumption allows for continuous monitoring without significantly impacting battery life.

AWS cloud services play a crucial role in data storage, analysis, and visualization. Data collected by the ESP32 is transmitted to an AWS server, where it is stored in a secure and scalable database. AWS's powerful analytical tools enable real-time monitoring of Formaldehyde levels and the identification of any potential trends or anomalies. The cloud infrastructure also facilitates the development of user-friendly dashboards for visualizing data and providing insightful reports.

The integration of these components creates a comprehensive system capable of accurately detecting Formaldehyde levels in environments. By leveraging the sensor's sensitivity, the microcontroller's processing power, and the cloud's scalability, this research provides a practical, portable and cost-effective solution for monitoring indoor air quality and promoting healthier living environments.

Finally, the research explores the feasibility of deploying this system in real-world scenarios. This involves evaluating the system's scalability, cost-effectiveness, and ease of implementation in various indoor as well as outdoor settings. The research aims to demonstrate the practicality of this system as a viable solution for improving air quality and promoting healthier living environments.

IV. EXPERIMENTAL SETUP

The schematic of developed system is as shown in fig-3 that consists of the CH_2O Sensor Module, an ESP32 microcontroller. The CH_2O Sensor Module is a compact and readily available sensor module specifically designed for measuring Formaldehyde concentrations in ambient air. It utilizes an electrochemical sensor technology that provides high sensitivity and accuracy in detecting Formaldehyde. The ESP32 microcontroller, chosen for its processing power and versatility, acts as the central control unit for the system. It is responsible for interfacing with the CH_2O Sensor Module, acquiring data from the sensor, and transmitting the collected data wirelessly to the cloud server. The ESP32's built-in Wi-Fi capabilities enable seamless communication with the cloud platform.

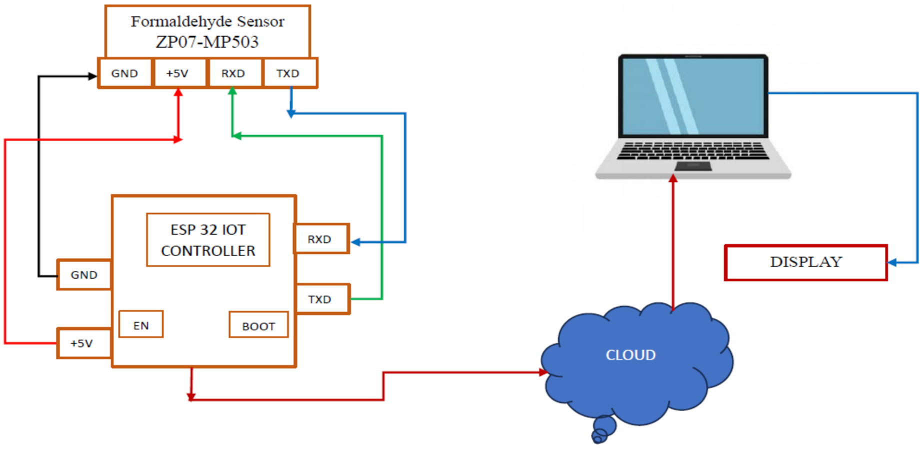


Fig-3: Circuit Diagram of IoT Based System for Detection of Formaldehyde

The graph represents the sensitivity of a sensor to various gases at different concentrations. The x-axis represents the concentration (ppm), and the y-axis represents the sensor's response (Rs/Ro). A higher Rs/Ro value indicates a greater response to the gas.

Formaldehyde's Characteristics:
Based on the graph, as shown in the fig-4 below [15], we can observe the following characteristics of formaldehyde's

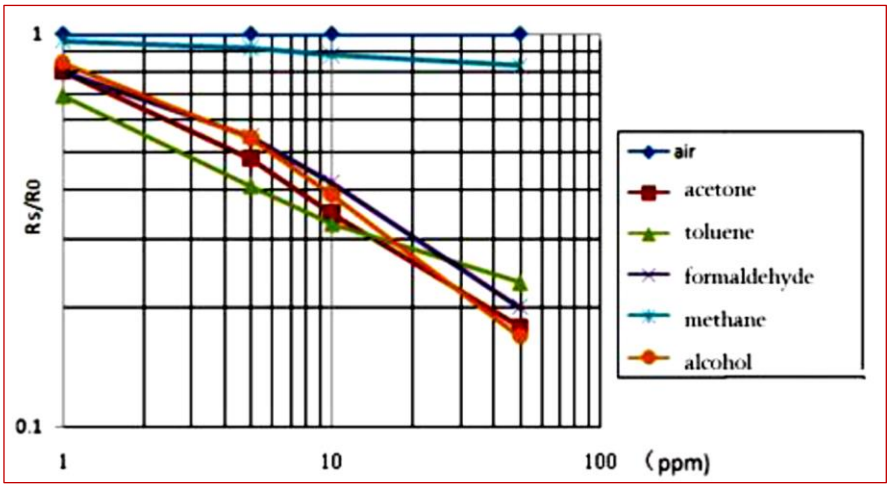


Fig-4: characteristics of formaldehyde's sensitivity

sensitivity: Sensitivity at Low Concentrations: Formaldehyde appears to be quite sensitive even at low concentrations. This is evident from the steep slope of its curve at lower ppm values.

Saturation: As the concentration increases, the formaldehyde curve seems to plateau, suggesting that the sensor's response may saturate at higher levels.we can propose a potential model based on these observations. A common model for sensor response to gases is:

$$Rs/_{R0} = A * (C^n) \quad \text{---------} \quad (1)$$

Where:
Rs/Ro is the sensor response
A is a constant related to the sensor's sensitivity
C is the concentration of the gas
n is a power that determines the rate of change in response with concentration.

Figure-5 below show the experimental setup, which includes ZPHZ01B a multi sensor module that is interfaced with the ESP32 Microcontroller. The set up is initially used to collect the formaldehyde samples for the testing purpose for a span of two hours. Also, this setup is useful for collecting other environmental parameters like temperature, Humidity along with common pollutants like Carbon Dioxide, Carbon Monoxide, Nitrogen etc. The setup was initially experimented for Two Hours to test the overall working and the monitoring of the targeted VOC i. e. formaldehyde.

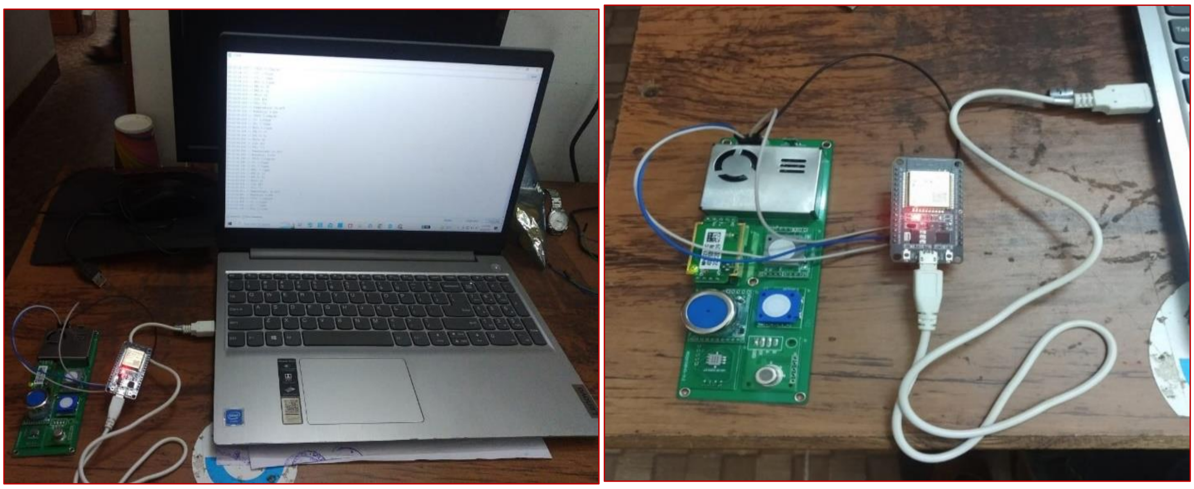
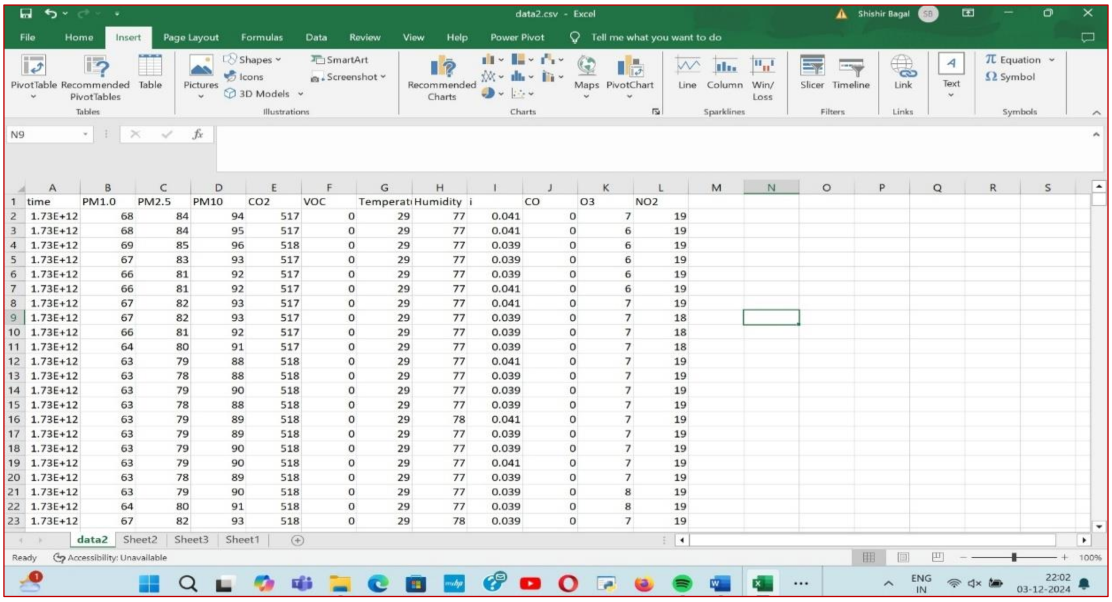


Fig-5: Experimental setup, consisting ZPHS01B interfaced with the ESP32 Microcontroller.

V. EXPERIMENTAL RESULTS

Table-1 below shows the samples collected against the formaldehyde monitoring. The experimental results show the effectiveness of the system that accurately detects the Formaldehyde levels in the air. The system consistently provided accurate readings for the Formaldehyde concentrations, validating the reliability of the CH_2O Sensor Module and the ESP32 microcontroller. The system was working as per the expectations and buffering the collected samples on the cloud. The cloud was established using Amazon Web Services (AWS). The sample rate collection was set to 0.5 seconds.

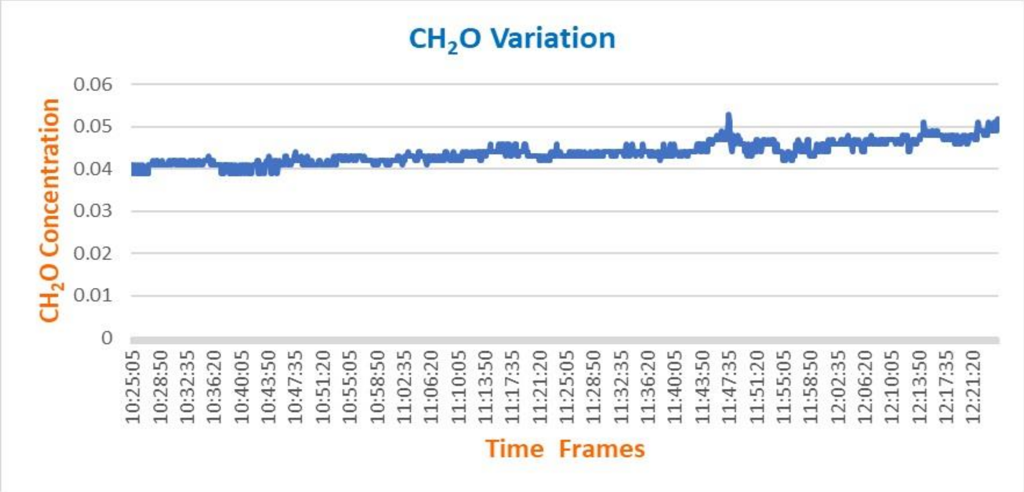


time	PM1.0	PM2.5	PM10	CO2	VOC	Temperat	Humidity	i	CO	O3	NO2
1.73E+12	68	84	94	517	0	29	77	0.041	0	7	19
1.73E+12	68	84	95	517	0	29	77	0.041	0	6	19
1.73E+12	69	85	96	518	0	29	77	0.039	0	6	19
1.73E+12	67	83	93	517	0	29	77	0.039	0	6	19
1.73E+12	66	81	92	517	0	29	77	0.039	0	6	19
1.73E+12	66	81	92	517	0	29	77	0.041	0	6	19
1.73E+12	67	82	93	517	0	29	77	0.041	0	7	19
1.73E+12	67	82	93	517	0	29	77	0.039	0	7	18
1.73E+12	66	81	92	517	0	29	77	0.039	0	7	18
1.73E+12	64	80	91	517	0	29	77	0.039	0	7	18
1.73E+12	63	79	88	518	0	29	77	0.041	0	7	19
1.73E+12	63	78	88	518	0	29	77	0.039	0	7	19
1.73E+12	63	79	90	518	0	29	77	0.039	0	7	19
1.73E+12	63	78	88	518	0	29	77	0.039	0	7	19
1.73E+12	63	79	89	518	0	29	78	0.041	0	7	19
1.73E+12	63	79	89	518	0	29	77	0.039	0	7	19
1.73E+12	63	79	90	518	0	29	77	0.039	0	7	19
1.73E+12	63	79	90	518	0	29	77	0.041	0	7	19
1.73E+12	63	78	89	518	0	29	77	0.039	0	7	19
1.73E+12	63	79	90	518	0	29	77	0.039	0	8	19
1.73E+12	64	80	91	518	0	29	77	0.039	0	8	19
1.73E+12	67	82	93	518	0	29	78	0.039	0	7	19

Table-1: Formaldehyde concentrations with respect to time

CH_2O Variation with Time

The variations of formaldehyde concentration with respect to time are shown in the graph. The CH_2O concentrations are varying within a range of approximately 0.03 to 0.04 mg/m3. From the graph, it is quite evident that the formaldehyde concentrations are almost steady for most of the time with some spikes in between.



Graph-1: Representation of Formaldehyde variation with respect to time.

Changes in temperature, differences in reactant concentrations, or other environmental variables can all be blamed for these surges. Additionally, it is evident that the formaldehyde concentration is gradually increasing, suggesting that the formaldehyde being continuously released.

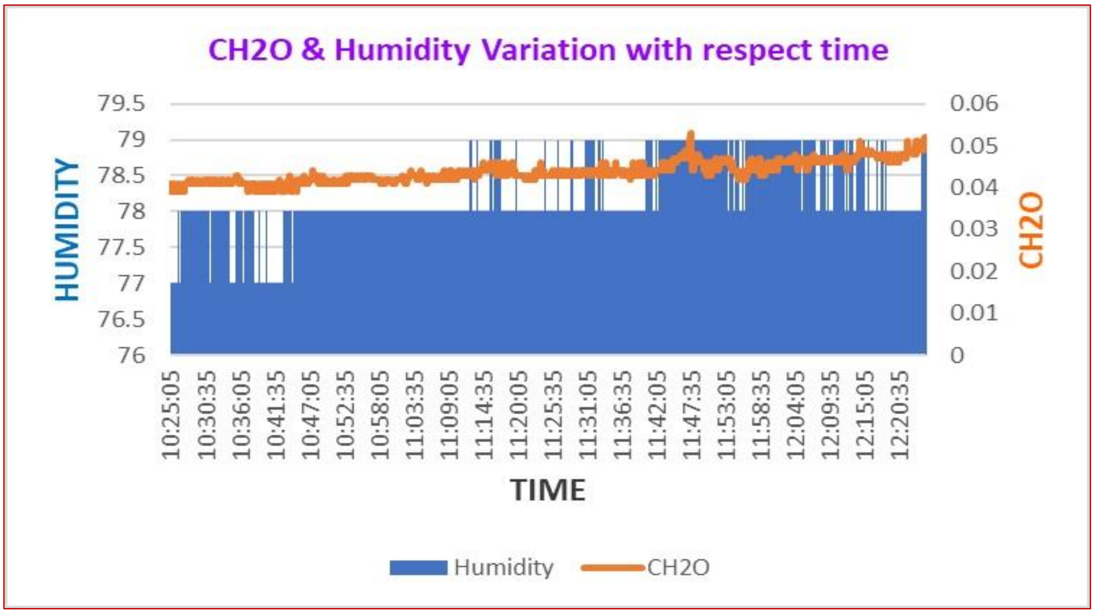
The time at which fluctuations are witnessed can be helpful to provide further information about the underlying processes: rapid fluctuations may indicate rapid chemical reactions or environmental changes, while slower changes may indicate longer-term trends.

CH_2O variation with respect to Humidity and Time -

The graph indicates that the content of CH2O and humidity are strongly correlated. CH2O concentration rises with increasing humidity. Numerous reasons could account for this association.

Increased emission: More humidity may make it easier for surfaces or materials to emit CH2O. For instance, formaldehyde, which is frequently present in building materials, may outgas when there is an increase in moisture.

Decreased Absorption: Surfaces' capacity to absorb CH2O may also be diminished by increased humidity. As a result, there would be more CH2O in the atmosphere.
The concentration of CH2O is shown by the orange line. It displays a more intricate pattern. After a brief upward tendency, there is a period of comparatively steady concentration. The CH_2O concentration begins to rise rapidly at the time of the humidity peak (11:30), peaking at the end of the observation period. Humidity is shown by the blue line. It exhibits a notable rise beginning at approximately 10:45, peaking at 11:30, and then progressively declining until the conclusion of the observation time.



Graph-2: Representation of Formaldehyde variation with respect to time.

VI. CONCLUSION

This presented work demonstrates the development monitoring system consisting of CH_2O Sensor Module and ESP32 microcontroller, coupled with AWS cloud services, for detecting and quantifying Volatile Organic Compounds levels in air. This system offers a promising approach to air quality monitoring, particularly for Formaldehyde, a common volatile organic compound (VOC) that can pose health risks. The data analysis showed, strong correlations between CH_2O levels and temperature and humidity, highlighting the importance of considering these factors in assessing indoor air quality.
The research demonstrates the feasibility and practicality of utilizing low-cost and readily available technologies for developing effective and reliable air quality monitoring systems. This approach is particularly relevant in the context of increasing awareness about the importance of air quality and the need for affordable and accessible monitoring solutions. The system's ability to provide real-time data, coupled with the data analysis and visualization features provided by AWS cloud services, would empowers individuals to take proactive steps towards improving air quality and safeguarding their health. This real-time monitoring capability enables users to identify potential issues promptly and implement necessary measures to mitigate exposure to harmful pollutants.

REFERENCES

[1] World Health Organization, “Ambient Air Pollution: A global assessment of exposure and burden of disease,” Geneva, 2016.
[2] *7 Million Premature Deaths Annually Linked to Air Pollution*. Accessed: Apr. 27, 2019. [Online]. Available: https://www.who.int/phe/eNews_63.pdf
[3] WHO Regional Office, “Air Quality Guidelines,” *Air. Qual. Guidel.*, vol. 22, no. 8, pp. 1-8, 2000.
[4] Changhai Peng, Kun Qian, and Chenyang Wang, “Design and Application of a VOC-Monitoring System Based on a ZigBee Wireless Sensor Network”, IEEE SENSORS JOURNAL, VOL. 15, NO. 4, APRIL 2015, DOI - 10.1109/JSEN.2014.2374156.
[5] João B. A. Gomes, Joel J. P. C. Rodrigues, Ricardo A. L. Rabêlo, Neeraj Kumar and Sergey Kozlov, “IoT-Enabled Gas Sensors: Technologies, Applications, and Opportunities”, Journal of Sensors and Actuators [MPDI], December 2019.
[6] Dan Zhang, Simon S. Woo, “Real Time Localized Air Quality Monitoring and Prediction Through Mobile and Fixed IoT Sensing Network”, IEEE Access, Multidisciplinary, Rapid Review, *DOI 10.1109/ACCESS.2020.2993547.*

[7] Rajib Saha, M M R Manu, Aminul Hoque, S N M Azizul Hoque, “Monitoring Air Quality of Dhaka using IoT: Effects of COVID-19”, IEEE Xplore 2021, 2nd International Conference on robotics, Electrical and Signal Processing Techniques (ICREST)

[8] Dylan Wall, Paul McCullagh, Ian Cleland and Raymond Bond, “Development of an Internet of Things (IoT) solution to monitor and analyse indoor air quality”, Internet of Things 14, 100392, www.elsevier.com/locate/iot https://doi.org/10.1016/j.iot.2021.100392.

[9] Rady Purbakawaca, Arief Sabdo Yuwono, I. Dewa Made Subrata, Supandi and Husin Alatas, Ambient Air Monitoring System With Adaptive Performance Stability”, IEEE Access, *Digital Object Identifier 10.1109/ACCESS.2022.3222329*

[10] Ramik Rawal, “Air Quality Monitoring System”, International Journal of Computational Science and Engineering, ISSN 2249-4251 Volume 9, Number 1 (2019), pp. 1-9

[11] Waheb A Jabbar, Tanasrji Subramaniam, Andre Emelio Ong, Mohd. Iqbal Shub’Ib, wenyan Wu, Mario A. de Oliveria, “LoRaWAN-Based IoT System Implementation for Long-Range Outdoor Air Quality Monitoring”, Internet of Things, Volume 19, August 2022, doi.org/10.1016/j.iot. 2022.100540.

[12] Yu-Lin Zhao “Development of IoT Technologies for Air Pollution Prevention and Improvement, *Aerosol and Air Quality Research*, 20: 2874–2888, 2020, ISSN: 1680-8584 print / 2071-1409 online, doi.org/10.4209/aaqr.2020.05.0255

[13] M. Anitha* and L. S. Kumar, “Development of an IoT-Enabled Air Pollution Monitoring and Air Purifier System”, MAPAN-Journal of Metrology Society of India (September 2023) 38(3):669– 688, doi.org/10.1007/s12647-023-00660-y

[14] Rady Purbakawaca, Arief Sabdo Yuwono, I. Dewa Subrata, Supandi, Husin Alatas, “Ambient Air Monitoring System with Adaptive Performance Stability”, IEEE Access, *Digital Object Identifier 10.1109/ACCESS.2022.3222329*

[15] Air-Quality Detection Module (Model：ZP07-MP503）User’s Manual, Zhengzhou Winsen Electronics Technology Co., Ltd