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Development of a Non-Invasive Co2 Breath Sensor with Iot Integration

Siti Aisah Mat Junos @ Yunus[1], Muhammad Arfan Khairol Annuar [1], Siti Amaniah Mohd Chachuli[1], Muzalifah Mohd Said[1], Hanissah Mohamad @ Sulaiman[1], Nur Hazahsha Shamsudin[2]

[1]Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia, [2]Fakulti Teknologi dan Kejuruteraan Elektrik, Universiti Teknikal Malaysia Melaka (UTeM), 76100 Durian Tunggal, Melaka, Malaysia

Corresponding Author Email: aisah@utem.edu.my

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Abstract

Breath analysis offers a non-invasive, rapid, and cost-effective method for diagnosing respiratory diseases and monitoring various health conditions. However, non-invasive breath analysis techniques often suffer from lower sensitivity and specificity compared to invasive methods, primarily due to the lack of standardized protocols. While invasive methods provide greater accuracy, they are associated with increased discomfort and risk. This study focuses on enhancing the precision and reliability of non-invasive breath sensors by developing a breath sensor using the commercially available MH-Z14A CO2 sensor. Breath samples were collected from smokers and non-smokers using Tedlar bags and analysed to detect CO2 levels. The sensor's output was processed through an ESP32, providing real-time CO2 concentration readings. Results revealed that smokers exhibited longer response and recovery times, attributed to elevated CO2 levels, while sensitivity analysis demonstrated the sensor's ability to detect minute variations in CO2 concentrations. These findings underscore the potential of this sensor for non-invasive respiratory monitoring and early detection of respiratory conditions.

Keywords: Breath Analyser, Carbon Dioxide, IoT, MH-Z14A, Non-Invasive, Pulse-Width Modulation (PWM), Tedlar bag

Introduction

According to the World Health Organization (WHO), respiratory diseases contribute to more than four million premature deaths annually. By 2030, Chronic Obstructive Pulmonary Diseases (COPD) are projected to become the third leading cause of death worldwide based on WHO EMRO (2024) Chronic obstructive pulmonary disease (COPD). Available at:

https://www.emro.who.int/health-topics/chronic-obstructive-pulmonary-disease copd/index.html (Accessed: Jan. 10, 2024). Healthcare facilities need expensive technology and personnel to diagnose these illnesses, making preventive check-ups unlikely for everyone. Computed tomography, forced oscillation tests, and exhaled breath analysis are IoT integration methods for respiratory disease prediction (D. Hashoul & H. Haick, 2019). Recent advances in chemical-based sensor technologies have enabled cost-effective non-invasive embedded systems called e-noses (Saidi et al., 2019). IoT offer flexible and timely cloud computing transfer and processing of sensor and wearable device data, allowing providers of healthcare speedier access (Lutz & Coradi, 2022). Given the high costs of gas detectors, using commercial sensors to construct an exhaled human breath sensor might save money. Commercial breath analysis sensors are cost-effective and usable but may have sensitivity, selectivity, stability, and repeatability issues (Smith & Jones, 2021).

In recent years, sensors and e-Noses have shown promise as powerful diagnostic tools for breath analysis, addressing clinical problems (Amal & Haick, 2020). Based on this problem, the development of affordable and non-invasive early predictiction solutions and developed improved respiratory diseases prediction analytics. There are several previous studies regarding breath analyser. Existing exhaled breath sensor technologies for focusing on changes in electrical resistance, sensor sensitivity, and selectivity (Ramanathan et al., 2023), measured the concentration of carbon dioxide in the exhaled air (Ramanathan et al.,Fuadi et al., 2023), (Hong et al., 2018), evaluate sensor response time (Fuadi et al., 2023) and importance of short response and recovery times for sensors used in breath analysis (Kaloumenou et al., 2022). This research provides new perspectives on gas analysis in exhaled breath. These studies help advance respiratory analysis research by detecting health issues and monitoring the environment.

Based on the previously mentioned results, the main things needed to develop an exhaled human breath sensor is ensuring reproducibility, high sensisivity, and good resolution of the sensor, as well as achieving a low limit of detection and increased selectivity to detect volatile organic compounds (VOCs) in exhaled breath. Additionally, it is essential to maintain a stable baseline in the absence of gas-target biomarkers, enable full recovery of the sensor after gas removal, and ensure short response and recovery times. By implementing the internet of things in healthcare, it can enable the collection and analysis of data from smart devices and sensors, allowing for continuous monitoring of health metrics (Salama et al., 2023). Portable healthcare monitoring systems utilise IoT technology to monitor patients' physiological indicators in real-time and automatically maintain databases. Thus, the project will entail evaluating the sensor's parameters such as response time, recovery time and sensitivity of sensor and incorporating the human breath sensor into an Internet of Things (IoT) application. This project will primarily focus on analysing the data obtained from the commercial sensor that will be utilised in this project.

Methodology

System Architecture for Breath Sensing and Data Acquisition

The block diagram illustrates in Figure 1 the architecture of a breath sensor system designed for real-time data acquisition and analysis. The primary components include the MH-Z14A CO_2 sensor, Tedlar Bag, ESP32 microcontroller, and the Blynk IoT platform.

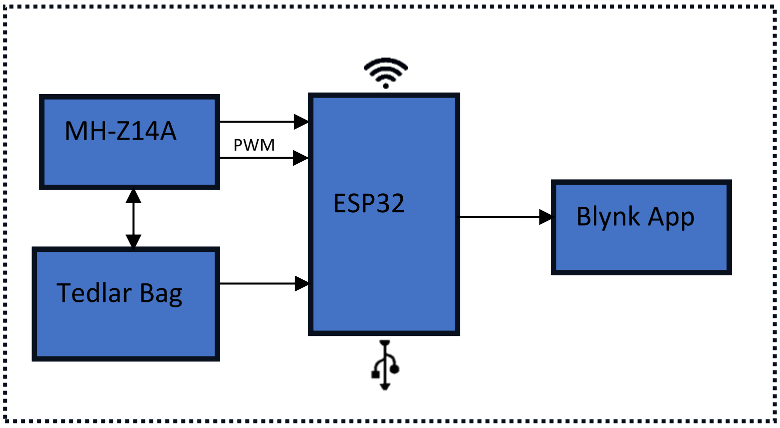


Figure 1: Block diagram for development of exhaled human breath system

Sensor Unit MH-Z14A is the collected breath is analysed using the MH-Z14A CO_2 gas sensor uses non-dispersive infrared (NDIR) technology, a commercially available sensor capable of detecting carbon dioxide concentrations. The sensor provides two types of output are analogue signal and pulse-width modulation (PWM) signal. The analogue signal is a continuous voltage that represents the measured CO_2 concentration and the PWM signal is a digital representation of the CO_2 concentration, expressed as a duty cycle. The physical display of the MH-Z14A gas sensor is shown in Figure 2.

Figure 2: MH-Z14A non-dispersive infrared gas sensor

Breath Sample Collection is exhaled breath samples collected in a Tedlar Bag. The tedlar bag is a specialized container designed to collect and preserve gas samples. The primary objective is to guarantee the preservation of the collected gases in an uncontaminated state to ensure precise measurements. The bag contains vital elements: the inlet valve for introducing gas samples acquired, for example, through human exhalation, and the outlet valve for regulated gas release or connection to an analytical device for analysis afterwards. This study employs a tedlar bag to collect exhaled air from individuals, allowing for differentiation between non-smokers and smokers. The collected samples are then subjected to analysis. The concept of tedlar bag is shown in Figure 3.

Figure 3: Tedlar bag

Microcontroller ESP32 serves as the central processing unit for the system. It receives the sensor outputs in analogue and PWM, processes the data, and transmits it to external platforms. The ESP32 is programmed via USB using the Arduino IDE to execute the required signal processing and communication tasks. The physical component of the ESP32 as shown in Figure 4.

Figure 4: ESP32 microcontroller

Blynk Platform is the data visualization and cloud integration using the processed data transmitted to the Blynk Cloud via a wireless connection. Real-time visualization of sensor readings is achieved through the Blynk App, providing an intuitive interface for monitoring and analysis. The system's integration with the cloud enables remote access and further data processing. Blynk was used to create a custom user interface that displayed real-time output voltage and CO2 concentration graphs. Blynk's seamless integration and advanced data management improved the breath analysis system's operating efficiency and efficacy, demonstrating its IoT applicability.

This architecture ensures accurate collection, processing, and visualization of breath data, enabling applications in real-time monitoring and diagnostic studies. The use of the MH-Z14A sensor and ESP32 microcontroller allows for a flexible and efficient design suitable for an IoT-based exhaled human breath monitoring system.

Development and Testing of an IoT-Enabled Breath Sensor Prototype

A prototype of an IoT-enabled breath sensor was developed to evaluate its functionality in monitoring exhaled carbon dioxide. The system integrates an ESP32 microcontroller, the MH-Z14A carbon dioxide sensor, and a modified food-grade container designed to store gas samples. A hose tube was implemented to regulate the flow of carbon dioxide from a custom

Tedlar bag into the gas-sealed container. Initial tests revealed design limitations, prompting iterative optimizations to enhance the efficiency and accuracy of gas collection.

The prototype, depicted in Figure 5, facilitates remote respiratory monitoring by leveraging IoT connectivity. The integration of the ESP32 microcontroller and MH-Z14A sensor enables real-time data acquisition, forming the basis for potential applications in health diagnostics and personalized wellness monitoring.

Figure 5: Prototype of the IoT-enabled breath sensor system

The decision to construct the Tedlar bag independently was motivated by the need for a cost-effective alternative to commercial options. A resealable storage bag (dimensions: 14 cm x 20 cm) equipped with two valves was developed to enable controlled airflow. Despite initial challenges in achieving an airtight seal, iterative testing and design modifications improved its reliability. The final design, shown in Figure 6, enables accurate and consistent breath sample collection. Exhaled breath is directed into the bag via an inlet valve, and the collected sample is subsequently transferred to the gas-sealed container for analysis. The DIY Tedlar bag represents an innovative, practical, and economical solution for human breath sampling.

Figure 6: DIY Tedlar bag for breath sample collection

To ensure accurate data collection, a systematic preheating process was employed to calibrate the sensor by removing residual carbon dioxide. This step optimizes the sensor's performance and ensures precise measurements when analysing breath samples using the controlled setup. The prototype, connected to the Tedlar bag as depicted in **Figure 7a**, facilitates a seamless gas collection process, while the controlled gas flow mechanism illustrated in **Figure 7b** maintains sample integrity and ensures reliable data acquisition. These steps are critical for achieving consistent and reproducible results in breath composition analysis.

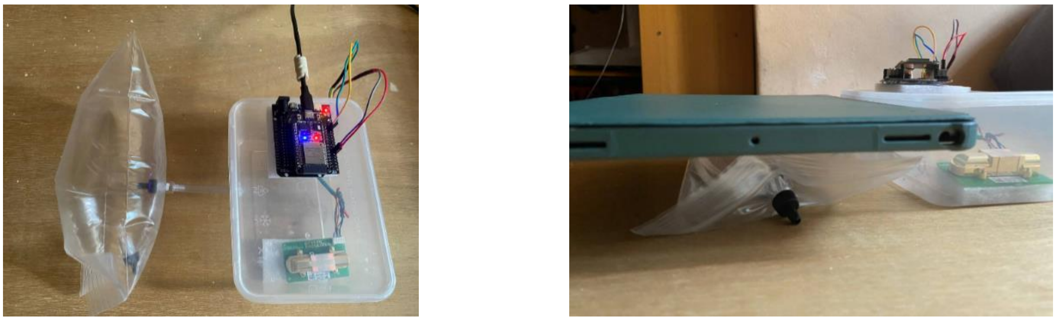

(a) (b)

Figure 7: Data Analysis Techniques and Sampling Process: (a) Prototype connected with the Tedlar bag for gas collection. (b) Controlled gas flow mechanism during sampling.

Data Analysis Process

The data analysis process involved the systematic transmission of sensor data to the **Blynk Cloud**, ensuring the integrity of the dataset for subsequent analysis. Once stored in the cloud, the data was exported as a **CSV file** and imported into **OriginPro** software for detailed examination. OriginPro was selected for its advanced analytical tools, which facilitated the generation of precise graphical representations.

To evaluate the temporal dynamics of breath composition, the **response time** and **recovery time** of the sensor were assessed. OriginPro’s built-in gadgets for response and recovery time analysis were applied to the output voltage graph, enabling a refined examination of these temporal features. The **response time** refers to the period required for the sensor to detect a change in carbon dioxide concentration, while the **recovery time** denotes the duration for the sensor to return to its baseline state.

Each breath sample was analysed individually to quantify the response and recovery times, ensuring accuracy and reproducibility. On the output voltage graph, the **yellow-shaded region** represents the response time, while the **blue-shaded region** corresponds to the recovery time. These visual markers provided a clear and intuitive understanding of the sensor's performance under varying breath sample conditions. An illustration of the response and recovery time analysis is presented in **Figure 8**.

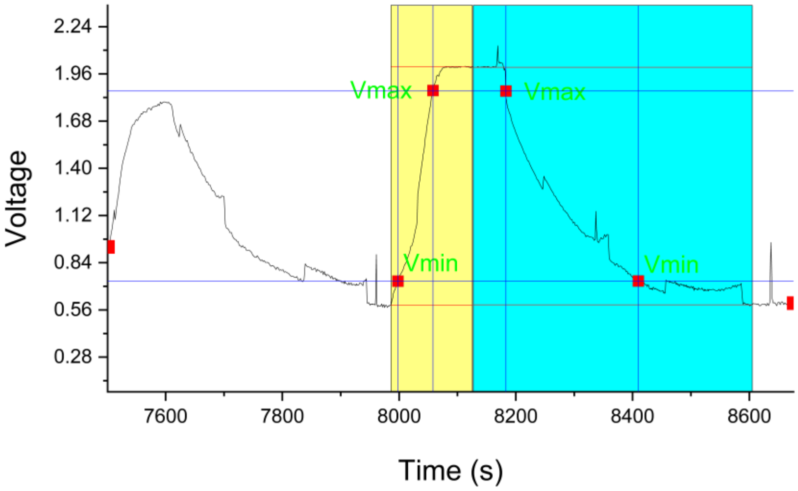


Figure 8: Analysis of response and recovery times based on the output voltage graph.

Finding and Discussion

Data Collection of Exhaled Smoker and Non-Smoker Samples

The data collection process focused on obtaining exhaled breath samples from individuals classified as either **smokers** or **non-smokers**. Each participant was assigned a unique identifier to ensure accurate tagging and classification of the collected data. This distinction allowed for a comparative analysis of the differences in carbon dioxide levels and sensor response characteristics between the two groups.

Breath samples were collected using a **DIY Tedlar bag**, which ensured precise and reliable sample capture. Participants exhaled directly into the bag through an inlet valve, and the collected samples were then transferred to the prototype system for analysis. The **MH-Z14A carbon dioxide sensor** interfaced with the **ESP32 microcontroller** measured the carbon dioxide concentration of each sample, and the resulting data was transmitted to the **Blynk Cloud.**

The dataset included a total of 12 samples, comprising both smokers (n=5) and non-smokers (n=7). The **CSV file** exported from the Blynk Cloud was imported into **OriginPro** software for advanced visualization and analysis. Graphs of **output voltage versus time** were generated for each sample, enabling the identification of the sensor's response and recovery times. These temporal features are critical for understanding the dynamic behaviour of exhaled carbon dioxide across different participant groups.

Table 1 outlines the classification of the samples, while **Figure 9** provides a visual representation of the output voltage variations over time for all collected samples. The distinction between smokers and non-smokers is evident in the sensor's response and recovery patterns, highlighting the potential application of the system in health diagnostics and respiratory monitoring.

Table 1
Classification of Breath Samples

Sample	Behaviour
1	Non-smoker (NS1)
2	Non-smoker (NS2)
3	Non-smoker (NS3)
4	Non-smoker (NS4)
5	Smoker (S1)
6	Smoker (S2)
7	Smoker (S3)
8	Smoker (S4)
9	Smoker (S5)
10	Non-smoker (NS5)
11	Non-smoker (NS6)
12	Non-smoker (NS7)

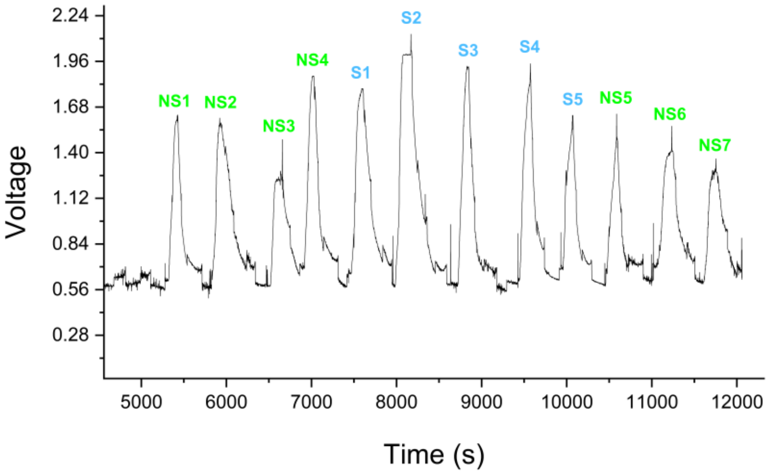


Figure 9: Graph of output voltage versus time for all exhaled breath samples, illustrating response and recovery times for smokers and non-smokers.

Response Time and Recovery Time

Figure 10 illustrates the comparison of response and recovery times for each gas sample, providing insights into the sensor’s dynamic performance across smoker and non-smoker groups.

The extended response times observed in smokers, as depicted in Figure 10(a), reflect a delayed reaction of the gas sensor to changes in carbon dioxide concentrations. This delay aligns with standard gas sensor behaviour, where stabilization requires additional time at higher gas levels. These findings emphasize the critical importance of rise time in gas sensors, particularly in applications such as breath analysers, which depend on the rapid detection of concentration changes.

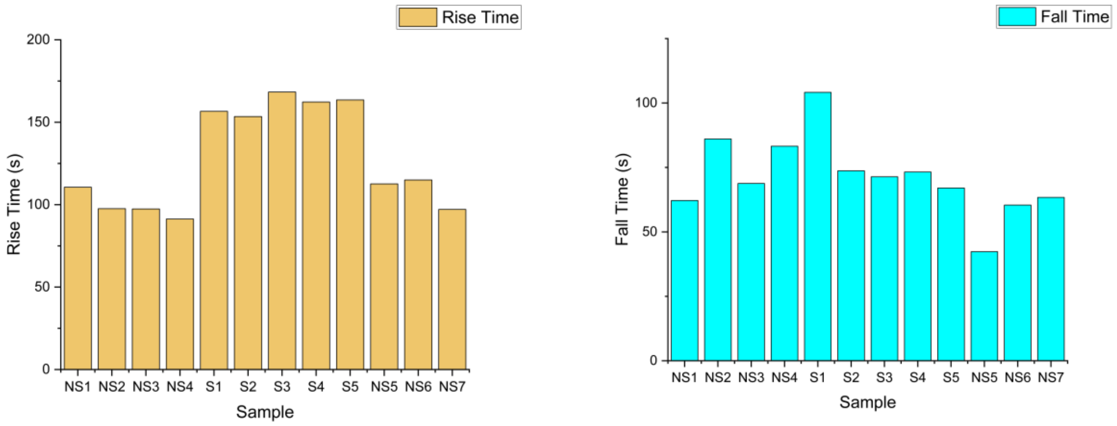
The prolonged response time in smokers could be linked to gases associated with smoking-related respiratory conditions, such as chronic obstructive pulmonary disease (COPD) (Laniado-Laborin, 2009). While these data do not establish a definitive diagnosis, the correlation between response times and potential respiratory issues enhances our understanding of the sensor's sensitivity to different breath compositions. This distinction between smoker and non-smoker breath samples highlights the utility of the prototype for identifying biomarkers related to respiratory health.

As shown in Figure 10(b), the recovery times for non-smokers consistently remain below 100 seconds, indicating a quicker return of the sensor to baseline conditions. Conversely, smokers exhibit a broader range of recovery times, with some samples demonstrating significantly prolonged durations. For example, Sample S1 displays an outlier with an exceptionally large recovery time, potentially indicative of data variability or an underlying abnormality. Additionally, variations in Sample S3 compared to other smoker samples suggest possible individual differences in exhaled gas composition.

The recovery time of gas samples is a critical parameter for assessing respiratory health. Longer recovery times in smokers may reflect delayed sensor reset due to elevated carbon dioxide levels, a condition often linked to smoking-induced respiratory complications such as COPD (Azuma et al., 2018). These findings further validate the role of recovery time in identifying respiratory issues, particularly for individuals with prolonged exhalation characteristics.

High carbon dioxide levels in exhaled breath are associated with various respiratory disorders, including COPD and irregular breathing patterns (Loeb *et al.*, 2024). Prolonged recovery times may signify higher concentrations of exhaled carbon dioxide, emphasizing the importance of precise monitoring to detect early respiratory anomalies. Additionally, excessive carbon dioxide levels can lead to increased blood acidity, a condition with potentially severe consequences. Monitoring carbon dioxide in exhaled air can aid in early diagnosis, personalized health evaluations, and proactive respiratory health management.

Finally, the ability to accurately measure response and recovery times provides valuable diagnostic information. For instance, high exhaled carbon dioxide concentrations and slow recovery times may indicate impaired respiratory function or delayed metabolic gas exchange. Since elevated carbon dioxide levels are known to increase respiratory rate, reduced sensor responsiveness or prolonged recovery may signal abnormal respiratory dynamics, necessitating further medical evaluation (Hernandez-Miranda & Birchmeier, 2015).



(a) (b)

Figure 10: Bar graph of each gas sample: (a) Response time (Rise time) and (b) Recovery time (Fall time)

Sensor Sensitivity

To evaluate the sensor's performance, sensitivity testing was conducted to assess its ability to distinguish variations in gas concentrations. Sensitivity is a crucial parameter for determining the sensor’s dynamic range and efficacy across different breath samples. The sensitivity calculation is based on a predefined formula expressed in Equation (1):

$$S = \frac{Vmax - Vmin\ (Recovery\ time)}{Vmax - Vmin\ (Response\ time)} \qquad (1)$$

Where:

- Vmax represents the peak output voltage during recovery.
- Vmin (Recovery time) denotes the lowest output voltage during the recovery phase.
- Vmin (Response time) signifies the lowest output voltage during the response phase.

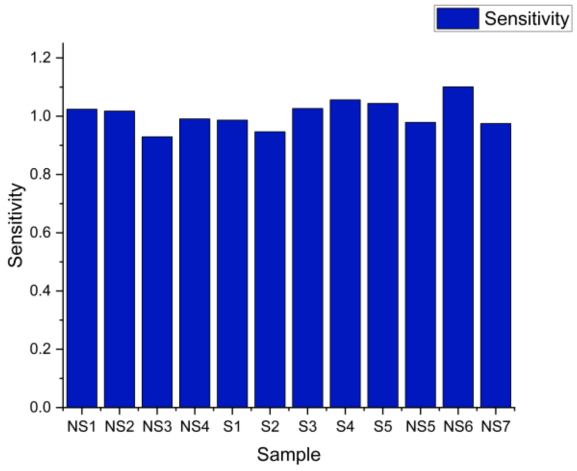


Figure 11: Visualizes the sensitivity comparison between non-smoker and smoker samples.

Enhanced sensitivity allows gas sensors to detect even minute variations in gas concentrations, which is critical for applications such as breath analysis (Lo Dayekh et al., 2022). Highly sensitive sensors can capture subtle fluctuations that less sensitive counterparts may overlook, ensuring more accurate and reliable measurements. In contrast, sensors with lower sensitivity may fail to detect minor changes, potentially leading to false readings or missed insights (D. Y. Nadargi *et al.*, 2023). This makes sensitivity a vital characteristic for ensuring accurate gas concentration monitoring.

Real-Time Monitoring via Blynk App

The **Blynk App** serves as an intuitive and real-time gas sampling platform, enabling comprehensive visualization and analysis of breath sample dynamics. The app utilizes analogue and PWM outputs from the sensor to compute carbon dioxide concentration, output voltage, and timestamps in real time, as shown in **Figure 12**.

Through customizable widgets, the Blynk App provides immediate visual feedback on gas sample analysis. By graphically displaying key parameters, such as breath composition and gas trends, the app enhances the accessibility and interpretation of data. Real-time monitoring enables rapid detection of abnormalities and behavioural trends, significantly improving the diagnostic potential of the breath analysis process. This functionality underscores the role of IoT technology in facilitating continuous and non-invasive health monitoring.

CO2 Concentration, Av (ppm): 611 ppm
CO2 Concentratio, PWM (p: 675 ppm
Output voltage (v): 0.67
Time (s): 5,438 s
Calibration: OFF

Figure 12: Blynk app widget interface

Conclusion and Future Work

This study successfully developed a non-invasive CO_2 breath sensor integrated with IoT technology, highlighting several key findings. The sensor demonstrated reliable performance in measuring response and recovery times and sensitivity across smoker and non-smoker samples. Prolonged response and recovery times observed in smoker samples indicated the sensor's potential to detect elevated CO_2 levels associated with smoking-related respiratory conditions. Integration with the Blynk IoT platform enabled real-time monitoring and analysis, enhancing its application in health diagnostics.

These findings underscore the potential of the IoT-enabled breath sensor for early detection of respiratory anomalies and personalized health monitoring. Future work should focus on enhancing sensor selectivity for additional biomarkers, improving accuracy under variable environmental conditions, and conducting extensive clinical validations to strengthen its diagnostic reliability.

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References

WHO EMRO | Chronic obstructive pulmonary disease (COPD) | Health topics. Accessed: Jan. 10, 2024. [Online]. Available: https://www.emro.who.int/health-topics/chronic-obstructive-pulmonary-disease-copd/index.html

Hashoul, D., & Haick, H. (2019). Sensors for detecting pulmonary diseases from exhaled breath. European Respiratory Review, vol. 28, no. 152. https://doi.10.1183/16000617.0011

Saidi, T., Zaim, O., Moufid, M., El Bari, N., Ionescu, R., & Bouchikhi, B. (2018). Exhaled breath analysis using electronic nose and gas chromatography–mass spectrometry for non-invasive diagnosis of chronic kidney disease, diabetes mellitus and healthy subjects. Sens Actuators B Chem, vol. 257, pp. 178–188. https://doi.10.1016/J.SNB.2017.10.178

Lutz, É. & Coradi, P.C. (2022). Applications of new technologies for monitoring and predicting grains quality stored: Sensors, Internet of Things, and Artificial Intelligence. Measurement, vol. 188, p. 110609. https://doi. 10.1016/J.MEASUREMENT.2021.110609

Smith, J. & Jones, A. (2021). Breath analysis using commercial sensors: Benefits in terms of cost-effectiveness and usability, but potential drawbacks in sensitivity, selectivity, stability, and reproducibility. vol. 10, no. 3, pp. 123–145

Amal, H. & Haick, H. (2020). Point of care breath analysis systems. Advanced Nanomaterials for Inexpensive Gas Microsensors: Synthesis, Integration and Applications, pp. 315–334. https://doi.10.1016/B978-0-12-814827-3.00014-1

Ramanathan, S., Malarvili, M. B. & Gopinath, S. C. B. (2023). Assessing respiratory complications by carbon dioxide sensing platforms: Advancements in infrared radiation technology and IoT integration. Arabian Journal of Chemistry, vol. 16, no. 2, p. 104478, Feb. https://doi.10.1016/J.ARABJC.2022.104478

Hong, C. S., Ghani, A. S. A. & Khairuddin, I. M. (2018). Development of an Electronic Kit for detecting asthma in Human Respiratory System. IOP Conf Ser Mater Sci Eng, vol. 319, no. 1, p. 012040. https://doi.10.1088/1757-899X/319/1/012040

Fuadi, R. M., Yulianto, E., Irianto, B. G. & Mishra, A. (2023). Design of Carbon Dioxide Levels Measurement in Human Expiration Using EtCO2 Capnography Method. Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics, vol. 5, no. 1. https://doi.10.35882/IJEEEMI.V5I1.266

Kaloumenou, M., Skotadis, E., Lagopati, N., Efstathopoulos, E. & Tsoukalas, D. (2022). Breath Analysis: A Promising Tool for Disease Diagnosis—The Role of Sensors. Sensors (Basel), vol. 22, no. 3. https://doi.10.3390/S22031238

Salama, R., Al-Turjman, F., Chaudhary, P. & Yadav, S. P. (2023). Benefits of Internet of Things (IoT) Applications in Health care - An Overview. 2023 International Conference on Computational Intelligence, Communication Technology and Networking, CICTN 2023, pp. 778–784. https://doi.10.1109/CICTN57981.2023.10141452

Laniado-Laborin, R. (2009). Smoking and Chronic Obstructive Pulmonary Disease (COPD). Parallel Epidemics of the 21st Century. Int J Environ Res Public Health, vol. 6, no. 1, p. 209. https://doi. 10.3390/IJERPH6010209

Azuma, K., Kagi, N., Yanagi, U. & Osawa, H. (2018). Effects of low-level inhalation exposure to carbon dioxide in indoor environments: A short review on human health and psychomotor performance. Environ Int, vol. 121, no. Pt 1, pp. 51–56. https://doi.10.1016/J.ENVINT.2018.08.059

Loeb, E. (2024). Association between occupational exposure and chronic obstructive pulmonary disease and respiratory symptoms in the Spanish population. Arch Bronconeumol, vol. 60, no. 1, pp. 16–22. https://doi.10.1016/J.ARBRES.2023.10.014

Hernandez-Miranda, L. R. & Birchmeier, C. (2015). CO2 in the spotlight. Elife, vol. 4. https://doi.10.7554/ELIFE.08086

Dayekh, M. Lo., Hussain, S. A., & Hussain, S. A. (2022). Gas Sensor and Sensitivity. Metal-Oxide Gas Sensors. https://doi.10.5772/INTECHOPEN.108040

Nadargi, D. Y. (2023). Gas sensors and factors influencing sensing mechanism with a special focus on MOS sensors. Journal of Materials Science 2022 58:2, vol. 58, no. 2, pp. 559–582. https://doi.10.1007/S10853-022-08072-0