DEVELOPMENT OF EXHALED HUMAN BREATH SENSOR USING IOT

MUHAMMAD ARFAN BIN KHAIROL ANNUAR

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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MUHAMMAD ARFAN BIN KHAIROL ANNUAR

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Technology and Engineering
Universiti Teknikal Malaysia Melaka

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJUTERAAN ELEKTRONIK DAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : DEVELOPMENT OF EXHALED HUMAN BREATH SENSOR USING IOT

Sesi Pengajian : 2023/2024

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SITI AISAH BINTI MAT JUNOS @ YUNUS
Pensyarah
Fakulti Teknologi Dan Kejuruteraan Elektronik Dan Komputer (FTKEK)
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SITI AISAH BINTI MAT JUNOS @ YUNUS
Pensyarah
Fakulti Teknologi Dan Kejuruteraan Elektronik Dan Komputer (FTKEK)
Universiti Teknikal Malaysia Melaka (UTeM)

Supervisor Name : ....

Date : 23/01/2024

DEDICATION

This project is dedicated to my parents, who have been a constant source of encouragement and support throughout my educational journey. The completion of this undertaking has been propelled by their constant support and guidance. In addition, I would like to thank my supervisor and panel for their guidance and assistance throughout the duration of this project. Their expertise and knowledge have been indispensable in ensuring this project's success.

ABSTRACT

Breath analysis has the potential to diagnose respiratory diseases and monitor various health conditions in a non-invasive, rapid, and cost-effective manner. Non-invasive methods for breath analysis have lower sensitivity and specificity compared to invasive methods due to the absence of standardized protocols. Invasive methods are more accurate but come with increased discomfort and risk. Non-invasive breath collection and analysis are necessary to enhance the precision and dependability of breath-based commercial sensors. This project involves creating a breath sensor using a commercially available sensor. The MH-Z14A was utilized as a commercial sensor for detecting CO2 levels. Breath samples were collected using a tedlar bag. The sample will consist of individuals non-smoking and smoking behaviors. The sensor will detect samples and connect them to the ESP32 to obtain an output voltage representing the CO2 concentration. The breath analysis will be measured in terms of response time, recovery time, and sensitivity. The data analysis will be integrated with the IoT platform for further processing and utilization.

ABSTRAK

Analisis nafas mempunyai potensi untuk mendiagnosis penyakit pernafasan dan memantau pelbagai keadaan kesihatan dengan cara yang tidak invasif, cepat dan kos efektif. Kaedah bukan invasif untuk analisis nafas mempunyai sensitiviti dan kekhususan yang lebih rendah berbanding kaedah invasif kerana ketiadaan protokol piawai. Kaedah invasif adalah lebih tepat tetapi datang dengan peningkatan ketidakselesaan dan risiko. Pengumpulan dan analisis nafas bukan invasif adalah perlu untuk meningkatkan ketepatan dan kebolehpercayaan penderia komersial berasaskan nafas. Projek ini melibatkan penciptaan penderia nafas menggunakan penderia yang tersedia secara komersial. MH-Z14A telah digunakan sebagai sensor komersial untuk mengesan tahap CO2. Sampel nafas dikumpul menggunakan beg Tedlar. Sampel akan terdiri daripada individu yang tidak merokok dan tingkah laku merokok. Sensor akan mengesan sampel dan menyambungkannya ke ESP32 untuk mendapatkan voltan keluaran yang mewakili kepekatan CO2. Analisis nafas akan diukur dari segi masa tindak balas, masa pemulihan, dan kepekaan. Analisis data akan disepadukan dengan platform IoT untuk pemprosesan dan penggunaan selanjutnya

ACKNOWLEDGEMENTS

I owe a great debt of appreciation to Allah S.W.T., who provided me with the inspiration and energy to write my thesis. The author's efforts alone will not be enough to finish a project of this scale. I would want to thank everyone who participated in the survey and provided feedback and assistance for this final project/dissertation.

My supervisor has been an invaluable source of advice and inspiration throughout the process of writing this dissertation, and I would want to begin by formally recognising and thanking him. I would like to extend my gratitude to him for his intelligent supervision, constant support, constructive comments, and innovative ideas throughout the research process. I would also like to thank everyone who participated in interviews (both formal and informal) and shared their insights and experiences with me.

Last but not least, I would like to express my gratitude to my loving parents and extended family, without whom I never would have had the motivation to finish my dissertation. I appreciate the patience you showed me when I was struggling.

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LIST OF SYMBOLS AND ABBREVIATIONS

CO2	:	Carbon Dioxide
O2	:	Oxygen
IoT	:	Internet of Things
VOC	:	Volatile Organic Compound
eNose	:	Electronic Nose
PPM	:	Parts Per Million
IDE	:	Integrated Development Environment
UART	:	Universal Asynchronous Receiver Transmitter
PWM	:	Pulse Width Modulation
COPD	:	Chronic Obstructive Pulmonary Disease
UI	:	User Interface
API	:	Application Programming Interface
SPI	:	Serial Peripheral Interface
ADC	:	Analog Digital Converter

CHAPTER 1

INTRODUCTION

1.1 Project Background

Breath analysis has emerged as a promising approach for diagnosing respiratory diseases and monitoring various health conditions. It offers a non-invasive, rapid, and cost-effective method compared to traditional invasive techniques. By analysing the composition of exhaled human breath, valuable information about the presence of specific biomarkers and the overall health status of an individual can be obtained. However, the lack of standardized protocols and the limited accuracy and reliability of non-invasive breath-based commercial sensors have hindered their widespread adoption.

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 [1] . Late diagnosis of respiratory diseases often leads to high death rates, as symptoms become apparent only when patients seek medical attention. Healthcare facilities require costly resources, including equipment and healthcare professionals, to diagnose these conditions, making regular preventive check-ups unlikely for the entire population. To address this challenge, the development of affordable and non-invasive early prediction solutions and developed improved respiratory disease prediction analytics.

The utilization of Internet of Things (IoT) in the development of medical applications has introduced the capability to analyse patterns and predict diseases without the need for healthcare professionals. Various integration approaches of IoT have been applied in predicting respiratory diseases, such as computed tomography analysis, forced oscillation tests, and exhaled breath analysis [2]. Notably, recent advancements in chemical-based sensor technologies have made it possible to create cost-affective non-invasive embedded systems commonly known as e-noses [3]. These e-noses can detect volatile organic compounds (VOCs) present in collected breath profiles. The IoT enables flexible and schedules transmission and processing of data from sensor and wearable devices through cloud computing, facilitating faster access for healthcare professionals [4].

1.2 Problem Statement

Given the high costs associated with the gas detector market, utilizing commercial sensors for the development of an exhaled human breath sensor would be a cost-effective approach to prevent excessive expenses. Commercial sensors have benefits in terms of cost-effectiveness and usability but may have drawbacks in terms of sensitivity, selectivity, stability, and reproducibility when used for breath analysis [5]. Addressing that, the main of this project is to optimize the use of commercial sensors in breath analysis, including sensor performance, data analysis, and validation protocols, to realize their full potential as non-invasive diagnostic tools using self-made tedlar bag for collecting sample.

1.3 Objectives

There are several objectives for this project which are:

1. To develop exhaled human breath sensor using the commercial sensor.
2. To analyse human breath analysis in terms of response time, recovery time, and sensitivity.
3. To integrate the human breath sensor with IoT application.

1.4 Scope of the Project

The aim of this project is to develop an exhaled human breath sensor using the MH-Z14A commercial sensor. The scope of work includes constructing a self-made tedlar bag using a resealable bag and valve, developing the prototype human breath sensor, and collecting 12 breath samples from different smoking behaviors. The sensor will be connected to an ESP32 microcontroller to measure the output voltage indicating the CO2 concentration. The project will involve analysing the sensor's parameters and integrating the human breath sensor with an IoT application. This project will focus more on analyse the data get it from the commercial sensor that will used in this project.

1.5 Outline of the Report

This report provides the introduction, problem statement, objectives of the project in Chapter 1, followed by the literature review of research papers of the similar topic in Chapter 2. Chapter 3 describes the methodology applied in the implementation of exhaled human breath sensor using IoT while Chapter 4 is about analysis or results obtained. Finally, Chapter 5 illustrates the conclusion of the overall project and recommendations for future work.

CHAPTER 2

BACKGROUND STUDY

This chapter will discuss sources or articles that are related to the project. There are many sources or researchers done before and from there details about this project are known and can understand briefly about the project. In this chapter, the theoretical background, literature reviews of previous work, and the summaries about the previous work will be covered.

2.1 Gas Sensors

Gas sensors detect specific gas-phase substances and their levels [6]. There has been a rising interest in developing high-performance, cost-effective, and durable gas sensors due to the increasing need for monitoring air quality and gas leaks. The global market size of gas sensors was valued at 1.16 billion USD in 2020 and is projected to reach 1.86 billion USD by 2026 [7]. By integrating gas sensors into the

Internet of Things, they are expected to play a significant role in smart cities and intelligent building markets as per market demands [7].

Furthermore, there is potential for growth through incorporating gas sensors into wearable devices such as smartwatches for personalised health tracking [8]. Additionally, susceptible hydrogen gas sensors have significant implications across various stages within hydrogen-based fuel cell technologies used in green energy transportation while also essential from a safety standpoint during production, storage, delivery, and daily use of hydrogen [9].

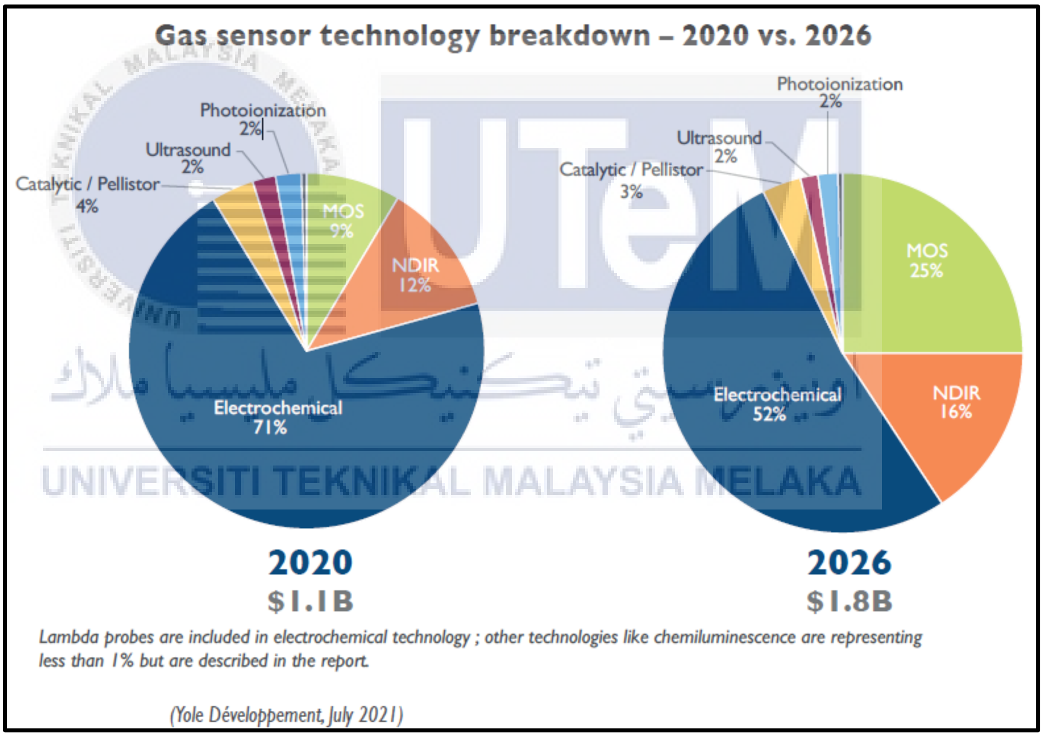


Figure 2.1: Market size and share of the gas sensor market by type of technology [7].

Based on the distribution of market share across technology types in Figure 2.1, four primary categories of commercialised gas sensors exist: electrochemical, optical, conductometric, and calorimetric. These are categorised based on varying operational principles, with specific descriptions detailing their working methods and device structures.

2.1.1 Optical gas sensors

Optical sensor devices transform changes in optical conditions resulting from the concentration of target compounds [10]. The non-dispersive infrared gas sensor is widely utilised as an optical gas sensor. Figure 2.2 illustrates the typical configuration of an NDIR gas sensor, consisting of an infrared source, a gas chamber for light interaction with the gas, a specialised optical filter to select the target gas's characteristic wavelength range, and a photodetector for sensing purposes.

Due to the distinct properties of infrared absorption for each gas, NDIR gas sensors demonstrate high selectivity and specificity. As a result, the sensors are quite expensive because of the high cost associated with the laser source and the infrared detector. In addition, the sensors are challenging to condense into portable gadgets, leading to a significant decrease in their widespread potential for use.

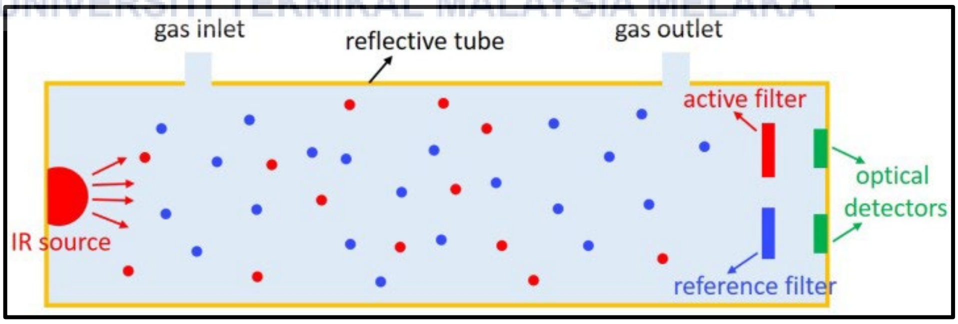


Figure 2.2: The structure of optical gas sensors [11].

2.1.2 Working principle of optical gas sensors

Optical gas sensors, such as non-dispersive infrared sensors, detect and quantify gas levels using the unique optical absorption properties of different gas types. NDIR sensors use infrared radiation to quantify the absorption of gas molecules, enabling the identification and assessment of gas levels in various scenarios. These sensors have attracted considerable interest because of their heightened sensitivity, small size, and possible incorporation with other devices for signal processing and communication on a chip [12].

NDIR gas sensors utilise a U-tube optical path cavity, demonstrating improved thermal response and enhanced sensitivity. This setup effectively converts transmitted light intensity into an analogue voltage, enabling precise measurement of CO2 gas concentration [13]. Additionally, the arrangement and size of the openings in the sensor container are vital for swiftly and precisely measuring gas levels.

Figure 2.3 illustrates two different designs of non-dispersive infrared sensors, which belong to the category of optical sensors, further enhancing our comprehension of this area.

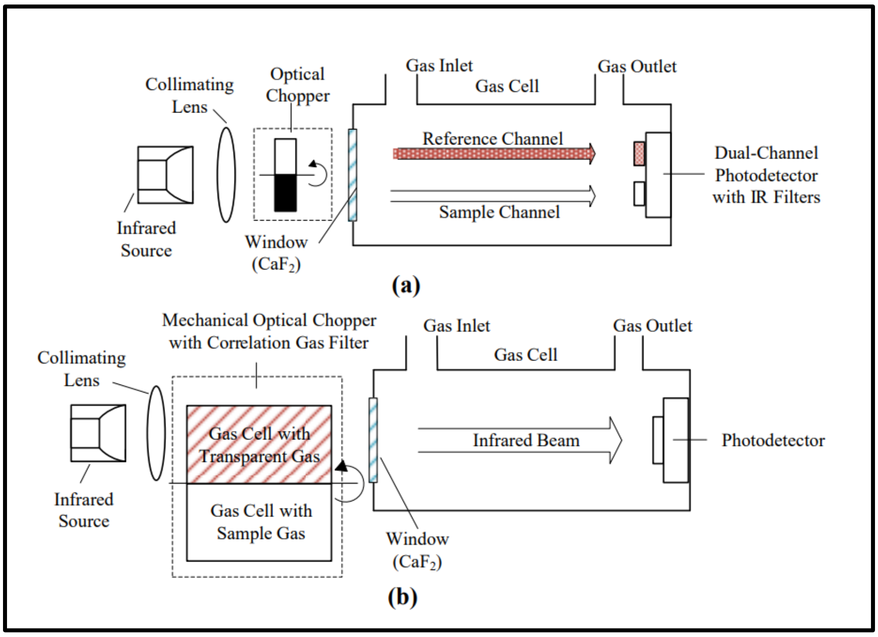


Figure 2.3: Non-dispersive infrared sensor design: (a) structure of a double beam NDIR sensor, modified from [14] and (b) single-beam non-dispersive infrared sensor design utilizing a correlation gas filter method, adapted from [15].

NDIR gas sensors employ a light source that interacts with a gas medium and a detector to quantify gas concentrations. The light sources may include quantum cascade lasers, light-emitting diodes, or thermal emitters, while the detectors can be photodiodes, thermopiles, or pyroelectrics [16].

2.1.3 Response Time, Recovery Time, and Sensitivity in Gas Sensors

Gas sensors rely on parameters such as response time, recovery time, and sensitivity for proper functioning. The sensor's response time is the duration it takes to detect and react to the presence of a gas, whereas the recovery time denotes how long it takes for the sensor to revert to its original state after being exposed to the gas. The sensor's sensitivity refers to its capability to identify and quantify the presence of a gas. Various factors, including the sensor material composition, morphology, and testing conditions, influence these parameters [17].

Gas sensors often utilise metal oxides, polymer nanocomposites, and carbon-based nanomaterials because of their advantageous characteristics like high heat resistance, transparency to light, and wide band gap [18]. Optimising these parameters is essential for advancing effective gas sensors, and different approaches have been utilised to accomplish this, such as manipulating the structure of the sensitive material.

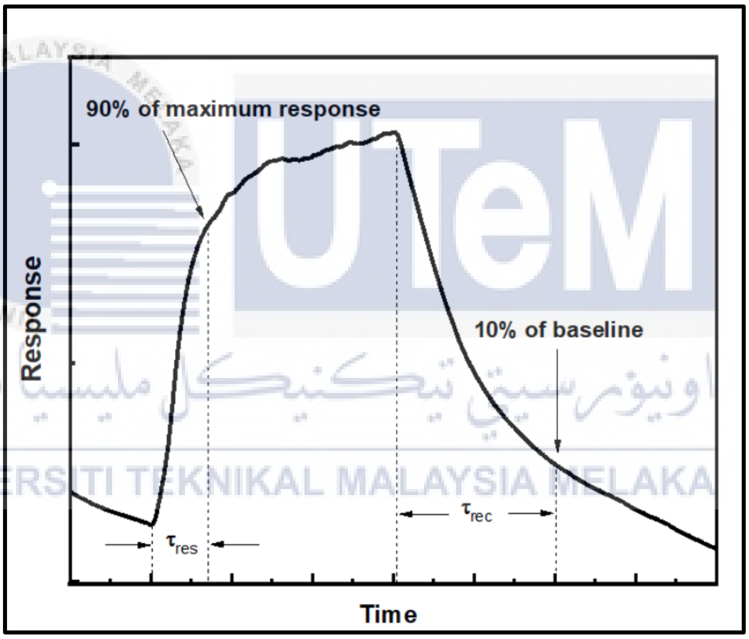


Figure 2.4: The response and recovery times [19].

After introducing the analyte gas, the response time indicates how long the sensor output signal takes to reach 90% of its maximum value, as illustrated in Figure 2.4 (τres). The recovery time is the period for the sensor output signal to reduce to 10% of its original value following the disconnection of the analyte gas. The value is depicted in Figure 2.4 as (τrec).

Gas sensor sensitivity refers to the degree of change in gas sensor resistance when exposed to a specific target gas. The thin film's resistance change rate is defined in the presence or absence of gas [20]. Sensitivity refers to the amount of input change needed to produce a one-unit output change. When the sensor response is linear, sensitivity remains consistent throughout the sensor's range and corresponds to the incline of the straight-line graph (as depicted in Figure 2.5). An optimal sensor will exhibit substantial and consistent sensitivity. Non-linearity in the sensor's response leads to varying sensitivity across the sensor range, necessitating the calculation of the derivative of S with respect to x (dS/Dx) for its determination.

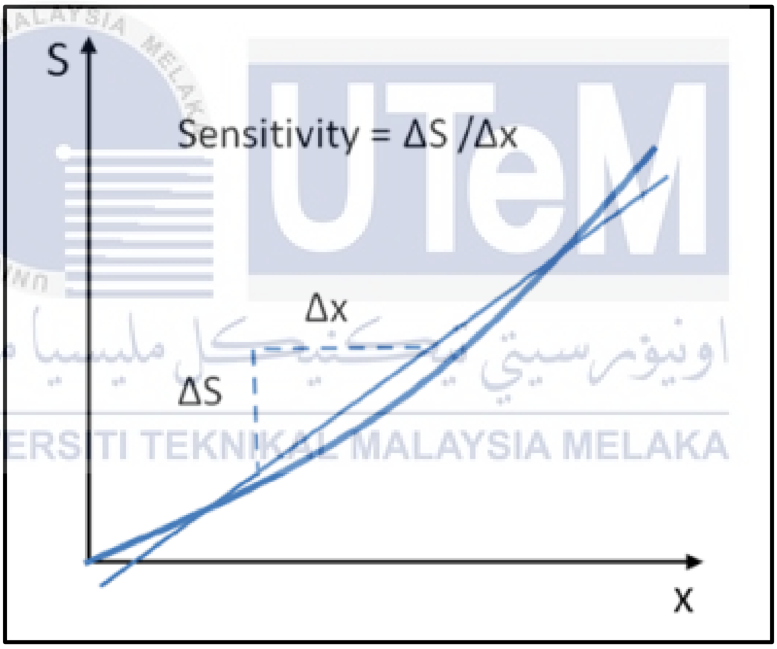


Figure 2.5: Sensitivity of sensor [21].

2.1.4 Application of NDIR gas sensor

NDIR gas sensors are utilized in a variety of applications. These devices can continuously observe the thermal runaway progression of lithium-ion batteries, offering an advance notification system for battery safety [22]. NDIR sensors are also capable of selectively detecting gases with overlapping absorption spectra. This enables the accurate measurement of the concentration of a specific gas by modifying the absorption data acquired in the optic channel containing overlapping gas spectra [23].

Furthermore, NDIR gas sensors have the capability to measure the concentration of CO2 gas in the air, which renders them appropriate for environmental surveillance. NDIR sensors are also employed for the control and monitoring of small-scale wood gasifiers in block heating power plants. Additionally, NDIR CO2 sensors play a critical role in evaluating indoor air quality and overseeing ventilation to minimize the spread of airborne diseases such as COVID-19 [24].

2.2 Breath Analysis in Health Monitoring

Breath analysis presents an appealing approach for non-invasive health monitoring. It consists of identifying metabolites in exhaled breath aerosol samples, offering valuable insights into assessing one's health condition and the effectiveness of treatments [25].

Breath analysis has extensively utilised mass spectrometry-based methods, providing efficient processing and minimal sample preparation. Additionally, advancements in breath analyser systems have allowed for precise measurement and calibration methods, facilitating the assessment of breath gas concentration. This has led to improved optimisation of gas sensor functions and enhanced measurement accuracy [26]. These systems are intended to be inexpensive, user-friendly, and appropriate for health condition surveillance.

2.2.1 The Importance of Breath Analysis

Breath analysis is a significant study area with possible scientific and medical research uses. Detecting volatile organic compounds in exhaled breath can offer valuable insights into health status and treatment effectiveness. Various illnesses have been associated with alterations in breath composition, indicating the potential of using breath analysis for diagnosing diseases [27].

Breath analysis has also been employed to track ketosis in individuals with ketogenic glycogen storage conditions, offering a non-invasive method for forecasting levels of ketones in the bloodstream [28]. Overall, breath analysis could transform the diagnosis of diseases by offering a non-invasive alternative to conventional invasive techniques.

2.2.2 Types of Data Acquired Through Breath Analysis

Analysis of breath samples can offer important information for diagnostic and monitoring objectives. Various techniques and technologies have been employed to examine exhaled breath specimens. Solid phase microextraction-gas chromatography/mass spectrometry (SPME-GC/MS) analysis was utilized to detect volatile organic compounds in exhaled breath samples obtained from healthy individuals, smokers, and e-cigarette users [29].

A metal oxide chemo resistive sensor-based electronic nose (e-nose) was utilized to differentiate between the breath samples of individuals with Diabetes Mellitus, Renal Failure, Liver Cirrhosis, and those in good health. Analytical techniques conducted in a laboratory setting, such as gas chromatography-mass spectrometry and point-of-care real-time analysis utilizing proton transfer reaction-mass spectrometry, have been employed to assess exhaled breath samples within the intensive care unit for monitoring objectives. Sensors can collect information about a person's breath and examine it to detect volatile organic compound biomarkers for diagnosing different conditions [30].

2.3 IoT Applications in Health Monitoring

The Internet of Things allows healthcare providers to track their patients remotely, enhancing the delivery of healthcare and patient results. The Blynk IoT platform is commonly used alongside these health monitoring systems to offer an easy-to-use interface for visualising and managing data.

2.3.1 Introduction to IoT in Health Monitoring

Implementing the Internet of Things in healthcare has resulted in sophisticated health surveillance mechanisms. IoT technologies facilitate the gathering and examination of information from intelligent devices and sensors, enabling ongoing surveillance of health measurements. Doctors and healthcare professionals can utilise this information to remotely track patients' well-being and offer individualised medical records [31]. The Internet of Things also allows for the automated gathering and examination of data, which results in enhanced effectiveness within healthcare operations. Portable healthcare monitoring systems utilise IoT technology to monitor patients' physiological indicators in real-time and automatically maintain databases.

Furthermore, IoT sensors can supply up-to-the-minute environmental data for observing crop well-being and surroundings [32]. The Internet of Everything builds upon IoT by linking and optimising all accessible resources, such as people, data, and technology, across various sectors like transportation, healthcare, agriculture, energy, and manufacturing. IoT technologies enhance health monitoring systems through remote surveillance, automation, and effective data gathering and analysis.

2.3.2 Data Collection and Analytics

Using Internet of Things technology enhances the efficiency of data collection from various health devices. The Internet of Things facilitates the collection of information from health-related equipment like sensors and actuators, enabling the observation of different health metrics. The collected health data can be analysed to provide insights. Improving healthcare outcomes requires understanding data trends, patterns, and connections. Health parameters that can be tracked using IoT devices encompass vital signs such as heart rate, blood pressure, body temperature, activity levels, and sleeping patterns.

2.4 Related Work

2.4.1 Existing Exhaled Breath Sensor Technologies

Ying Li et al. carried out research that focused on analysing the concentration and composition of specific gases present in exhaled breath. They employed a variety of advanced sensors, such as Metal-oxide-semiconductor sensors, Surface acoustic wave sensors, Optical sensors, and Colorimetric sensors. Their approach involved utilizing gas sensor arrays for gathering data on the gases. In particular, they assessed exhaled Nitric Oxide levels in both healthy individuals and patients with lung cancer. The main gases under investigation were Nitrogen dioxide and ozone (O3), offering important insights into respiratory health and possible indicators of disease [33].

Rifky Maulana Fuadi et al. conducted a significant study focusing on the analysis of CO2 levels in human exhalation. They utilised the Cozir-WX-20 CO2 gas sensor to measure ppm CO2 concentration and evaluate sensor response time. Their approach involved two methods, known as main-stream and side-stream, providing a comprehensive strategy for CO2 analysis. The researchers performed experiments using CO2 gas from cylinders and medical air gas, specifically concentrating on carbon dioxide as their primary area of interest. This research contributes to understanding the dynamics of CO2 in human respiration and has implications for health monitoring and environmental studies [34].

Santheraleka Ramanathan et al. conducted a study on CO2 levels in exhaled breath, focusing on changes in electrical resistance, sensor sensitivity, and selectivity. They utilised various types of sensors, such as infrared CO2 gas sensors, non-dispersive infrared sensors, and metal oxide-based sensors. A distinctive aspect of their approach was the use of tunable diode laser technology for accurate CO2 measurement, setting their research apart in terms of precision and exactness. The sample analysed was carbon dioxide in exhaled breath, which holds significance for medical diagnostics and environmental monitoring purposes [35].

C. Sricharoen et al. introduced a new method that focuses on the exhalation flow rate, respiratory exchange ratio, oxygen (O2) levels, and carbon dioxide concentrations in the breath. They designed a portable breath analysis device using an electrochemical O2 sensor and a photoacoustic CO2 sensor. The study included examining participants' breaths before and after consuming a high-carbohydrate breakfast and after different durations of exercise. This research has significant implications for sports science, nutrition, and respiratory therapy [36].

A study by Cheow Shek Hong et al. made a significant contribution to the field by focusing on carbon dioxide levels in exhaled air. They developed an electronic prototype utilizing the MH-Z14A CO2 sensor and a Metal oxide semiconductor pellet sensor and collected data on exhaled CO2 from both healthy individuals and asthmatics. This research provided important knowledge about respiratory conditions such as asthma, highlighting its potential for creating accessible devices for monitoring respiratory health [37].

The combined findings of these studies contribute to our comprehension of analysing exhaled breath for gases, presenting novel viewpoints and approaches. The significance of these studies extends from diagnosing health conditions to monitoring the environment, playing a crucial role in progressing respiratory analysis research.

Table 2.1: Comparison of Existing Exhaled Breath Sensor Technologies.

Authors	Parameter	Sensor	Method	Sample	Gas
Ying Li et al. (2023) [33]	The concentration and type of specific gases in exhaled breath are measured	Metal-oxide-semiconductor (MOS) sensors, Surface acoustic wave (SAW) sensors, Optical sensors and Colorimetric sensors	Gas sensor arrays collect information from gases	Exhaled NO was measured in healthy and lung cancer patients' breaths.	Nitrogen dioxide (NO2) and ozone (O3).
Rifky Maulana Fuadi et al. (2023) [34]	CO2 levels in human expiration, ppm CO2 concentration, and sensor response time	Cozir-WX-20 CO2 gas sensor	Main-stream method & Side-stream method	CO2 gas from cylinders & Medical air gas	Carbon dioxide (CO2)
Santheraleka Ramanathan et al. (2023) [35]	CO2 levels in exhaled breath, electrical resistance changes, sensitivity & selectivity.	Infrared (IR) CO2 gas sensors, non-dispersive infrared (NDIR) sensors & Metal oxide-based sensors	Tunable diode laser (TDL) technology for precise CO2 measurement	The sample measured is carbon dioxide (CO2) in exhaled breath	Carbon dioxide (CO2)

C. Sricharoen et al. (2023) [36]	Flow rate of the breath, Respiratory exchange rate ratio (RER) values & Oxygen (O2) and carbon dioxide (CO2) concentrations in exhaled breath	Electrochemical O2 sensor & Photoacoustic CO2 sensor	Development of a handheld breath analyser device	Exhaled breath of individuals before and after a high-carb breakfast and after varied training durations	Carbon dioxide (CO2)
Cheow Shek Hong et al. (2018) [37]	Concentration of carbon dioxide (CO2) in exhaled air	MH-Z14A carbon dioxide (CO2) & Metal oxide semiconductor (MOS) pellet	Designed a prototype electronic kit	Normal users' exhaled CO2 data & Asthmatics' exhaled CO2 levels	Carbon dioxide (CO2)

CHAPTER 3

METHODOLOGY

This chapter will cover each procedure or stage that was carried out and justify the selection of this specific approach.

3.1 Overview

In this chapter, the project's approach is succinctly outlined, ranging from initial planning to execution. It details the selection of essential hardware and software, such as the ESP32 microcontroller and Arduino IDE, and discusses the development of the prototype and data analysis methods. This chapter offers a clear understanding of the systematic processes employed in the project.

3.2 Flowchart

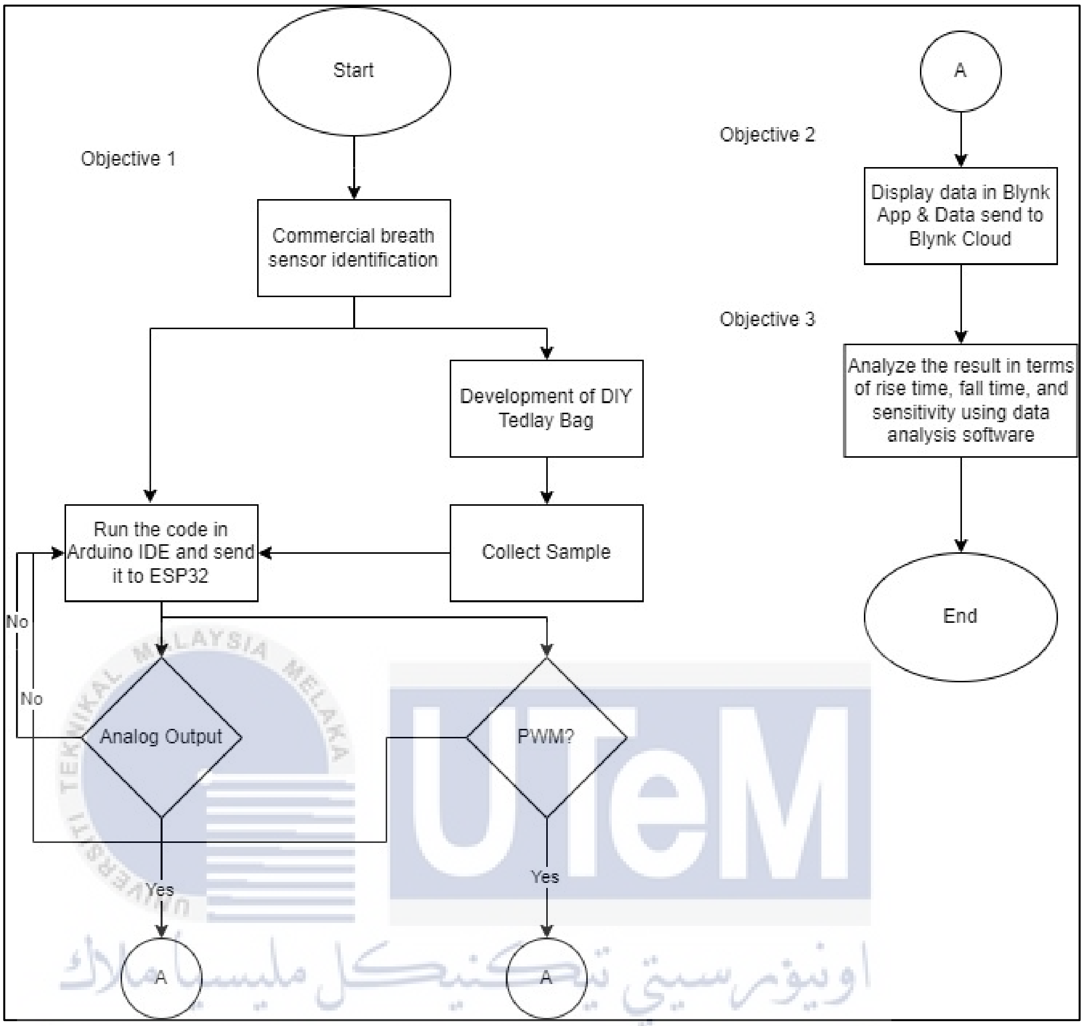


Figure 3.1: Flowchart for this project.

Based on Figure 3.1, The research methodology begins by selecting a suitable commercial sensor for the analysis of exhaled human breath. The MH-Z14A sensor is selected for its capacity to detect carbon dioxide CO2 gas, a prominent component of exhaled human breath gas. The breath samples for intake and outtake flow will be collected using a self-made tedlar bag that has two valves and a resealable bag. The bag will be properly sealed to ensure the accuracy of the breath samples, preventing any potential contamination. The sensor will go through calibration and be integrated into a prototype breath sensor system. The

ESP32 microcontroller serves as the intermediary between the sensor and the IoT application. The system will be designed to receive and analyse the output voltage from the MH-Z14A sensor, which acts as an indicator of the CO2 content in the breath samples collected. If the analog output reading is successful, the data will be smoothly displayed in the Blynk app. In addition, if a PWM output is successful, corresponding data will be displayed in the Blynk app. The incorporation of the breath sensor system into the Blynk app improves its accessibility and ability to monitor in real-time.

A sample size of 12 breath samples is collected from individuals who have different behaviours which is smokers and non-smokers, using the self-constructed Tedlar bag. To generate consistent pressure from the sample bag to the sensor will be used the mass. The MH-Z14A sensor is utilized to measure the CO2 concentration in each breath sample while capturing data on response time, recovery time, and sensitivity of the sensor for each sample. Graphical methods are used to analyse the collected data, including the CO2 concentration, response time, recovery time, and sensor sensitivity. The results are then exported to OriginPro and Excel software for further analysis. The data are processed to identify any trends or patterns in the breath analysis results, and the performance of the sensor is evaluated based on the defined parameters.

A prototype was constructed to validate the feasibility and operation of an IoT-enabled sensor for detecting human exhaled breath. The prototype incorporates an ESP32 microprocessor, a CO2 gas sensor MH-Z14A, and a modified food container as a confined area for gas accumulation. The arrangement was optimized to ensure efficient gas collection, considering feedback from initial testing. The development method involved precisely integrating the ESP32 microcontroller, CO2 gas sensor, and container configuration. This combination forms the basis for this project's prototype, essential for immediately monitoring and analysing carbon dioxide levels in exhaled breath. The sensor transmits data through IoT connectivity to a central system, enabling remote monitoring of respiratory patterns. This prototype plays a crucial role in this project, providing valuable insights into possible health diagnostics and personalized wellness tracking applications.

3.3 Project Planning and Milestones

Final year project is divided into two stages in which Part 1 is on background research, prototype design and preliminary data whereas Part 2 in on development of fully functional prototype with completed software, cloud server platform and mobile application (Blynk).

In FYP1, problem statement and objectives were defined based on the project title. A complete background research was executed to identify problem statements and objectives. Then, literature review was carried out for seven weeks to gather information on the methodologies used by other researchers to get the concentrations of CO2 using commercial sensor and allow the data to be uploaded to Internet and be visible to users. A first stage prototype was developed to be used for preliminary testing and data gathering. The circuit between ESP32 microcontroller and MH-Z14A sensor and the tedlar bags was developed to get the output voltage from the sensor and collecting gas samples to flow it through the sensor. The data was analysed in terms of response time, recovery time, and sensitivity and problems encountered during the process were evaluated and solutions were suggested to resolve them.

In FYP2, the hardware devices, programming language, cloud server platform and Blynk application to view the logged data were finalized before proceeding to build a fully functional prototype. The data uploading and user request functions were later combined with the code and tested numerous times to ensure they work properly as desired. Then, the finalized code was programming using Arduino IDE software, followed by preparing the project prototype.

When the final prototype is completed, calibration of sensor will be performed, and the prototype will be tested by using a gas sample which consists of different behaviour of smokers and non-smokers for testing. The collection of data would be performed for several days for further analysis.

Table 3.1 shows the Gantt Chart of FYP1 while Table 3.2 shows the Gantt Chart of FYP2.9.

Table 3.1: Gantt Chart of FYP1.

Aktiviti Projek *Project Activities*	**SEM I**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Identifying Project Title & Registration of Project Title	X										**SEMINAR PSM I**					
Preparation of Project Proposal		X	X	X												
Submission of Project Proposal				X	X											
Development prototype of human breath sensor						X	X	X								
Development of DIY Tedlar Bag						X	X	X	X							
Collecting and Processing Human Breath Sample							X	X	X	X		X	X			
Measured Output Parameter										X		X	X	X	X	X
Preparation of Report (Chapter 1, 2, 3)								X	X	X		X	X	X	X	X

Table 3.2: Gantt Chart of FYP2.

Aktiviti Projek *Project Activities*	**SEM II**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Project Continuation Registration	X													**SEMINAR PSM II**		
Analyze Output Parameter	X	X	X	X	X	X	X	X	X	X						
Construct IoT Part	X	X	X	X	X	X	X	X	X	X						
Preparation on Thesis Report							X	X	X	X						
INOTEK											X					
Submission of Thesis Draft to Supervisor												X	X			
Edit Corrected Thesis Report												X	X			
Submission of Final Thesis to Panel															X	X
Submission of Evaluation Marks to JK PSM															X	

3.4 System Architecture Block Diagram

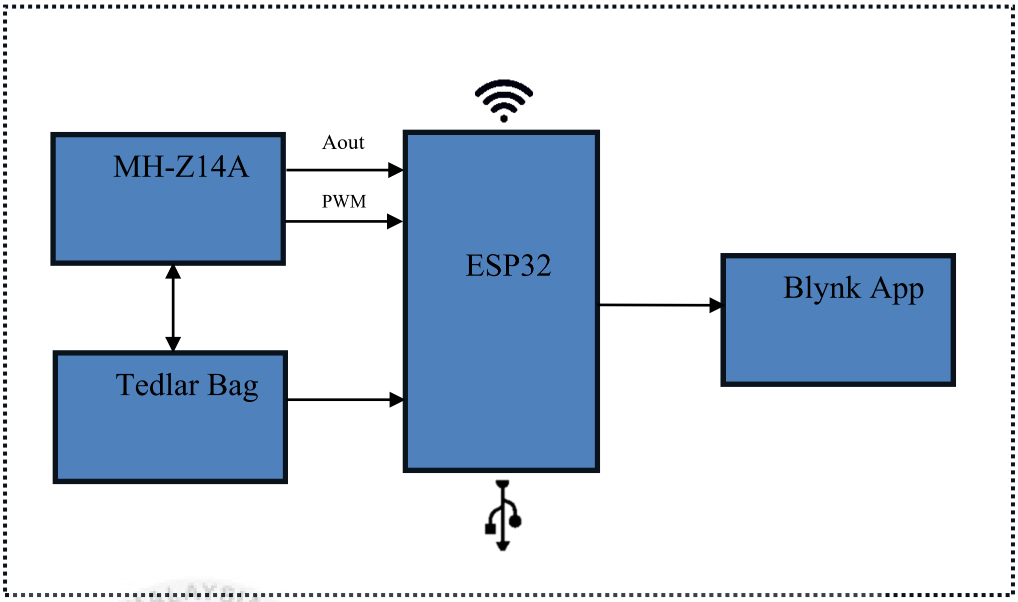


Figure 3.2: Block Diagram for development of exhaled human breath system.

Based on Figure 3.2, the system is controlled by microcontroller, with the ESP32 as the central component for the controlling and monitoring of two components which are the MH-Z14A & tedlar Bag. The ESP32 is programmed using the Arduino IDE to make the sensor work in a good condition and get a true result. The MH-Z14A is a carbon dioxide sensor that employs non-dispersive infrared (NDIR) technology to quantify the quantity of CO_2 in the atmosphere. The tedlar Bag is a specialized container used for the purpose of collecting and preserving gas samples, which can be analysed at a later time. The system additionally integrates with the Blynk App, a mobile application that empowers users to design personalized interfaces for their IoT devices. The Blynk App has the capability to exhibit the information generated by the system and enable users to manipulate it from a distance.

3.5 Solution Selection (Hardware)

During the selection of components for this research project, thorough evaluation was conducted to determine the characteristics that would enhance the successful implementation of the experiments. The selected solutions included the following essential elements:

3.5.1 Microcontroller ESP32

Figure 3.3: ESP32 Microcontroller.

Espressif Systems made the ESP32 microcontroller, which is the follow-up to the ESP8266 microcontroller. This microprocessor has a Wi-Fi module built right in, which makes it great for making systems that connect to the internet of things. The ESP32's pin out can be used to send and receive data as either an input or an output.

The ESP32 is a small microprocessor that has many functions on one chip. It has Bluetooth version 4.2, Wi-Fi 802.11 b/g/n, and other functions for peripheral devices. Xtensa LX6 with two cores and 32 bits of design is the CPU used in this chip. The peripheral address space is only 512 kilobytes, while the data and command address space is 4 gigabytes. There are 448 kilobytes of read-only memory (ROM), 520 kilobytes of static random-access memory (SRAM), two 8 kilobyte real-time clock (RTC) memories, and 4 megabytes of flash memory in the memory group. The chip has four SPI interfaces, two I2C interfaces, and an 18-pin ADC with 12 bits. These microcontrollers have many great features, such as being inexpensive, easy to programme, having enough I/O pins, and having a built-in Wi-Fi adapter for easy Internet connection. ESP32 is used in many boards, including the NodeMCU-32S, the Wemos LoLin32, the DOIT ESP32, the Sparkfun ESP32, and the AdafruitESP32.

3.5.2 MH-Z14A Infrared CO_2 Sensor

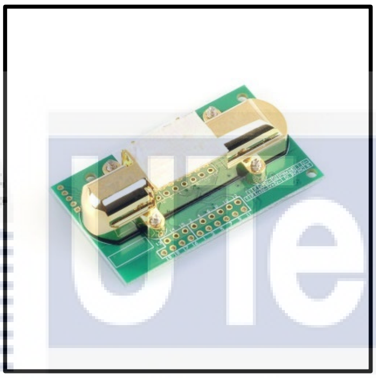


Figure 3.4: MH-Z14A NDIR gas sensor.

The MH-Z14 NDIR Infrared gas module is a compact sensor that use the non-dispersive infrared (NDIR) principle to identify the presence of carbon dioxide (CO2) in the atmosphere. The device exhibits excellent selectivity, does not rely on oxygen, and has a prolonged lifespan. The sensor is equipped with an integrated temperature adjustment function and offers UART output, analogue voltage output, and PWM output. The MH-Z14 NDIR Infrared Gas Module is used for the detection of carbon dioxide, CO2 presence in the atmosphere.

The MH-Z14A sensor is a carbon dioxide, CO2 sensor module that is widely utilised in diverse applications, such as monitoring indoor air quality, regulating

HVAC systems, and controlling industrial processes. The device utilises non-dispersive infrared (NDIR) technology to quantify the quantity of carbon dioxide, CO2 present in the atmosphere. The sensor possesses a measuring range spanning from 0 to 5000 ppm and offers a digital output signal that may be conveniently connected to microcontrollers or other electrical devices. In this project, the PWM and Analog output will be used for collecting data from the sensor and send it to the microcontroller.

3.5.3 Tedlar Bag

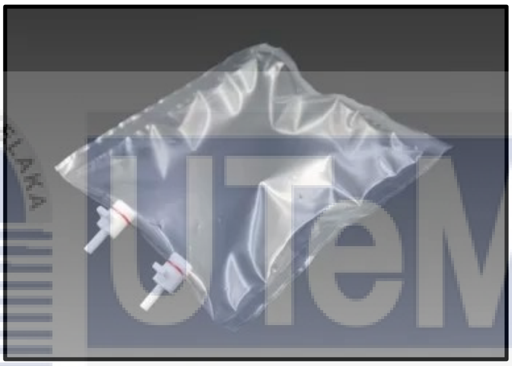


Figure 3.5: Tedlar Bag.

The tedlar bag is a specialised 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.

3.6 Solution Selection (Software)

This examines the crucial process of selecting the most appropriate software solutions in the complex field of software selection, with a specific investigation of three significant choices:

3.6.1 Arduino IDE

Figure 3.6: Arduino IDE.

The acronym IDE in Arduino stands for Integrated Development Environment. This legally approved program was created by Arduino.cc and was used to write, compile, and upload code to the Arduino devices. The software was used to program an ESP32 microcontroller, allowing for the smooth integration of an MH-Z14A gas sensor for live monitoring. The result of this endeavour was the creation of a functional gas monitoring system that can be accessed via the Blynk application. Arduino IDE is notable for its interoperability with a diverse range of Arduino modules and is well-known for its user-friendly interface, which streamlines the development process. Hence, the Arduino IDE played a crucial role in the project by offering a sturdy platform for programming microcontroller devices and greatly contributing to its successful implementation.

3.6.2 Blynk

Figure 3.7: Blynk Platform.

Blynk is a versatile IoT software platform for building and managing connected hardware solutions. This easy-to-use platform offers device setup, real-time sensor data visualization, mobile and web-based remote control, Over-The-Air firmware updates, secure cloud storage, robust data analytics, user access management, alert notifications, and automation. Blynk's drag-and-drop UI designer and simple APIs for hardware-application data sharing make it easy for developers of all levels to use. Blynk's smartphone and web apps enable diverse interfaces for linked hardware, making it a complete and accessible IoT solution.

3.6.3 OriginPro Software

Figure 3.8: OriginPro Software.

In this project, OriginPro, an advanced data analysis and graphing software, was essential. Its strengths in data visualization, statistical analysis, curve fitting, and creating professional graphs and charts made it ideal for this research. OriginPro enabled detailed data handling and sophisticated statistical evaluations, crucial for producing high-quality academic reports and presentations. A key application of OriginPro was in analysing response and recovery times from Blynk cloud data, streamlining the process and allowing for accurate assessment of system performance. This significantly contributed to the project's success.

3.7 Development of Prototype

Figure 3.9: Prototype of Project.

A prototype was constructed to validate the feasibility and operation of an IoT-enabled sensor for detecting human exhaled breath. This prototype incorporates an ESP32 microprocessor, a CO_2 gas sensor MH-Z14A, and a modified food container as a confined area for gas accumulation. The tedlar bag, containing CO_2 gas, flows into the gas-locked container and is controlled by a hose tube. After several design iterations, the arrangement was optimised to ensure efficient gas collection based on feedback from initial testing.

The development method integrated the ESP32 microcontroller, CO2 gas sensor, and container configuration to create a prototype for monitoring carbon dioxide levels in exhaled breath. The sensor transmits data through IoT connectivity to enable remote monitoring of respiratory patterns. This prototype is essential for gaining insights into potential health diagnostics and personalized wellness tracking applications.

3.8 Development of Tedlar Bag

Figure 3.10: Self Made tedlar Bag.

The decision to make the tedlar bag independently was driven by the necessity of reducing expenses linked to commercially available alternatives. A practical and economical solution was developed in response to the excessively high prices of commercially available tedlar bags. The tedlar bag is constructed simply from a resealable storage bag measuring 14(W) x 20(L) cm. It is equipped with two valves to control airflow in and out. This design provides a cost-effective option while guaranteeing meticulous regulation of the breath sample procedure and maintaining precision in our data collection efforts.

The tedlar bag, manufactured entirely from the resealable bag material, encountered difficulties achieving airtight sealing and preventing leakage around the valves. The reliability of the self-made tedlar bag for breath sample collection was strengthened by thorough testing and modifications, effectively addressing these concerns. The self-manufactured tedlar bag plays an essential role in the data-collecting process. It allows people to insert their breath into the bag through the inlet valves, facilitating controlled and accurate sampling. Combining an easy and effective approach, precise dimensions, and a valve mechanism improves the accuracy and consistency of the breath sample procedure. The self-constructed Tedlar bag, attached to the gas-locked container, is both a practical and cost-effective option. It is also crucial in this groundbreaking method of analysing human breath.

3.9 Data Analysis Techniques

The next part defines the methodologies employed to thoroughly analyse the gathered breath samples. These techniques are essential for comprehending the functionality of the breath sensor system and provide further information on the real-time monitoring of data using the Blynk App. It also explores in-depth analyses for all parameters. The combination of these analytical methods enhances the detailed assessment of the breath analysis approach utilized in this study.

3.9.1 Sensor Pre-heating and Gas Sampling

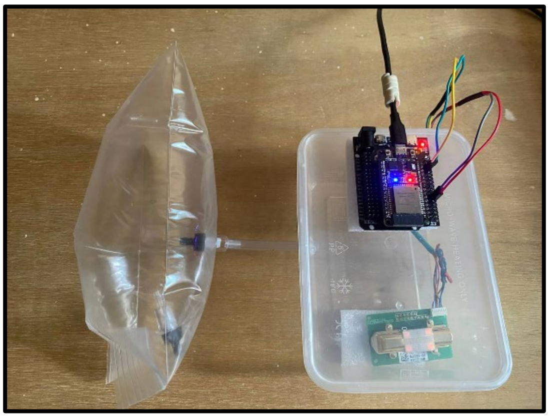


Figure 3.11: A Prototype Connected with Tedlar Bag.

Preheating the sensor guarantees accurate calibration and establishes an optimal environment for precise measurements. It is essential to carry out this procedure to determine the initial concentration and remove any remaining CO2 gas from the sensor. After being heated beforehand, the sensor is prepared to collect gas samples. This enables it to function at its best and produce dependable data regarding the composition of the breath samples obtained by connecting the tedlar bag to the prototype using a tube hose; a controlled setup is established, which enables accurate and calibrated measurements during the subsequent analysis.

3.9.2 Consistent Gas Release

Figure 3.12: Gas Flowing.

To ensure a reliable gas sampling process, the load and prototype are kept stable during the sampling phase. This helps to apply a consistent force, which facilitates the complete release of gas from the tedlar bag. This careful approach ensures a controlled and uniform gas flow, which contributes to the accuracy and reliability of the breath analysis. The stringent measures taken to prevent load movement and prototype lifting enhance the precision of the gas release process, which is crucial for obtaining trustworthy data on the breath sample composition.

3.9.3 Real-time Monitoring via Blynk App

Figure 3.13: Blynk App Widget Interface.

The Blynk App interface provides convenient real-time monitoring of the gas sampling operation. This versatile platform provides real-time readings of CO2 concentration from both analogue output and PWM, as well as output voltage (V) and timestamps. Additionally, it offers graphical visualizations of these breath analysis parameters. The Blynk App provides instant visual feedback that enhances data accessibility, allowing for quick observations and fast insights into the changing dynamics of breath sample analysis. The real-time monitoring capability is essential for quickly identifying any abnormalities or trends, enhancing the strength of the breath analysis process. Graphical representations enhance the comprehension of trends, improving the overall efficacy of capturing and interpreting breath composition.

3.9.4 Graphical Analysis and Temporal Assessment

In this part of the research, there is a two-step process that includes carefully evaluating samples and then analysing data to get more detailed information about how breath composition changes over time.

3.9.4.1 Sample Assessment

The initial step of the sample assessment was the methodical gathering of 12 breath samples, divided among seven individuals who do not smoke and five who smoke. The approach followed a systematic sequence, examining four samples from non-smokers, then proceeding to five samples from smokers, and finally completing the assessment of the remaining three samples from non-smokers.

A complicated integration approach was employed in the connection and loader setup, guaranteeing the precise attachment of the tedlar bag to the prototype using a setup iPad loader. This technique enabled precise force application, ensuring consistent stability during gas flow.

The utilization of the Blynk app for real-time monitoring was essential in guaranteeing the continuous advancement of gas flow. The constant monitoring method ensured the smooth flow of the gas, enhancing the accuracy of the assessment.

After the gas discharge was finished, an intentional 30-second delay was established to facilitate the mixing of gases inside the tedlar bag. Following this stage, the container's cover opened, allowing the CO_2 gas to be released. This activity caused a decrease in concentration, which gradually returned to an average level.

The assessment process, characterized by its thoroughness, was methodically duplicated for each of the 12 samples. This approach followed a standardized protocol, guaranteeing consistency and dependability during the sample assessment phase.

3.9.4.2 Data Analysis Process

After the meticulous sample assessment, the data analysis phase aimed to provide a comprehensive visual understanding of the temporal dynamics inherent in breath composition. In the initial step, the collected data was systematically transmitted to the Blynk cloud, laying the groundwork for subsequent analyses. This robust foundation ensured the reliability and integrity of the dataset. Upon downloading the CSV file from the Blynk cloud, a methodical approach was taken to export it to OriginPro for comprehensive graph generation. Figure 3.14 illustrates how to generate and download the report. This involved crafting graphs that depicted output voltage, CO_2 concentration from the analogue output, and CO_2 concentration from PWM. These graphical representations served as essential visual aids, allowing for a detailed exploration of the dataset derived from the Blynk cloud. Figure 3.15 shows the data exported from the Blynk cloud into OriginPro.

The analysis delved further into the temporal aspects by applying rise time and fall time gadgets from OriginPro to the output voltage graph. This nuanced approach provided valuable insights into the response and recovery time, crucial components in understanding the breath composition dynamics. Each breath sample underwent a detailed and personalized analysis, focusing on response and recovery times. Figure 3.16 shows the use of gadgets to analyse response time and recovery time and Figure 3.17 shows how to analyse the response time and recovery time on the graph plotted.

This granular examination comprehensively understood the variations and patterns inherent in the breath samples. The outcomes of these individual analyses were methodically catalogued into a consolidated table. Figure 3.18 shows the table provides a holistic overview, summarizing all the rise time and fall time data, facilitating a structured and organized presentation of the findings.

A comparative analysis was then undertaken, drawing distinctions between non-smokers and smokers. This involved utilizing both groups' compiled rise time and fall time data. The results of this comparative analysis were visually represented through bar graphs, effectively highlighting the temporal behavioural differences over time between the two distinct groups.

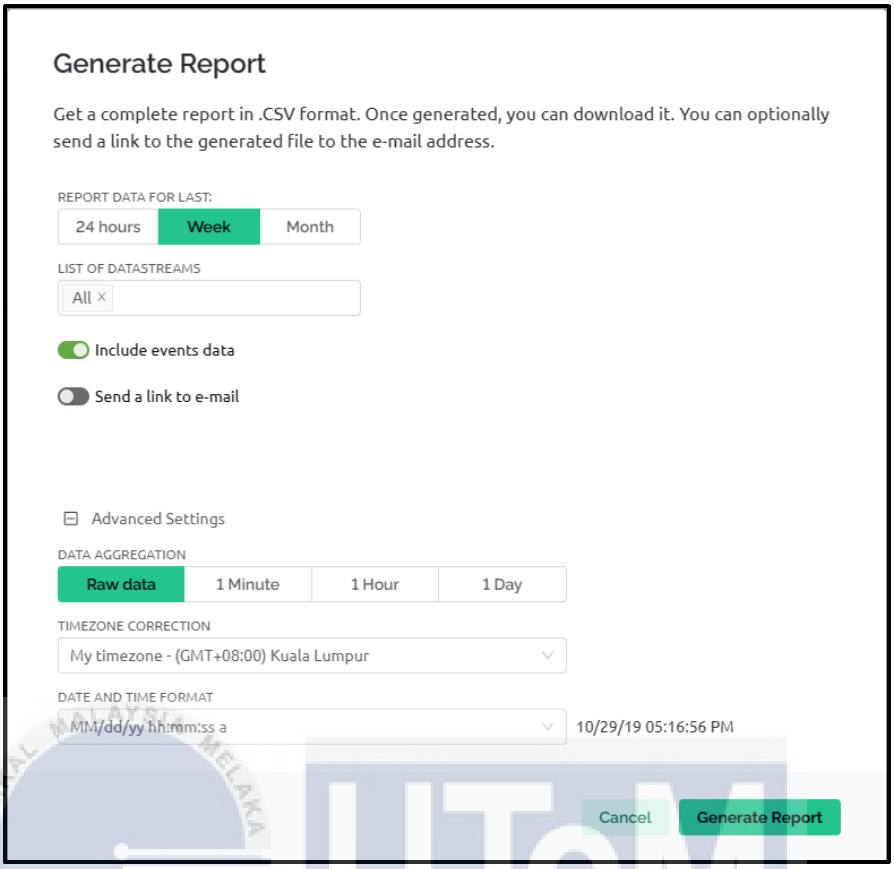
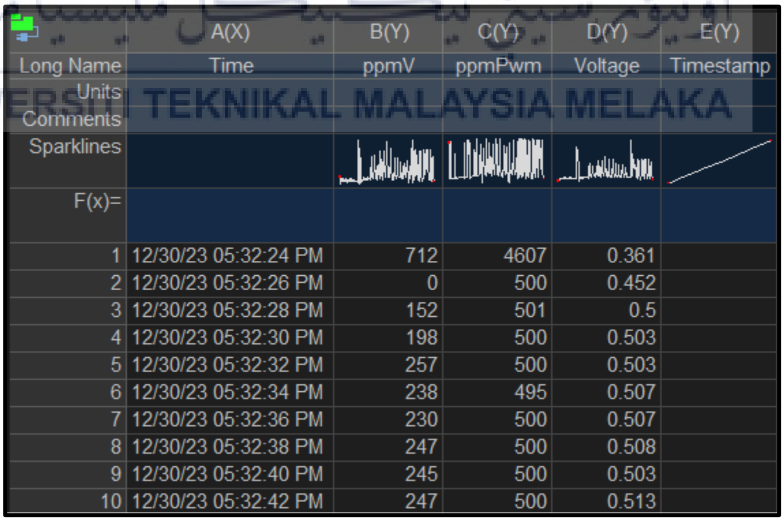


Figure 3.14: User interface for generating reports in CSV file.



	A(X)	B(Y)	C(Y)	D(Y)	E(Y)
Long Name	Time	ppmV	ppmPwm	Voltage	Timestamp
Units					
Comments					
Sparklines					
F(x)=					
1	12/30/23 05:32:24 PM	712	4607	0.361	
2	12/30/23 05:32:26 PM	0	500	0.452	
3	12/30/23 05:32:28 PM	152	501	0.5	
4	12/30/23 05:32:30 PM	198	500	0.503	
5	12/30/23 05:32:32 PM	257	500	0.503	
6	12/30/23 05:32:34 PM	238	495	0.507	
7	12/30/23 05:32:36 PM	230	500	0.507	
8	12/30/23 05:32:38 PM	247	500	0.508	
9	12/30/23 05:32:40 PM	245	500	0.503	
10	12/30/23 05:32:42 PM	247	500	0.513	

Figure 3.15: Data exported from Blynk Cloud into OriginPro.

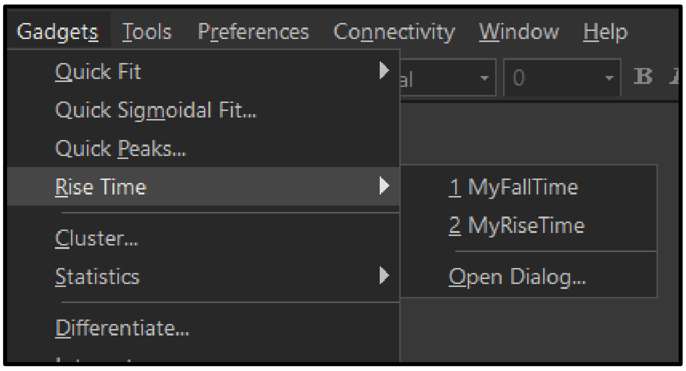


Figure 3.16: Rise time and Fall time gadgets in OriginPro Software.

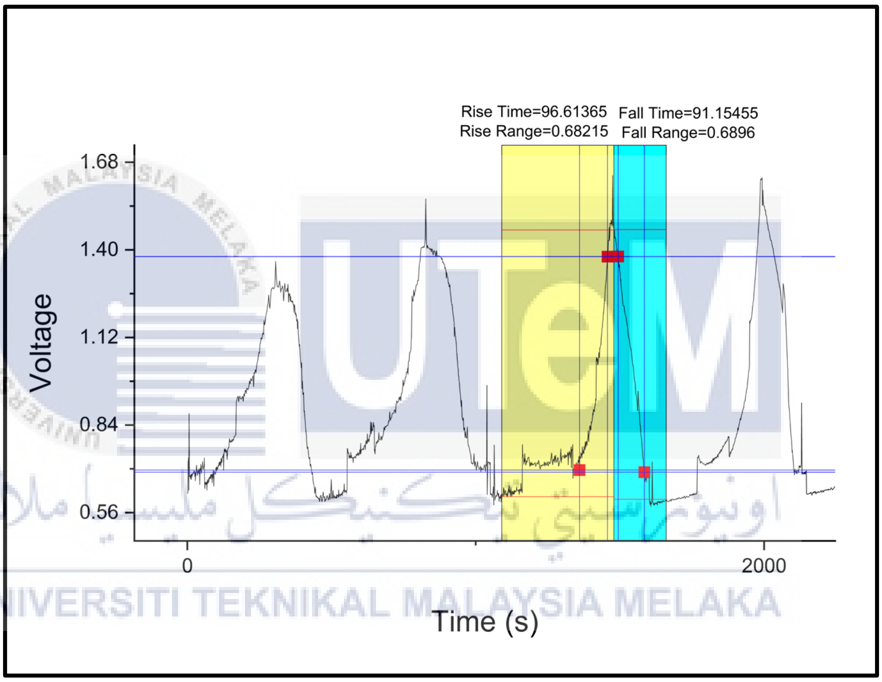


Figure 3.17: Analysis for response time and recovery time on output voltage graph.

	A(X)	B(Y)	C(Y)
Long Name	Dataset Identifier	Rise Time(s)	Fall Time(s)
F(x)=			
Categories			
1	Non-Smoker	110.58113	
2	Non-Smoker	97.56	
3	Non-Smoker	97.3875	
4	Non-Smoker	91.31434	
5	Smoker	156.59266	
6	Smoker	153.46156	
7	Smoker	168.32994	
8	Smoker	162.26476	
9	Smoker	163.49545	
10	Non-Smoker	112.59538	
11	Non-Smoker	115	
12	Non-Smoker	97.09722	
13	Non-Smoker		62.17212
14	Non-Smoker		86.05909
15	Non-Smoker		68.78462
16	Non-Smoker		83.25
17	Smoker		104.14879
18	Smoker		73.72222
19	Smoker		71.35938
20	Smoker		73.25714
21	Smoker		67.03117
22	Non-Smoker		42.31282
23	Non-Smoker		60.4287
24	Non-Smoker		63.4

Figure 3.18: Result of response time and recovery time for each sample.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will go over the results acquired as well as the theory associated with the project that was completed successfully. To analyse all the parameters and integrate the project with IoT application, various characteristics are observed and measured.

4.1 Collection Sample

In order to start analysing the gathered breath samples, it is essential to introduce crucial parameters that are fundamental to understanding the operational characteristics of the sensor used to detect human exhaled air. These parameters include the response time, which shows how the sensor responds to changes in the input [38], and the recovery time, which shows how long it takes to return to its original state after changes in the input [39].

The data has been manually entered into the OriginPro software from the CSV file downloaded from the Blynk cloud. This software now functions as the central storage location for our dataset, enabling the creation of detailed visualizations. In particular, the graph illustrating the correlation between output voltage and time has been precisely designed to include all gas samples. The dataset consists of separate samples representing individuals who do not smoke and individuals who smoke, with each sample carefully labelled to ensure unambiguous distinction.

Table 4.1 and Figure 4.1 shows each gas sample's detailed response and recovery graphs to the output voltage and its time change. The precise classification and tagging of samples contribute to a visually comprehensive illustration, enabling a thorough analysis of the various behaviours displayed by samples from non-smokers and smokers. The presentation of this information adheres to the scientific rigor that is essential for this analysis of the creation of an IoT-based sensor for detecting human exhaled breath.

Table 4.1: Participant Classification and Behaviour.

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)

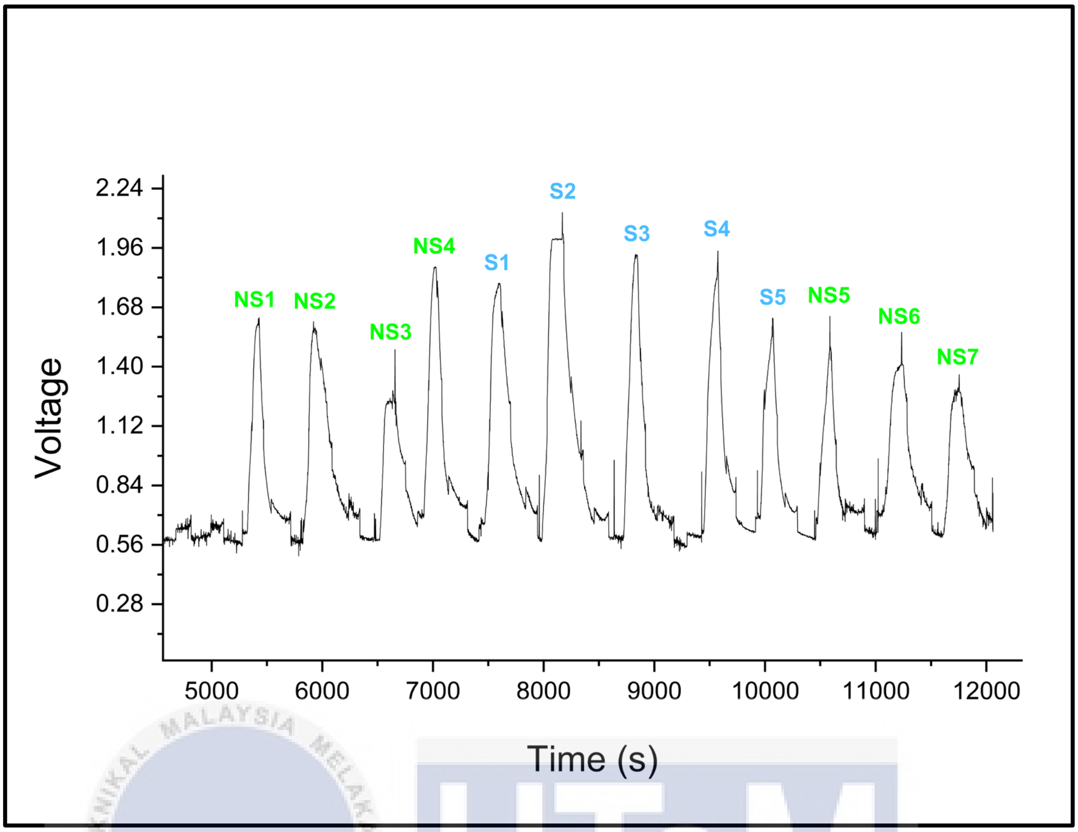


Figure 4.1: Graph of output voltage against time for all samples.

Figure 4.2 and Figure 4.3 show the CO2 concentration obtained by the sensor's analog output pin and PWM pin serves as an invaluable aid for continuously monitoring the levels of CO2 in the atmosphere. The graph depicts the CO2 concentration in parts per million, ppm over time for analog output pins and PWM pins. The graph's purpose is to present supplementary data regarding the concentration of CO2 in parts per million, ppm associated with each sample, which varies according to different behaviours.

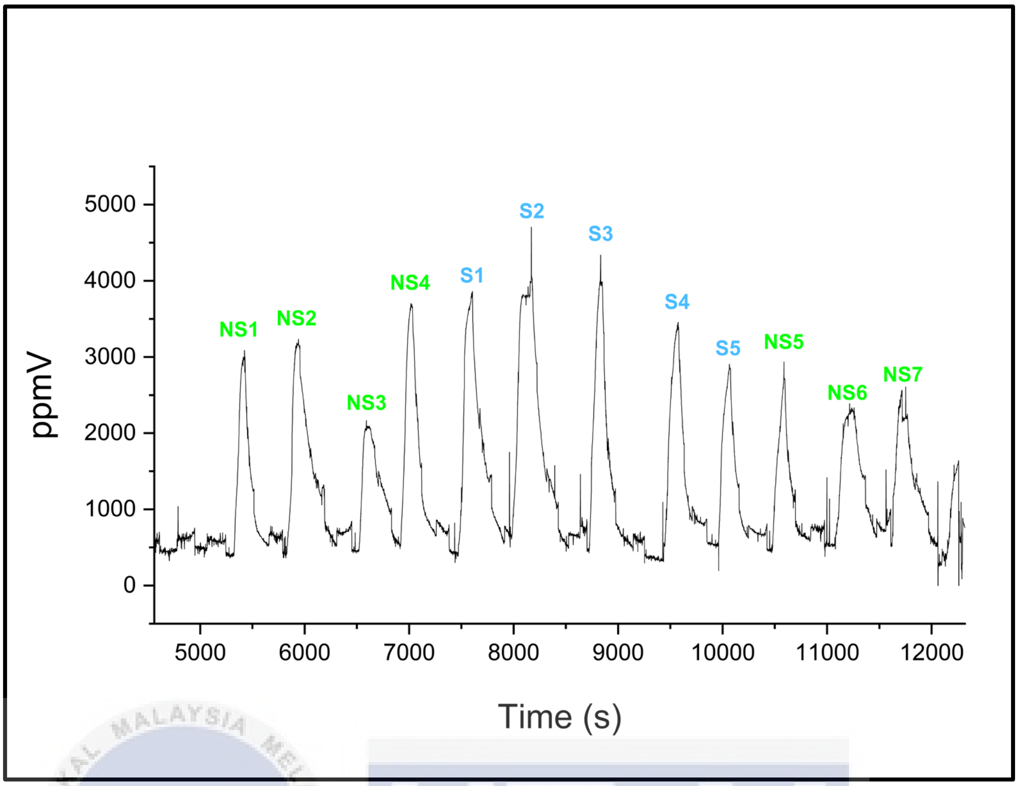


Figure 4.2: Graph of analog output against time for all samples.

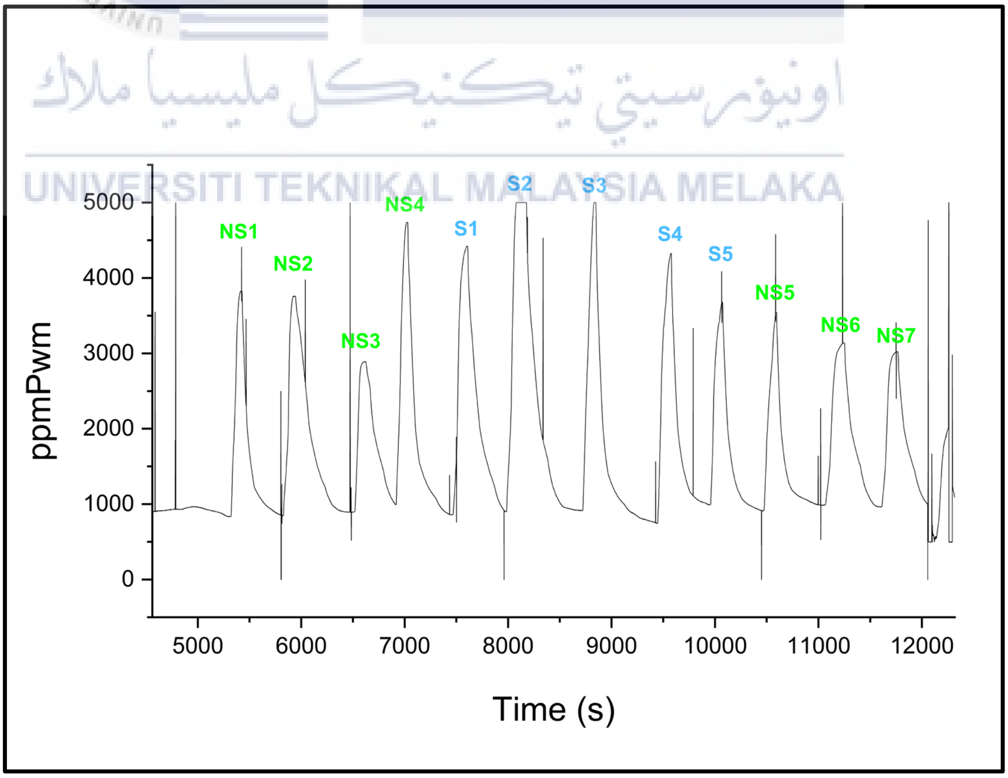


Figure 4.3: Graph of PWM output against time for all samples.

Monitoring the concentration of carbon dioxide, CO2 is essential for evaluating respiratory well-being. High levels of carbon dioxide, CO2 in exhaled breath can indicate respiratory problems or abnormalities in breathing patterns, offering significant information about an individual's respiratory well-being. Continuous monitoring of carbon dioxide levels in exhaled breath can assist in the early detection of respiratory illnesses and enhance personalized health evaluations, particularly for persons with existing respiratory problems or those at risk for acquiring respiratory disorders [40]. This proactive method of monitoring respiratory health aligns with the general objective of preventive healthcare and methods for early detection.

Accurate monitoring of carbon dioxide, CO2 levels within the body is essential due to the potential for high levels to cause acidity in the blood, leading to hazardous consequences. During the resting state, the respiratory rate is regulated by carbon dioxide, CO2 concentration. For instance, elevated amounts of carbon dioxide increase breathing in most animals, including humans. Having a reduced response to carbon dioxide may represent a severe risk to a person's health [41].

4.2 Gas Response Time

Response time is an important indicator of performance for sensors. It refers to the time it takes for a sensor to react to a 63.2% sudden change in the quantity it is measuring [42]. It is essential to differentiate between response time and the sensor's time constant, which refers to the time it takes for the sensor's reading or output to reach 63.2% of the entire step change in the measured variable [43]. Several variables affect the reaction time of a sensor, such as the characteristics of the substance being measured, the rate at which the substance flows, and the thermal conductivity of the materials used in the sensor's construction terials used in the sensor's construction [43].

The output signal voltage graph was extensively analysed to determine how long the IoT-enabled breath monitor took to respond. An additional feature called the "rise time" gadget in the OriginPro programme was needed for this task. By changing the response time preferences and setting the step height from 10% to 90%, it was possible to get an accurate representation of how the sensor responded. The output was added to the OriginPro form in an established way, which made it possible to look more closely at the rise time for each breath sample. Table 4.2 shows the response time results for both smokers and non-smokers.

Table 4.2: Sample of Response Time (s) for both behavior.

No.	Sample	Response Time (s)
1	NS1	110.58113
2	NS2	97.56000
3	NS3	97.3875
4	NS4	91.31434
5	S1	156.59266
6	S2	153.46156
7	S3	168.32994
8	S4	162.26476
9	S5	163.49545
10	NS5	112.59538
11	NS6	115.00000
12	NS7	97.09722

The comparison of gas sample response times in Table 4.2 shows apparent differences between individuals who do not smoke (NS) and those who smoke (S). Response times for individuals who do not smoke are faster, ranging from 91.31 to 115.00 seconds, while response times for smokers are more extended, ranging from 153.46 to 168.33 seconds. This difference in reaction times indicates a possible correlation between smoking and the amount of certain gases in exhaled breath.

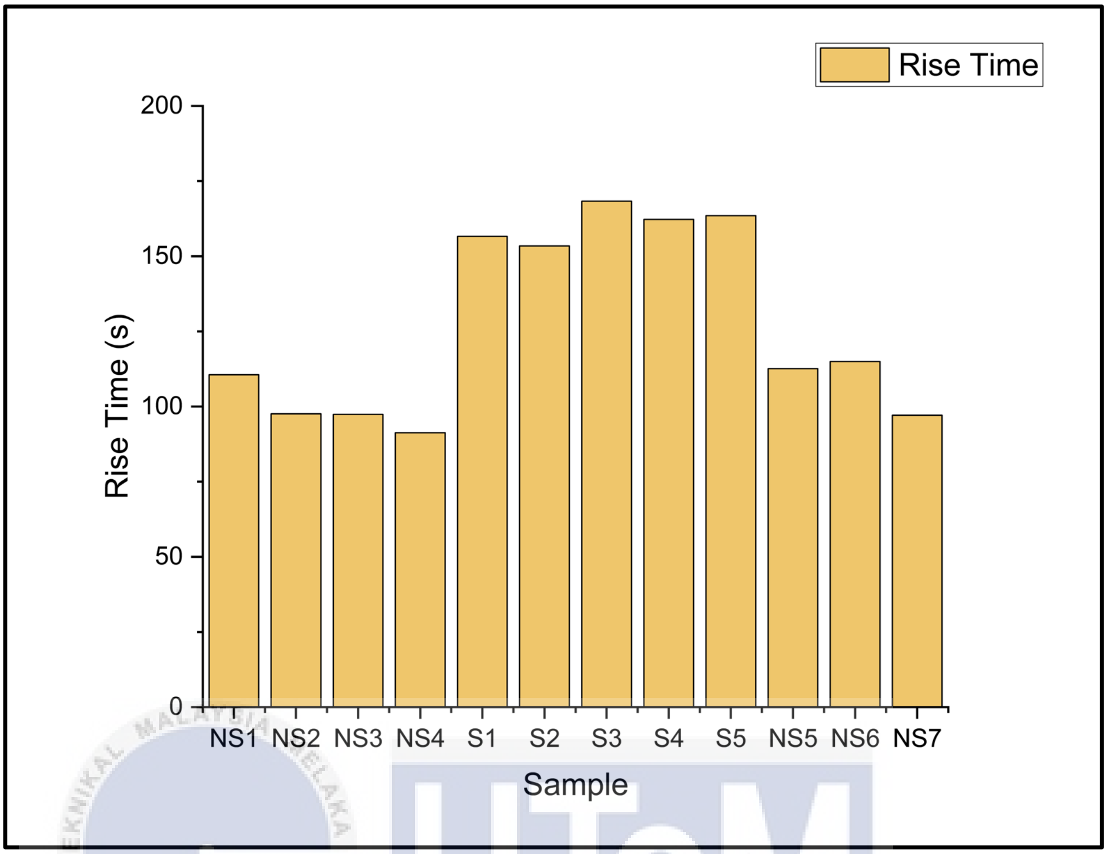


Figure 4.4: Rise Time Comparison between Non-Smokers and Smokers.

The extended increase in response times found in individuals who smoke, as illustrated in Figure 4.4, indicates a delayed reaction of the gas sensor to fluctuations in gas concentration. This delay indicates that the sensor requires additional time to detect and stabilize its output when exposed to elevated gas levels, which is consistent with the commonly accepted concept of sensor behaviour. However, placing these findings in the context of the sensor's essential features, the particular gas being evaluated, and the overall experimental setting is important.

The importance of rise time in gas sensors, as focused on different uses such as breath analyser sensors, highlights its value in detecting changes in gas concentrations. The correlation between extended durations of rising times in individuals who smoke, and the possible existence of gases related to respiratory problems caused by smoking, such as chronic obstructive pulmonary disease (COPD) or other lung diseases, offers a reasonable justification for the observed patterns. Although the data does not provide a conclusive diagnosis, the association between rise times and respiratory problems improves our comprehension of the sensor's sensitivity to various breath compositions, particularly in identifying between individuals who smoke and those who do not.

4.3 Gas Recovery Time

Recovery time is an important performance metric for sensors, indicating the time it takes for a sensor to return to its initial condition after the measured input quantity returns to its original value [44].

The assessment of the voltage output signal graph required a thorough examination to determine the recovery period of the IoT-enabled breath monitor. This time, the focus was on analysing the "fall time," using the corresponding feature in OriginPro software. Adjustments were applied to refine the response time settings, changing the step height from 90% to 10% to capture sensor recovery during fall time accurately. The obtained data was seamlessly integrated into OriginPro established format, enabling a detailed scrutiny of fall times associated with each breath sample. The findings from the fall time analysis for both smokers and non-smokers are presented in Table 4.3.

Table 4.3: Sample of Fall Time (s) for both behavior.

No.	Sample	Recovery Time (s)
1	NS1	62.17212
2	NS2	86.05909
3	NS3	68.78462
4	NS4	83.25
5	S1	104.14879
6	S2	73.72222
7	S3	71.35938
8	S4	73.25714
9	S5	67.03117
10	NS5	42.31282
11	NS6	60.4287
12	NS7	63.4

Table 4.3 displays the recovery speed of the gas sensor following changes, referred to as fall time, for non-smokers and smokers (S). Non-smokers generally exhibited quicker recovery times, ranging from 42.31 to 86.06 seconds. For instance, NS5 recovered in just 42.31 seconds, indicating effective gas clearance. In contrast, smokers had a more diverse range of recovery times, spanning from 67.03 to 104.15 seconds and generally taking longer to recover compared to non-smokers. For example, S1 had a longer recovery time of 104.15 seconds, which suggests a delayed sensor response to gas changes. The results align with the concept that fall time can provide insights into respiratory health. Longer fall times in smokers may indicate potential breathing issues associated with smoking-related conditions [45].

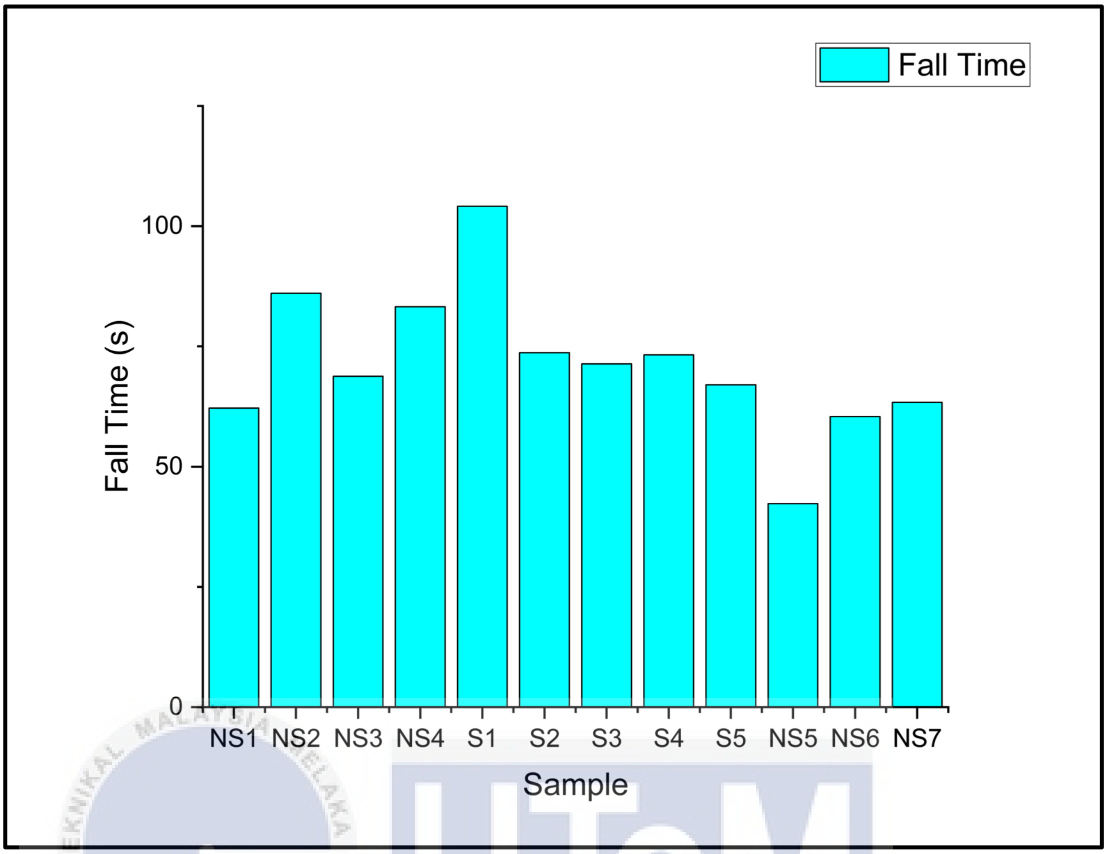


Figure 4.5: Fall Time Comparison between Non-Smokers and Smokers.

Based on Figure 4.5, analysis shows that individuals who do not smoke consistently exhibit shorter fall times, all falling below 100 seconds, which indicates a better performance on this "Fall Time" metric. Conversely, smokers (S1 to S5) demonstrate a broader range of fall times, mostly exceeding those of non-smokers, suggesting a potential influence of smoking on the "Fall Time" metric.

However, sample S1 stands out with a significantly higher fall time among smokers, indicating some level of variability or an outlier in the data. Examining the reasons behind the significant difference in S3 compared to other smokers could offer valuable insights.

Gas sample fall times are essential for evaluating respiratory health and detecting possible respiratory illnesses. These values indicate the speed at which a gas sensor returns to its initial state after registering fluctuations in gas levels. Gas sensor readings with extended fall times may suggest a delay in the recovery of the sensor signal and could suggest a higher concentration of CO2. Higher levels of carbon dioxide in exhaled breath may have health consequences, potentially contributing to respiratory ailments such as Chronic Obstructive Pulmonary Disease [46].

4.4 Sensitivity of Sensor

The evaluation of sensitivity is a key part of looking into the details of the sensor's performance. This part goes into detail about the sensitivity values that were found for each gas sample. This shows how sensitive the sensor is and how well it can tell the difference between changes in gas concentrations. Using a set formula as in equation (4.1), the sensitivity analysis shows numerical values that give useful information about the gas sensor's dynamic range and how well it works with different types of breath.

$$S = \frac{Vmax - Vmin\ (Recovery\ Time)}{Vmax - Vmin\ (Response\ Time)} \tag{4.1}$$

In the formula:

- Vmax is the output voltage at its highest level during the healing phase.
- During the healing phase, Vmin (recovery Time) shows the lowest output voltage.
- During the reaction time phase, Vmin (response Time) shows the lowest output voltage.

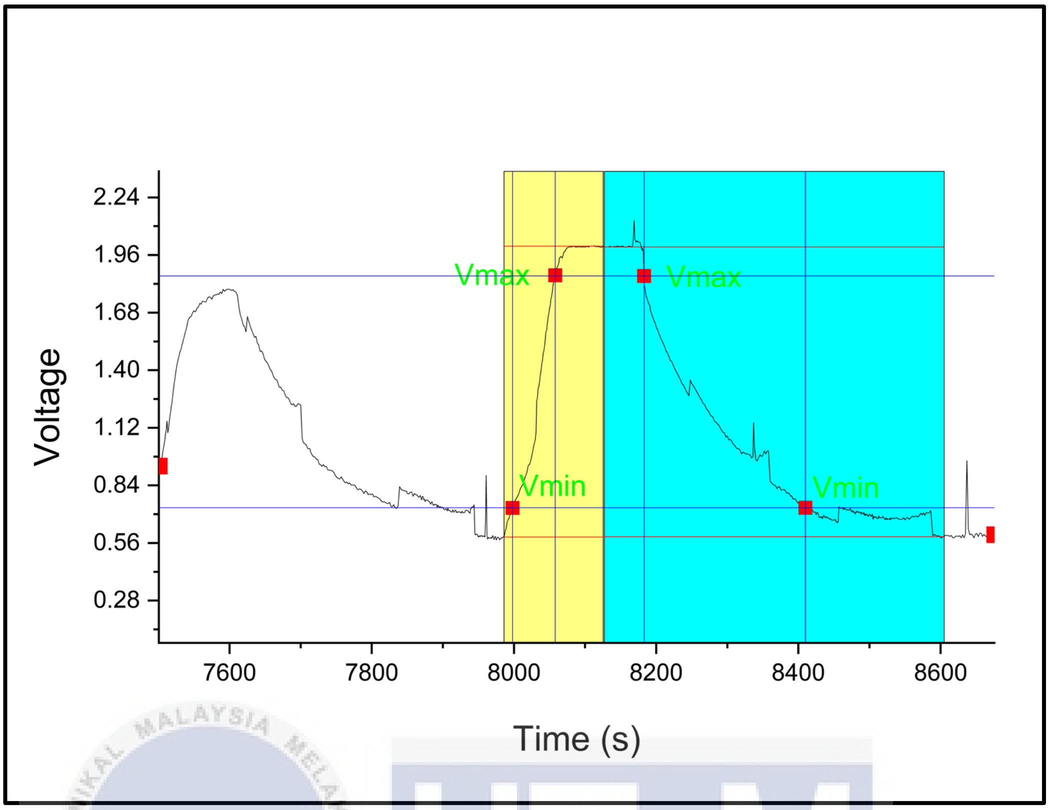


Figure 4.6: Vmax and Vmin for Response Time and Recovery Time.

The graph depicted in Figure 4.6 demonstrates the dynamic response characteristics of the sensor, highlighting the locations of Vmin and Vmax for both the response time and recovery time. This graphical depiction clearly explains the sensor's performance at these significant stages. The data for this research was derived from a comprehensive graph that included all 12 samples, encompassing non-smoker and smoker samples. Using the previously mentioned sensitivity calculation requires knowledge of the response time and recovery time positions of Vmin and Vmax. This approach provides a methodical and comprehensive way to assess the sensor's responsiveness to variations in gas concentrations across several samples, thereby enhancing our understanding of its performance characteristics.

Table 4.4: Sensitivity each sample of gas

No.	Sample	Sensitivity
1	NS1	1.02396
2	NS2	1.01781
3	NS3	0.92933
4	NS4	0.99082
5	S1	0.98667
6	S2	0.94682
7	S3	1.02652
8	S4	1.05632
9	S5	1.0438
10	NS5	0.97901
11	NS6	1.10079
12	NS7	0.975

Table 4.4 shows the sensitivity values obtained by applying a (4.1) formula to each gas sample, indicating the sensor's ability to detect changes in gas concentrations. Upon thorough analysis of the findings, a significant variation in sensitivity values is observed among both non-smokers (NS) and smokers (S). NS6 demonstrates a maximum sensitivity of 1.10079 among individuals who do not smoke, suggesting that the sensor is particularly receptive to this non-smoker group. In contrast, NS3 exhibits a somewhat lower sensitivity of 0.92933. Among smokers, S4 demonstrates the maximum sensitivity with a value of 1.05632, while S2 exhibits a comparatively lower sensitivity of 0.94682. The sensitivity study offers a comprehensive comprehension of the sensor's ability to detect small changes in gas concentrations. This comparative evaluation analyses the sensor's ability to

differentiate between the breath compositions of non-smokers and smokers accurately, providing insight into its discriminating capabilities.

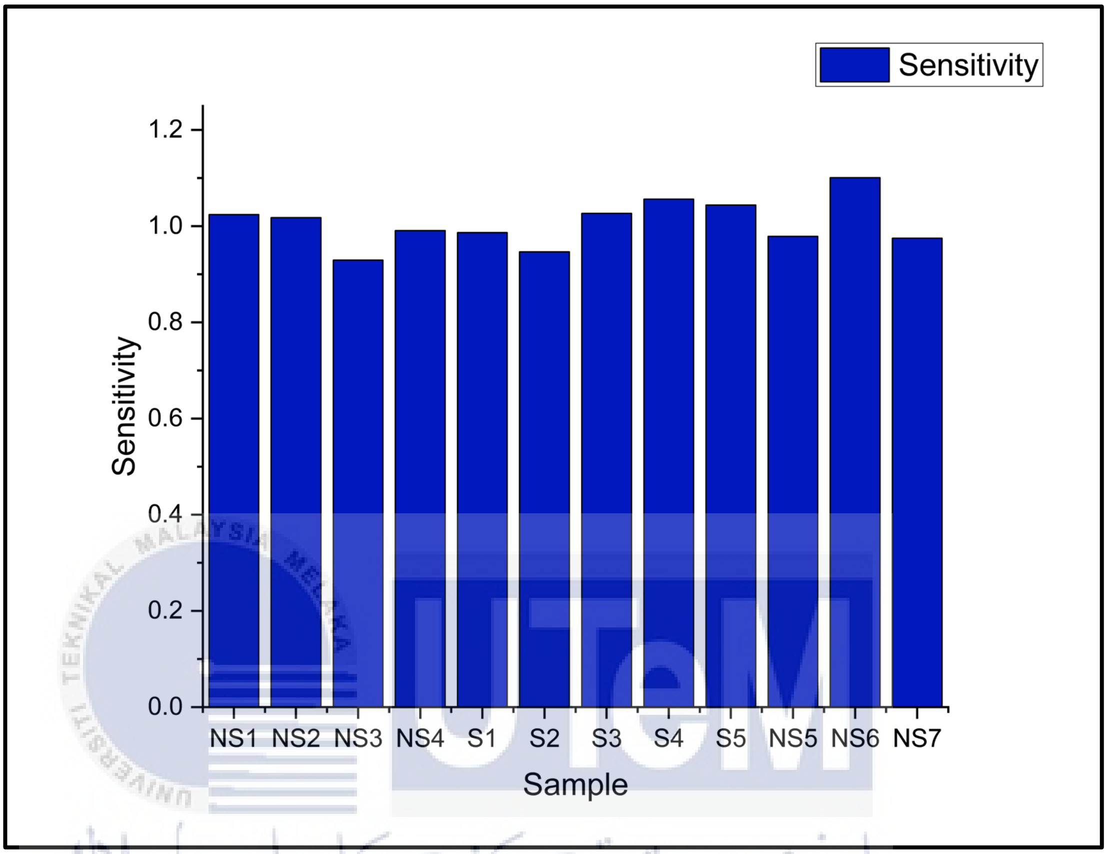


Figure 4.7: Sensitivity plotted between Non-Smokers and Smokers.

The findings were elucidated through a bar graph, juxtaposing the sensitivity levels of seven non-smokers (NS) against seven smokers (S). The x-axis bore the label "Sample," encompassing 14 distinct samples: NS1 to NS4 representing non-smokers and S1 to S7 for smokers. Meanwhile, the y-axis was designated as "sensitivity," featuring a scale from 0 to 1.2. Notably, except for NS3, all bars attained or surpassed a sensitivity level of 0.8. NS3 exhibited a notably lower sensitivity level, slightly exceeding 0.6. The discerned pattern implies an absence of a clear distinction in sensitivity between non-smokers and smokers, underscoring the presence of diverse sensitivity levels within both groups.

Increased sensitivity in gas sensors allows for more efficient detection of small changes in gas concentrations [47].

A more sensitive sensor is much better for measuring gas concentrations, especially when picking up on small changes in gas levels, which is essential. The increased sensitivity of an advanced sensor enables the detection of small changes in gas levels that could go unnoticed by less sensitive alternatives. Conversely, a sensor with lower sensitivity may restrict detecting slight differences, which could result in inaccurate measurements or undetected findings [48].

4.5 Sustainability and Environmental Impact

The project dedicated to creating a human exhaled breath sensor integrated with IoT applications aligns significantly with Sustainable Development Goals 3 and 11 in an academic context. In relation to SDG 3, which focuses on promoting Good Health and Well-being, the project plays a crucial role in enabling early detection of respiratory diseases and other medical conditions through breath analysis. This can potentially lead to improved treatment outcomes and patient care. The incorporation of IoT allows for real-time monitoring of health parameters, paving the way for personalized healthcare approaches and effective management of chronic diseases. Additionally, data aggregation from these sensors holds potential in bolstering public health research and contributing to preventive strategies.

Figure 4.8: Sustainable Development Goals related to project.

Regarding SDG 11 aimed at Sustainable Cities and Communities, the project's scope extends towards monitoring urban air quality by detecting environmental pollutants - particularly important in densely populated areas where air quality directly impacts public health. Furthermore, its compatibility with smart city networks contributes to creating more sustainable urban environments.

On the front of environmental sustainability, emphasis is placed on reducing the environmental footprint through designing energy-efficient and durable sensors integral in minimizing electronic waste. Data collected by these sensors also has potential influence over environmentally focused health policies as well as promotion of sustainable living environments due to their use of eco-friendly materials aligned with global efforts towards sustainable development.

Overall, this project not only represents significant progress within healthcare technology but also supports broader objectives related to urban sustainability alongside resonance with global agendas for sustainable development initiatives.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Chapter Introduction

In this final section, we contemplate the different aspects of the study entitled "Development of Exhaled Human Breath Sensor Using IoT." The objective is to summarise the main accomplishments of the project, discuss the obstacles and constraints faced, suggest potential avenues for future research and advancement, and ultimately recapitulate the fundamental conclusions derived from this endeavour.

5.2 Project Achievement

The project effectively accomplished its main goal of creating a breath sensor that utilises commercial sensors and integrates with IoT technology. This advancement marks an important progression in health monitoring, providing a new method for non-invasive health analysis and personalised healthcare management. The sensor showed encouraging potential for analysing human breath by measuring response time, recovery time, and sensitivity. Furthermore, the integration with IoT allowed real-time data monitoring and analysis, thereby improving the device's usefulness for continuous health tracking and ambient air quality assessment.

5.3 Project Problem & Limitations

The project encountered numerous difficulties and constraints despite its achievements. A primary concern was the calibration and precision of the sensor under different environmental circumstances. The sensor's susceptibility to changes in humidity and temperature presented challenges in maintaining consistent and dependable readings. Furthermore, the narrow range of detectable gases limited the potential applications for health diagnostics. On a technical level, issues with the stability and durability of IoT integration were experienced, affecting real-time data transmission and processing effectiveness.

5.4 Future Work & Recommendations

Future work and recommendations for this project include enhancing sensor accuracy through advanced calibration techniques and improved materials, which will aid in achieving reliable performance under varying environmental conditions. Additionally, expanding the gas detection range by integrating different sensor types is suggested to broaden the scope of health diagnostics. Improving IoT integration is also critical in enhancing data transmission stability and processing efficiency for better real-time monitoring. An environmental impact study, especially in urban areas, is recommended to ensure alignment with sustainability goals (SDG 11).

Lastly, conducting clinical trials to validate the sensor's medical efficacy is essential for further development and application in healthcare settings.

5.5 Conclusion

In conclusion, the project "Development of Exhaled Human Breath Sensor Using IoT" marks a significant advancement in health monitoring technologies. While it achieved notable milestones in developing and integrating a novel sensor system, it highlighted critical areas for improvement and future exploration. The project's alignment with SDGs 3 and 11 underscores its potential to contribute to public health and sustainable urban development. As the field of health monitoring technology evolves, this project lays the groundwork for future innovations that promise to enhance personal health management and contribute to the broader goal of sustainable, health-focused technological development.

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