COST-EFFECTIVE MONITORING SYSTEM FOR BIOMEDICAL AND CLEANROOM FACILITIES

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APRIL 2023 G – SHAWWAL 1444 H

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A senior project report submitted in partial fulfillment of the requirements for the degree of

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بسم الله الرحمن الرحيم
والصلاة والسلام على خير الورى عدَّ
الحصى والرمل والثرى
وعلى آله وأصحابه ومن تبع هداهم
واهتدى
نحمد الله العلي القدير الذي قدَّرنا على
إنهاء هذا المشروع في الوقت المحدد

Dedication statement

“We are students of electronics and communication engineering, dedicating our senior design project, cost-effective cleanroom monitoring system, to Allah the almightly then to our beloved families, friends and muslims.

To begin with, we extend our dedication for this project to Allah the Almighty, followed by a tribute to our parents. They have served as the guiding beacons in our lives, enabling us to chase our aspirations and dreams. Therefore, our accomplishments in this academic endeavor would not have materialized without the unwavering love, counsel, and backing they provided. We attribute our success to their altruistic endeavors, recognizing that this project would not have come to fruition without their indispensable support.

Furthermore, we extend our dedication for this project to our friends and the briliant individuals within the field of Electronics Engineering who have served as a wellspring of inspiration for us in choosing this honorable vocation.In addition, we express our gratitude to our educators and advisors, who have played a essential role in steering us through this voyage of exploration and education. Their steadfast backing and motivation have motivated us with the assurance needed to confront obstacles and aim for the pinnacle of achievement.

In summary, we dedicate our graduation project, Cost-effective Cleanroom Monitoring System, to our families, friends, Muslims in the world, and to Allah. Also, we aspire for this project to stand as a symbol of optimism and a testament to the potential of human innovation and benevolence in improving the well-being of humanity. ”

ABSTRACT

Cost-effective Monitoring System for Biomedical and Cleanroom Facilities

There are some critical processes occurring inside semiconductor factories and hospitals that need to be monitored carefully. Here comes the role of the cleanroom, which is a closed and controlled room that has specific conditions and environment. Unfortunately, the available monitoring systems for cleanrooms in the market are very expensive and it is difficult to afford it. After doing a lot of research and meetings we found that the main problem is that the available monitoring systems are mostly expensive and not suitable for all kinds of cleanrooms and from that we chose our higher objectives which are designing an expandable and cost-effective monitoring system for biomedical and cleanroom facilities.

In this report we created three alternatives to solve our defined problem. For the first alternative we used a smart monitoring system using IoT (Internet of things), for the second alternative we connected and wired all components together and used multiplexers to group all similar sensors. In addition, for the last alternative, we used subsystems to monitor the cleanroom where each subsystem was monitoring at least three things which are temperature, humidity, and pressure. After doing the evaluations and comparisons between these three alternatives, we found out that the second alternative is the best one then we chose it to be our baseline design. After that, to mature our baseline design we did a lot of research and after that we added some sensors to the baseline design which are particle sensor, motion sensor, and some gases sensors.

Index Terms — Monitoring system, cleanroom, particle sensor, Temperature and humidity and pressure sensors, Decision-making Analysis

ACKNOWLEDGEMENT

The project team extends its gratitude to Allah for His wisdom and generosity that enabled us to successfully complete the project. We would also like to express our appreciation to Dr. Nebras Sobahi, our advisor, for his encouragement and assistance, which played a crucial role in the project's completion. Additionally, we want to acknowledge the support of our families, laboratory engineers, and graduated students who stood by us, providing motivation and encouragement throughout the journey.

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CHAPTER – 1 INTRODUCTION

1.1 ABOUT THE PROJECT

First of all, a cleanroom is a room containing a regulated environment that is controlled and monitored by reliable systems. Therefore, the air flow inside the cleanroom is filtered to remove the airborne particles inside the cleanroom. Moreover, cleanrooms can be found in hospitals and some semiconductor manufacturers that include critical processes. These critical processes like storing materials and sensitive surgeries require precise and regulated environments. So, to ensure the safety and succeeding for these processes, reliable monitoring and controlling systems are required. Furthermore, monitoring systems are used to precisely monitor the inside environment of the cleanroom including the temperature and humidity, pressure, and particles in the air. However, most of the available monitoring systems in the market are expensive and not suitable for all kind of cleanrooms. For instance, the range of the cost of some monitoring systems can be from 200,000 SR up to 1 million SR. So, the aim of this project is to design a cost-effective monitoring system that is suitable for most kind of cleanrooms.

1.2 BACKGROUND

In hospitals and semiconductors factories there are some critical processes occurring that require some specific circumstances and places. Therefore, the materials' storage rooms also required specific circumstances to save the stored materials from damaging. The rooms that are used for these applications are called cleanrooms. A cleanroom is a closed and controlled room that has specific conditions and environment. For instance, the environments' parameters like humidity, temperature, and pressure have fixed range that can't be exceeded. In addition, the airflow of the cleanroom also needs to be filtered since the air might carry out some dust and waste that will affect the applications running inside the cleanroom. Furthermore, these cleanrooms include controlling and monitoring systems that precisely monitor and control the environment of the cleanroom.

However, this project will only focus on monitoring the cleanroom and ignore the control part. First, to monitor the cleanroom it's required to have knowledge about the classifications that are used to classify the cleanroom. There are global standards used in classifying the cleanroom such as the Federal Standard 209 (FS 209E) and ISO 14644-1 standard [1]. In addition, the FS 209E is the first standard used to classify the cleanrooms and these standards have been replaced with the new standards which are ISO 14644-1 [1]. However, these standards are classified based on number of particles inside the cleanroom. In addition, the number of particles is presented based on the size of the particle. The size of the particles described by one particle per meter cube (1particle /m^3) [1]. The following table represents the classifications of the cleanroom based on acceptance concentration for each kind of particle [1].

Table 1: ISO 14644-1 Cleanroom Standards [1].

ISO Classification number (N)	Maximum concentration limits (particles/m^3 of air) for particles equal to and larger than the considered sizes shown below					
	0.1um	0.2um	0.3um	0.5um	1um	5um
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1 000	237	102	35	8	
ISO Class 4	10 000	2 370	1020	352	83	
ISO Class 5	100 000	23700	10 200	3 520	832	29
ISO Class 6	1000 000	237 000	102 000	35 200	8 320	293
ISO Class 7				352 000	83 200	2 930
ISO Class 8				3 520 000	832 000	29 300
ISO Class 9				35 200 000	8 320 000	293 000

These classifications have been classified based on the application of the cleanrooms. Either in hospitals or semiconductors manufacturing, each process requires a specific environment to achieve its purposes. However, the environment of the cleanroom also needs to be monitored including temperature, humidity, and pressure. Also, gases like NH3, Methane and chemicals need to be monitored since that the leakage of these chemicals may lead into huge hazards inside the cleanroom.

Moreover, after cleaning the image about the cleanroom. It's important to mention reasons for designing a monitoring system for the cleanroom.

Cleanrooms are sensitive areas that include sensitive machines and materials that may defect due to any small change in the environment around them. However, defects in these materials cost the hospitals and manufacturers a huge amount of money. In addition, the damage of unexpected changes in the environment can also affect the staff and workers inside the cleanrooms. It’s required to ensure the safety of all these resources to avoid waste and hazards. It’s required to ensure the safety of all these resources to avoid waste and hazards. On the other hand, if we check the available monitoring systems from the economic side, we find that most of the current products in the market are mostly expensive. The total cost of a comprehensive monitoring system requires a high budget which makes it difficult for small laboratory cleanrooms to afford it. So, it's required to design an expandable cost-effective monitoring system that is affordable for small cleanrooms and can be expanded to work on bigger cleanrooms.

CHAPTER – 2 CONCEPTUAL DESIGN

2.1 SITUATION DESCRIPTION

The first step is exploring the current situation of the problem. It's recommended to describe the situation and then come up with a statement that clearly represents the main issue.

To begin with, cleanrooms are closed places that require some strict conditions. It contains critical processes that must be precisely monitored and controlled. Therefore, there are some troubles that may happen in cleanrooms like fire and leakage of gases and chemicals. In addition, the environment of these cleanrooms must be precisely monitored by reliable systems including monitoring the temperature, humidity, and pressure. For instance, if some changes happened in the accepted limit of the temperature, the machines and stored materials inside the cleanroom might be defected. Furthermore, the damage from these accidents can also go to the workers and staff inside the cleaning room. For example, the workers' safety can be in danger if there is toxic gas or chemical leakage in the worker area inside the cleanroom. However, the available monitoring systems in the market are mostly expensive. So, the hospitals and factories are setting high budgets for monitoring systems to ensure the safety of their resources including machines, materials, and human resources. On the other hand, the small cleanrooms like laboratory rooms in the hospitals and some universities can't afford these monitoring systems due to their high cost. So, a cost-effective monitoring system that achieves the basic requirements is required to suit all different kinds of cleanrooms.

2.2 PROBLEM STATEMENT

Monitoring systems play an essential role in following up the operations that take place inside the cleanroom. If there are many matters happening inside the cleanroom that might affect the materials and staff inside the cleanroom, a reliable monitoring system is required. As a first step, it is recommended to thoroughly investigate the situation of the problem and hence come up with problem statements that explain the main issue from different perspectives. To complete this step, an approach called Statement/restatement will be used to explore the problem from various perspectives. Furthermore, at the end of this process, a new problem statement, that clearly describes the main issue of designing this project, will be clarified.

2.2.1 Statement – Restatement Technique

This technique is used to revise the initial problem statement by generating new problem statements based on some triggers. In addition, these triggers help in thinking about the problem from different perspectives. Then, we will be able to revise the initial problem statement into the final problem statement which is more precise and meaningful. Furthermore, this technique and triggers are taken from Strategies for Creative Problem-Solving book by H. Scott Folger [2]. The following list represents the process of statement-restatement technique and the final problem statement.

Initial problem statement: Monitoring systems for biomedical and cleanroom facilities are mostly expensive.

Trigger-1: Vary the stress pattern try placing emphasis on different words and phrases.

<u>Monitoring systems</u> for biomedical and cleanroom facilities are mostly expensive.

1. Does monitoring system need to be precise and reliable?

Monitoring systems for <u>biomedical and cleanroom facilities</u> are mostly expensive.

1. What parameters should be monitored in the cleanrooms?
2. Why do cleanrooms have to be monitored?
3. Do all cleanrooms have the same monitoring system?

Monitoring systems for biomedical and cleanroom facilities <u>are mostly expensive.</u>

1. What are the available products in the market?
2. Is it beneficial to make cheap monitoring systems?

The idea in applying this trigger to the problem statement is to try think about the problem from different perspectives by placing emphasis on different phrases and think deeply about it. Then, the results will be statements that clearly describe the keywords in the problem statement.

Trigger-2: Choose a term that has an explicit definition and substitute the explicit definition in each place that term appears.

Monitoring systems for biomedical and cleanroom facilities are mostly expensive.

1. What should be the cost of the monitoring system?
2. How can we determine if the monitoring system is cheap or expensive?
3. Why monitoring system shouldn't be expensive?

This trigger let us think about an essential term in the problem statement and how it's related to the main issue. In addition, it lets us think about the chosen term more deeply to get a clear understanding.

Trigger-3: make an opposite statement, change positives to negatives, and vice versa.

1. How can we make the monitoring system cheap?
2. What are the things that will make the monitoring system less expensive?

Making an opposite statement helps in imagining the problem clearly. Therefore, this trigger also helps in thinking about the level that we want to reach by making a cheap monitoring system.

Trigger-4: change “every” to “some”, “always” to “sometimes”, “sometimes” to “never”, and vice versa.

1. Monitoring systems for biomedical and cleanroom facilities are non-expensive.

This trigger makes us think why not all available monitoring systems are expensive.

Trigger-5: replace “persuasive words” in the problem statement such as “obviously”, “clearly”, and “certainly” with the argument it is supposed to be replacing.

1. Monitoring systems for biomedical and cleanroom facilities are clearly expensive.

Trigger-6: express words in the form of an equation or picture, and vice versa

1. $E = \frac{Q}{C}$

The parameter (E) represents the efficiency of the monitoring system and (C) is related to the cost of the system. In addition, the last parameter (Q) represents the quality of the monitoring system which is about how good is the system in monitoring the environment of the cleanroom. Therefore, the above equation describes the relation between the quality and the cost of the monitoring system. Increasing the quality and decreasing the cost led to high efficiency monitoring systems and vice versa.

Discussion:

To sum up everything that has been stated in this section, now the main issue became more clearly, and we are able to determine new problem statement that give precise meaning to main issue that this design is aiming to solve. However, the new problem statement: (the available monitoring systems are mostly expensive and not suitable for all kinds of cleanrooms).

2.3 PROJECT OBJECTIVES

The objectives of this project are to design a cost-effective monitoring system for closed environments. Since that the available products in the markets are mostly expensive, this project is aiming to improve the economy of monitoring systems for cleanrooms. In addition, the monitoring system is required to work with some sub-systems depending on the functions of the cleanroom. This project is aiming to design an expandable monitoring system that has the capability to accept multiple sub-systems. Furthermore, the other technical objectives of the project are designing a monitoring system that can be used in the cleanroom and monitoring the inside environment of any closed environment. This includes monitoring humidity, temperature, pressure and detecting particles in air inside the internal environment of the cleanrooms. Therefore, one of the most important objectives of this project is having an alarm system that will arise of any matter happening during the monitoring process.

2.4 PRODUCT DESIGN SPECIFICATIONS (PDS)

After several meetings with the customer, finally we came up with the design specification for the product. The function for this product is to monitor clean room facilities and alarm the user if there is any problem with the monitored clean room. Also, we should not forget that our product must be cost effective so, the following are the tables for product design specifications:

Table 2: In-scope specifications (Musts)

Musts in abbreviated form	Explanation

Expandable	The product must have the capability to connect to multiple sub-systems inside the cleanroom as much as needed and monitor the internal environment.
Monitor by itself	The product must monitor by itself without human intervention.
Backup battery	The product must have a backup battery that lasts at least for three hours.
Ability to measure three environmental factors	The factors that must be measured in the clean room are humidity, temperature, and particles in air.
SMS alarming	The product must alarm the user by sending SMS messages.

Table 3: Out-of-scope specifications (Wants)

Wants in abbreviated form	Explanation
Low cost	The total cost of the product doesn't exceed 2,500 SR.
Detect motions	The product can discover passed out people by using motion detector.
Ability to work in cleanrooms	The product can be used in different kinds of cleanrooms (Biomedical facilities, controlled storages, semiconductor cleanrooms).
Wi-Fi alarming	Besides using SMS messages, the product can alarm the user using Wi-Fi
Displaying the data	The product displays the data continuously via internet website

Table 4: Realistic assumptions

Assumptions in abbreviated form	Explanation
Provided power supply	The cleanroom is provided with a power supply to operate the product.
Availability of the product components	The product components can be obtained and delivered to Jeddah.
Controlled air conditioning	The cleanroom that will use the product should be controlled with air handling units and separated controlled air conditioning.

Table 5: Project risks

Risk	Remedy
The product components are not available in Jeddah.	Ordering the product components from online websites.
The product cost exceeds the required cost limit.	Trying to search for cheap parts or reduce the efficiency of the product with cheaper alternatives.
There is a conflict between the team members.	Checking the responsibilities in the deliverables of the project and reporting the conflicts to the advisor.
Facing difficulty in the product design process due to lack of experience.	Trying to check for online solutions and asking some experts.

2.4.1 APPLICABLE ENGINEERING STANDARDS

2.4.1.1 ISO 14644-1 (Associated controlled environments and cleanrooms) [3]:

ISO 14644-1:2015 air cleanliness in terms of concentration of airborne particles for cleanrooms and clean zones is specified and classified in this standard. For example, semiconductor and medicine factories should follow at least class 100 or higher cause their products can’t handle high concentration in air particles.

2.4.1.2 Saudi Council of Engineers (SCE) [4]:

GE-T9 (Magnetism and Electricity):

Engineers should be able to apply the Ohm and Kirchhoff circuit laws and they should have the knowledge of basic concepts of magnetic and electric quantities.

Also, they should have the ability to apply fundamentals of AC circuits and the ability to perform complex algebra.

GE-T12 (Project Management):

Engineers should be able to apply the fundamentals of project management (monitoring of project progress, scheduling techniques, work breakdown structure) and they should be able to understand the key issues related to the project liability, contract, and organization.

GE-T13 (Ethics and Professionalism):

Engineers should be able to observe standards, recognize the difference between what is ethical and what is legal, be familiar with codes of ethics in the engineering profession, be able to understand intellectual property issues, and be able to observe safety and ethical issues while making decisions.

2.4.1.3 Institute of Electrical and Electronics Engineers (IEEE) [5]:

P802.11:

Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications describe and specify the physical layer (PHY) and a set of media access control (MAC) for implementing wireless local area network (WLAN) (also known as Wi-Fi) computer communication in 24 frequency bands, including but not limited to the following frequency bands: 2.4 GHz, 5 GHz, 6 GHz, and 60 GHz. IEEE 802.11 is the most used wireless network standard all around the world. The realistic reason for that is to allow devices to communicate with each other and access the internet wirelessly.

2.4.2 REALISTIC CONSTRAINTS

One of the aspects that the customer focused on when conducting meetings was the restrictions that should not be crossed. It's required to explore the project from another perspective which focuses on the limitations and constraints that should not be violated. However, the following constraints are given from the customer and the design project should follow them:

- The total cost of the product must not exceed 3,500 SR.
- The operations inside the cleanroom must not be affected by the product’s material.
- The product must always be in operation mode.

- The product must be ready to use by the scheduled deadline.

Based on the information presented earlier in this chapter, you should clearly state the function of the device (to be designed). This section should include a discrete list of in-scope specifications (*i.e.* musts), out-of-scope specifications (*i.e.* wants), relevant engineering standards, realistic assumptions, constraints (*i.e.* limits or restrictions on the design) and project risks (*i.e.* mention any possible issues or problems that have the potential to arise but have not yet occurred, also, discuss any possible remedies).

2.5 LITERATURE REVIEW

One of the most important parts of any project is doing literature review. To understand any problem or idea, you must read and get knowledge about the previous research and products about your problem. However, after reading about the old research and papers, you will have enough knowledge about what people did and what is missing in their projects and what is needed to improve. This section will include a list of old research and products about the monitoring system in the cleanroom. The idea of each research will be described in addition to the advantages and disadvantages. Therefore, the gained knowledge from these Research will help in improving the project and generating design alternatives that will solve the problem statement of this project.

One project that found very interesting and somehow like our desired capstone project is a real-time air monitoring system [6]. The objective of this project was to install a real-time air monitoring System to detect hazardous levels of various gases and other environmental hazards and send alarms in one or two ways to protect people and sensitive places. Researchers focused on this system to detect carbon monoxide gas (CO(g)), natural gas (methane), smoke (particulate levels), humidity, and temperature. Once a detected substance exceeds a threshold level, an SMS will be sent by the system and an electrical circuit break will turn off the source of heightened particulate or gas levels. Therefore, we can see in the figures (1,2) some of the main electrical components of this project.

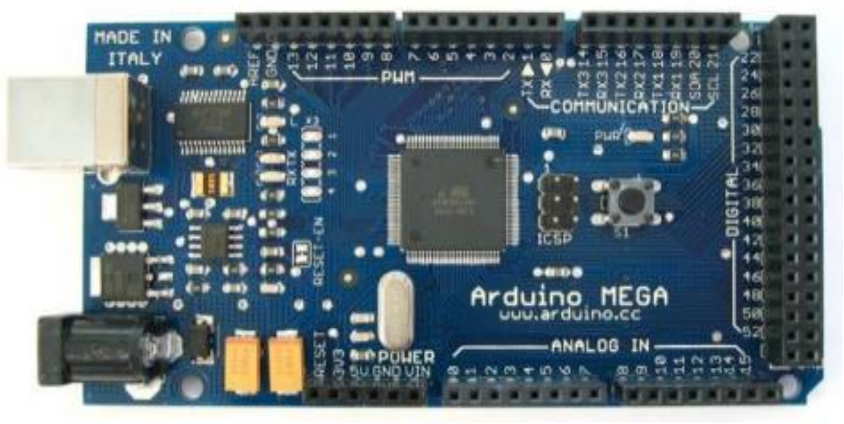

Figure 1: Arduino mega controller for the real-rime air monitoring system.

Figure 2: The GSM module used to send SMS massages.

Another project found was an automated relative humidity and temperature control system [7]. The aim of this project was to automatically control and monitor temperature and humidity in banana tissue culture laboratory to provide appropriate temperature and humidity for banana which is essential to maintain the fast growth and resistant to diseases and infection. A white box was used to test the prototype and simulate the banana tissue culture laboratory. Once the temperature exceeds a threshold value the cooler will operate and once it goes below another threshold value the heater will operate. In addition, the figure (3) below represents a prototype that describe the application of this project.

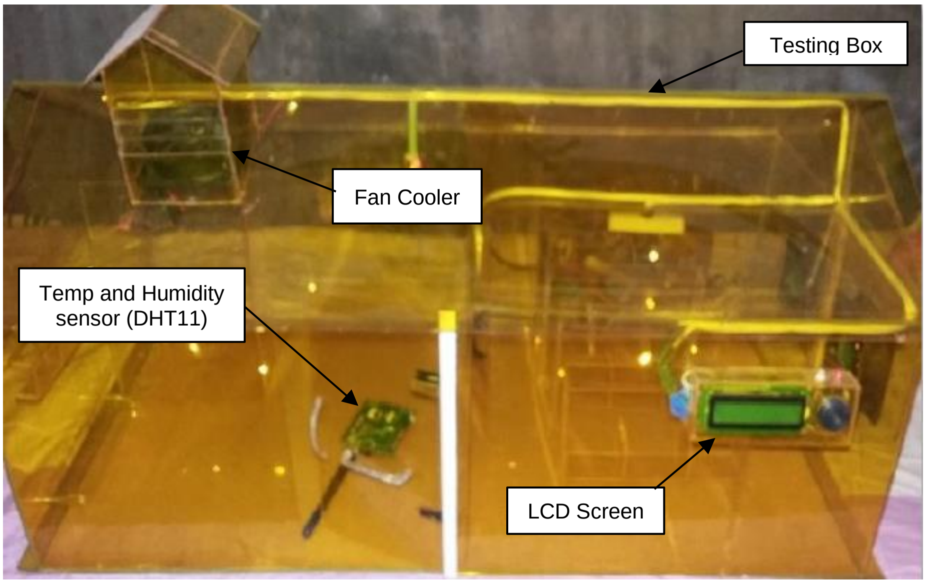

Figure 3: Prototype application of automated relative humidity and temperature control system.

Moreover, another founded project was aiming to develop low-cost solutions for monitoring ventilation parameters in underground mines using the Internet of Things (IoT) [8]. NodeMCU was used in this project to connect it to the Internet to carry out the online monitor. The sensors connected to the NodeMCU so connected to the website.

In addition, another project introduced an integration of the attendance system and the facility booking system for the university cleanroom application, which could significantly reduce human effort when compared to traditional paper-based booking and attendance systems [9]. The PHP programming languages integrated with the MySQL database were used to develop the booking system, while the Radio Frequency Identification (RFID) technology was chosen for the attendance system because it is less expensive than other technologies. The web-based booking system was developed successfully because it included dual functions for users and administrators for booking and managing [9]. This website is linked to the RFID technology attendance system. The attendance system was used to control and record the user, allowing only the user who was granted access to the laboratory based on the booking request to enter, as well as to record the entering and leaving times. This system integration can assist the laboratory assistant in efficiently managing the laboratory and thus maintaining a clean environment in the university cleanroom laboratory. In addition, the figures (4,5) mentioned below describe the overview and the flowchart of the integration attendance monitoring system.

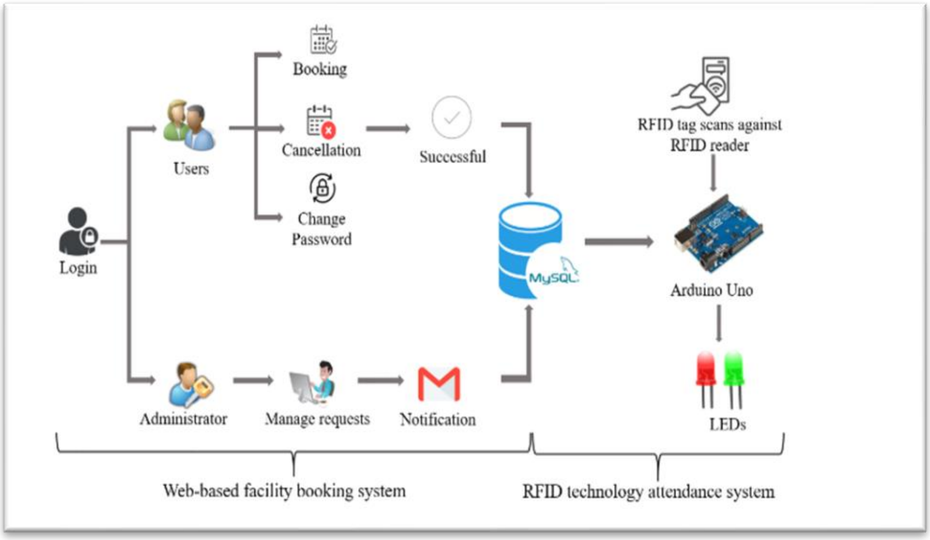

Figure 4: Integration of attendance monitoring system overview.

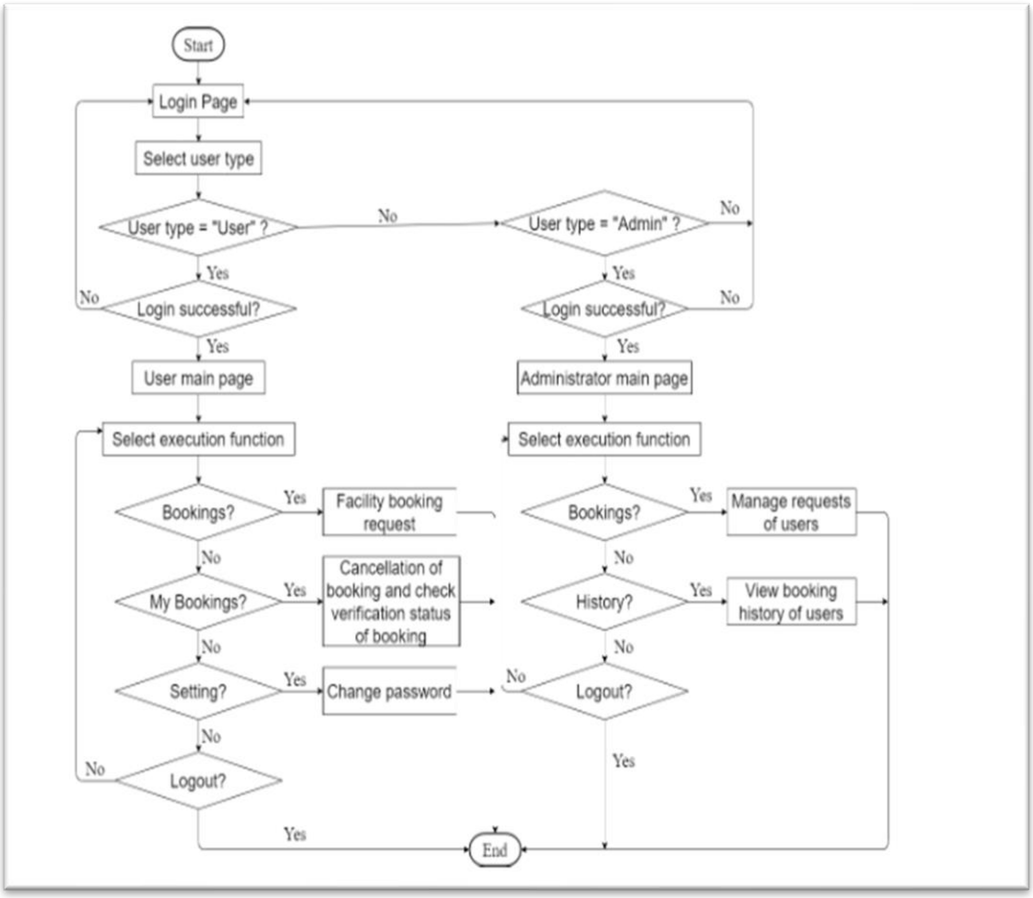

Figure 5: Integration of attendance monitoring system overall process flow chart.

Furthermore, there is also a paper presenting an Internet of Things (IoT) system for real-time PM monitoring named iDust [10]. This system is based on a WEMOS D1 mini microcontroller and a PMS5003 PM sensor that incorporates scattering principle to measure the value of particles suspended in the air (PM10, PM2.5, and

PM1.0). Through a Web dashboard for data visualization and remote notifications, the building manager can plan interventions for enhanced IAQ and ambient assisted living (AAL) as shown in figures (6,7) [10]. This paper is helpful because the researchers added a sensor for the number of particles in the air to the monitor system. They linked the monitoring system with a website for visualization data.

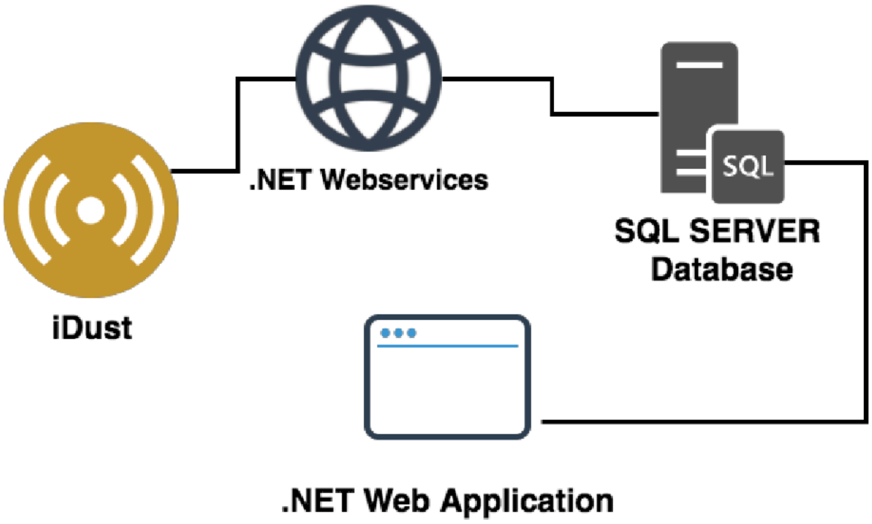

Figure 6: IOT for real-time particle monitoring system overview.

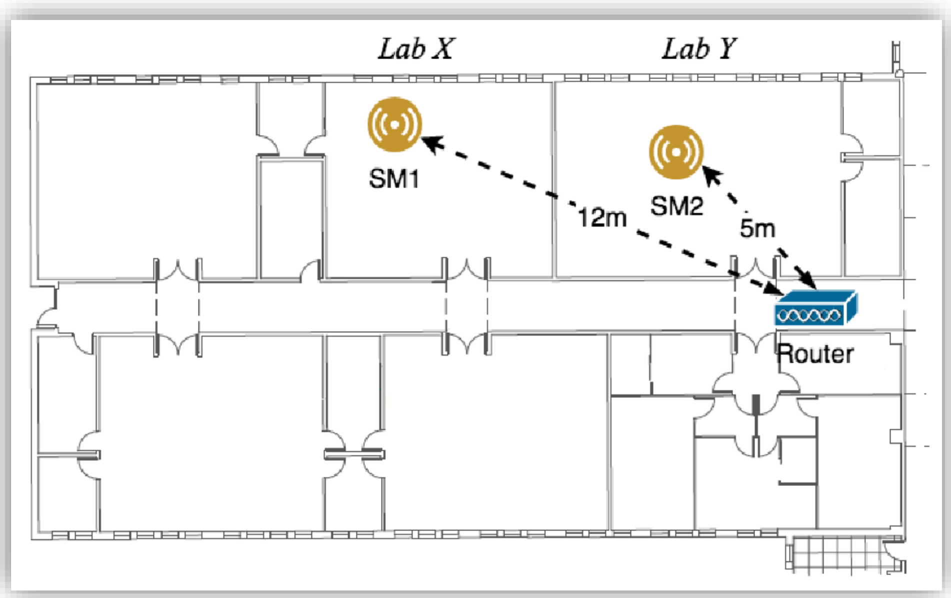

Figure 7: IOT for real-time particle monitoring system 2D projection sketch.

However, another article introduces an industrial tank temperature, pressure, and humidity control system [11]. The idea of this article is to use a microcontroller that connects the inputs and outputs. In addition, it linked several sensors to the microcontroller like temperature, pressure, and humidity sensors. The figure (8) below represents the main idea of this article and how the microcontroller control the inputs and outputs.

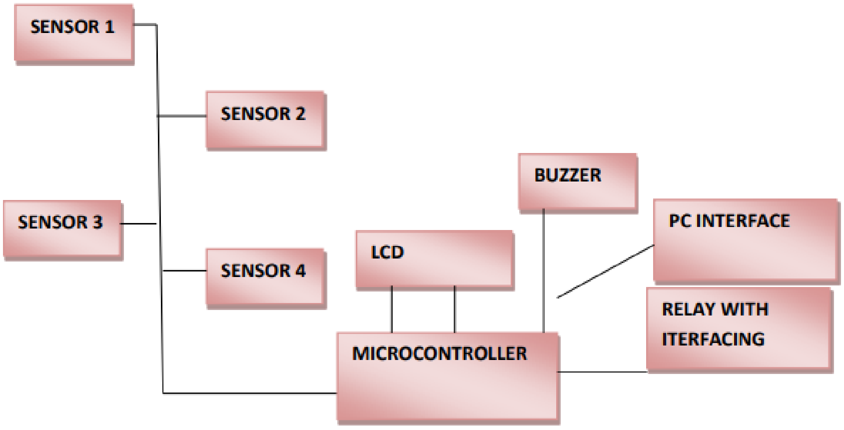

Figure 8: Tank temperature, pressure, and humidity controller block diagram.

However, the combination of the IOT and cloud computing in the medical-assisted environment is urgently needed because of the fast development of cloud computing and computer science technology. Another additional research was focusing more on individual development of the single technique and quite less research on the field of medical monitoring and managing service application have been conducted [12]. Moreover, this research represents the studies and analysis of the application of cloud computing and the Internet of Things on the field of medical environment.

For most developing countries, indoor air pollution (IAP) is a relevant area of concern as it has a direct impact on death and illness [13]. coal and biomass (crop residues, wood, dung, and charcoal) are the primary source of domestic energy used for around 3 billion people throughout the world, and indoor air quality (IAQ) leaves a direct impact on overall health and work efficiency because humans spend 80–90% of their routine time indoors. The main idea in this paper is the discussion of the use of wireless technologies for the development of cyber-physical systems for real-time monitoring. Moreover, we can see in this paper the components of the system like the microcontrollers used for designing and challenges in the development of real-time monitoring systems. Also, we can see in this paper some new ideas and scopes in the field of IAQ monitoring for the researchers.

On the other hand, there are two types of cleanrooms which are industrial cleanrooms and biomedical and pharmaceutical cleanrooms. Each type of cleanroom requires monitoring and controlling the air indoor and outdoor of the cleanroom. This paper describes the process of designing air conditioning monitoring system for cleanroom using ABB AC500 series PLC, Kingsview software, and the industrial Ethernet communication [14]. The system controls the temperature and airflow using sensors and draught fan. It measures the indoor and outdoor temperature and keeps monitoring if there is a detection outside the accepted range or not. The figures (9,10) below represent the flowcharts of controlling the temperature and humidity separately. Note than each flowchart describes the process where the values of the parameters are on the range or out.

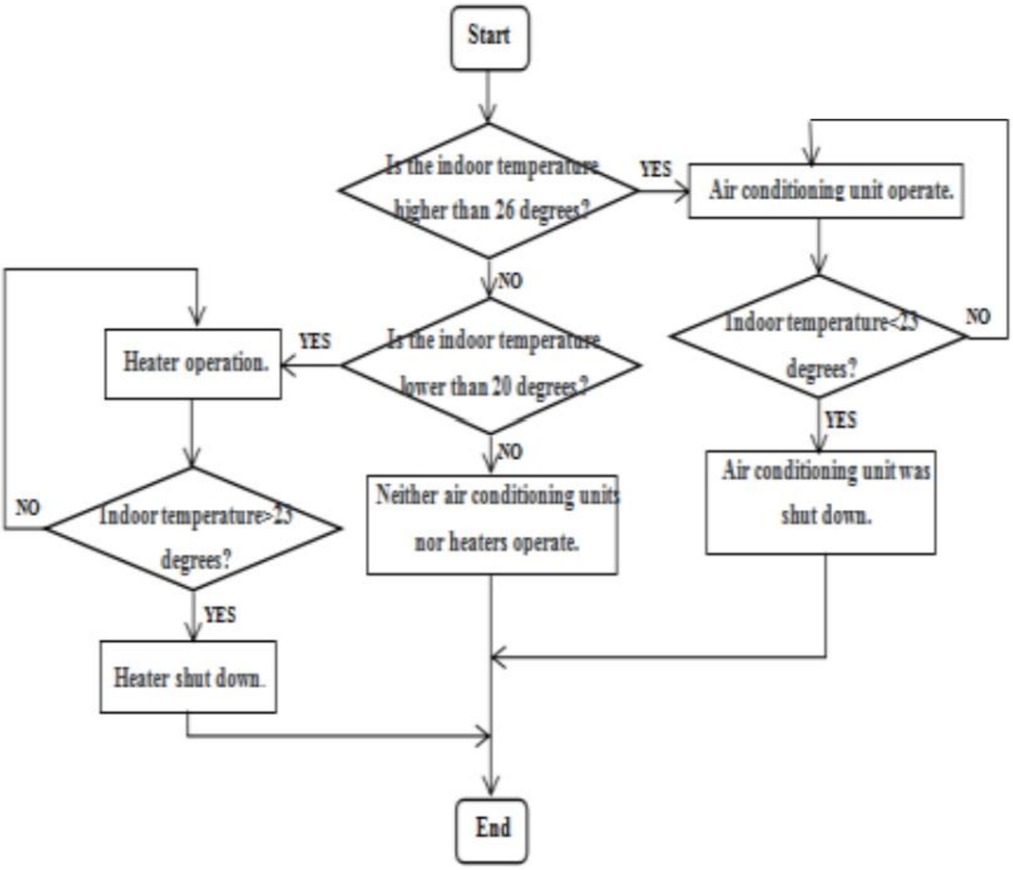

Figure 9: Air conditioning monitoring system flow chart for temperature.

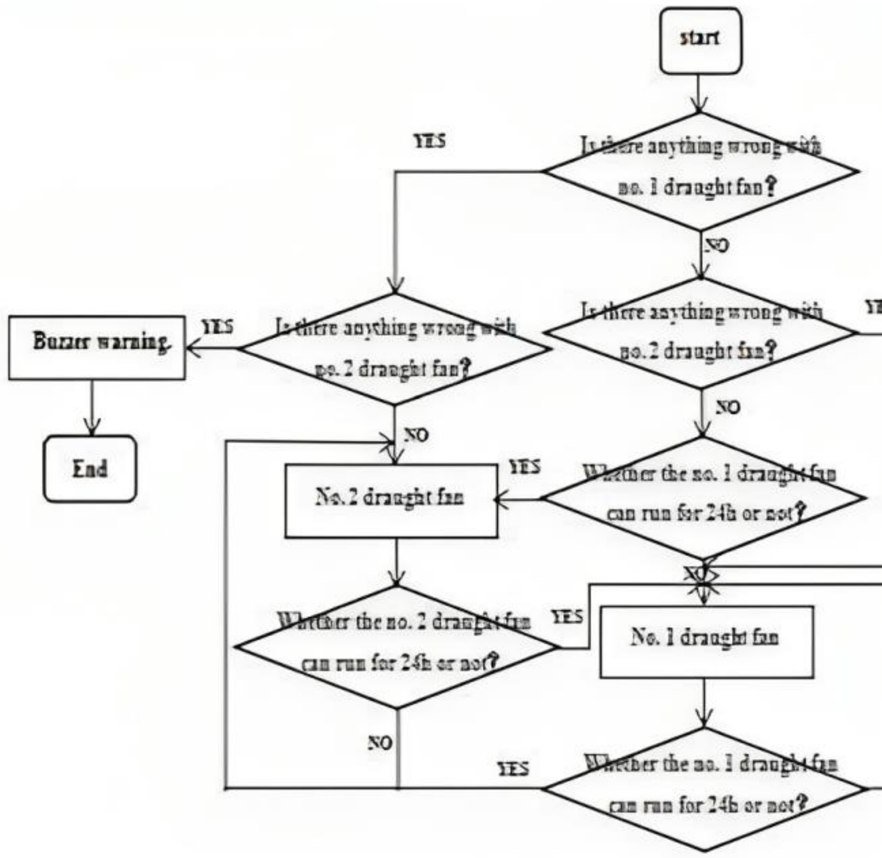

Figure 10: Air conditioning monitoring system flow chart for humidity.

Moreover, another founded paper was about monitoring cleanroom environment includes continuous monitoring the variable parameters like temperature, humidity, and pressure. This paper aimed to design a smart monitoring system using internet of things (IOT) to monitor an important parameter inside the cleanroom such as humidity, temperature, and pressure [15]. This paper tested monitoring the parameter using modeled cleanroom to improve the quality of monitoring systems and ensure having reliable system. In addition, this project used Arduino mega as a microcontroller, ESP 8266 Wi-Fi module, DHT 11 as an integrated temperature and humidity sensor, HX710B as a pressure sensor. In addition, the process of this design has been described by the flowchart mentioned in the figure (11) below:

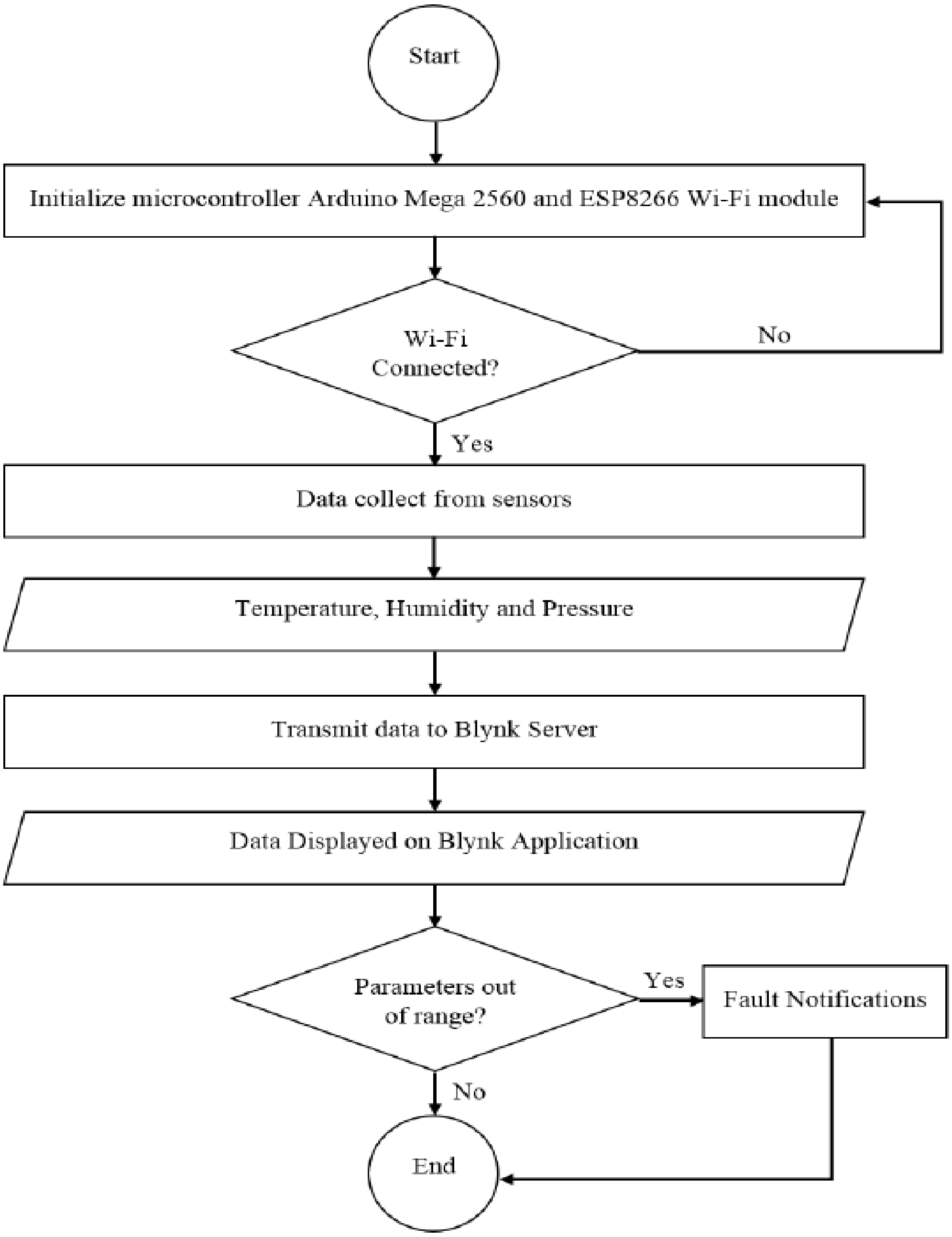

Figure 11: IOT monitoring system flowchart.

Moreover, the following paper aims to design an internet of thing-based temperature and humidity monitoring system [16]. The system uses wireless sensor networks to measure temperature and humidity. In addition, the system also included PID controller to ensure the limit of the humidity and temperature. Therefore, since measuring temperature and humidity are independent from each other, a control system is required to ensure the stability for each parameter. Also, the overview of the system has been described in the following figure (12). Note that this system was only focusing on monitoring the temperature and humidity of the cleanroom.

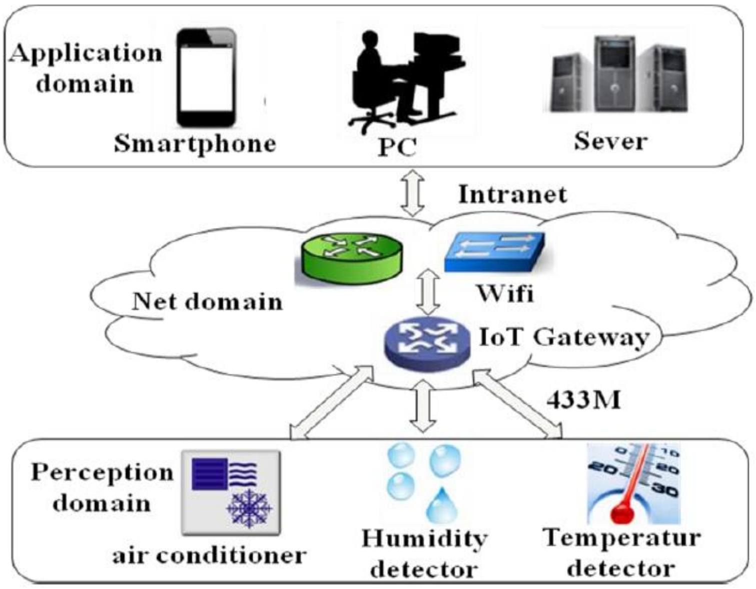

Figure 12: IOT humidity and temperature monitoring system block diagram.

In material synthesis and nanofabrication labs, safety is a critical issue and needs to be ensured. The following paper introduces the development of an embedded system with gas sensors to detect and monitor gases and chemical species in a material synthesis and nanofabrication facilities [17]. Therefore, the sensors used in sensing the chemical elements and gases are mostly expensive and unaffordable for small research labs. So, the main objective of this research is designing a cost-effective microcontroller-based gas and air quality detection and monitoring system for nanofabrication labs. This system can monitor and detect chemicals like butane, IPA and acetone and display the results on an LCD inside the facility or outside [17]. In addition, the system will send an alarm by Emil if the any gas exceeds the accepted limit.

Moreover, the preparation of aseptic products required very strict conditions, according to the guidelines like the ECGGMP (European Commission Guide to Good Manufacturing Practices) or the USP (United States Pharmacopoeia) [18]. This includes all the facilities, equipment, surfaces, and personnel that are assigned to the production process. Therefore, to ensure that condition, monitoring program is required to maintain and continuously check the conditions. This article represents the background and a proposal for a microbiological monitoring procedure depending on commonly accepted standards for cleanroom facilities [18]. To begin with, the surfaces inside the controlled environment must be smooth, unbreakable, and impervious to reduce the accumulation of particles. In addition, all the inputs and output terminals of the room should be highly sterile. However, for the monitoring system there are some variables that need to be monitored. These variables are temperature, humidity, pressure differential between the outside and the cleanroom and the pressure gradient in the cleanroom. Moreover, to filter the particles in air inside the controlled environment, there are some high-efficiency filters called HEPA filters [18]. These Filters are used to filter the air from particles and ensure the quality of air based on the national standards of cleanroom classifications.

However, another article represented here which is about how to track ammonia gas with high efficiency [19]. It uses a microchip combining extraction, concentration, phase separation, reaction, and detection for practical application (ammonia detection) in the semiconductor industry [19]. This article could help us to know the mechanism of analysis and also how the gases affect the cleanroom's efficiency.

Moreover, another founded source was a book called Clean Room Technology in ART Clinic [20]. This book is about clean rooms and the technologies used in clean rooms facilities [20]. There are six sections in this book and every section explains a specific thing about clean rooms. The first section was about the basic components of clean rooms, clean rooms classifications, and their technologies. In addition, the second section describes the designing and construction of clean rooms. Also, the third section was talking about operations and monitoring in clean rooms. Therefore, the fourth section talks about quality management in clean room assisted reproductive units. The fifth section talks about clinical outcomes and new developments, and lastly, the sixth section was about international experience and some case studies.

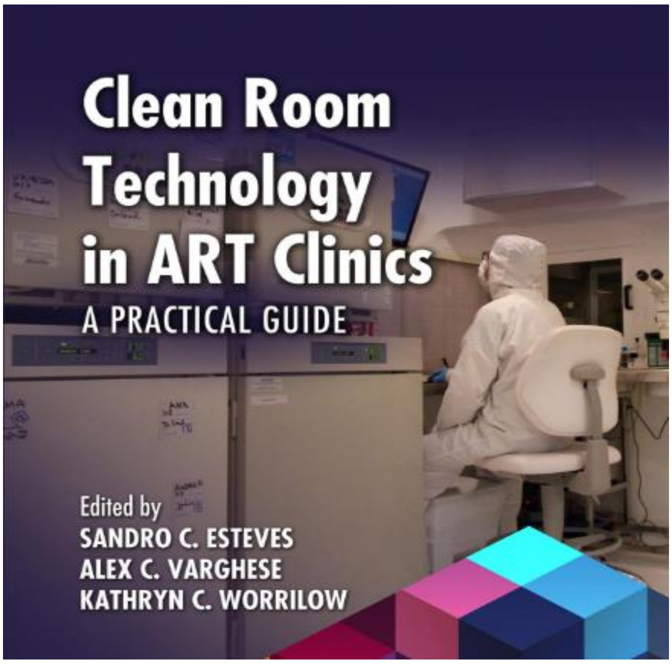

Figure 13: Cleanroom technology in ART clinic book.

Furthermore, another article came up with a new way to track small particles [21]. It reduces the usual tube length to calculate the number of particles in the air. In this study, to solve this problem, a multiple regression model was created. This model can correct the measurement error due to the decrease in efficiency by sampling tube length [21].

Moving on to another research. Designing monitoring system for cleanroom's environments requires monitoring every corner and space inside the cleanroom. One of the ways to design a monitoring system is to design a monitoring system based on Wireless Sensor Networks (WSNs) [22]. This paper includes the process of building a monitoring system based on WSNs. Firstly, a clustering-based network is used to build the monitoring system. This cluster-based network is inspired by LEACH (Low Energy Adaptive Cluster Hierarchy) [22].

Moreover, Airborne particles could be solid or liquid objects that take place within cumulative distribution [23]. This journal introduces the nature of the particles and the way to design a monitoring system to monitor the particles in cleanroom environments for stem cell cultures. In addition, this journal mentioned the particle counter devices and their selection method. Particle counter device determined based on the environment of the cleanroom and monitoring purpose.

Furthermore, we also explore the current available products on the market to understand the economy of the monitoring system in better way. The first product was GS1 industrial grade Wi-fi [24]. This device has many specifications. First it monitors via Wi-Fi, Mobile Cellular and Ethernet Communications Options. It only senses heat, humidity, and light. It could be used in medical supply, Server rooms, Agriculture, Horticulture, Cold-Chain storage, and Warehouse. Powered Via Battery or External Power Supply [24]. In addition, the cost of this product is around $159.00, and the following figure (14) represents an example of the product.

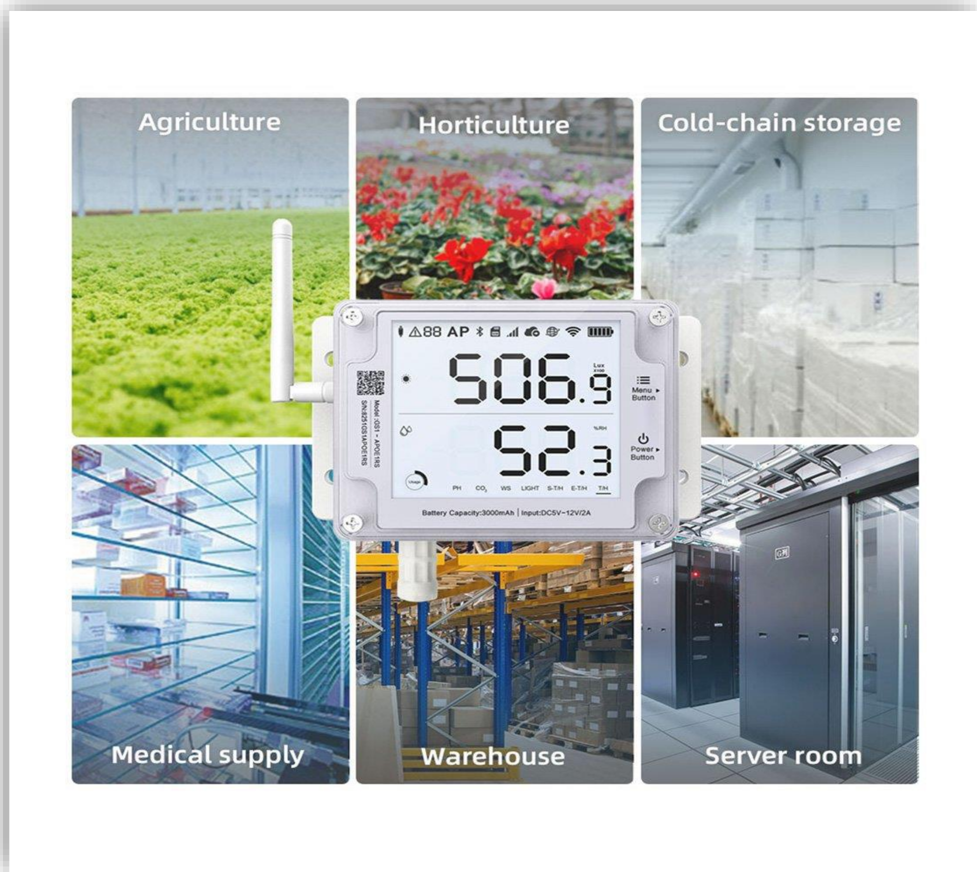

Figure 14: Humidity data logger.

Another device which is, INKBIRDPLUS air quality monitor [25]. This device is one of the best devices available on the market. It has many sensitivities. It detects (Carbon Dioxide (CO_2), Volatile Organic Compound (TVOC), Formaldehyde (HCHO), temperature and humidity,) [25]. In addition, it has a good design and a decent display, and its cost was 264 SAR [25].

Another device founded only monitors temperature. It has six channels. It has a touch screen display. Very accurate in sensing temperatures. [26] the following figure (15) represent an example of the product.

Figure 15: RS485 IR monitoring system.

2.5.1 Discussion

To sum up, most of the previous projects and research were focusing on monitoring one or two parameters of the inside environment of the cleanroom. In addition, the aim of this project is to design a generic and expandable monitoring system that will monitor most of the parameters of the inside environment in the cleanroom and capable of getting additional sub-systems. For instance, the system should monitor the temperature, humidity, pressure and detect the particles in the air. Therefore, the available products in the market are mostly expensive. So, this project is trying to design a cost-effective monitoring system that will improve the marketing of the monitoring systems for biomedical and cleanrooms facilities. Therefore, all gained knowledge from these products and research will help in generating alternative solutions for this project.

2.6 THEORETICAL BACKGROUND AND ANALYSIS

This section includes the methods, equations and techniques that have been used during working on this project. These techniques are representing basic sciences, engineering sciences, and mathematics that helped in making decisions and analyzing the monitoring system to generate the alternative solutions.

To begin with, there are many creative theoretical techniques that help in decision making process. In this project, we used some techniques that were mentioned in Strategies for Creative Problem-Solving book by H. Scott Folger [2]. The first method was Statement restatement method [2]. This method helps in defining the problem statement. The idea of this technique is to try to explore the main issue that the project aims to solve from different perspectives. Therefore, these techniques apply six triggers that help in generating new problem statements. The six triggers have been applied and mentioned in section 2.2.1 of this report. However, another technique from the book will be used during the process which is KT analysis [2]. KT analysis helps in comparing the alternative solutions. The idea of the KT analysis is to list the in-scope objectives of your design and check if the alternatives are able to achieve the objectives or not. Each alternative should go with all the in-scope objectives to continue on the second part of the KT analysis. On the other hand, each alternative that can't achieve one of the in-scope objectives will be immediately rejected. The second part of KT analysis is checking the ability of achieving the out-scope objectives. Each objective will have a weight from 0-9 based on the importance of the objective for the project. Then each alternative will be rated from 0-9 based on the ability if achieving this objective. Then, take the sum of the multiplication of weight and rate of each alternative and the highest total will be the best alternative to choose.

Moreover, there are also some mathematical equations that will help in this design project. For instance, the system contains a temperature sensor. And since we are going to measure the temperature, it's required to convert the out signal into a temperature degree in C°. To convert the output signal into the temperature degree, we will use the following formula [27].

$$T = -46.85 + 175.72 \times \frac{S_T}{2^{16}} \tag{1}$$

Where T is in C° and S_T represent the output signal. In addition, this formula is Ignoring chosen resolution.

2.7 ANALYZING ALTERNATIVE SOLUTIONS

In this section, we will start generating alternative solutions for this design project. First, alternatives will be generated to try to solve the problem in different ways. In addition, each alternative has its own unique design and components that will be described. For each design, the musts are achieved. First the system has a backup battery that will operate when the relay switches to it once electricity failure happens to the main source power. The three alternatives below have the three sensors particle humidity temperature and could be more than three. For each one except for the particle sensor, it consists of sub-systems that could be generic. The systems are standalone and send an alarming SMS automatically. However, after generating the alternatives, we will use KT analysis technique to compare between the alternative solutions and determine the best alternative that will be used as a baseline design.

2.7.1 Alternative 1:

In this alternative, the aim is to design a smart monitoring system using IoT (Internet of things). The system will measure the parameters using sensors and then transmit the data to Blynk server. Blynk server will analyze the transmitted data and check if the measured values exceeded the accepted range or not. If a value detected out of the range, the Blynk application will send an alarm notification to the safety department notifying of a matter happened during the monitoring process. Moreover, ESP8266 will connect to the Twilio website which will send an alarm SMS. Therefore, the main components that will be used in this design is listed as follow:

- Relay (5V)
- Battery(5V)
- Humidity and Temperature sensors (SHT20)
- Pressure sensors (BMP180)
- Particle sensor (PMS9003M)
- ESP8266 Wi-Fi module
- Blynk Application
- Twilio website

However, this design will be able to achieve the in-scope specifications of the project since it has an alarming system and can monitor the internal environment of the cleanroom including temperature, humidity, and particles. For the out scope, this alternative can achieve two items where the system alarm using Wi-Fi and the total cost will never approach 2500 SR. The following figure (16) represents the block diagram for the monitoring process.

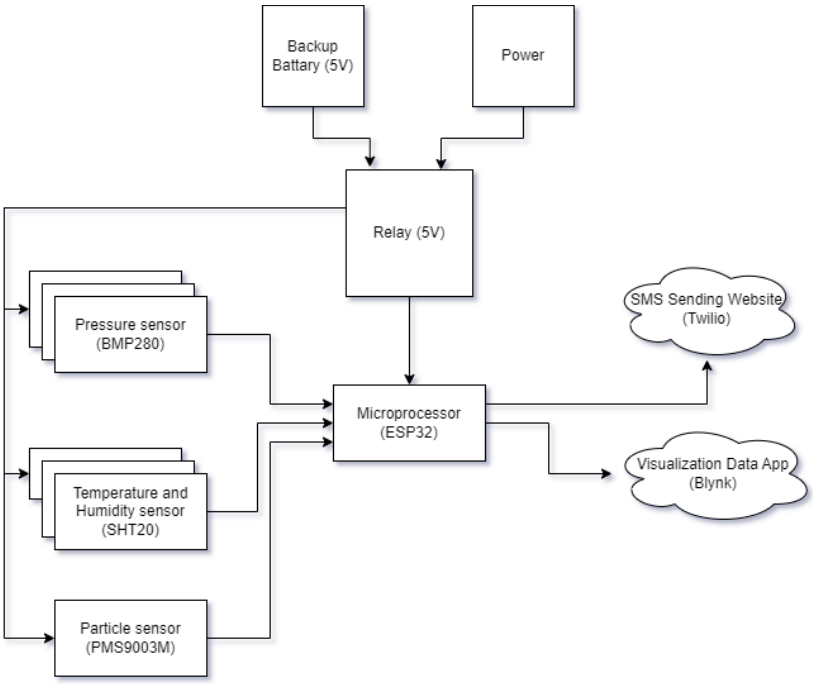

Figure 16: Block Diagram of alternative 1 using (IOT).

2.7.2 Alternative 2:

This alternative connects and wires all components together. The process of the alternative's system is arranged as follows. First, the sensors of each category except for the particle sensor will be connected to one multiplexer. Based on the multiplexer, there will be a capacitance for 8 sensors under one multiplexer as shown in figure (17) below and the system will be with only three sensors at beginning which are particle sensor, temperature and humidity sensor, and pressure sensor where the customer can add BMP280 sensor and SHT20 sensor within the specific range. Then the multiplexer will be connected to the Raspberry Pi. The Raspberry Pi will keep measuring the sensors continuously. Once there is a signal from these sensors it will sense an alarm SMS using GSMS900A. Moreover, this alternative will be able to achieve the out scope regarding the cost where it will not exceed the desired cost (2500 SR). Also, by the flexibility of the system, the system can operate in different types of clean rooms.

The system's components are:

- Relay (5V)
- Battery (5V)
- Humidity and Temperature sensors (SHT20)
- Particle sensor (PMS9003M)

- Pressure sensors (BMP180)
- GSMS900A
- Raspberry Pi
- Multiplexer (CD74HC4051-EP)
- Multiplexer (TCA9548A)

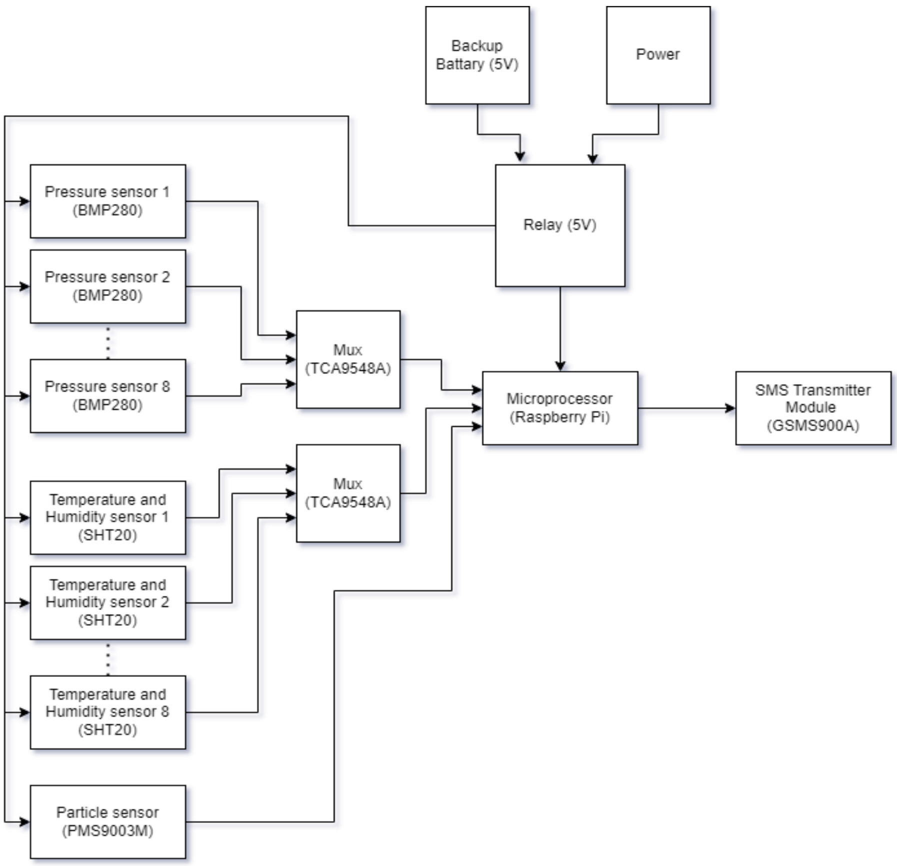

Figure 17: Block Diagram of alternative 2 using multiplexers and Raspberry PI.

2.7.3 Alternative 3:

The alternative in figure (18) below uses Master-Slave method. In such a huge clean room there is a need to add more sensors to cover the area. The Master-Slave method will provide that by setting three sensors (pressure humidity and temperature) with nano Arduino that will be the controller of that set as seen in figure (19). For the particle sensor, it will be connected to the ESP32 SIM800l (Master) directly. If a big clean room must be provided, the problem will be solved by adding more sets to the system. Each set is connected to the ESP32 SIM800l (Master) that is responsible for doing actions. The ESP32 SIM800l by itself, can receive the data from the slaves and analysis it then can send an alarm SMS. The Master-Slave method would help to indicate the source of issue if it occurred while the system still working and sense as well. Moving on to the out scopes, the alternative fulfill the out scopes regarding the expandability and ability to use the system in any clean room. Unfortunately, compared to the other alternatives, the system does not implement the high-level objectives in order to the high cost. Where the repetition of the sub-systems will deplete the budget with high cost. The alternative’s components are:

- Relay (5V)
- Battery (5V)
- Humidity and Temperature sensors (SHT20)
- Pressure sensors (BMP180)
- Particle sensor (PMS9003M)
- Arduino Nano
- ESP32 SIM800l

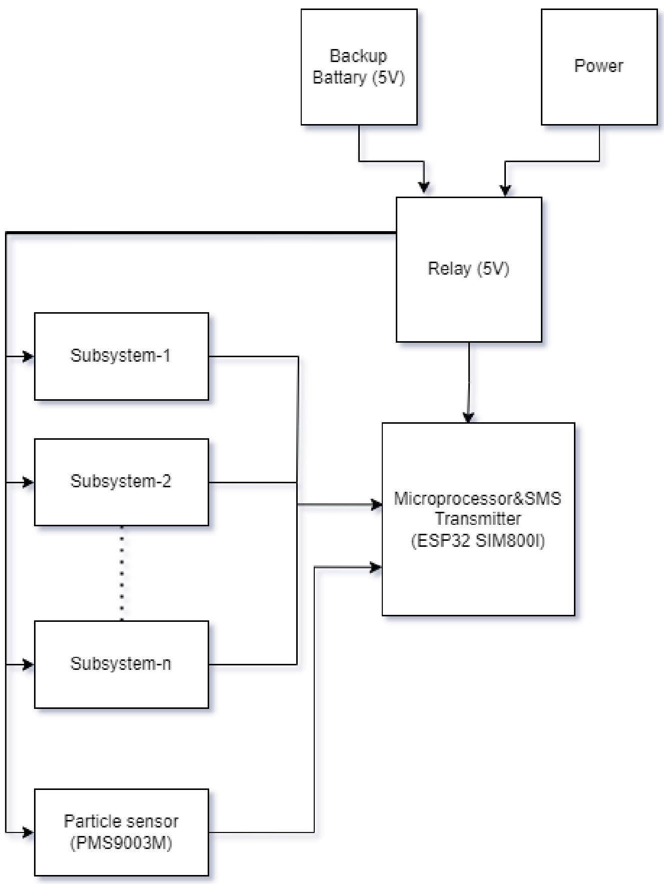

Figure 18: Block Diagram of alternative 3 using subsystems.

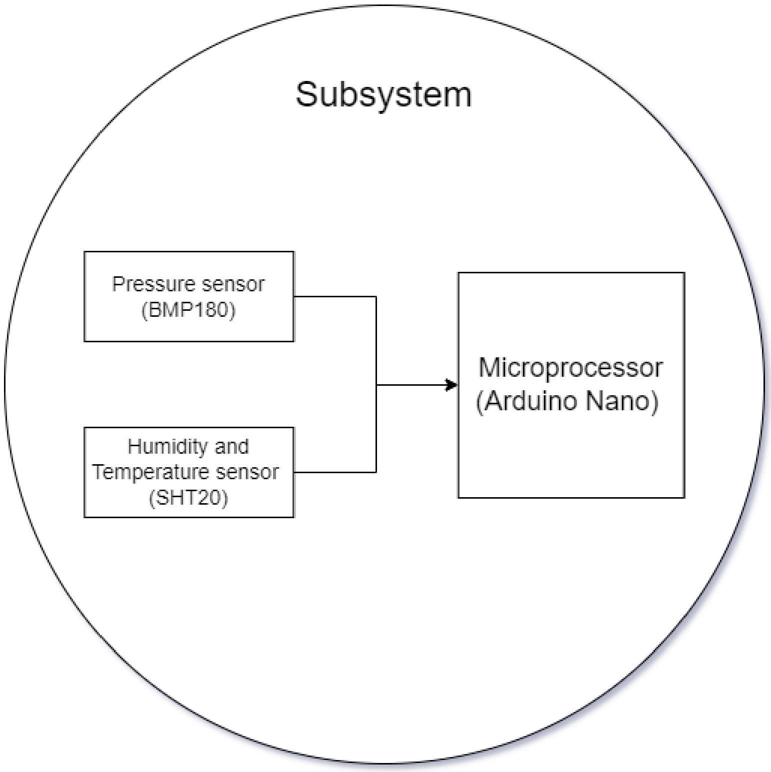

Figure 19: Block Diagram of the subsystem of Alternative 3.

Comparing between the alternatives:

Table 6: : KT Decision Analysis

KT Decision Analysis								
Artifacts:			Alternative 1		Alternative 2		Alternative 3	
Must	The system has the capability to monitor the internal environment and connect to multiple sub-systems inside the cleanroom as much as needed.		GO		GO		GO	
	The system must monitor by itself without human intervention.		GO		GO		GO	
	Include backup rechargeable battery for power outages situations that last at least for three hours.		GO		GO		GO	
	The system must measure the humidity, particles, and temperature.		GO		GO		GO	
	The system can alarm safety and security departments by sending SMS messages.		GO		GO		GO	
Wants		**Weight**	**Rate**	**Score**	**Rate**	**Score**	**Rate**	**Score**
The cost is lower than 2,500 SR.		8	8	64	7	56	2	16
The system detects motions in staff area to protect passed out people.		7	4	28	8	56	5	35
The system work with many kinds of cleanrooms		6	4	24	7	42	6	36
The system can use Wi-Fi in the alarming system		5	7	35	3	15	6	30
Touch screen used to display the parameter adjustment		4	7	28	4	16	3	12
		Total 1 =179			**Total 2=185**		**Total 2 =129**	

2.7.4 Discussion

After comparing the generated alternative solutions using KT analysis, we found that the best alternative design is alternative no.2. this alternative was the best solution that will achieve the project musts and wants in most effective way. However, this design is determined as a baseline design that will be improved and matured to achieve the desired objectives of this project.

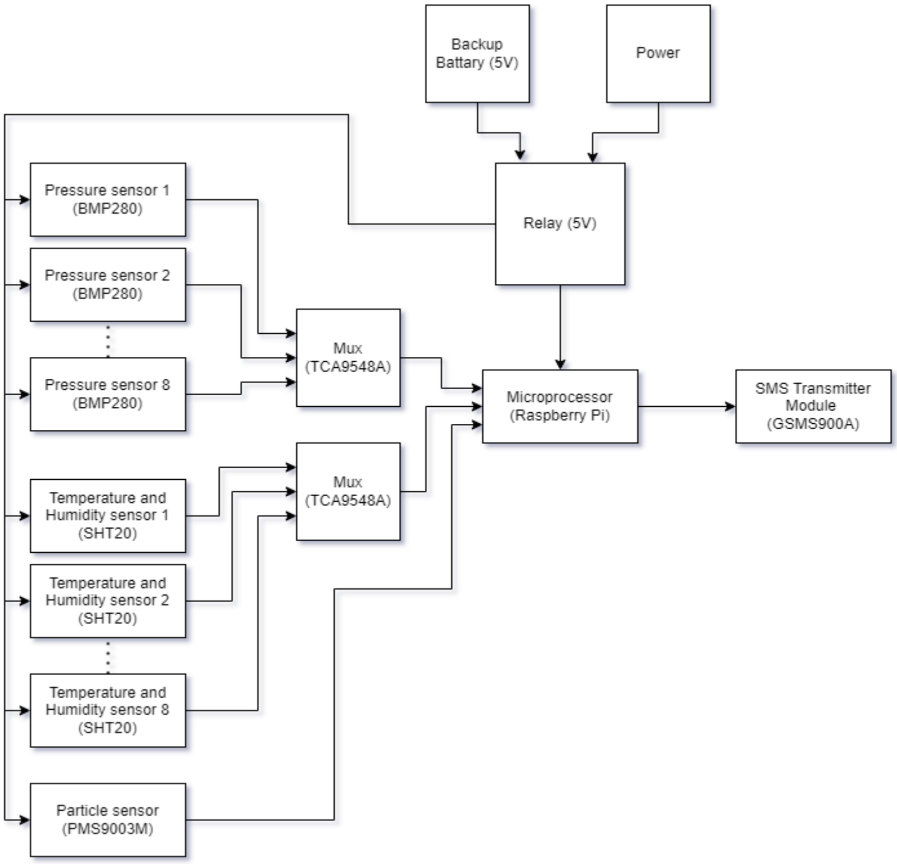

Figure 20: Baseline Design based on KT analysis.

2.8 MATURING BASELINE DESIGN

The second alternative was determined to be used as the baseline design of this project. In this section, we all start adjusting and maturing the baseline design. In addition, it's required to improve the system to make it different and better than the available systems. Therefore, from the research that we did about this topic, we found that most of the current systems only focused on some parameters of the environment in the cleanrooms. For instance, we found some monitoring systems that only monitor the temperature and humidity. Also, there were some systems that only focus on monitoring the pressure and gases inside the clean room. On the other hand, the aim of this design is to combine all these ideas in one design to make a comprehensive monitoring system that can monitor the cleanroom in a more effective way. However, to expand the design, we added the following parts to increase functions of the system.

- RCLW-0516 Motion Sensor.
- PMS9003M Particle Sensor.
- MQ-2 Smoke Sensor.
- MQ-137 NH3 Gas sensor.
- MQ-4 Methane Sensor.
- ThingSpeak cloud.

The above parts have been added to expand the system. For instance, we wanted the system to monitor the particles and motions in the cleanroom. In addition, a motion sensor has been added to detect the motions of worker in the cleanroom. This will help protect the workers and staff inside the cleaning room. Also, we add some gas sensors to monitor gases in the cleanroom and prevent gas leakage matters. However, NH_3 and Methane gases are the most common gases that may leak and cause matters inside the cleanrooms. Therefore, ThingSpeak Cloud hase been added to present a periodic reading from the sensors. This feature is just an extra feature to the system that keeps the users informed continuously with the situation in the cleanroom. Although this extra feature depends on Wi-Fi connection, the monitoring system will keep working in its main functions even if the system lost the Wi-Fi connection.

Furthermore, we found that there are some parts in the system that can be replaced with better components to enhance the performance of the system. So, we replaced the Arduino Uno processor and GSMS900A with ESP32 SIM800I. This processor can achieve the same functions of the Arduino Uno processor and contains an internal GSM module to send SMS messages. It also has the ability to be connected to Wi-Fi which will help in using ThingSpeak. The figure (21) below represents the adjusted block diagram for the baseline design.

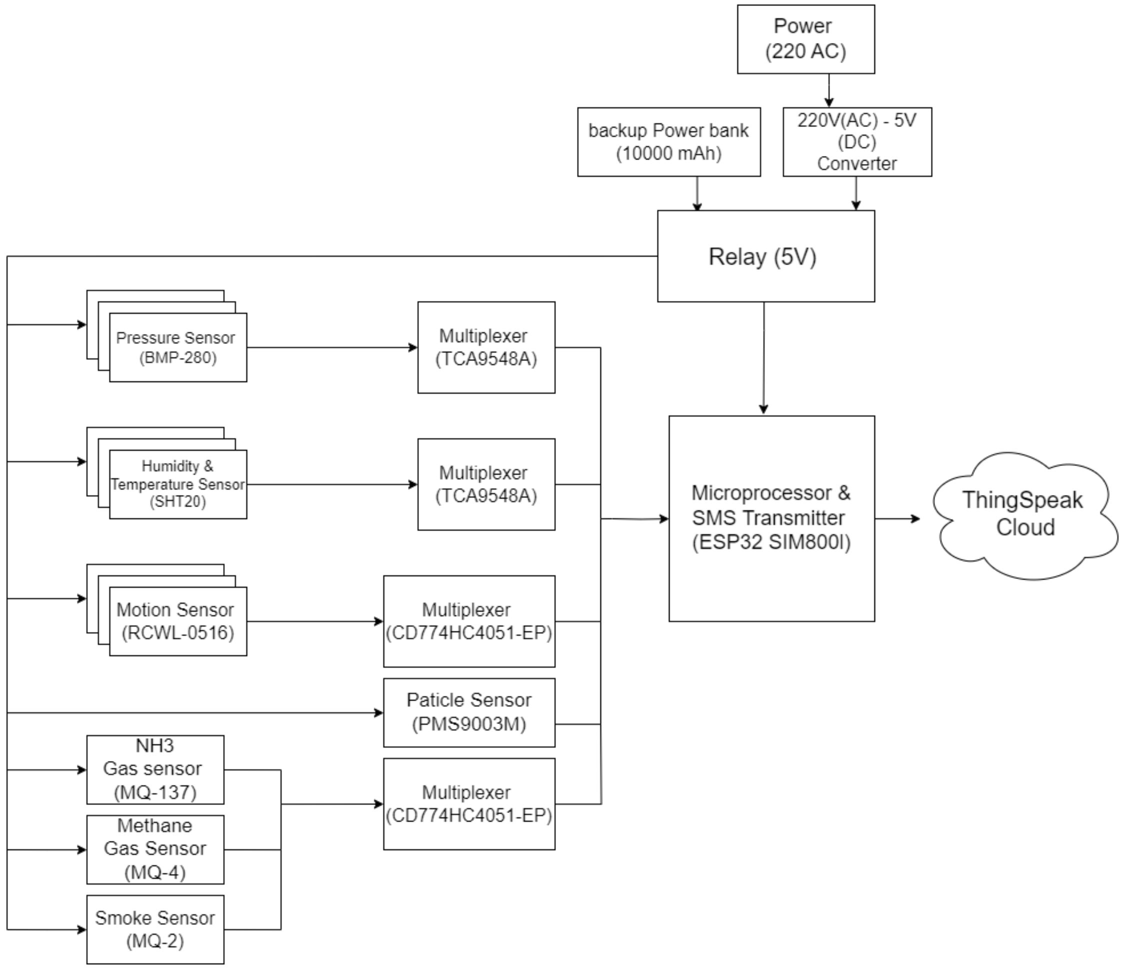

Figure 21: The Matured Baseline Design Block Diagram.

CHAPTER – 3 PRODUCT BASELINE DESIGN

3.1 BLOCK DIAGRAM

After maturing and adjusting the baseline design, now we have the full block diagram for the baseline design. The following figure (22,23) respresent the detailed block diagram after maturing the baseline design.

First, the system will include an AC power supply that is connected to an AC-DC converter. In addition, there will be a backup power bank controlled by Rely to feed the system if the min power supply has been turned off. Then, the power will be separated among the system to feed the sensors and the main processer which is ESP32 SIM800I. Therefore, each block of the sensors represents a group of sensors that are separated inside the cleanroom based on the area of the place. In addition, each group of the sensors is connected to a multiplexer that collects the data from sensors and transmits it to the main processer ESP32. The processer will analyze the transmitted data from the multiplexers and then send it via Wi-fi to server cloud and server application. Then, the processer will take the analyzed data and check if there is a matter or violation in the analyzed data, the internal GSM in the process will send an SMS as an alarm notification notifying for matter happening in the cleanroom.

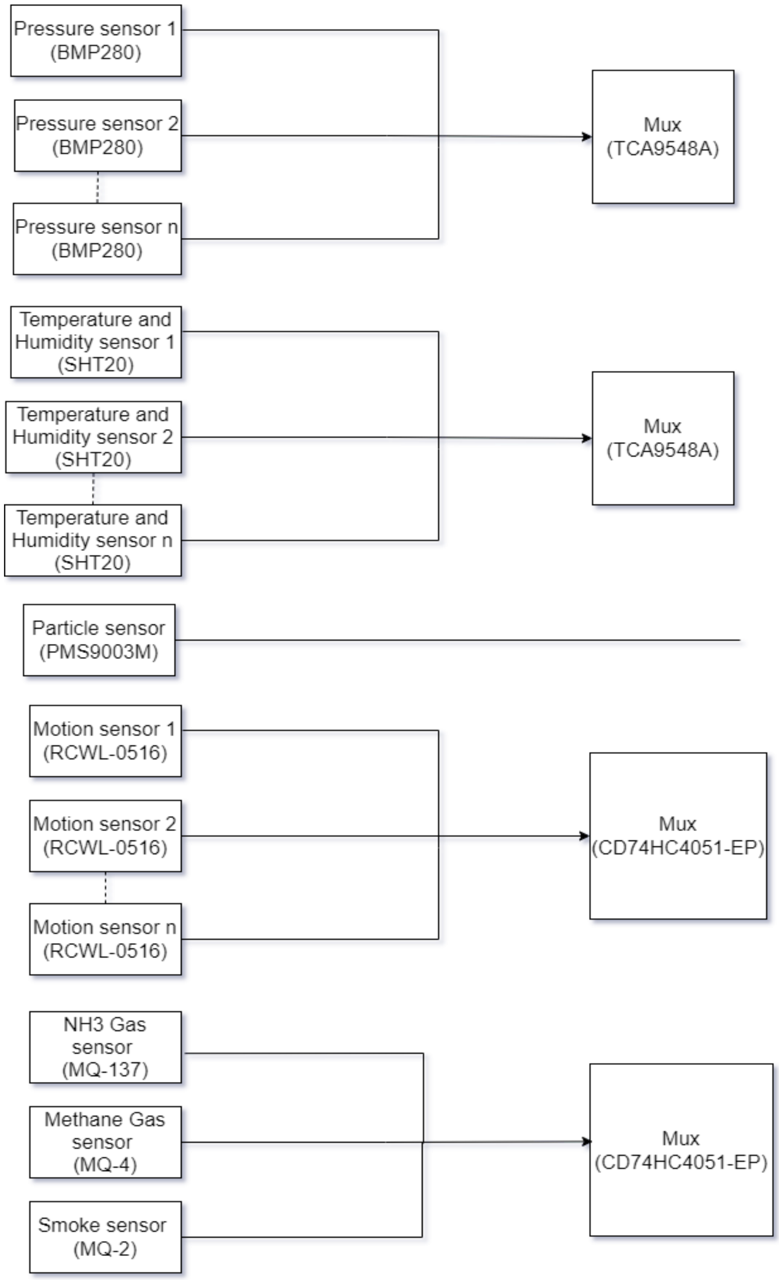

Figure 22: Block Diagram for multiplexers and sensor.

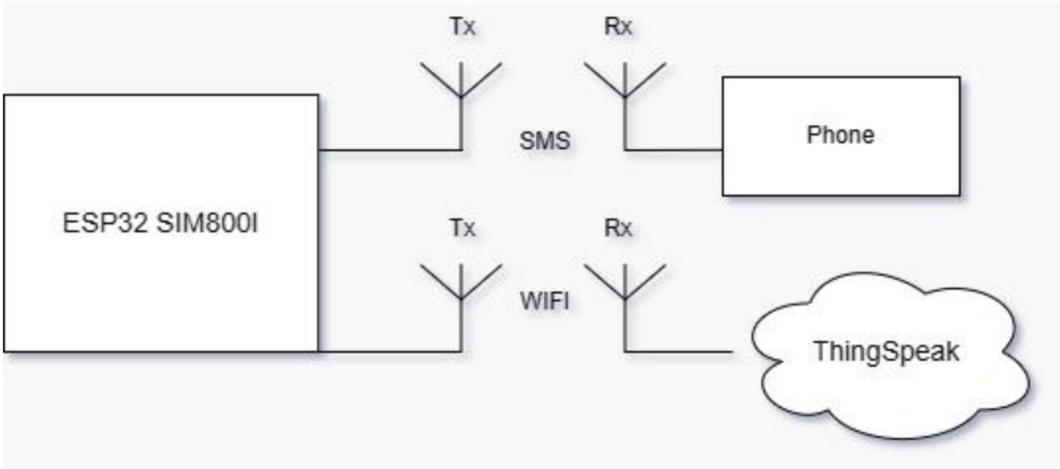

Figure 23: Block Diagram for ESP32 processer.

Sketch the functional block diagram (should be a more detailed one from the one shown in the previous chapter) of the final version of the optimum design, which is the system you started with at the beginning of this semester. Describe the diagram in few paragraphs as needed.

3.2 SYSTEM DESCRITPION

In this section, we will start explaining the system in more detail. Each block function in the block diagram will be explained in more detail. In addition, the circuit and components of the system will be described. Therefore, the electrical components' specifications and the relevant engineering standards. However, we will also do the simulation for some functions of the main system using Proteus software.

3.2.1 Circuit schematics

This subsection talks about the circuit schematics and the components used to install the system. The main component is ESP32 which is the component that does the arithmetic operations and controls the other components. Also, the circuit schematic shows how similar sensors share one multiplexer to expand the system as much as possible. Moreover, the circuit schematic shows the relay that is used to switch to the backup battery once the power goes out from the main AC power. In addition, the full circuit schematic is represented in the figure (24) mentioned below:

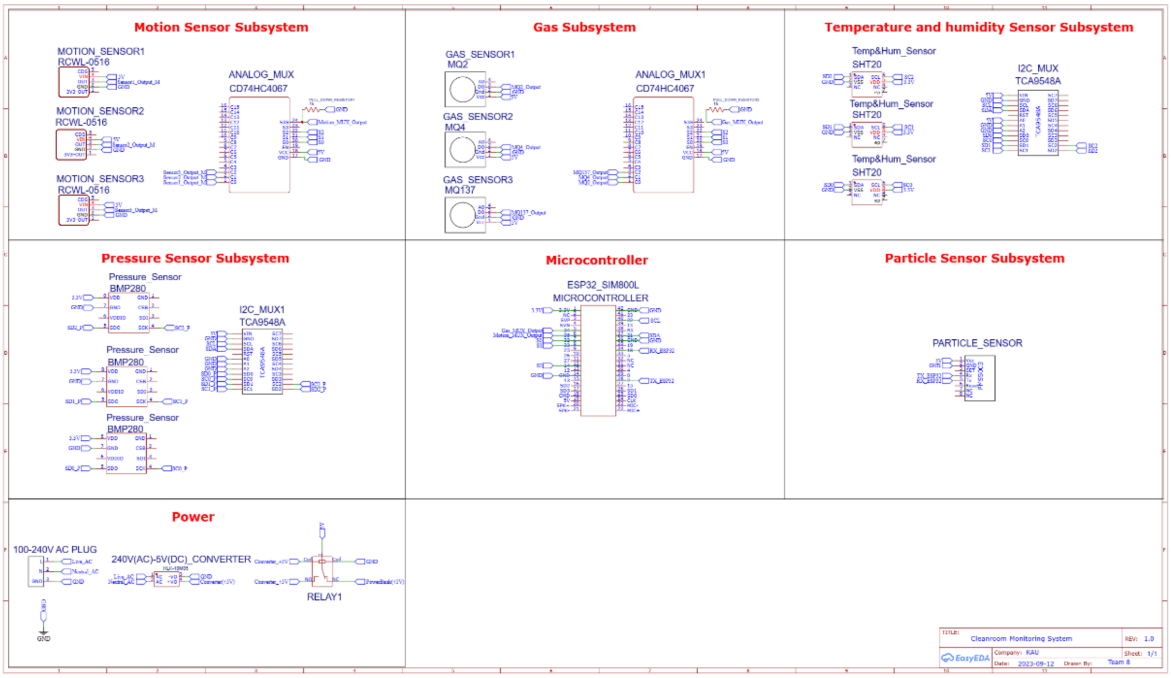

Figure 24: Circuit schematic.

3.2.2 Circuit component specifications

This section includes the list of the electrical components used in the design with the specifications of each component.

- **220AC – 5DC Convertor** [28]:

This converter will be used to convert the input AC voltage coming from the source into 5V DC voltage. The figure (25) and table (6) below represent the 3D CAD of the converter and its specifications.

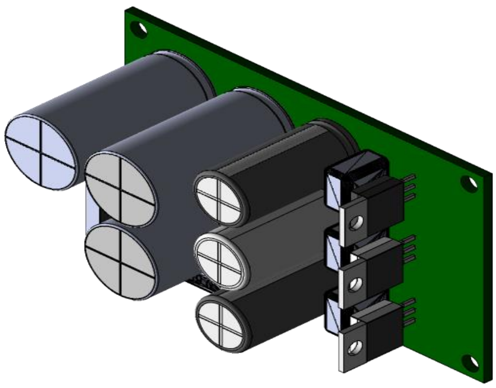

Figure 25: 220AC – 5DC convertor [29].

Table 7: 220AC – 5DC Convertor Specifications

Working temperature	-20 C to 70 C
Input voltage range	AC 45V-277V DC 65V-390V

Output voltage	5V ± 0.15
Output current	5V0mA-700mA
Test resistance	7 ohm (4.9 volts)
Output power	3.5W
Efficiency	80 – 70 %

- **Power Bank** [30]:

Figure 26: 20 mAh power bank from Anker [31].

Table 8: Power Bank Specifications

Capacity	20 mAh / 72 Wh
Input	5V – 2A
Normal output	5V – 2A
Quick charge 3.0 output	5-8V – 3A, 8-10V – 2.4A, 10-12V – 2A
Size	170 x 82 x 22 mm / 6.7 x 3.2 x 0.9 in
Weight	396 g / 14 oz

- **Relay (5V)** [32]**:**

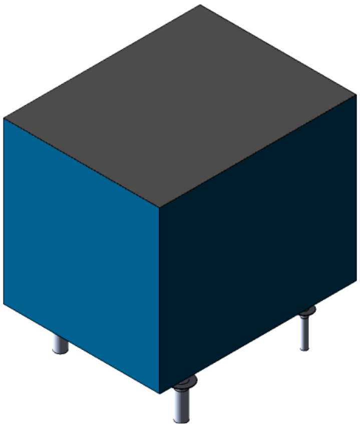

Figure 27: Relay (5V) [33].

Table 9: Relay (5V) Specifications

Operating Voltage Range	5V DC
Supply Current (A)	0.185
Operating Temperature (°C)	-25°C to +70°C
Opt. Relative Humidity (RH)	45 to 85%
Storage condition	-25°C to +70°C

Length (mm)	26.85
Width (mm)	31.6
Height (mm)	19.5
Weight (gm)	24
Shipment Weight	0.025 kg
Shipment Dimensions	3 × 4 × 2 cm

- **BMP280** [34]**:**

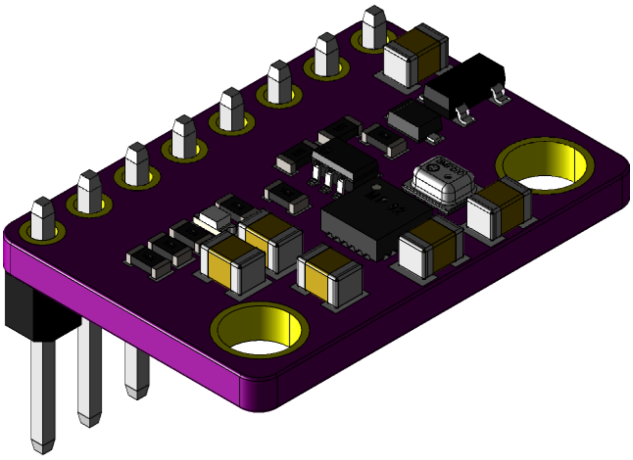

Figure 28: BMP280 [35].

Table 10: BMP280 Specifications

Supply Voltage (V)	1.71V to 3.6V
Current Consumption	2.7uA at 1Hz
Interface Type	I2C
Max I2C Speed	3.4Mhz
Pressure Range	300hPa to 1100hPa (+9000m to -500m)
PCB Size (mm)	11.5×15
Shipment Weight	1.3 g
Dimensions	15 × 12 × 2 mm

- **SHT20** [27]**:**

Figure 29: SHT20 I2C Temperature and Humidity [27].

Table 11: SHT20-Relative Humidity

Parameter	Condition	Value	Units
Resolution	12 bit	0.04	%RH
	8 bit	0.7	%RH
Accuracy tolerance	typ	±3.0	%RH
	max		%RH
Repeatability		±0.1	%RH
Hysteresis		±1	%RH
Nonlinearity		<0.1	%RH
Response time	τ 63%	8	s
Operating Range	extended	0 to 100	%RH
Long Term Drift	Typ.	< 0.25	%RH/yr

Table 12: SHT20- Temperature

Parameter	Condition	Value	Units
Resolution	14 bit	0.01	°C
	12 bit	0.04	°C
Accuracy tolerance	typ	±0.3	°C
	max	see Figure 3	°C
Repeatability		±0.1	°C
Operating Range	extended	-40 t0 125	°C
Response Time	τ 63%	5 to 30	s
Long Term Drift	Typ.	< 0.02	°C/yr

- **RCLW-0516** [36]**:**

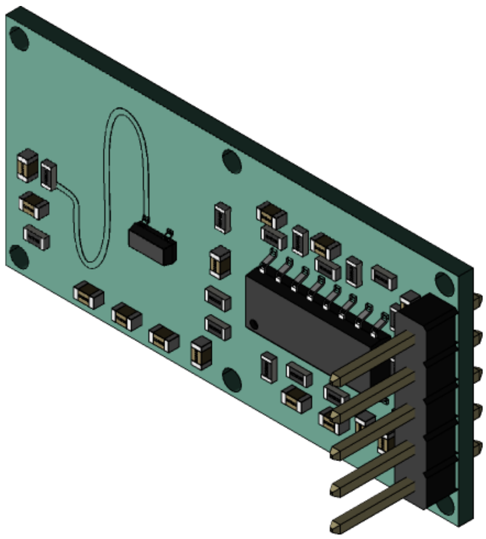

Figure 30: RCLW-0516 [37].

Table 13: RCLW-0516 Specifications

Product code	HCSENS0040
Supply Voltage	5V dc
Supply Current	>3mA (2.8mA typical)
Operating frequency	~3.2GHz
Transmit power	20mW (typical) / 30mW (max)
Size	36mm x 17mm

- **PMS9003M** [38]**:**

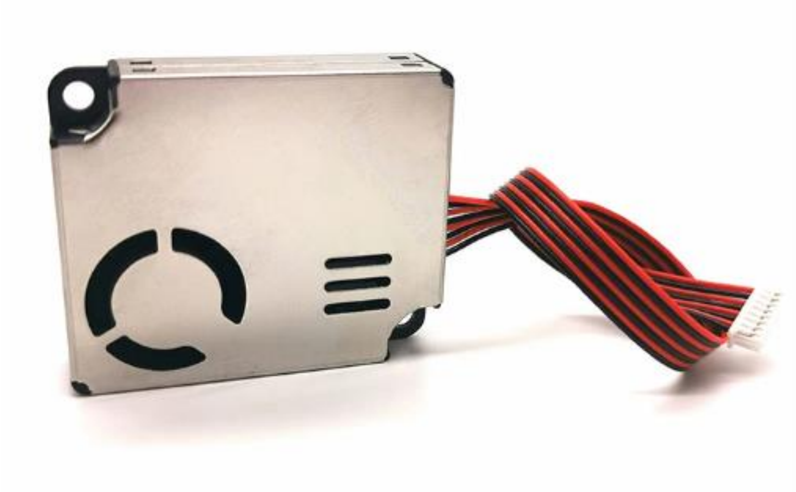

Figure 31:PMS9003M [39].

Table 14: PMS9003M Specifications

Parameter	**Index**	**Unit**
Particle Range of measurement	0.3~1.0；1.0~2.5；2.5~10	Micrometer（μm）
Particle Counting Efficiency	50%@0.3μm 98%@>=0.5μm	
Particle Effective Range （PM2.5 standard）	0~500	μg/m³
Particle Maximum Range （PM2.5 standard）*	≥1000	μg/m³
Particle Resolution	1	μg/m³
Particle Maximum Consistency Error (PM2.5 standard data)	±10%@100~500μg/m³ ±10μg/m³@0~100μg/m³	
Particle Standard Volume	0.1）	Litre（L
Single Response Time	≤1	Second（s）
Total Response Time	≤10	Second（s）
DC Power Supply	Typ:5.0 Min:4.5 Max: 5.5	Volt（V）
Active Current	≤100	Milliampere（mA）
Standby Current	≤1	Milliampere（mA）
Interface Level	L <0.8 @ 3.3 H >2.7@3.3	Volt（V）

Working Temperature Range	-10 ~ +60	℃
Working Humidity Range	0~95%	
Storage Temperature Range	-40 ~ +80	℃
MTTF	≥15000	Hour
Physical Size	48×40×12	Millimeter（mm）

- **Multiplexer (CD74HC4051-Q1) [40]:**

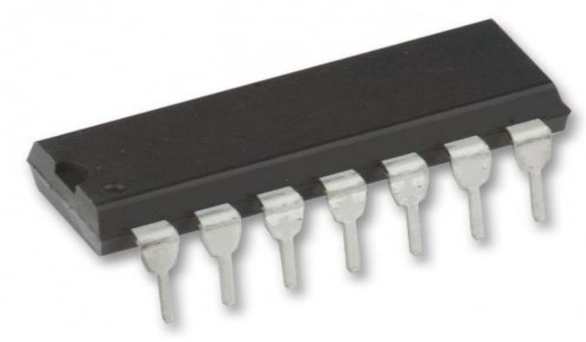

Figure 32: Multiplexer [41].

Table 15: Recommended Operating Conditions For CD74HC4051-Q1

			MIN	MAX	UNIT
VCC	**Supply voltage**		2	6	V
	Supply voltage, $V_{CC} - V_{EE}$		2	10	V
VEE	**Supply voltage**		0	−6	V
VIH	**High level- input voltage**	V_{CC} = 2 V	1.5		V
		V_{CC} = 4.5 V	3.15		
		V_{CC} = 6 V	4.2		
VIL	**Low level- input voltage**	V_{CC} = 2 V		0.5	V
		V_{CC} = 4.5 V		1.35	
		V_{CC} = 6 V		1.8	
V_I	**Input control voltage**		0	VCC	V
VIS	**Analog switch I/O voltage**		VEE	VCC	V
tt	**Input transition (rise and fall) time**	V_{CC} = 2 V	0	1000	ns
		V_{CC} = 4.5 V	0	500	
		V_{CC} = 6 V	0	400	
TA	**Operating free-air temperature**		−40	125	°C

o **ESP32 SIM800l** [42]**:**

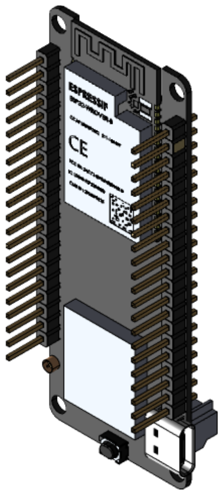

Figure 33: ESP32 SIM800l [43].

Table 16: ESP32 SIM800l Specifications

Supply voltage	3.8V – 4.2V
Recommended supply voltage	4V
Power consumption	sleep mode < 2.0mA idle mode < 7.0mA GSM transmission (avg): 350 mA GSM transmission (peek): 2000mA
Module size	25 x 23cm
Interface	UART (max. 2.8V) and AT commands
SIM card socket	microSIM (bottom side)
Supported frequencies	Quad Band (850 / 950 / 1800 /1900 MHz)
Antenna connector	IPX
Status signaling	LED
Working temperature range	-40 do + 85 ° C

o **MQ-4** [44]**:**

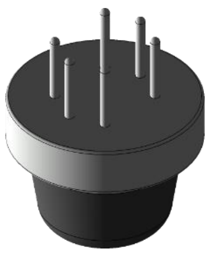

Figure 34: MQ-4 [45].

Table 17: MQ-4 Specifications

Model No.	MQ-4
Sensor Type	Semiconductor
Standard Encapsulation	Bakelite (Black Bakelite)

Detection Gas			Natural gas/ Methane
Concentration			300-10000ppm (Natural gas / Methane)
Circuit	Loop Voltage	V_c	≤24V DC
	Heater Voltage	V_H	5.0V±0.2V ACorDC
	Load Resistance	R_L	Adjustable
Character	Heater Resistance	R_H	31Ω±3Ω（Room Tem.）
	Heater consumption	P_H	≤900mW
	Sensing Resistance	R_s	2KΩ-20KΩ(in 5000ppm CH_4)
	Sensitivity	S	Rs(in air)/Rs(5000ppm CH_4)≥5
	Slope	α	≤0.6(R5000ppm/R3000ppm CH4)
Condition	Tem. Humidity		20℃±2℃；65%±5%RH
	Standard test circuit		Vc:5.0V±0.1V； V_H: 5.0V±0.1V
	Preheat time		Over 48 hours

- **MQ-2** [46]**:**

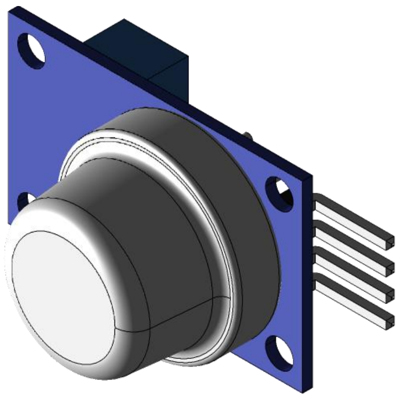

Figure 35: MQ-2 [47].

Table 18: MQ-2 Specifications

Model No.			MQ-2
Sensor Type			Semiconductor
Standard Encapsulation			Bakelite (Black Bakelite)
Detection Gas			Combustible gas and smoke
Concentration			300-10000ppm (Combustible gas)
Circuit	Loop Voltage	V_c	≤24V DC
	Heater Voltage	V_H	5.0V±0.2V AC or DC
	Load Resistance	R_L	Adjustable
Character	Heater Resistance	R_H	31Ω±3Ω（Room Tem. ）
	Heater consumption	P_H	≤900mW
	Sensing	R_s	2KΩ-20KΩ (in 100ppm NH_3)

	Resistance		
	Sensitivity	S	Rs (in air)/Rs (100ppm NH_3) ≥5
	Slope	α	≤0.6(R100ppm/R50ppm NH3)
Condition	Tem. Humidity		20℃±2℃；65%±5%RH
	Standard test circuit		Vc:5.0V±0.1V； V_H: 5.0V±0.1V
	Preheat time		Over 48 hours

- **MQ-137** [48]**:**

Figure 36: MQ-137 Sensor [49].

Table 19: MQ-137 Specifications

Model No.			MQ137
Sensor Type			Semiconductor
Standard Encapsulation			Bakelite (Black Bakelite)
Detection Gas			Ammonia
Concentration			5-500ppm (Ammonia)
Circuit	Loop Voltage	V_c	≤24V DC
	Heater Voltage	V_H	5.0V±0.2V ACorDC
	Load Resistance	R_L	Adjustable
Character	Heater Resistance	R_H	31Ω±3Ω（Room Tem.）
	Heater consumption	P_H	≤900mW
	Sensing Resistance	R_s	2KΩ-15KΩ(in 50ppm NH_3)
	Sensitivity	S	Rs(in air)/Rs(5000ppm CH_4)≥5
	Slope	α	≤0.6(R100ppm/R50ppm NH3)
Condition	Tem. Humidity		20℃±2℃；65%±5%RH
	Standard test circuit		Vc: 5.0V±0.1V； V_H: 5.0V±0.1V
	Preheat time		Over 48 hours

- **TCA9548A** [50]**:**

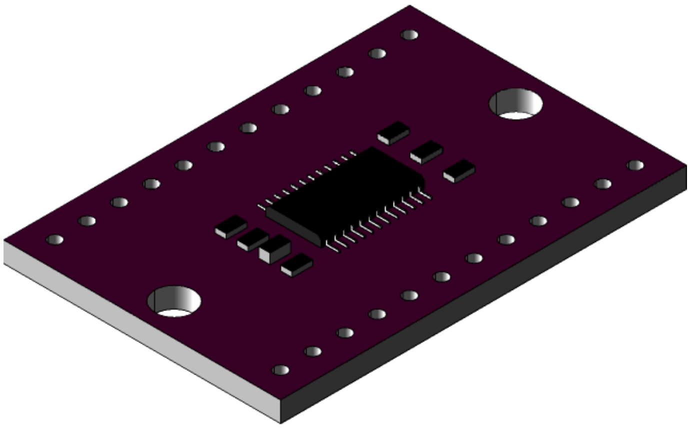

Figure 37: TCA9548A Multiplexer [50].

Table 20: TCA9548A Specifications

			MIN	**MAX**	**UNIT**
V_{CC}	Supply voltage		-0.5	7	V
V_I	Input voltage (2)		-0.5	7	V
I_I	Input current		-20	20	mA
I_O	Output current		-25		mA
I_{CC}	Supply current		-100	100	mA
T_{stg}	Storage temperature		-65	150	°C
T_J	Max Junction Temperature	V_{CC} ≤ 3.6 V		130	℃
		V_{CC} ≤ 5.5 V		90	

3.2.3 Flowcharts for software blocks

The flow chart for the product is shown in this subsection. It illustrates the steps that the product takes to perform its required function. First, the product will collect the data from the sensors after connecting all system components to the power supply. Then, the data will be shown in the Blynk app using Blynk server and the ESP32 will send SMS messages once the sensors observe that the detected factors are exceeding the threshold values. The figure (38,39) below represents the flowchart of the design.

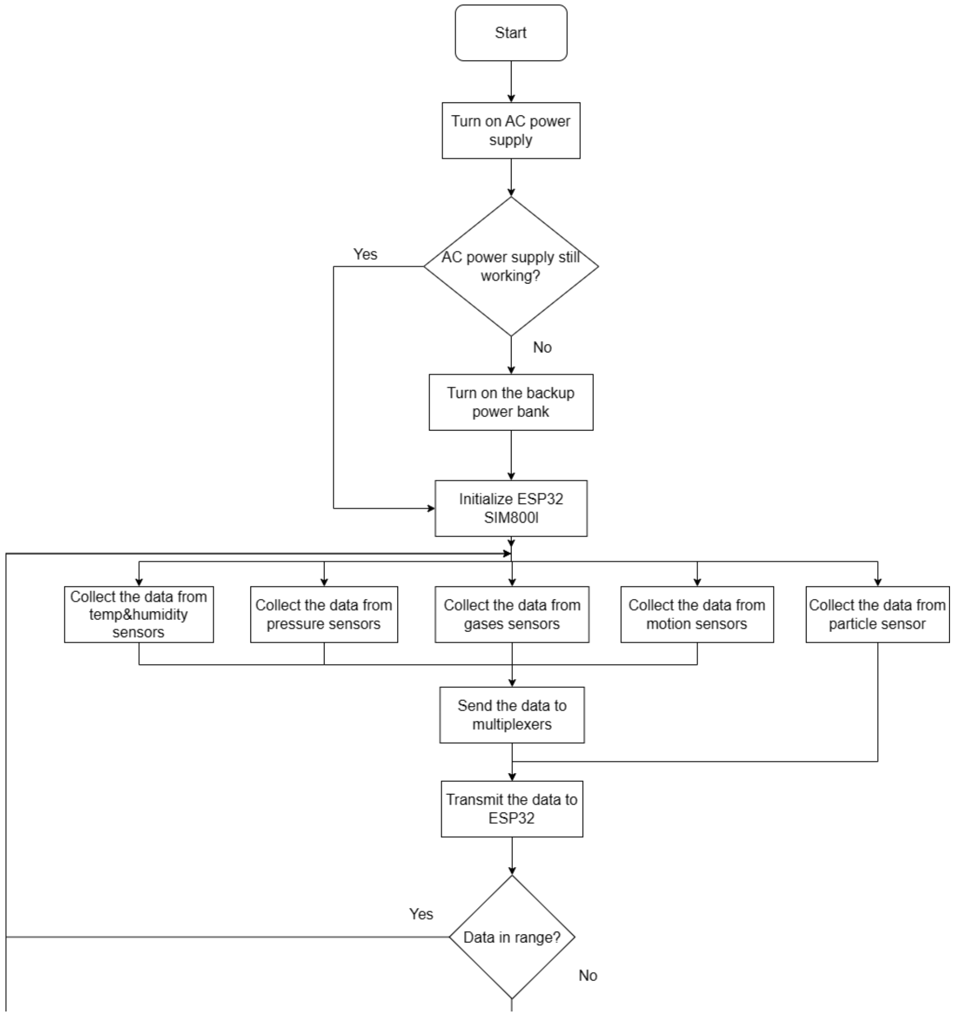

Figure 38: Flowchart Part 1

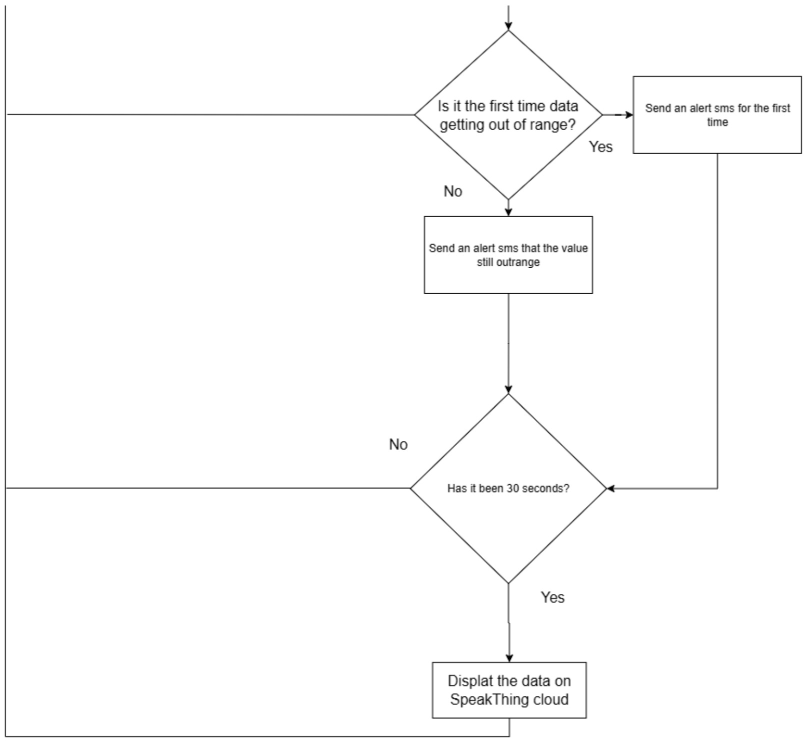

Figure 39: Flowchart Part 2.

3.2.4 Relative Engineering Standards

In this design we applied the engineering standards that mentioned in section 2.4.1 in this report. For instance, the standard ISO 14644-1 has been used to determine the particle sensor. The device that is used in this design is PMS9003M. as we can see in table 13, the PMS9003M is applying the ISO 14644-1 standards in its performance and specifications. However, another example of applying engineering standards is using the ESP32. This device follows the standard P802.11 that mentioned in section 2.4. It uses Wi-Fi communications following the P802. 11 standards to represent the measured data from sensor in Blynk application.

3.2.5 Possible aesthetics

The design of project can be more professional with some additional aesthetics. For instance, in order to make the design simple, the system's components can be shown in PCB (Printed Circuit Board) module which will make design looks simple and weight less. Regarding the safety, the design can be covered by safety case using 3D printer.

3.2.6 System Inputs and Outputs

The system will work with input power 220 AC and has a backup power supply with 1000 mAh. In addition, the inputs for the system are the reading of the data from the sensors inside the cleanroom which are motion sensor, particle sensor, temperature and humidity sensor, pressure sensor, smoke sensor, methane gas sensor, and ammonia gas sensor. Therefore, this system has two outputs and can send the data to the user in two ways. One way or one output is showing the data continuously through ThingSpeak cloud using internet of things. The other output is sending SMS messages to the user once the thresholds values of the sensors are exceeded.

However, the ranges and accepted values of the parameters will be setting based on the Class 100 (ISO-5) standard for cleanroom since it is the most common and applicable standard. The following list represents the ranges for each parameter based on ISO-5 standard classifications.

- Temperature degree [51]
    - 20° - 24°
    - $\pm$ 1 degree's variation
- Relative humidity [51]
    - 30% - 60%
    - $\pm$ 5% degree's variation
- Atmospheric Pressure [52]
    - $\pm$ 1013 hPa
    - $\pm$ 10 hPa Variation.
- Particle [53]
    - Particles size $\geq$ 0.1 um
        - (100,000) particle/m^3
    - Particles size $\geq$ 0.2 um
        - (23,700) particle/m^3
    - Particles size $\geq$ 0.3 um
        - (10,200) particle/m^3
    - Particles size $\geq$ 0.5 um
        - (3,520) particle/m^3
    - Particles size $\geq$ 1 um (
        - 832) particle/m^3
    - Particles size $\geq$ 5 um
        - (29) particle/m^3

Therefore, for the gases and motion detection, there is no specified ranges since it will work as weather there is a leakage in gases or motion detection inside the cleanroom or not. The alarming will work based on the condition of the sensor's detection.

3.2.7 Operating Instructions

In this subsection we will show the operating instruction that every user should follow to use our system.

1- Setup the system and the sensors in their appropriate places.
2- Ensure that all sensors are connected to the power supply.
3- Make the initial position of the relay connected to the main power supply.

4- After connecting the power to the product, make sure that you can see the data on ThingSpeak cloud.
5- Do not substitute sensor locations at the multiplexer inputs.
6- If you want to add a new sensor, add it to a multiplexer that has sensors like it.
7- Do not attempt to add sensors that the system does not use.

3.3 SIMULATION RESULTS

Here we will show the simulation results for some parts of the system after connecting and testing the design components. In addition, the software that we used to simulate our design was Proteus software. The following figures represent the simulation results for some of the subsystems.

3.3.1 Gas Sensors Simulation:

Here in MQ-4 simulation, two modes of the sensor were simulated where one of them ON and the other is OFF. The schematic shows the output as a digital signal and that is the goal to understand the way of how the sensor works as seen in figure (40) below. However, the MQ-4 sensor gives the data as an analog signal.

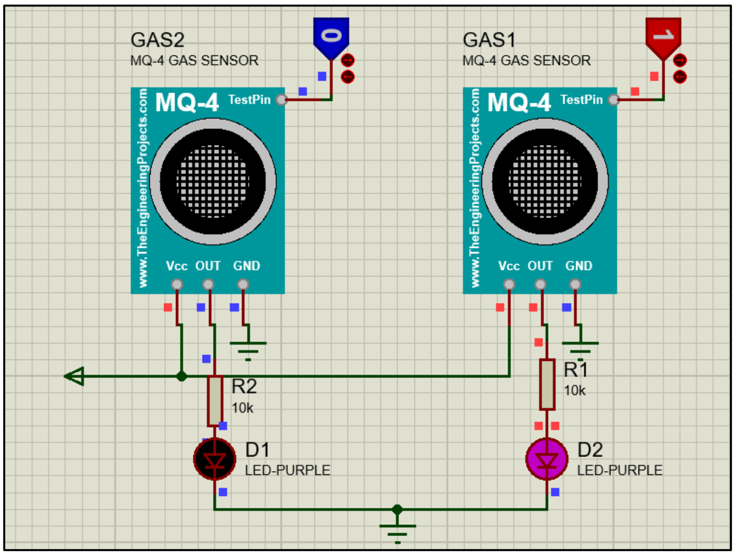

Figure 40: Gas Sensors Simulation.

3.3.2 Multiplexer analog output:

The main principle of analog Multiplexer's work is to decrease the number of analog pins. To clear that, the circuit simulation below in figure (41), uses an Arduino as example to show that there is only one analog pin connected to the Arduino that is represent the value of seven analog pins (Potentiometer) connected to the Multiplexer (74HC4051).

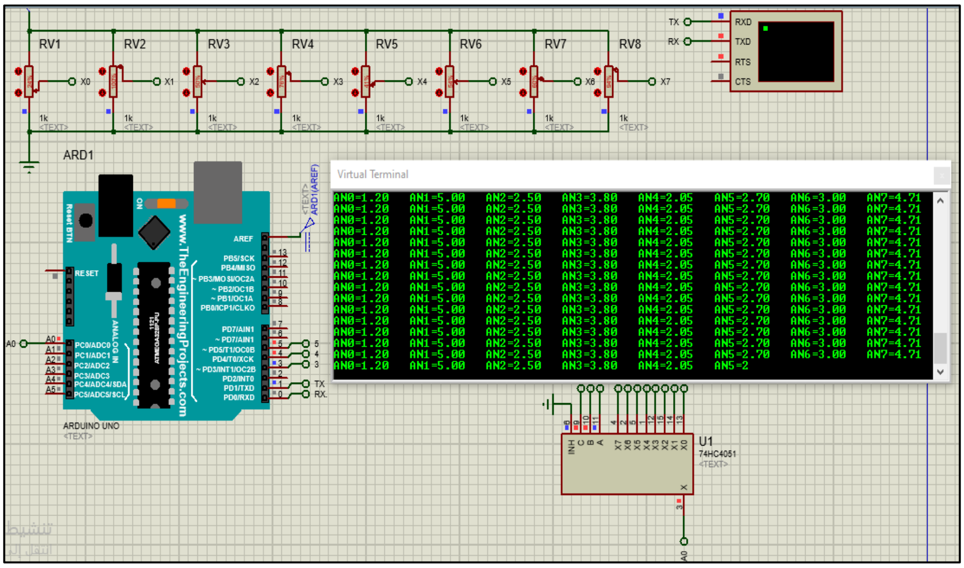

Figure 41: Multiplexer Simulation.

CHAPTER – 4 IMPLEMENTATION

The practical implementation and validation of the Cleanroom Monitoring System's subsystems are covered in this chapter. After validating the subsystem for monitoring gases, we move on to test the subsystems for monitoring particles, motion, temperature, humidity, and pressure. We also evaluate the effectiveness of the SMS alarming system. The procedure and results of these validation tests are thoroughly described in this chapter. IN addition, this chapter shows the integration of all subsystems into the entire Cleanroom Monitoring System, highlighting its ability to continuously monitor different parameters and transmit data to a cloud platform. Furthermore, the system's operations and effectiveness in real world are going to be explained in detail in this chapter.

4.1 VALIDATING GASES MONITORING SUBSYSTEM

In implementing cleanroom monitoring system, the first step is to validate the inputs to the system. Firstly, we will start validating the gas monitoring subsystem of the system, which are NH3 gas sensor (MQ-137), Methane gas sensor (MQ-4) and smoke sensor (MQ-2). Therefore, it's important to test the inputs from these sensors to ensure the reliability of the system. However, note that these gas sensors are digital sensor that either give high or low when detecting the determined gases. In addition, CD774HC4051-EP analog multiplexer will be used with ESP32 SIM800l microprocessor to analyze the reading from the sensors. The following Fig (42) represents the block diagram of this essential task.

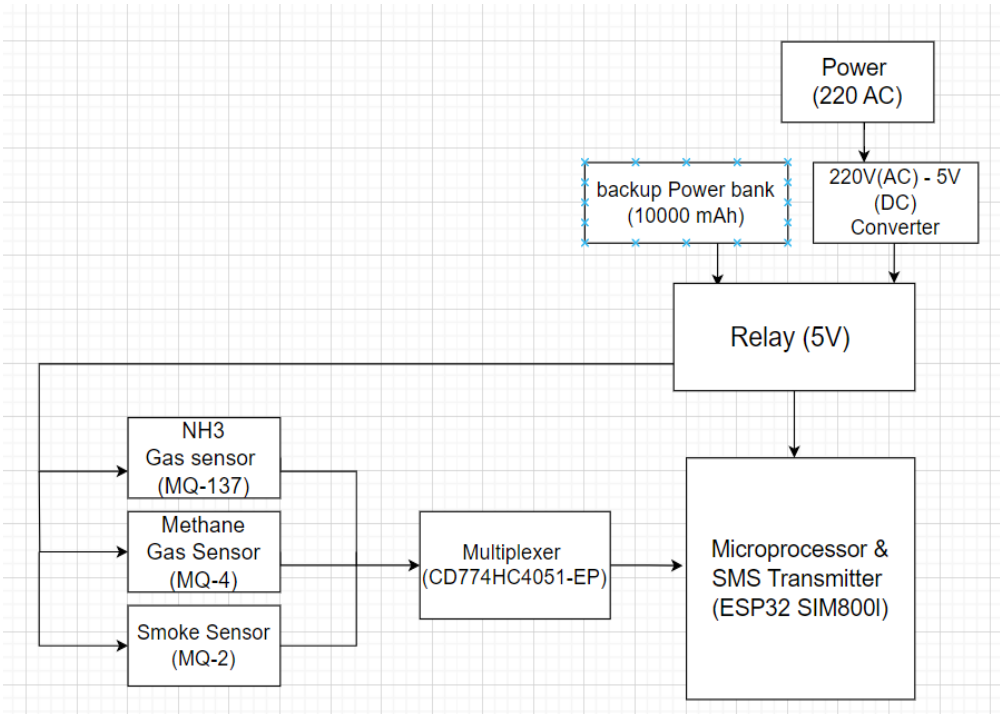

Figure 42: Gas sensors integration block diagram.

4.1.1 First trial

To begin with, we decided to test the sensors individually without the multiplexer to test the output of each sensor separately. First, we tested the MQ-4 Methane gas sensor by connecting it with the ESP32 SIM800l microprocessor to test the efficiency and reliability of the sensor. the following Fig (43) represent the circuit schematic used in this test.

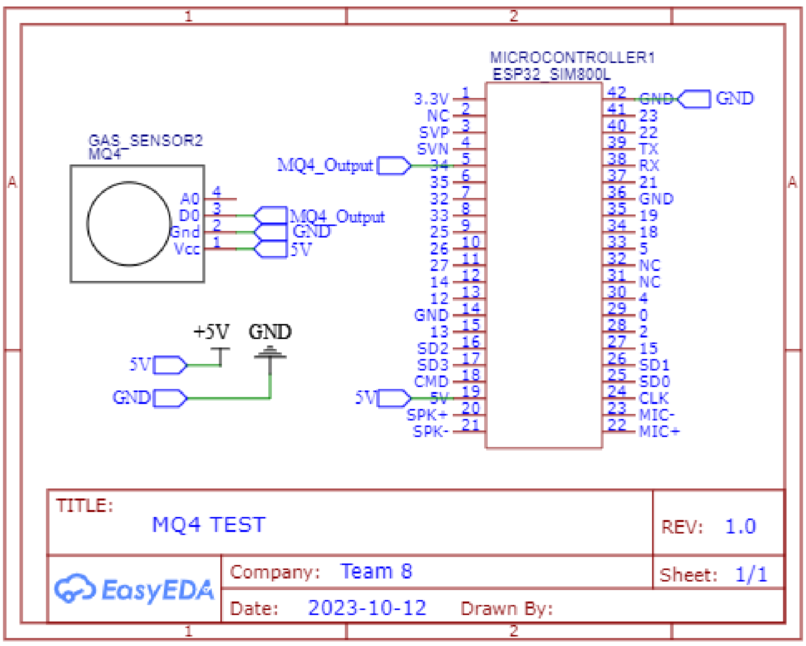

Figure 43: Circuit Schematic for first trial of MQ-4 gas Sensor Validation.

At normal condition, where no gas leakage detecting, the output signal from the sensor is high. This means that the sensor gives a high signal representing safe environment and normal condition. However, when there is a leakage in Methane gas detecting, the output from the sensor give low (0). This condition has been testing using lighter that leak methane gas.

However, since that all gases sensors used in this project are from the same model, which is MQ-4, the experiment results became similar to each other. In addition, the output is also similar to the previous experiment except that the detected gas in the first experiment was Methane gas and now it is smoke sensor MQ-2. Furthermore, the same situation goes to the third gas sensor which is MQ-137 NH3 sensor. the output is similar, and the sensors represent effective values which reflect its precision and reliability to be used in cleanroom monitoring system.

4.1.2 Second trial

The second trial was aiming to validate the sensors using the multiplexer to test the ability of the system to accept adding multiple sensors to the system. The following Fig (44) represents the circuit schematic for this trial.

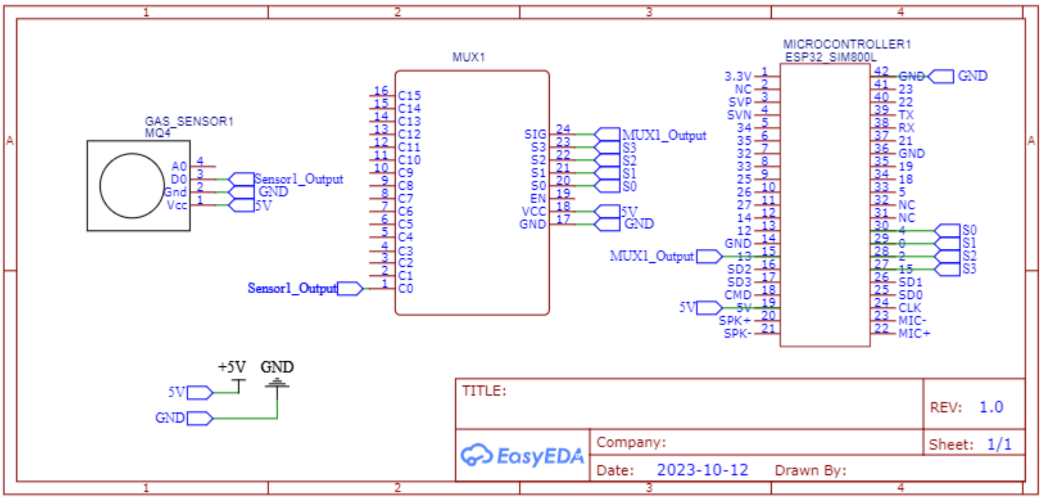

Figure 44: Circuit Schematic for Second Trial of Gas Sensors Validation.

In this trail, we tested each sensor individually with the multiplexer to test the ability of the microprocessor to read the gathered data from sensor that collected to an analog multiplexer. However, the circuit schematic mentioned in Fig (44) above, will be used for all the three gas sensors since they are work with the same approach.

However, as represented in the results from this experiment, there was a problem happened which is representing fake values from the free pins in the multiplexer. The free pins in the multiplexer that is not connected to sensors was giving random values to the microprocessor which leads to the inability to deal with it. These results have been appearing with the all three gas sensors which are MQ-137, MQ-4 and MQ-2. Therefore, this problem is required to be fixed before trying to validate all the three sensors together.

4.1.3 Third trial

The third trial aimed to validate the sensors all together with one multiplexer to test the ability of the microprocessor to analyze the collected data from each sensor without any issue. first of all, there was a problem detected during the second trail which is fake values appeared from the free pins in the multiplexer. This problem has been fixed by connecting a pull-down resistor with 1k ohm to the free pins in the multiplexer. The pull-down resistor will remove the fake values collected from these pins and make the pins give nothing to the microprocessor. The following Fig(45) shows the circuit schematic to integrate the gas sensors with multiplexer.

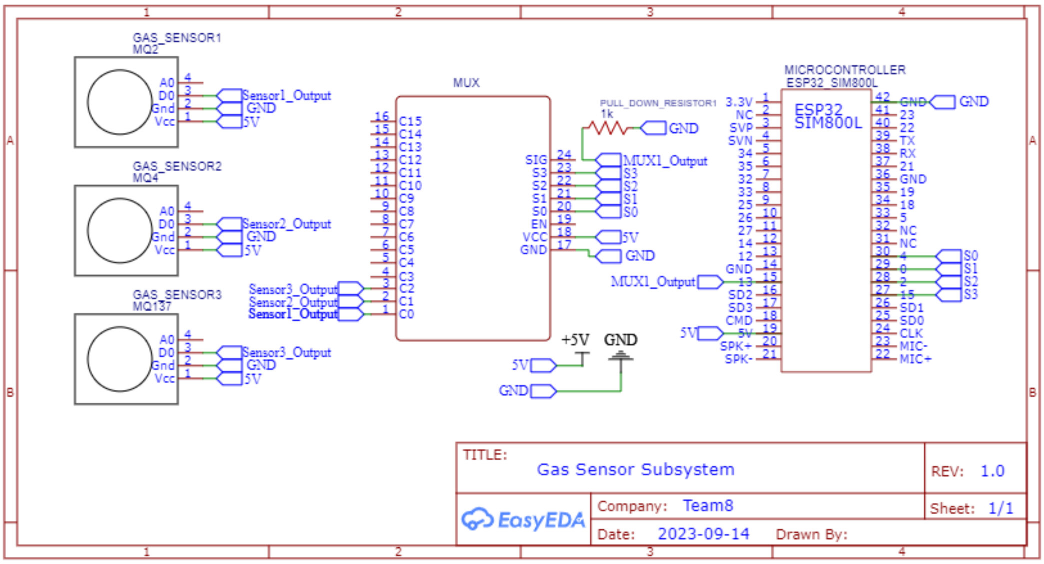

Figure 45: Final Circuit Schematic for Gas Sensors Validation.

However, the results from this trial were successfully efficient. The collected data from the sensors reflects the precise response of the sensors. In addition, the microprocessor was able to analyze the data from the sensors effectively without any fake values. The Fig(46) below shows the results from this trial on the serial monitor.

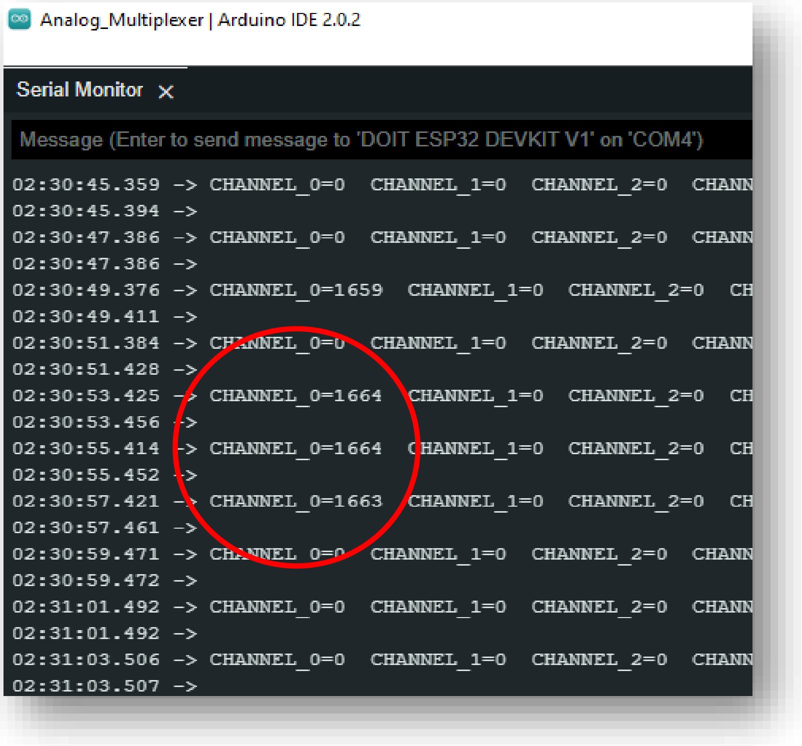

Figure 46: Results of Gas Sensors Validation in The Serial Monitor.

Note than all channels in the multiplexer are giving nothing since except for the first channel (channel 0). In shows a value since there is gas leakage detected from the sensor that connected to the channel 0. The following Fig(47) represents the hardware connection of this essential task.

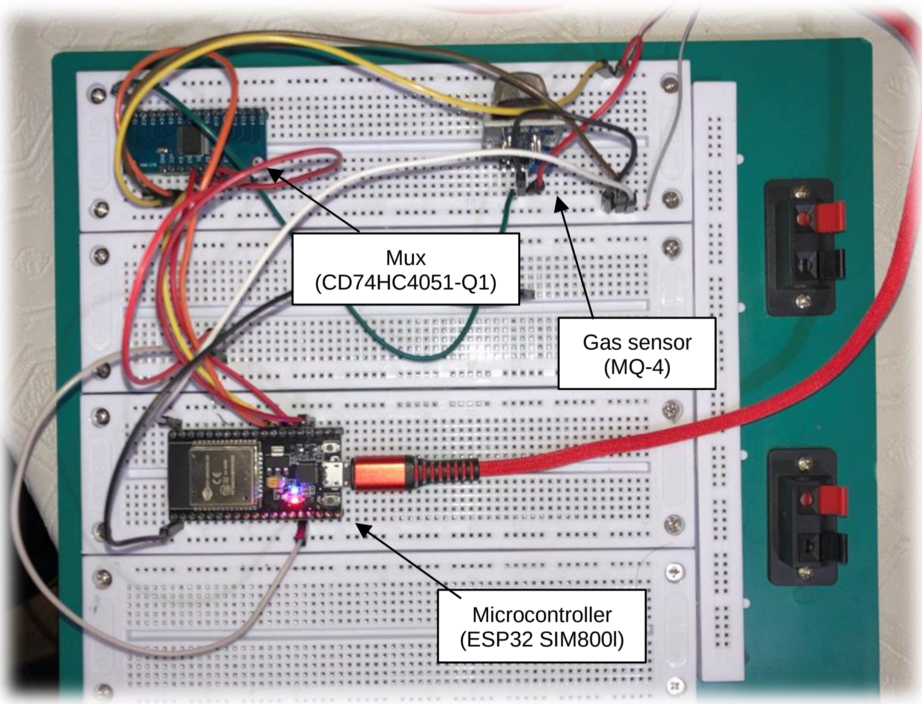

Figure 47: Hardware connection for gases monitoring subsystem.

4.2 VALIDATING PARTICLE MONITORING SUBSYSTEM

One of the musts of this project is detecting the particles inside the cleanroom. So, it is an essential task to validate the particle detector used in this monitoring system to test the precision and reliability of the device to be used inside the cleanroom. In addition, the particle detector used in this project is PMS9003M. Therefore, the following fig (48) represents the block diagram used in this task to validate the particle detector.

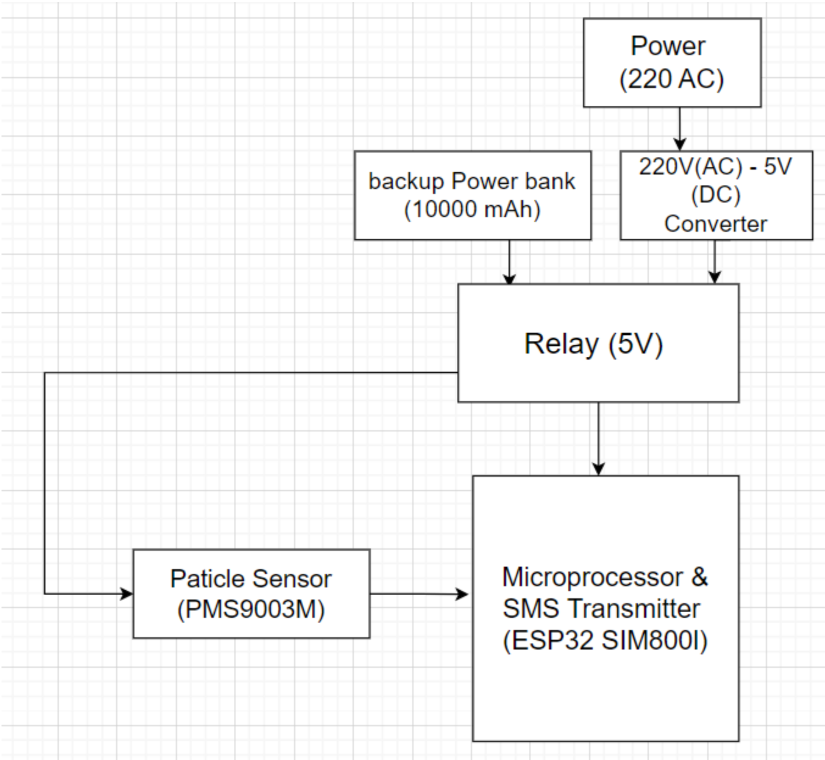

Figure 48: Block diagram of particle detector.

However, the monitoring system will be used inside the cleanrooms that follow ISO-5 classification (Class 100) since it is the most common standard in cleanrooms. This means that the sizes of particles that need to be monitored are 0.3, 0.5 ,1 and 5 micron (um) to achieve ISO-5 standard specifications. Therefore, the following trails will test the precision of the particle detector by testing it in different environments and compare the results.

4.2.1 First trial

The first trial focus in testing the particle detector under normal conditions like in living room. The particle detector has been setting in the living room and connect it to the ESP32 SIM800l microprocessor. In addition, the following Fig (49) represents the circuit schematic used in this task.

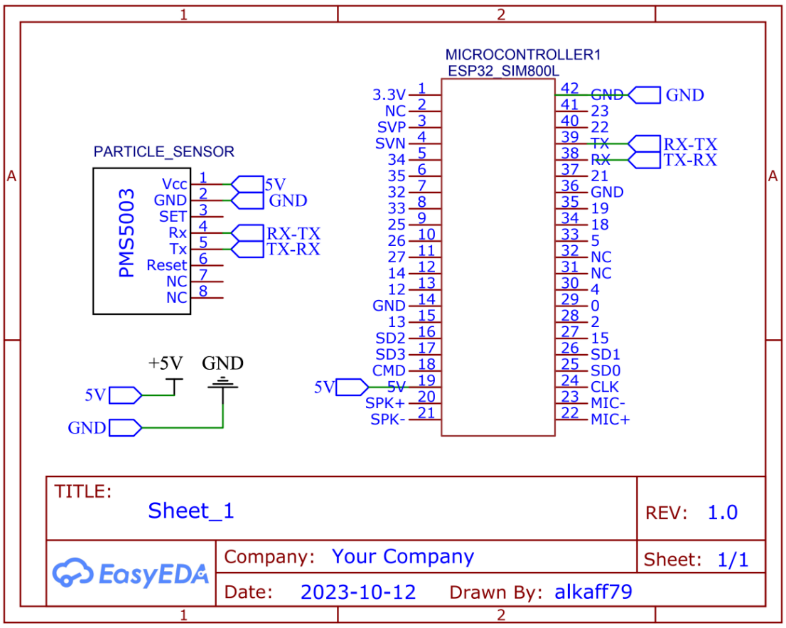

Figure 49: Circuit Schematic for Particle Detector Validation.

Moreover, the expected results were to moderate values since that living room do not contain a lot of dust and aerosols. In addition, the following Fig (50) shows the results in the serial monitor and the number of particles detected inside the living room.

```
---------------------------------------
Concentration Units (standard)
PM 1.0: 27            PM 2.5: 48            PM 10: 49
---------------------------------------
Concentration Units (environmental)
PM 1.0: 25            PM 2.5: 42            PM 10: 49
---------------------------------------
Particles > 0.3um / 0.1L air:4266
Particles > 0.5um / 0.1L air:1271
Particles > 1.0um / 0.1L air:342
Particles > 2.5um / 0.1L air:33
Particles > 5.0um / 0.1L air:0
Particles > 10.0 um / 0.1L air:0
---------------------------------------


---------------------------------------
Concentration Units (standard)
PM 1.0: 27            PM 2.5: 47            PM 10: 49
---------------------------------------
Concentration Units (environmental)
PM 1.0: 25            PM 2.5: 41            PM 10: 49
---------------------------------------
Particles > 0.3um / 0.1L air:4242
Particles > 0.5um / 0.1L air:1263
Particles > 1.0um / 0.1L air:339
Particles > 2.5um / 0.1L air:35
Particles > 5.0um / 0.1L air:2
Particles > 10.0 um / 0.1L air:0
---------------------------------------
```

Figure 50: Results of validating particle detector in living room.

Therefore, the output of this trial will be compared with the second and third trails to ensure the precision and accuracy of the particle detector.

4.2.2 Second trial

The second trial aimed to test the particle detector in places that contain high percentage of dust and aerosols. In addition, this trial aims to check whether the particle detector is giving real reading or not. In this trial, we put the particle detector inside an old storage room which contain high amount of dust and aerosols. Therefore, the circuit schematic used in the first trial will be the same in this trial and for the third trial as well. The following Fig(51) represents the output of the particle detector inside the storage room.

```
---------------------------------------
Concentration Units (standard)
PM 1.0: 79          PM 2.5: 166          PM 10: 181
---------------------------------------
Concentration Units (environmental)
PM 1.0: 54          PM 2.5: 116          PM 10: 126
---------------------------------------
Particles > 0.3um / 0.1L air:11109
Particles > 0.5um / 0.1L air:3703
Particles > 1.0um / 0.1L air:1389
Particles > 2.5um / 0.1L air:144
Particles > 5.0um / 0.1L air:17
Particles > 10.0 um / 0.1L air:0
---------------------------------------
---------------------------------------
Concentration Units (standard)
PM 1.0: 71          PM 2.5: 166          PM 10: 187
---------------------------------------
Concentration Units (environmental)
PM 1.0: 49          PM 2.5: 116          PM 10: 131
---------------------------------------
Particles > 0.3um / 0.1L air:10407
Particles > 0.5um / 0.1L air:3469
Particles > 1.0um / 0.1L air:1322
Particles > 2.5um / 0.1L air:186
Particles > 5.0um / 0.1L air:26
---------------------------------------
```

Figure 51: Results of validating particle detector in storage room.

Note that that the number of particles detected inside the storage room is more than the particles in the living room which make since, because the old storage room usually contains high amount of dusts comparing to living room.

4.2.3 Third trial

Since that the particle detector has been testing in places that high and moderate number of particles, now it's time to test the particle detector in an environment that has less amount of dust and aerosols. In addition, the output of this trial is expected to become with a number of particles that is lower than the first and second trial. The particle detector operated inside a home fridge in this trial which has a fewer amount of dust comparing the oven. However, as mentioned before, the circuit schematic for this trial will be the same schematic used in the first trail in Fig (49). Therefore, the following Fig (52) represent the result from operating the particle detector inside a house fridge.

```
---------------------------------------
Concentration Units (standard)
PM 1.0: 21          PM 2.5: 33          PM 10: 38
---------------------------------------
Concentration Units (environmental)
PM 1.0: 22          PM 2.5: 34          PM 10: 40
---------------------------------------
Particles > 0.3um / 0.1L air:2526
Particles > 0.5um / 0.1L air:842
Particles > 1.0um / 0.1L air:247
Particles > 2.5um / 0.1L air:11
Particles > 5.0um / 0.1L air:6
Particles > 10.0 um / 0.1L air:2
---------------------------------------
---------------------------------------
Concentration Units (standard)
PM 1.0: 21          PM 2.5: 32          PM 10: 37
---------------------------------------
Concentration Units (environmental)
PM 1.0: 22          PM 2.5: 33          PM 10: 39
---------------------------------------
Particles > 0.3um / 0.1L air:2469
Particles > 0.5um / 0.1L air:823
Particles > 1.0um / 0.1L air:219
Particles > 2.5um / 0.1L air:11
Particles > 5.0um / 0.1L air:6
Particles > 10.0 um / 0.1L air:4
---------------------------------------
```

Figure 52: Results of validating particle detector in home fridge.

Note that the results show that the fridge has a lower number of particles inside the house fridge. This means that the particle detector PMS9003M is reliable to be used in the cleanroom monitoring system. The results from the three trials ensured the precision and accuracy of the particle detector that expected to work efficiently in the monitoring system inside the cleanroom.

4.3 VALIDATING MOTION MONITORING SYSTEM

To begin with, the system is required to monitor the motion inside the cleanroom. The sensor is expected to detect any kind of motions inside the cleanroom within specific time interval. In addition, the motions supposed to monitored in the time where no worker inside the cleanroom. The motions are prohibited except at working hours. In addition, the block diagram shows in Fig(53) below represents the process of this essential task.

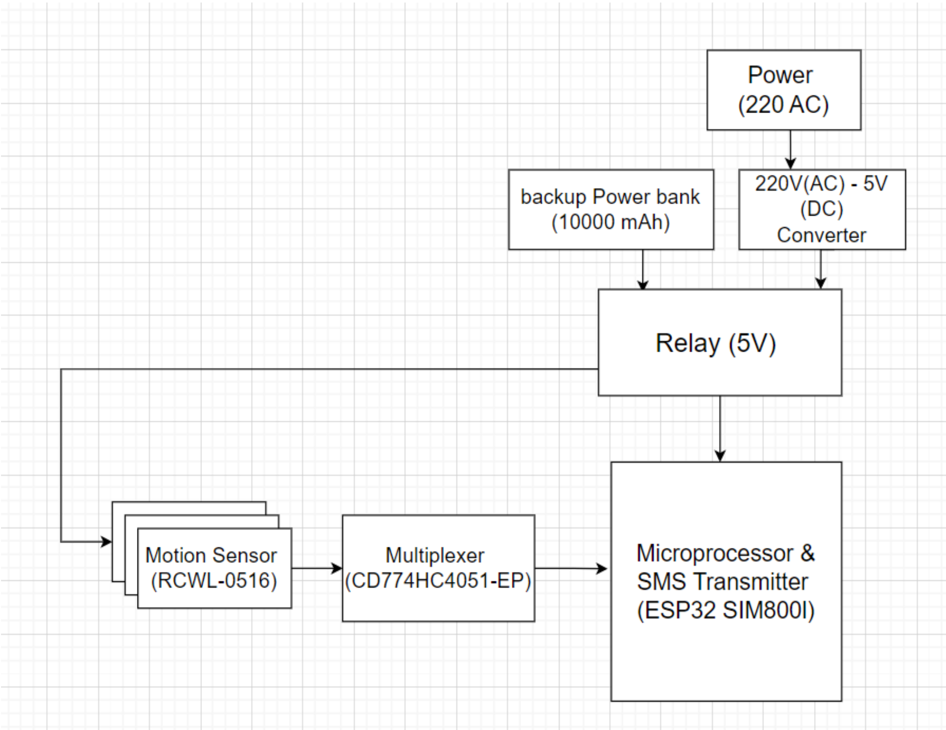

Figure 53: Block diagram of motion sensor validation.

The microprocessor will read the data from the motion sensor and then will analyze the data to make decisions based on the situation. However, the following trials will explain the validation process of the motion sensor to ensure its precision and reliability in monitoring the motions inside the cleanroom.

4.3.1 First trial

First of all, it is important to test the sensor alone to determine whether it is able to detect the motions and send signal to the microprocessor or not. The first trial is aiming to test the motion sensor alone with the microprocessor to test its precision and efficiency in detecting the motions. The following Fig(54) shows the circuit schematic used in this trial.

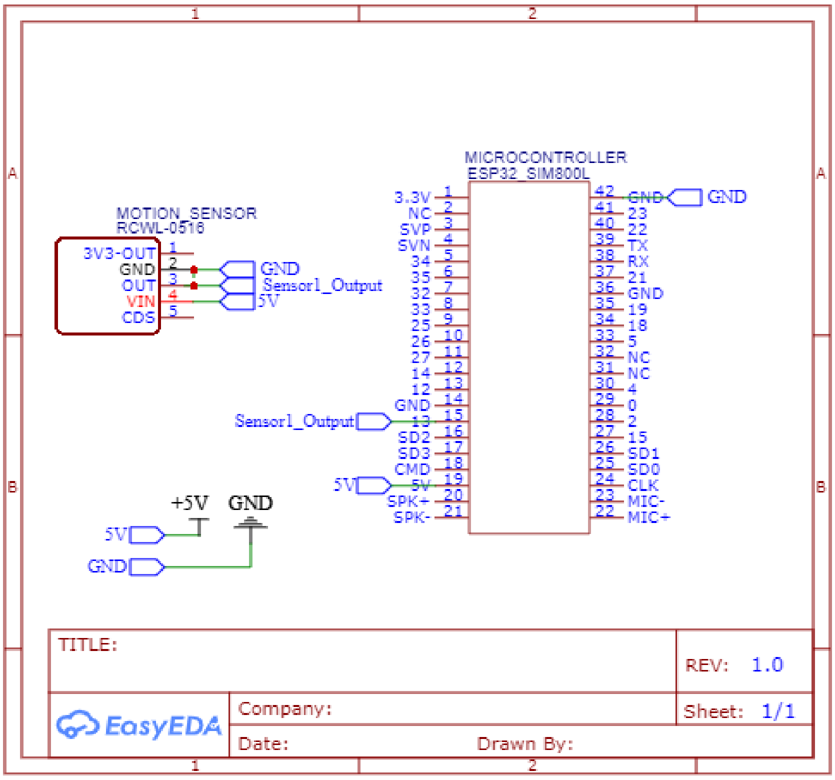

Figure 54: Circuit schematic of first trial of motion sensor validation.

However, the results from serial monitor had reflect the efficiency in detecting the motions from the sensor. therefore, note that the sensor is working as a digital sensor and not sending any signal when there is no motion detecting from the sensor (low mode). On the other hand, the sensor turns into high mode when the is a motion detected within the range of the sensor which is 10 meters and 180° degrees. In addition, the output signal from the sensor will remain in the high mode as long as the is a motion detected.

4.3.2 Second trial

The first trial aimed to validate the motion sensor alone with the microprocessor to check the precision and efficiency of the sensor. Now, the second trial will focus on testing the motion sensor along with the multiplexer to check whether the microprocessor will be able to collect and analyze the data from the sensor connected to the multiplexer. The following Fig(55) represents the circuit schematic for this trial which include the motion sensor with multiplexer and the microprocessor.

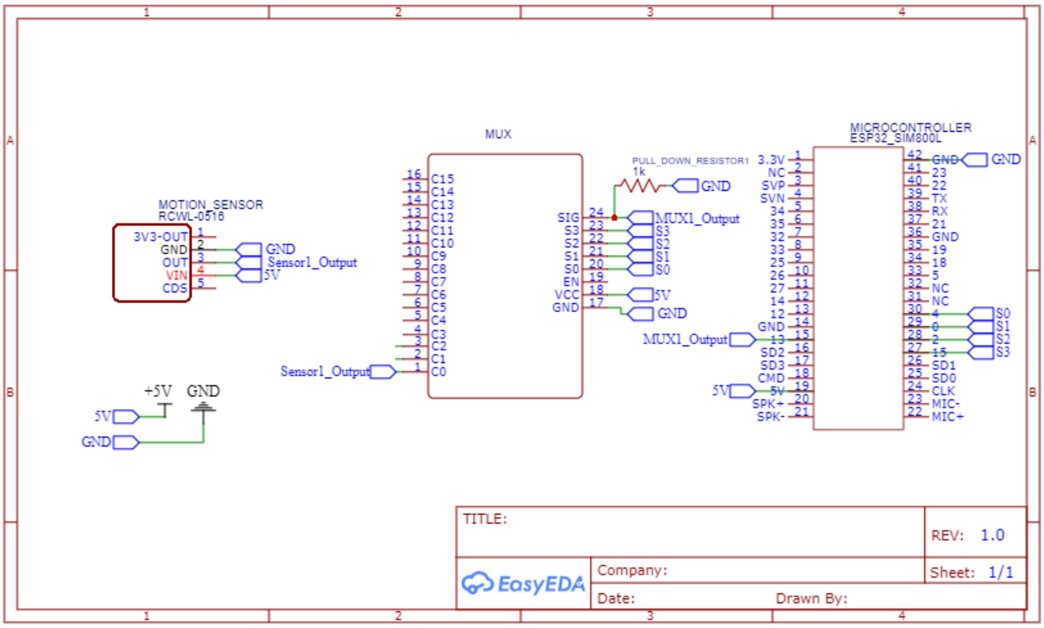

Figure 55: Circuit schematic of second trial of motion sensor validation.

However, the results from this experiment show that the microprocessor has the ability to collect the data from the sensor connected to the multiplexer. In addition, the results also include a problem from the free pins of the multiplexer which is the floating. The free pins the multiplexer gives fake values that might affect the analyzing process of the microprocessor. Also, the sensor is only detecting the motions within 180° degree from its location. So, its required at least to use two motion sensors facing each other to cover the whole area around the sensor's location.

4.3.3 Third trial

In the third trial, it is important to test the final version of the motion monitoring subsystem that will be a part of the main cleanroom monitoring system. This trial will include multi-motion sensors used with multiplexer. This means the system will be able to cover the whole area around the sensor with 360° degrees. Therefore, this trial will test the ability of the system to work within specific time based on the time specification of the cleanroom. The system is expected to be turned off during working hours, Then, it supposed to be turned on after the working hours ends to monitor the motion by using mechanical switch. The following circuit schematic in Fig(56) describe the final design of this task.

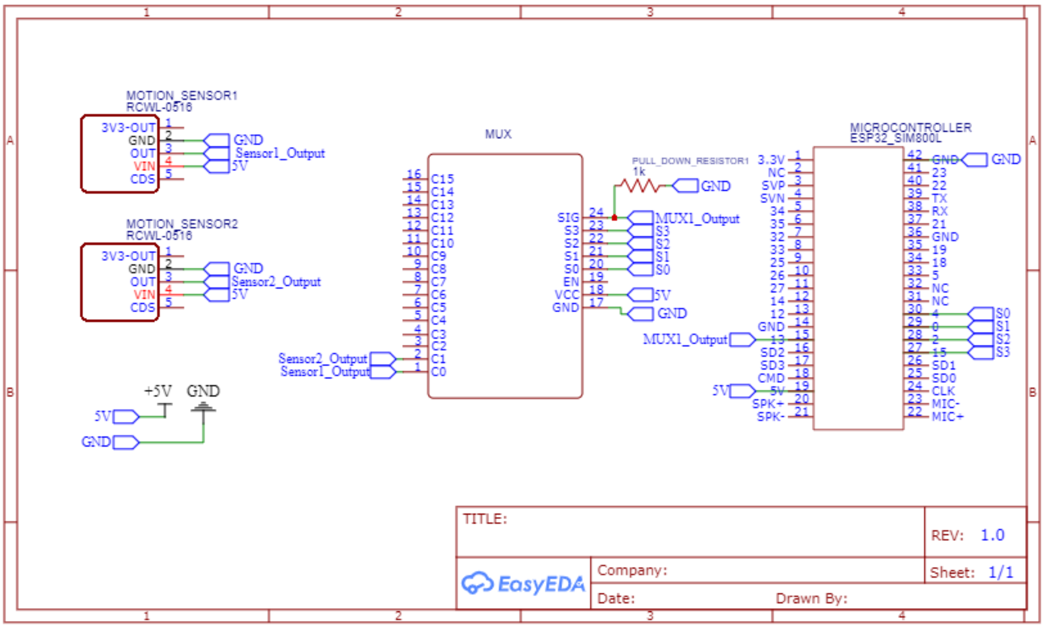

Figure 56: Circuit schematic of third trial of motion sensor validation.

However, the results from this experiment were effective that the system was able to detect the motion in the area around the sensors completely and precisely. In addition, the sensors were turned on and off using the mechanical switch without any issues. The Fig(57) below shows the hardware connection for the validating of motion monitoring subsystem.

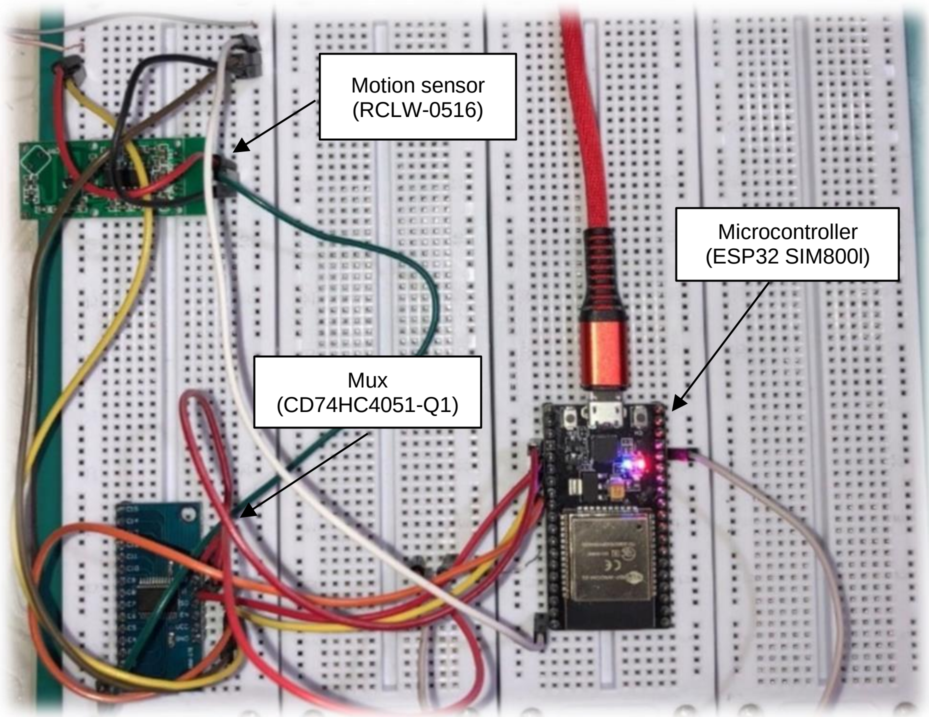

Figure 57: Hardware connection of validating motion monitoring subsystem.

4.4 VALIDATING TEMPERATURE, HUMIDITY AND PRESSURE MONITORING SUBSYSTEMS

To begin with, the remaining input sensors of this system are temperature and humidity sensor (SHT20) and pressure sensor (BMP2280). These sensors are different from other sensors in this system since they are using serial communication. The connection and transmitting of these sensors are following i2c communication system. In addition, both of them has almost the same process in collecting and analyzing the data from the environment. The only different is that one of them is measuring the atmospheric pressure in hPa and the other measures the percentage of relative humidity and temperature degree (C°) of the environment. Therefore, the following block diagram shows in Fig (58) represents the process of this essential task.

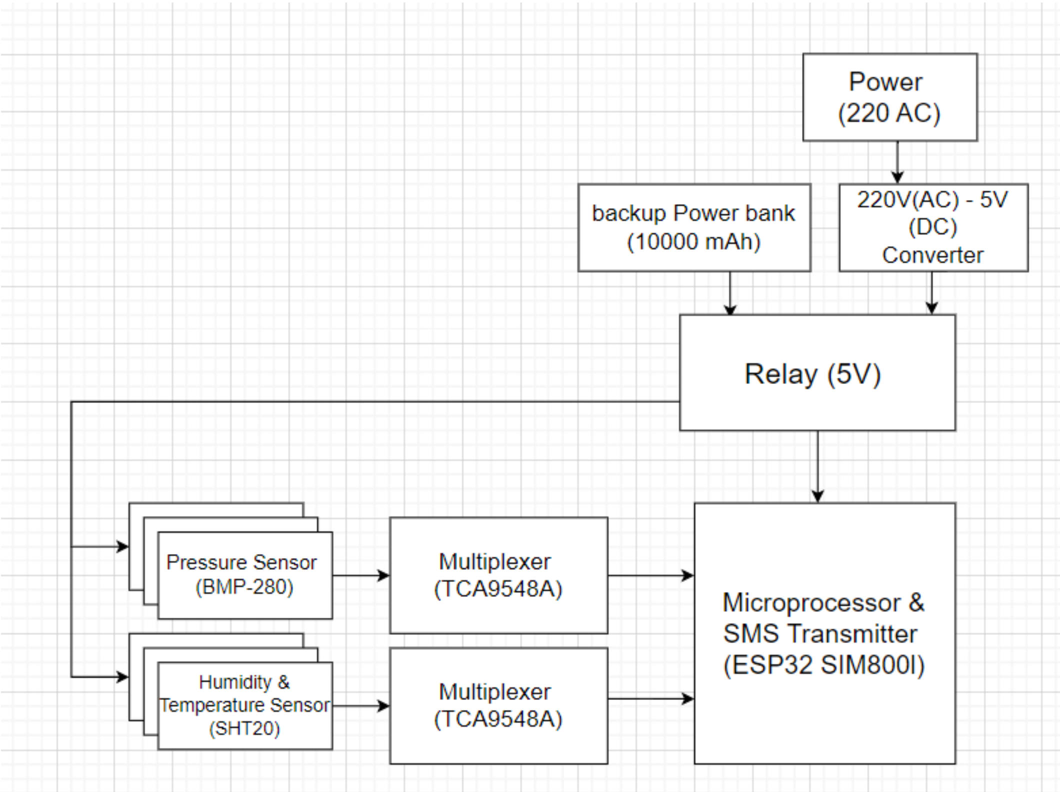

Figure 58: Block diagram of validating serial communication sensors.

4.4.1 First trial

The first trial focused on testing each sensor individually with the ESP32 SIM800l microprocessor. It is important to test each sensor to check whether the results from each sensor are precise and reliable or not. Therefore, firstly the temperature and humidity sensor (SHT20) will be tested in different environments to check if the reading of the sensor is reliable and give actual results. The sensor has been tested in living room and outside the house in afternoon. However, the system worked effectively without any issue. in addition, the precision of the SHT20 sensor in measuring the temperature and relative humidity was particularly effective.

Moreover, the other sensor that use serial communication was BMP280 pressure sensor. We tested the pressure sensor to check whether it is reliable to be used inside the cleanroom or not. Therefore, note that there are different kinds of pressures measured inside the cleanroom. For instance, there are, differential pressure, positive and negative pressure, and atmospheric pressure. The BMP280 sensor is measuring the atmospheric pressure of the standard cleanroom with respect to normal environment. Furthermore, the results from testing BMP280 were effective since that it gave reliable and practical results of the atmospheric pressure in the living room. In addition, the results have been compared with another atmospheric pressure sensor the check if the precision and efficiency of BMP280 sensor.

4.4.2 Second trial

After ensuring the precision and reliability of the sensors in the first trial, it's required to test the ability of the microprocessor to read the data from the sensors with multiplexer. In this trial, we will test the SHT20 temperature and humidity sensor connected to an i2c multiplexer and the microprocessor. The idea of using multiplexer is to test the ability of the system to accept multiple sensors. The results from this trial are expected to reflect the ability of the system to analyze the data from the multiplexer and determine which channel in the multiplexer is sending the data. The following Fig(59) represents the Circuit Schematic of the temperature and humidity monitoring subsystem.

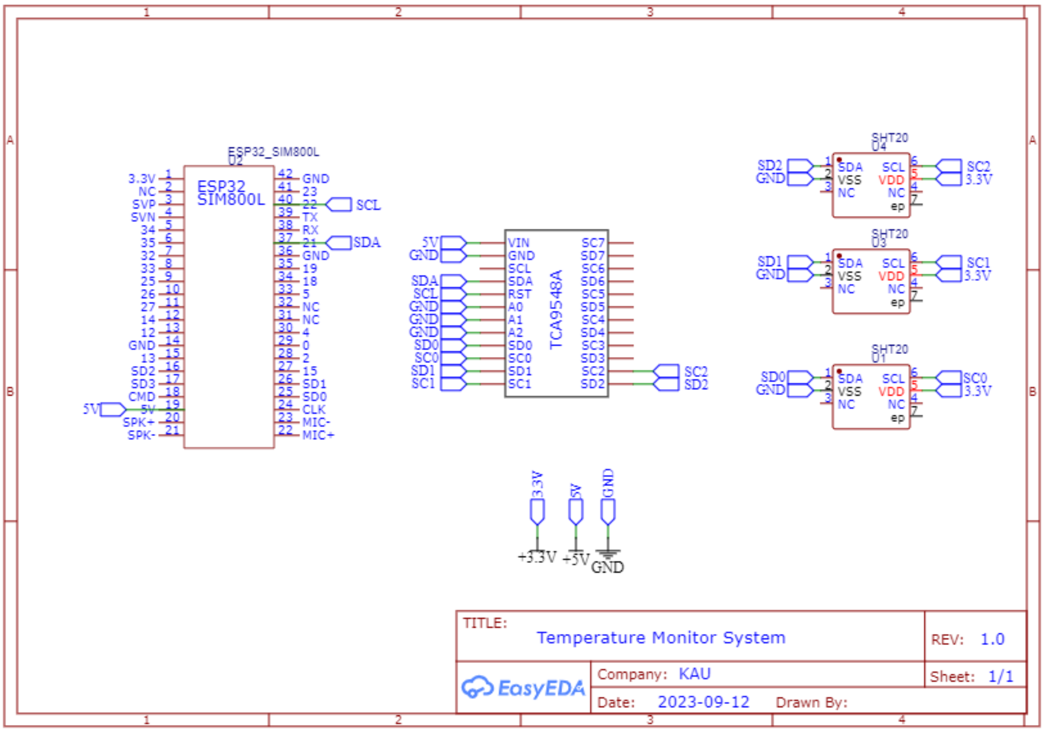

Figure 59: Temperature and Humidity Monitoring Subsystem Circuit Schematic.

Moreover, for pressure monitoring subsystem, same procedure will be implemented to check whether the system can monitor the pressure with multiplexer without any issue. In addition, the Circuit schematic of pressure monitoring system is represented in the following Fig(60).

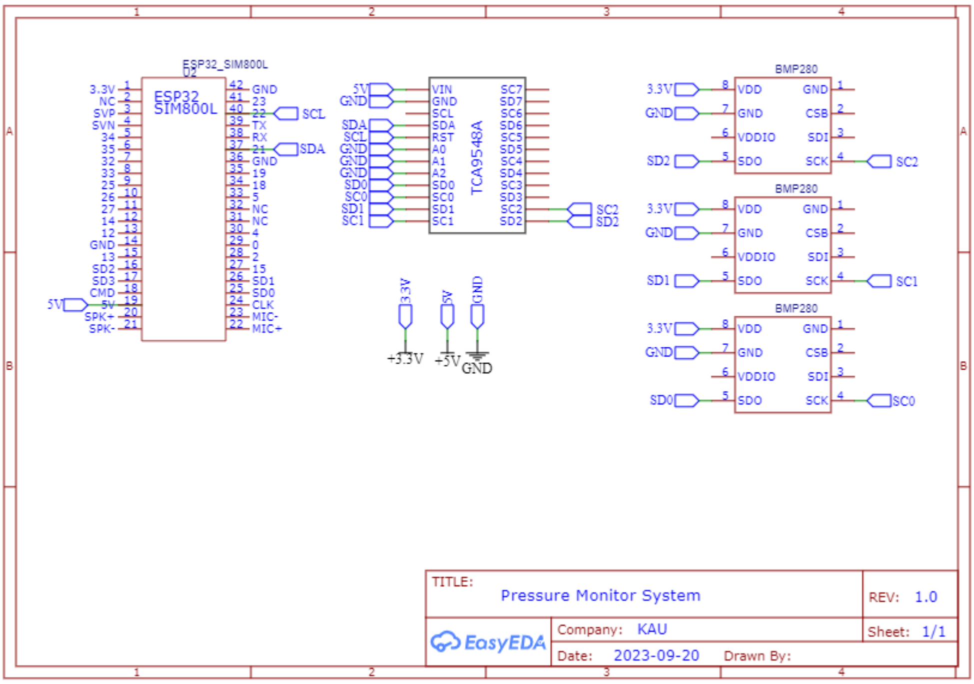

Figure 60: Pressure Monitoring Subsystem Circuit Schematic.

Therefore, the results from this trial were effective since the results were clear and practical. Also, the next trial will focus on developing the final version of the pressure and temperature and humidity subsystems.

4.4.3 Third trial

The third trial will include the final shape of the temperature, humidity, and pressure monitoring subsystems. We will test these two subsystems together since they are following i2c serial communication, which is the only part of the main system that use serial communication and serial communication pins. This trial will validate the two systems at the same time. Two i2c multiplexers will be connected to the microprocessor. The first multiplexer will be connected to two SHT20 sensors to collect the data of relative humidity and temperature. The following Fig(61) represents the hardware connection for validating the temperature and humidity monitoring subsystem.

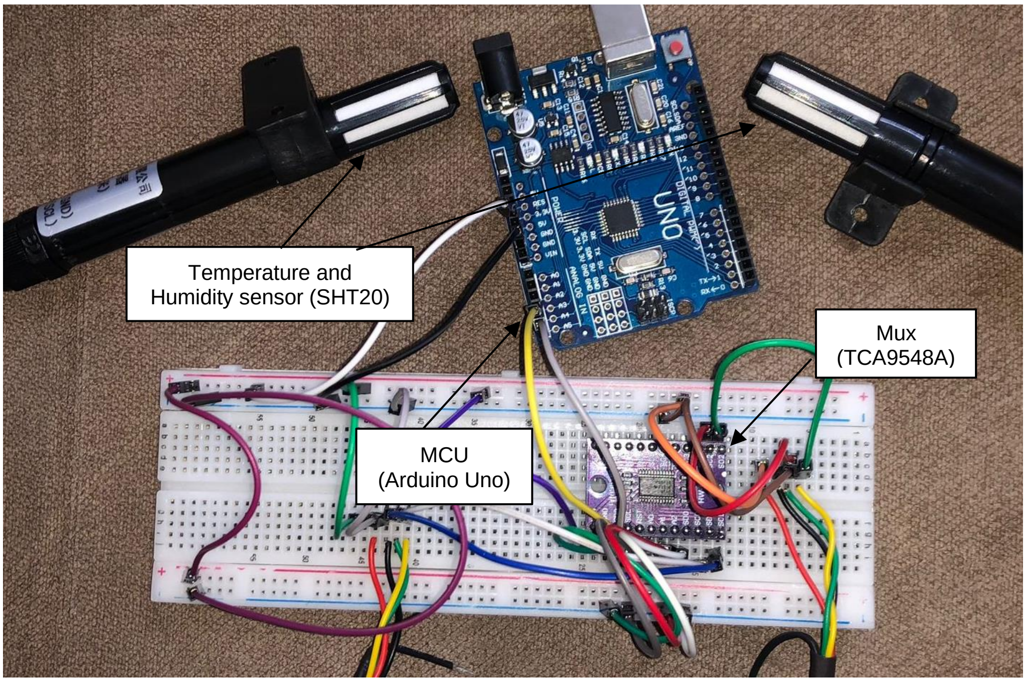

Figure 61: Hardware connection for validating temp & humidity monitoring subsystem.

On the other hand, the second multiplexer will have two BMP280 sensors to collect the data of atmospheric pressure. The following Fig(62) represents the hardware connection for validating the pressure monitoring subsystem.

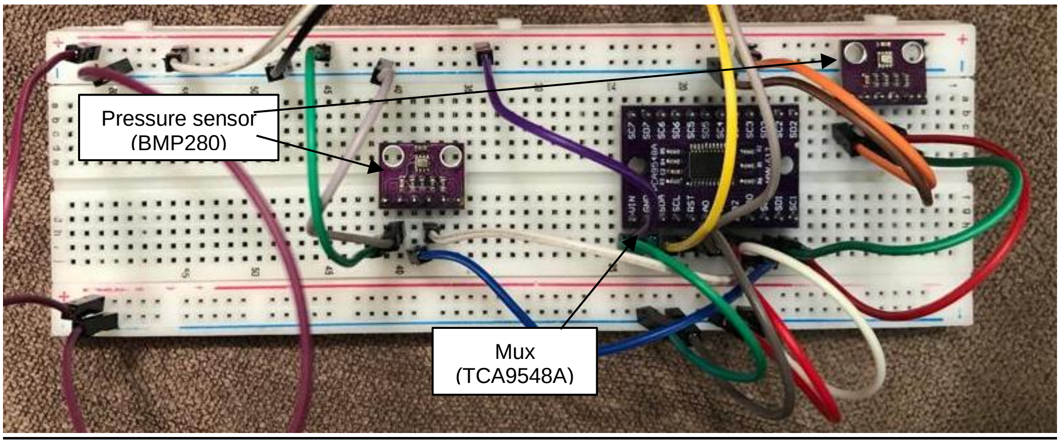

Figure 62: Hardware connection for validating pressure monitoring subsystem.

However, the results of this trial were acceptable. The data had an efficient precision. Therefore, there was a problem gathered during implementing this trial. there was a delay with few seconds in collecting the data which may affect during the implementation the main system including all the other subsystems.

4.5 VALIDATING SMS ALARMING SYSTEM

SMS alarming system is a part of the main system, which is monitoring system, that describe the output of this product. The system is supposed to warn in case of any environmental parameter monitored in the cleanroom is going out the permissible range. Or in case of leakage of hazard gases. Therefore, this essential task will be implemented to ensure the quality and precision of the built SMS alarming system in this product. However, the microprocessor of this monitoring system, which is ESP32 SIM800l, is integrated with SMS transmitter. This means that the microprocessor will analyze the input and send the outputs by itself to the specified phone number. In addition, each trial will test and validate the SMS alarming system in different scenarios to check whether it is reliable or not.

4.5.1 First trial

To begin with, the first trial will focus on testing the SMS alarming system manually by using a pushbutton. The pushbutton is supposed to control the microprocessor to send the SMS alarming message anytime. The following circuit schematic in Fig(63) describe the process of this trial.

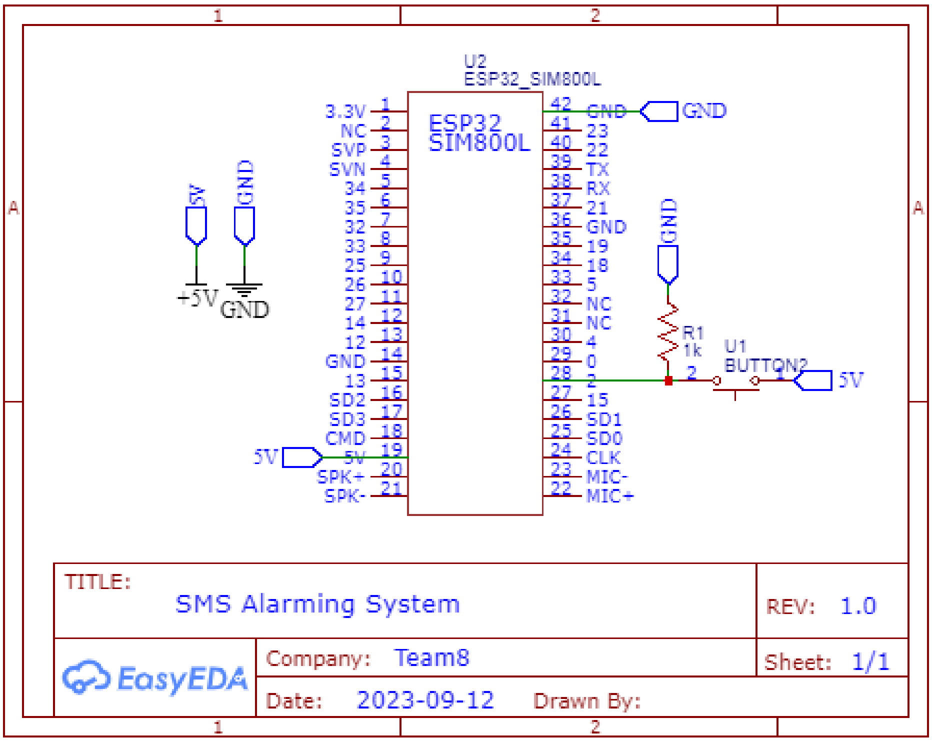

Figure 63: Circuit schematic for validating SMS alarming subsystem.

In addition, this trial will test the delay time in case of multiple pressed happened in the pushbutton.

Furthermore, the results from this trial were effective and reflected the precision of the ESP32 SIM800l microprocessor in sending SMS alarming messages. When the pushbutton pressed the microprocessor will send the specified message in the program to the determined phone number. The following Fig(64) shows an example of an SMS alarming message sent to the determined phone.

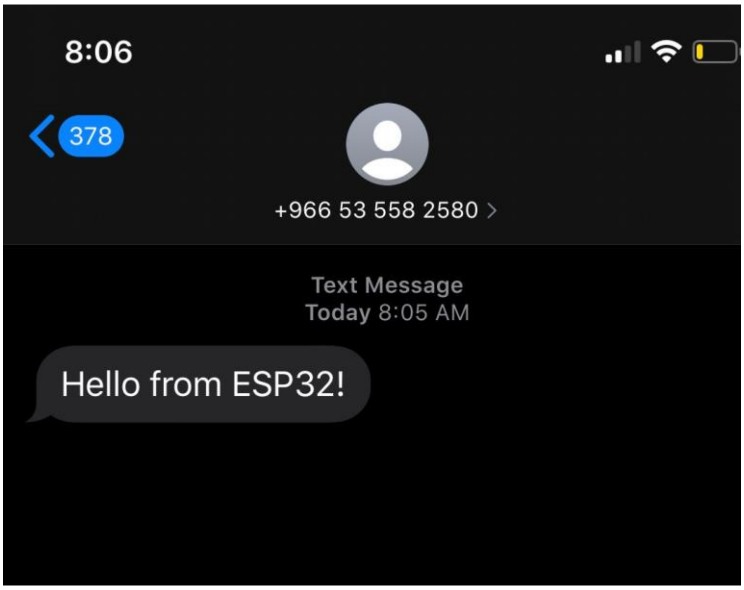

Figure 64: Screenshot of first trial's results of validating SMS alarming system.

However, when multiple pressed occurred, the microprocessor won't send multiple messages. The system will have a delay about 2 to 3 seconds after releasing the pressed pushbutton and then wait for another press.

4.5.2 Second trial

The second trial will validate the SMS alarming system automatically with sensors. In this trial we will validate the system using some of the system's sensors to test the ability of the alarming system to keep up with the normal and abnormal conditions of the cleanroom. Therefore, the sensors that going to be used during this validation are motion sensor RCLW-0516 and temperature and humidity sensor SHT20. The following Fig(65) represents the block diagram used in this trial.

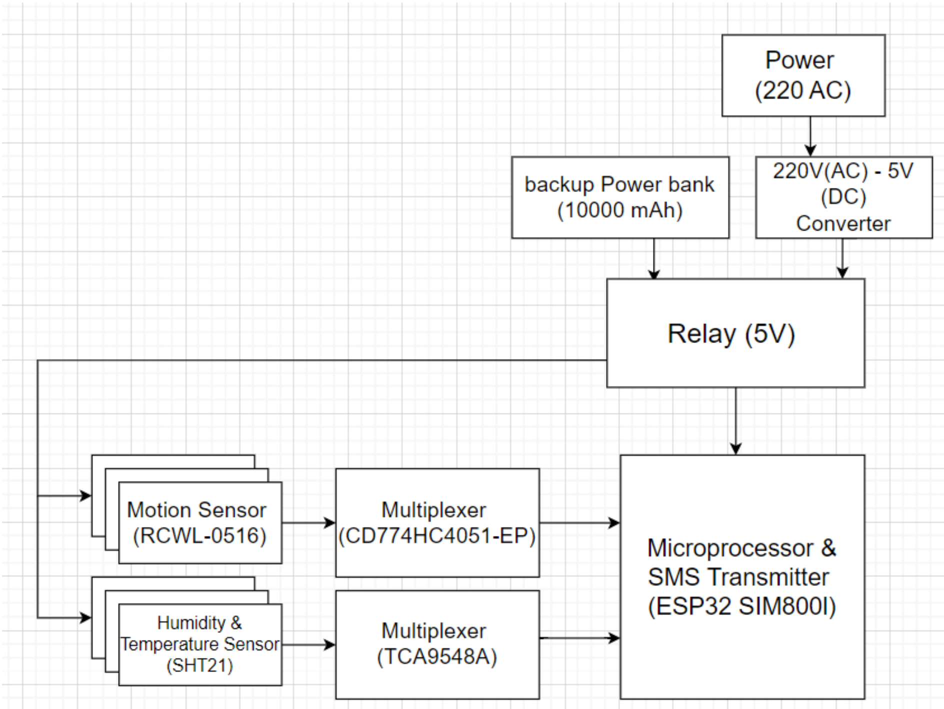

Figure 65: Block diagram of validating SMS alarming system with sensors.

The microprocessor is expected to be able to analyze the normal and abnormal conditions of the determined parameters. In addition, the integrated SMS transmitter supposed to send an alarming message upon an abnormal conditions condition happened.

4.5.3 Third trial

After testing the alarming system with the sensors, it's required to validate the alarming system with final setup. The alarming system is supposed to send an alarming message reporting for an abnormal condition occurred in the cleanroom.

In addition, the system will wait for 30 second and send another message reporting that the abnormal condition is still continuous. Therefore, after one minute, the system will start the same process again and send the first warning message in case of abnormal condition happened.

Moreover, the output from this trial was effective since that the SMS transmitter was able to send the first and second messages following up with the condition of the cleanroom. The alarming system has been tested with the sensors results such as the temperature out of the permissible range and detecting motions in the cleanroom. In addition, an example of the warning messages is represented in the following Fig(66).

Figure 66: Screenshot of third trial's results of validating SMS alarming system.

4.6 FINAL PRODUCT

To Begin with, the final product is a combination of the subsystems that has been implemented and mentioned in the previous sections. The final product which is cleanroom monitoring system is a comprehensive system that monitor the parameters of the environments in the cleanroom including the number of particles in air inside the cleanroom. In addition, the system is supposed to monitor all of the determined parameters at the same time continuously without any issue. Also, the system should have the ability to interrupt and send warning messages and keep monitoring the parameters at the same time continuously.

Furthermore, the comprehensive final product has been developed based on the results from validating the subsystems. The following Fig(67) represents the circuit schematic for the final product of this project.

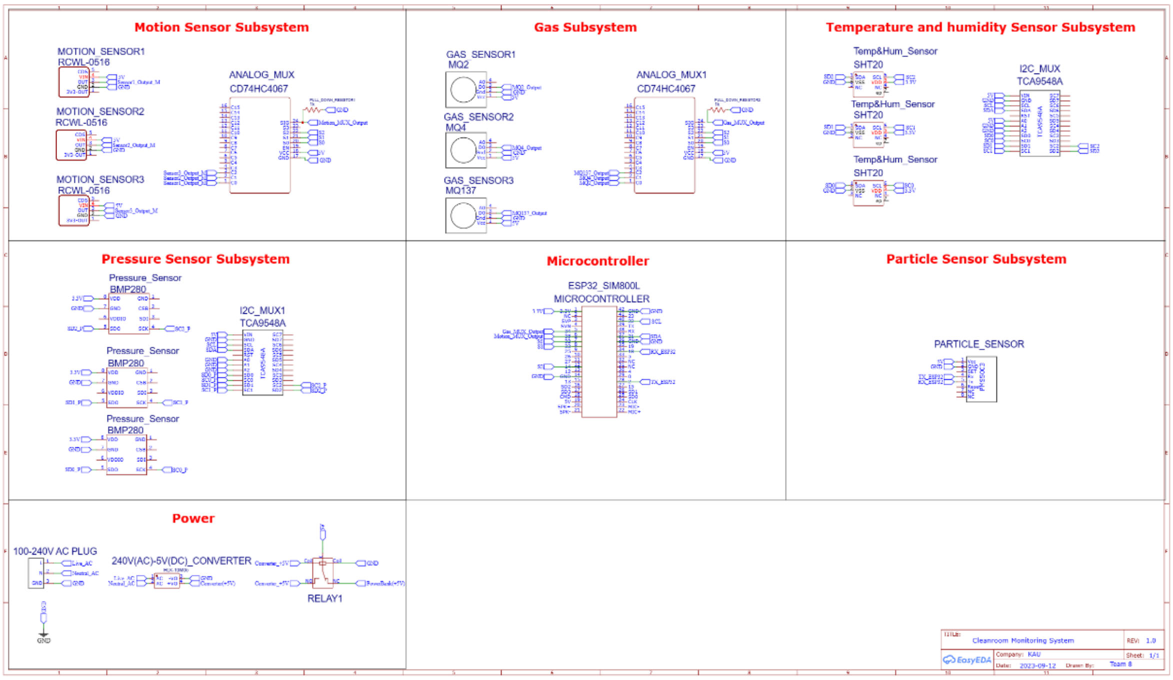

Figure 67: Circuit Schematic of The Final Product.

The Fig(67) above shows the details of the whole product including the subsystems, ESP32 SIM800l microprocessor and the power supply configuration as well. Note that some of the subsystems shows multiple sensors connected to the multiplexer. On the other hand, the prototype only has one sensor connected to the multiplexer. The idea of this multiple sensors is that the system is expandable and has the ability to add multiple sensors to it in case of requiring to measure bigger cleanroom. In addition, no editing is required on the main program of the microprocessor when adding more sensors to the system.

Therefore, the final product was effective since it has combined all the subsystems together and monitor all of them continuously. In addition, the system achieved some the wants requested from the customer of this project. The final product offers an online monitoring for the cleanroom parameters, which are temperature, relative humidity, atmospheric pressure, motions, smoke, NH3 gas and Methane gas inside the cleanroom. The online monitoring is offered on the ThingSpeak cloud. This cloud is developed by MathWorks that has developed MATLAB software as well. This cloud shows a statistical graph for the state of the sensors connected to the microprocessor. For instance, the following Fig (68) shows an example of the output in the ThingSpeak cloud which is continuously updated while the microprocessor is connected to the internet.

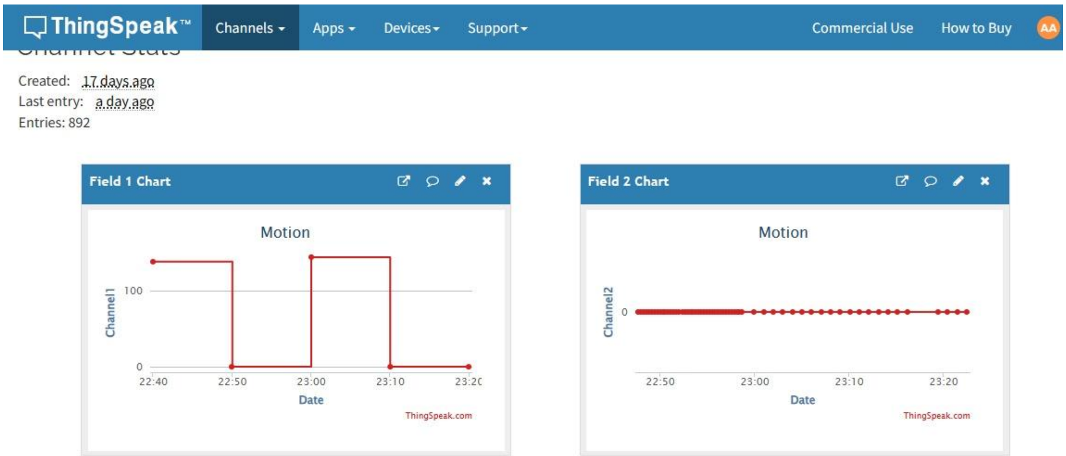

Figure 68: ThingSpeak Screenshot example.

The Fig(68) above shows an example of continuous reading of motions from the motion sensors. Note that the name of the graphs is represented with field which is related to the number of channels of the multiplexer that has motion sensors connected to it.

Moreover, the final prototype has been implemented on a breadboard and has the components of the system connected together with wires and cables. The following Fig(69,70) shows the hardware connection of the prototype.

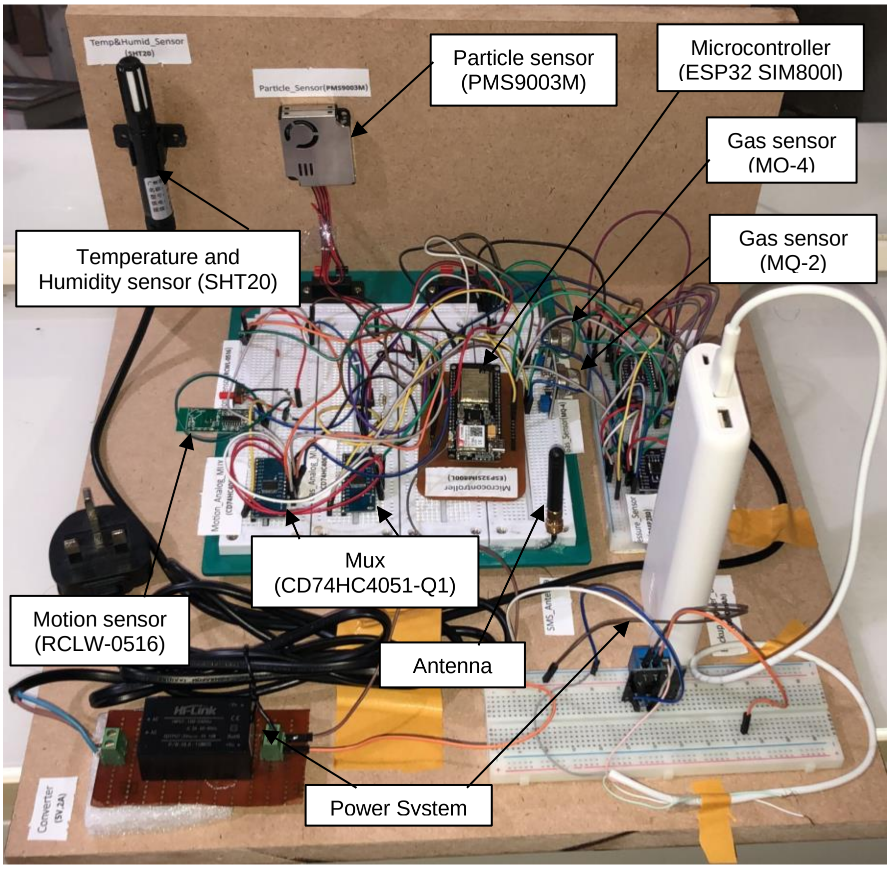

Figure 69: Hardware Connection for Final Prototype 1.

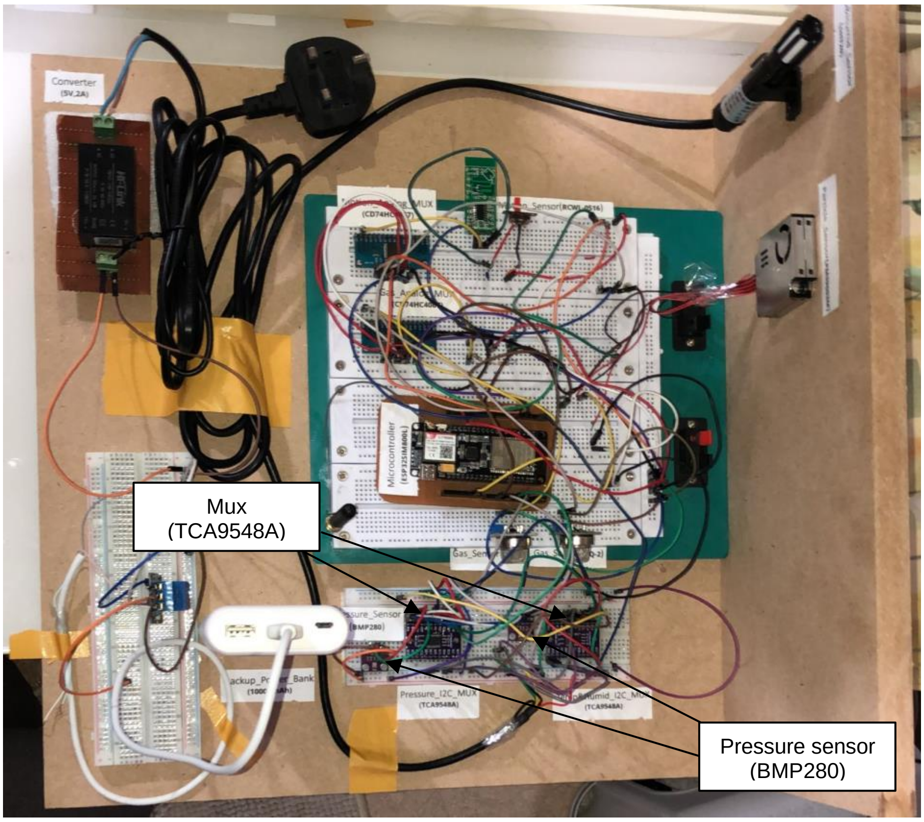

Figure 70: Hardware Connection for Final Prototype 2

The first Fig (69) above represents the hardware connection of the final product including all sensors, power supply connected from AC 220 with converter and the backup power bank that will feed the system with power in case of blackout situations. Therefore, the results and outcomes of this product will be discussed in detail in the next chapter.

CHAPTER – 5 RESULTS, DISCUSSION, AND CONCLUSIONS

5.1 RESULTS

After completing the implementation of all subsystems and the final product, now it is required to list the results and outcomes of the whole project. In addition, the results are going to be discussed and compared to the objectives of this project do determine whether the design has achieved the required objectives or not. However, the results of each subsystem will be listed in the following sections. Then, the final outcome will be presented from the comprehensive final product.

5.5.1 Results of Gases Monitoring Subsystem

First of all, as mentioned above in previous chapter 4, the gas sensors, which are NH3 gas sensor MQ-137, Methane gas sensor MQ-4, and Smoke gas sensor MQ-2, can be either analog or digital sensors that give high or low signals based on the condition of the sensor. In addition, these sensors are work with 5V input and the output is different based on the situation of the sensor. For instance, the output voltage in high condition, which is mean normal situation and no gas leakage, is approximately around 3.5V. however, in case of low signal situation, the output voltage from the sensor was around 0.15V which is almost zero volt. The following Fig(71,72) shows the results of measuring the voltage of methane gas sensor using multimeter.

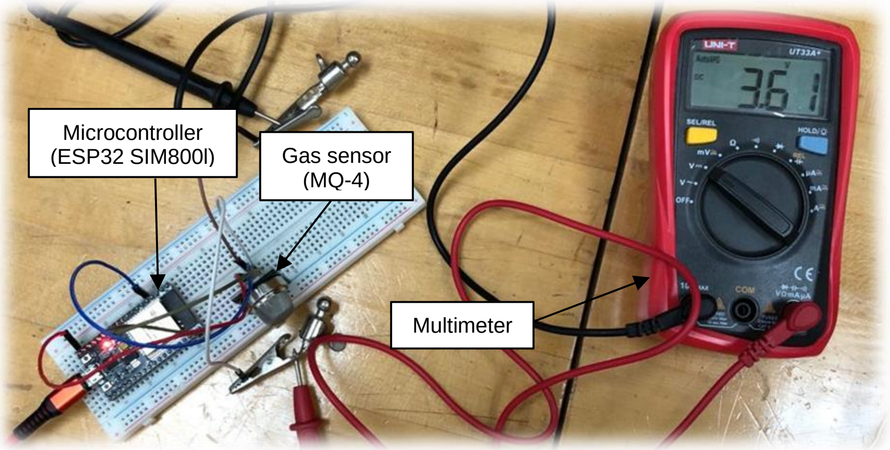

Figure 71: Output voltage measured from gas sensor (MQ-4) in high mode.

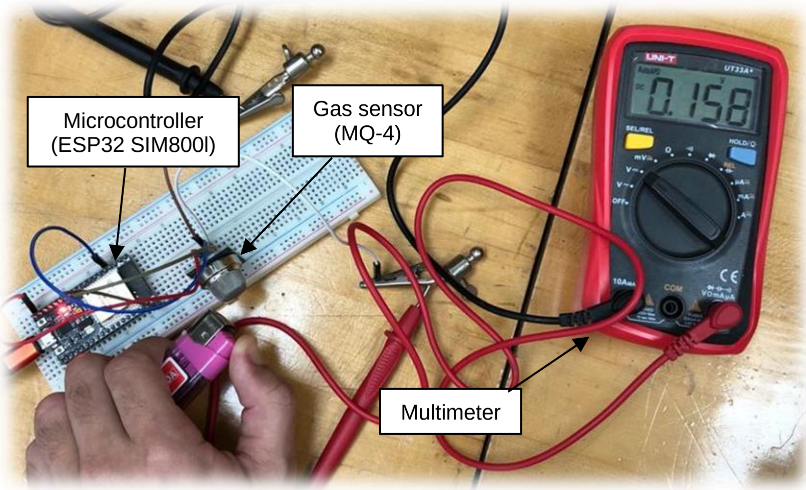

Figure 72: Output voltage measured from gas (MQ-4) sensor in low mode.

Therefore, the following Fig(73) shows a graph that represent the output from testing MQ-4 sensor based on digital configuration with respect to time.

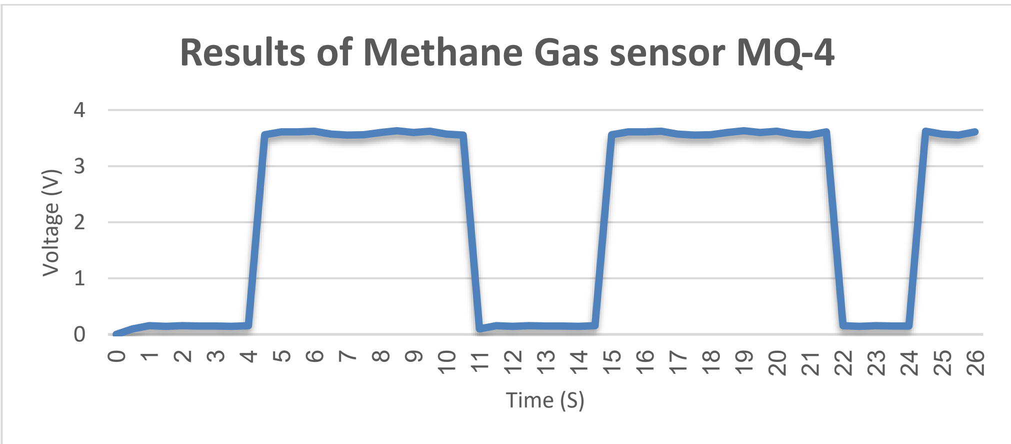

Figure 73: Results of Methane Gas sensor MQ-4.

However, the output current from the gas sensor has a situation similar to the voltage where the output current is zero when there is a gas leakage detecting (Low mode). On the other hand, the output current in high mode has a value that approximately around 0.38 mA. The following Fig (74,75) shows the measured output current from MQ-4 methane gas sensor.

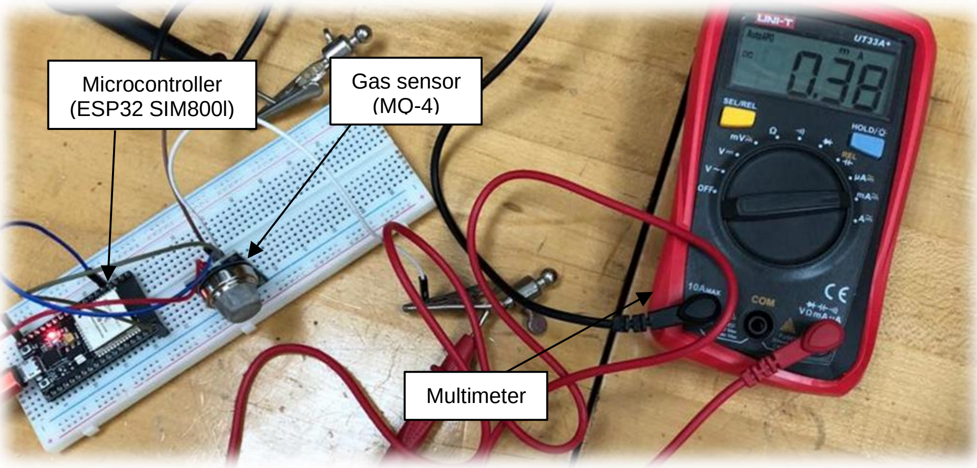

Figure 74: Output current measured from gas (MQ-4) sensor in high mode.

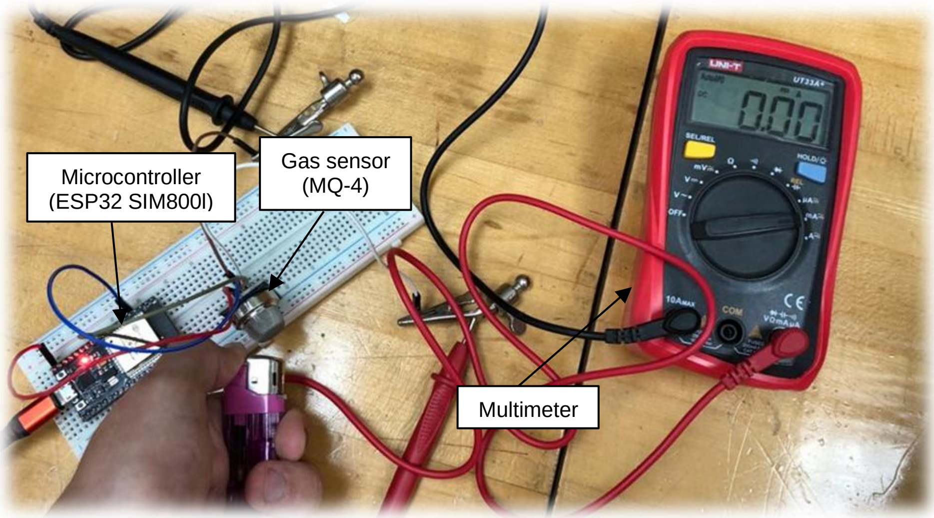

Figure 75: Output current measured from gas (MQ-4) sensor in low mode.

Furthermore, since that all of gas sensors are from the same model, which is MQ series, the results from the other sensors MQ-137 and MQ-2 became similar to the mentioned results above. The output voltage and current from the other two sensor became approximately similar values to the values of Methane gas sensor.

5.5.2 Results of Particle Monitoring Subsystem

The Particle Sensor (PMS9003M) will operate only with a 5V input voltage at first. In order to evaluate the sensor's precision in measuring and analyzing particulate matter, it was carefully evaluated in a real-world environment, such as living room, home fridge, and storage room. The information about particle concentration in the living room, home fridge, and storage room, however, is shown in the following Figs(76,77,78).

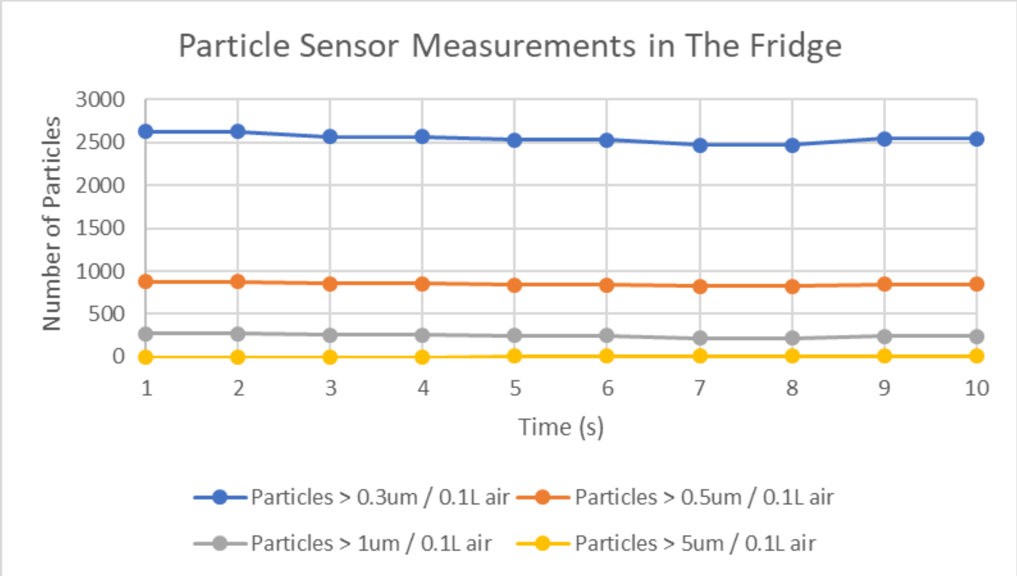

Figure 76: Particle Sensor Measurements in The Fridge.

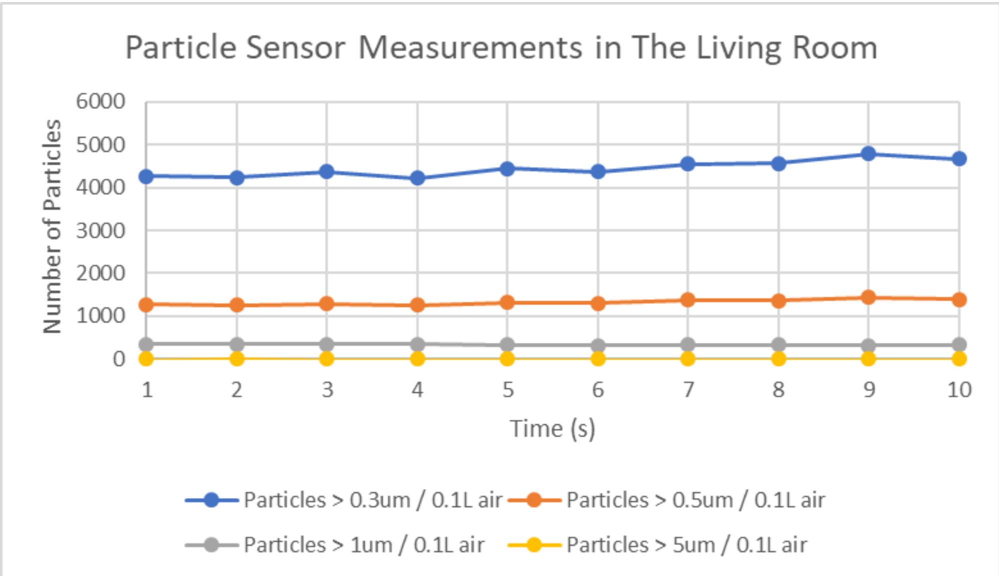

Figure 77: Particle Sensor Measurements in The Living Room.

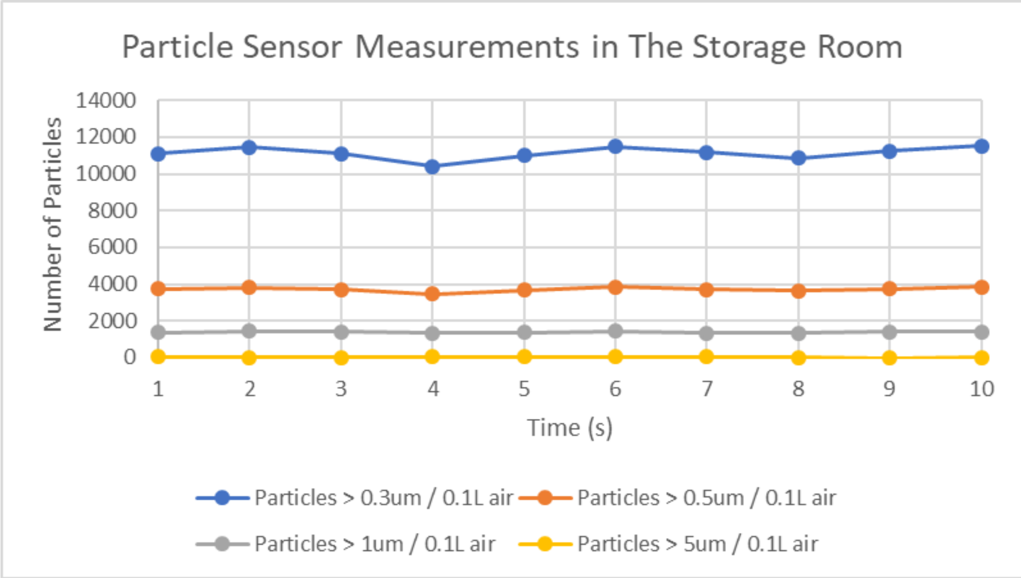

Figure 78: Particle Sensor Measurements in The Storage Room.

The figures illustrate four measurements for the particle sensor and each measurement shows the number of accumulated particles in um / 0.1 L air. Moreover, Fig(76) clearly shows that the number of particles > 0.3 um / 0.1 L air are approximately 2500 in the home fridge which is rational compared to the results in the living room and storage room.

Also, it's important to be aware that, unlike the SHT20 sensor, the Particle Sensor (PMS9003M) only runs on a 5V input voltage. The output voltage and current of the particle sensor remain constant, with the output voltage averaging 3.16V and the current at roughly 0.30 mA. The recorded voltage and current readings from the voltmeter are shown in the following Fig(79,80).

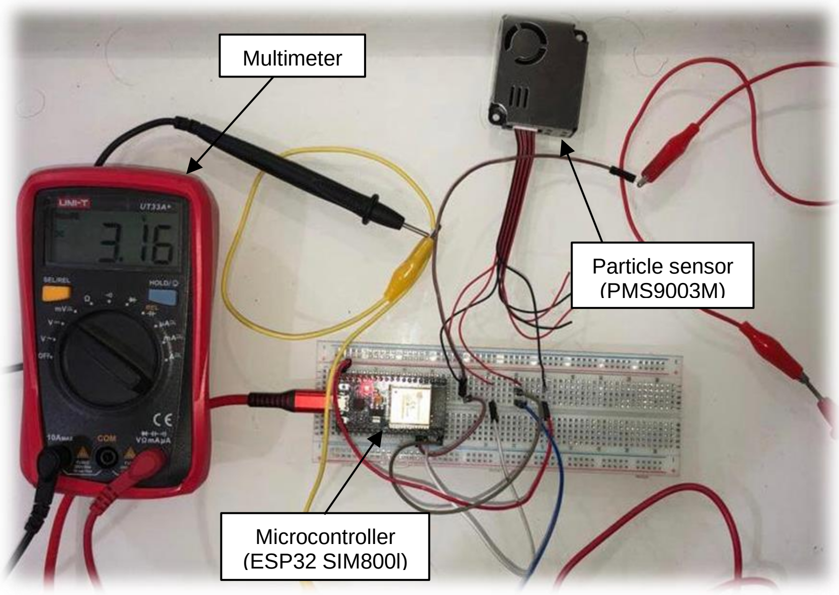

Figure 79: Output voltage measured from particle (PMS9003M) sensor.

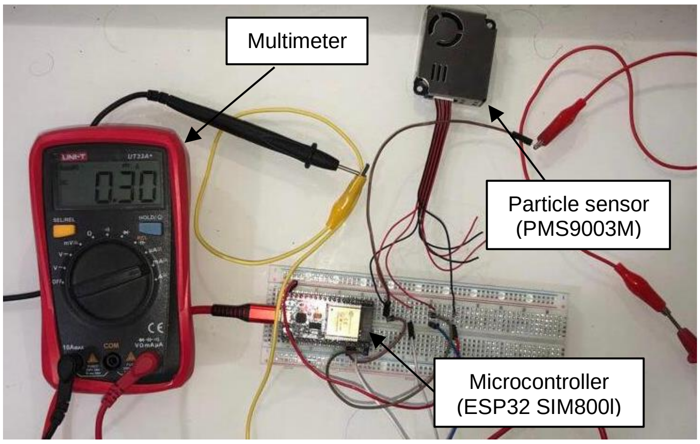

Figure 80: Output current measured from particle (PMS9003M) sensor.

5.5.3 Results of Motion Monitoring Subsystem

To begin with, the motion sensor RCLW-0516 require 5V to operate. Also, since that the sensor is working as a digital sensor that give high when detecting motions and give zero otherwise, the output voltage from sensor was around 3.3V in high mode and zero mode. The following Fig(81,82) shows the output voltage from the motion sensor measured using voltmeter.

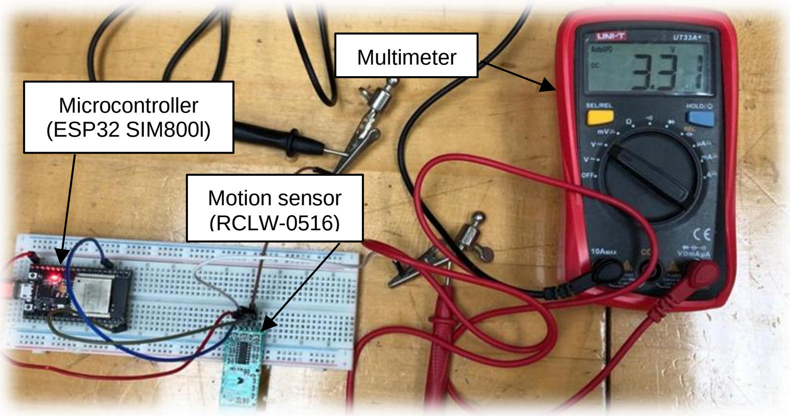

Figure 81: Output voltage measured from motion (RCLW-0516) sensor in high mode.

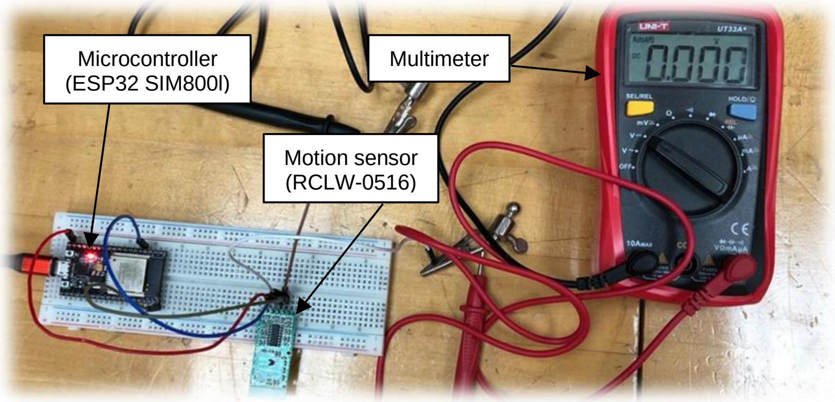

Figure 82: Output voltage measured from motion (RCLW-0516) sensor in low mode.

Remember that high mode given from the motion senor represents that the sensor is detecting motion. On the other hand, the low mode reflects the situation where no motion detecting and there is no response from the sensor at all. Therefore, the following Fig(83) represents a statistical representation for the validating the motion monitoring system within specific time interval.

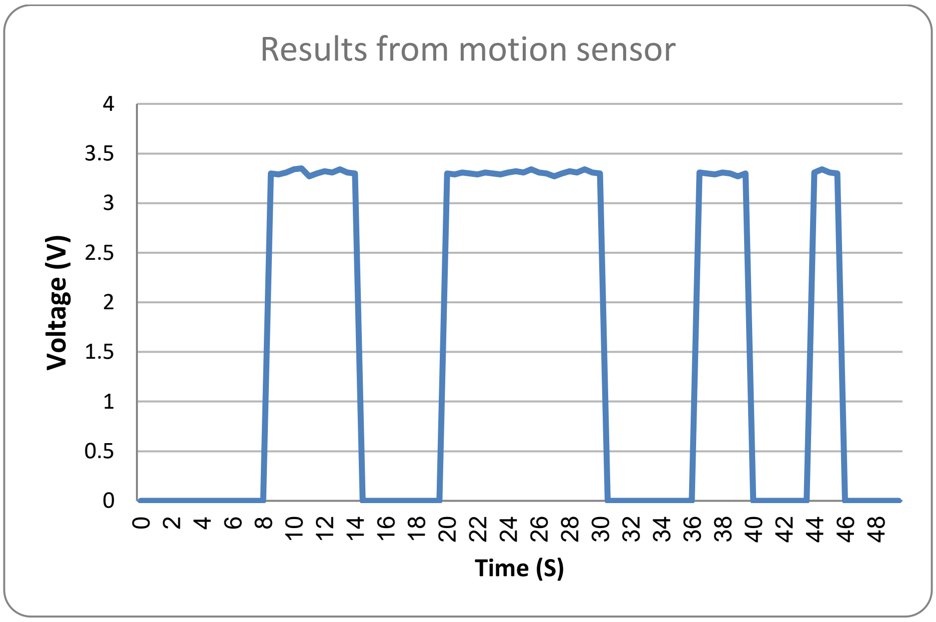

Figure 83: Results from motion sensor.

The above chart shows the response of the motion sensor for the motion detected within the range of the sensor. therefore, the output voltage was either zero or varying around 3.3V as represented in the above Fig(83). However, the behavior of the output current was similar to the voltage behavior since it gives zero when motion detected and give approximately 0.3 mA as shown in Fig(84) below.

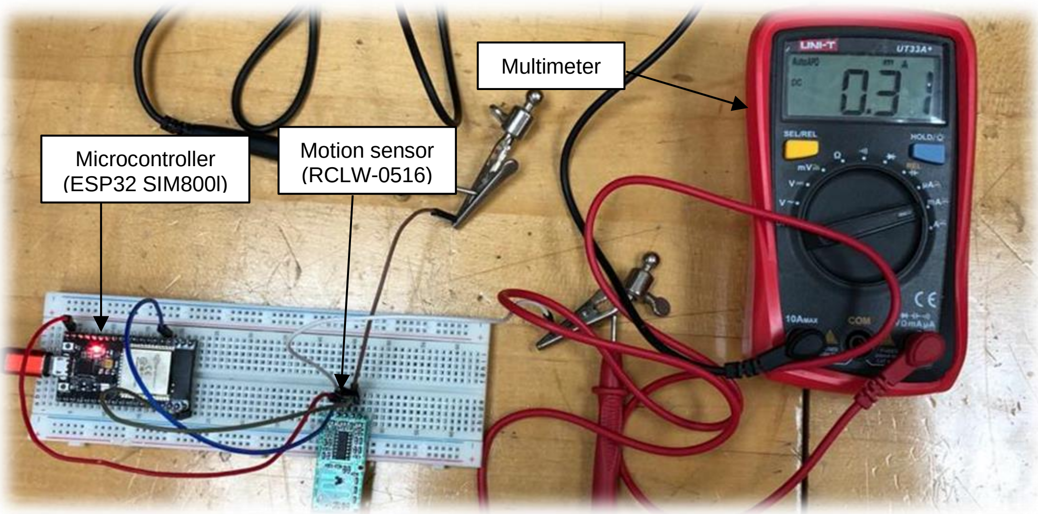

Figure 84: Output current measured from motion (RCLW-0516) sensor in high mode.

5.5.4 Results of Temperature & Humidity Monitoring Subsystem

First of all, the temperature and humidity sensor SHT20 required 3.3V input voltage to work. In addition, the sensor had tested and validated in living room to test the ability of the sensor to measure and analyze the temperature and humidity precisely. However, the following Fig(85) represents the collected data of temperature degree inside a living room.

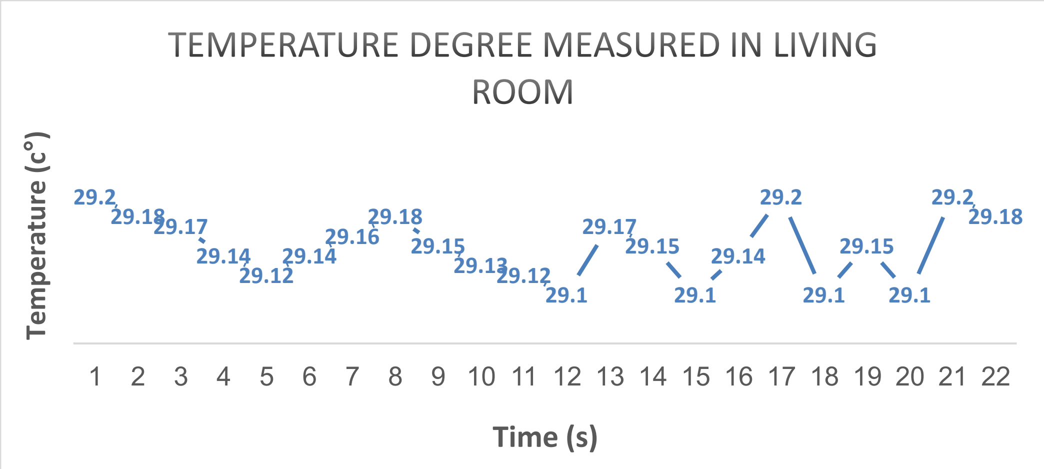

Figure 85: Results of temperature degree measured in living room.

The results mentioned in Fig(85) above has been compared with the measured temperature using thermometer. The sensor shows precise values since that the results from both thermometer and the sensor were approximately similar to each other.

Moreover, the relative humidity measured in the living room were also reflecting an efficient precision in the results. The following Fig(86) shows the percentage of relative humidity measured in a living room.

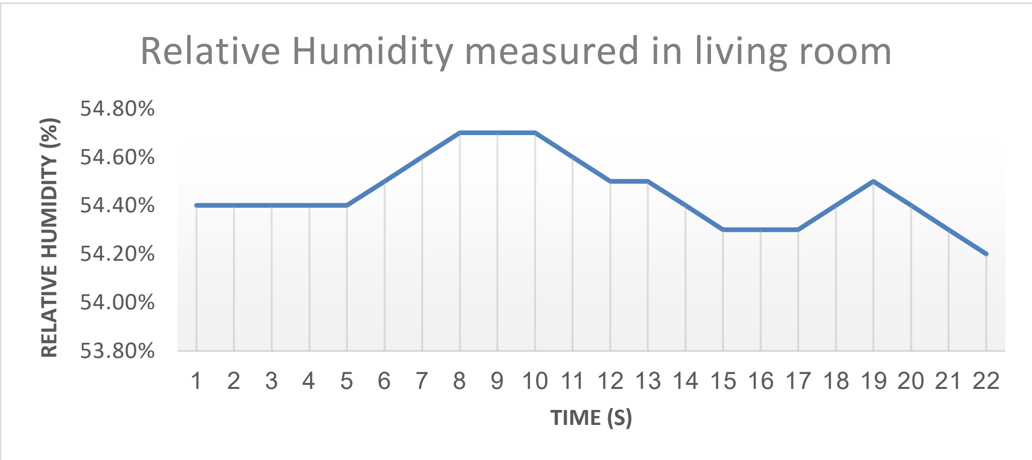

Figure 86: Results of relative humidity measured in living room.

The results mentioned in Fig(86) above show that the living room has a percentage of relative humidity around 54% which represents the actual relative humidity inside a normal living room.

Therefore, note that the SHT20 sensor work with 3.3V input voltage and has the ability to accept up to 5V. in addition, the output voltage and current from the sensor is approximately stable around specific values. For instance, the output voltage measured from the sensor is approximately 3.2V. and the current is around 0.28 mA. The following Fig(87,88) shows the measured current and voltage using the voltmeter.

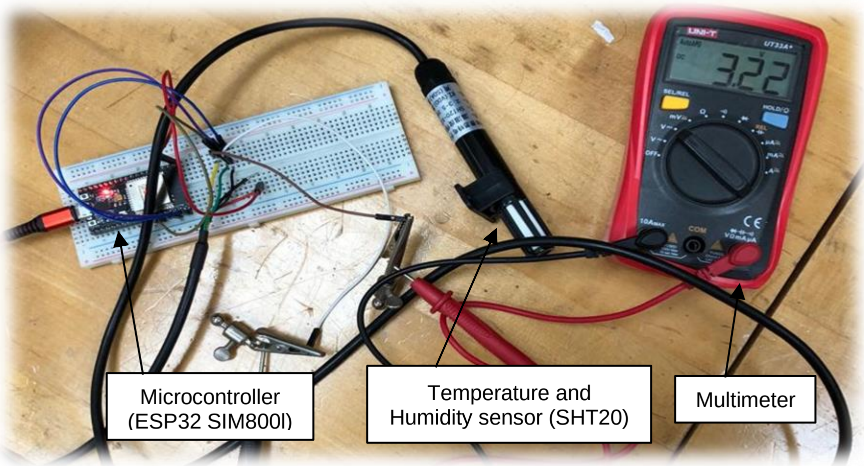

Figure 87: Output voltage measured from temp and humidity (SHT20) sensor.

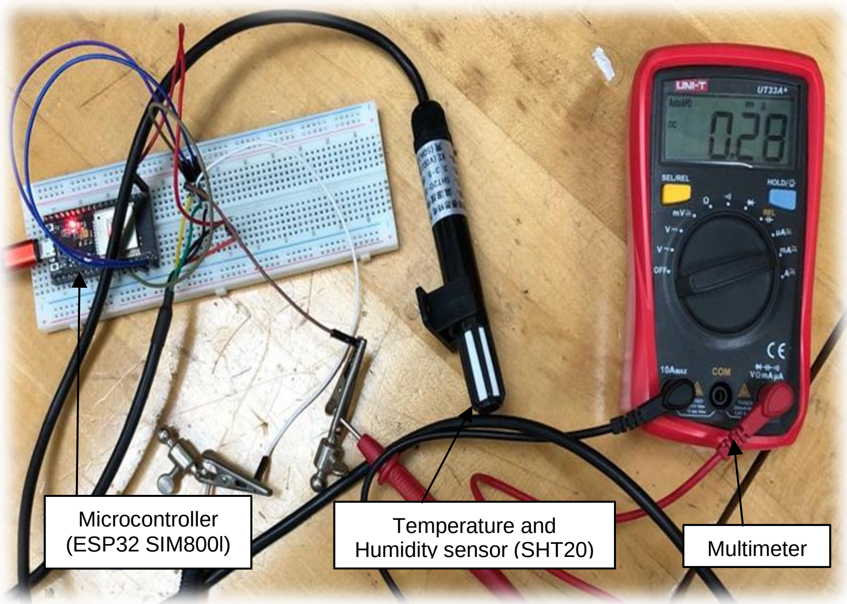

Figure 88: output current measured from temp and humidity (SHT20) sensor.

5.5.5 Results of Pressure Monitoring Subsystem

The Pressure Sensor (BMP280) requires a 3.3V input voltage to operate properly at first. In order to evaluate this sensor's accuracy in monitoring and analyzing air pressure, it also conducted numerous testing and validation in a living room setting. The information gathered is shown in Fig(89) below, which shows the fluctuations in atmospheric pressure levels inside the living room.

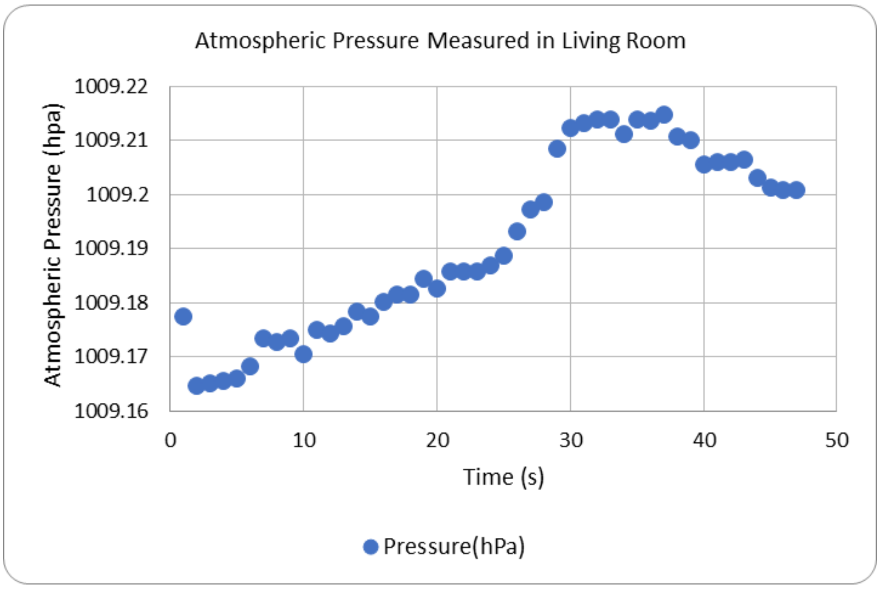

Figure 89: Results of atmospheric pressure measured in living room.

According to the results shown in Fig(89), the recorded readings from the Pressure Sensor (BMP280) fluctuate between 1009.16 hPa and 1009.22 hPa. These variations demonstrate the dynamic nature of pressure changes in the surroundings and serve as a representation of the atmospheric pressure levels measured in the living room.

In addition, it's essential to be aware that the Pressure Sensor (BMP280) works effectively with a 3.3V input voltage. The sensor also keeps its output voltage and current stable, with the output voltage measuring about 3.31V and the current circling around 0.30 mA. As shown in Figs(90,91), these measurements were made using an oscilloscope for voltage and a multimeter for current.

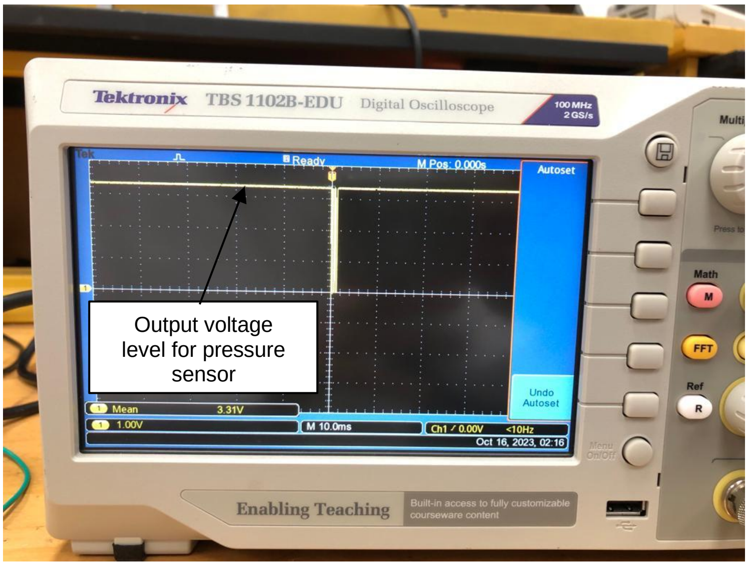

Figure 90: Output voltage measured from Pressure (BMP280) sensor.

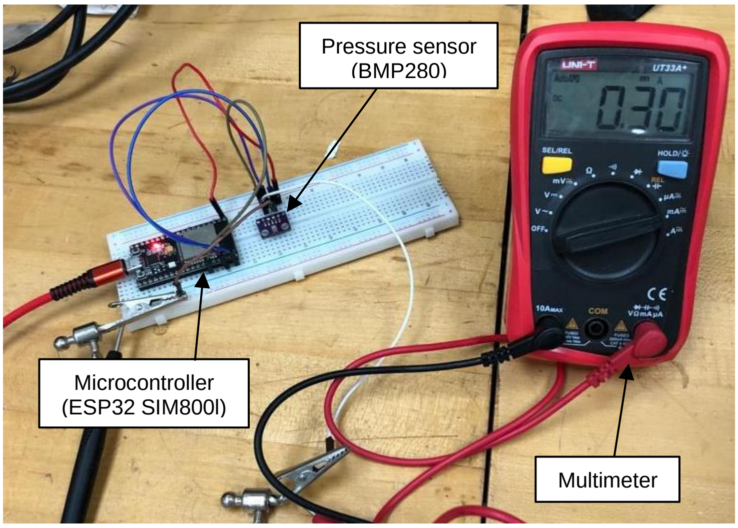

Figure 91: Output current measured from pressure (BMP280) sensor.

5.5.6 Results of The Final Comprehensive Prototype

After combining all parts and subsystems together and developing a prototype of the final product, it's required to measure the outputs from the system again. In addition, it's required to compare the results from the main system with the results from the subsystems to ensure that the final results are achieving the requirements as it did in the subsystem. Therefore, it's important to test the different cases for each parameter of the subsystems to check if there is any interrupt between the subsystems or they can work smoothly together is required.

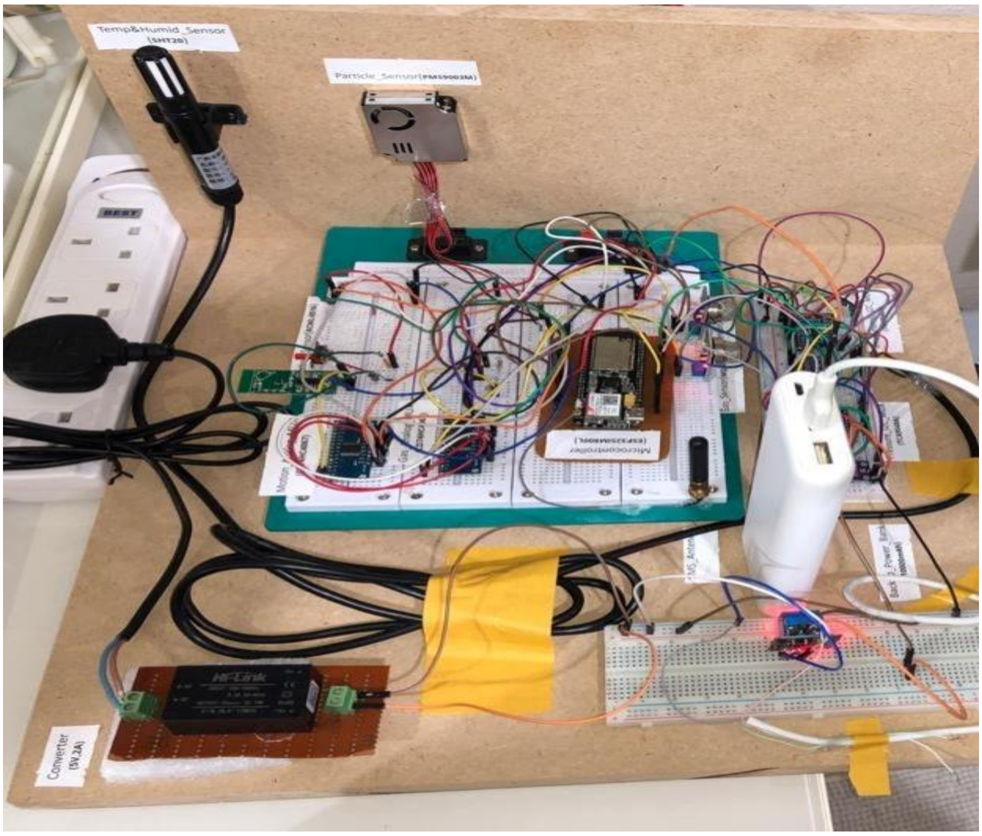

Figure 92: Final Prototype with power on.

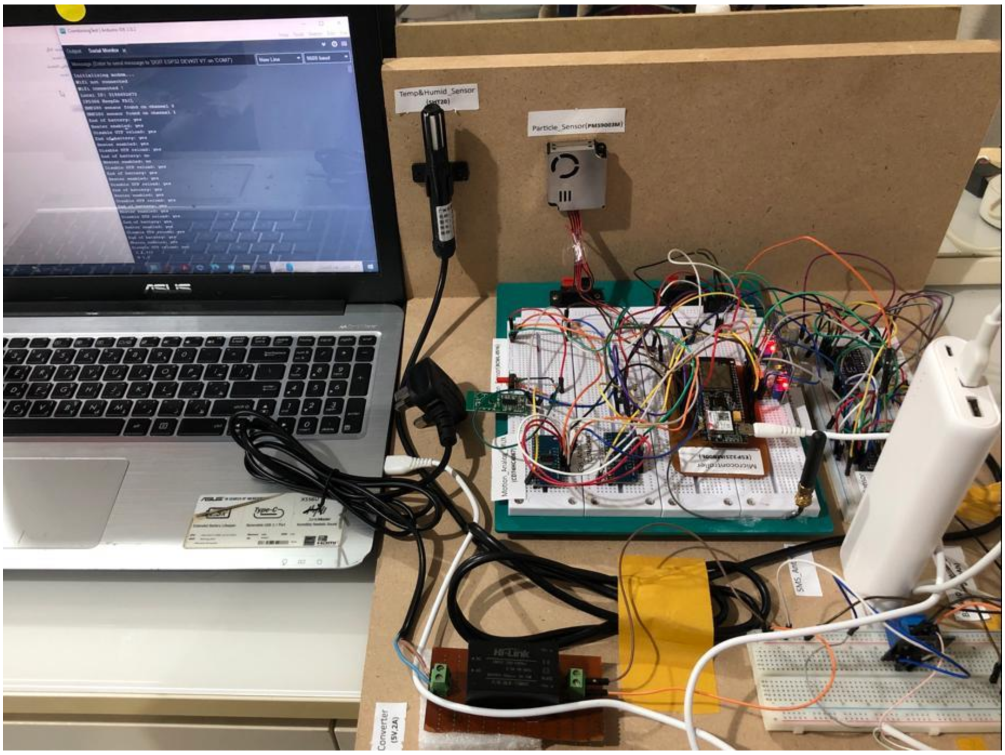

Figure 93: Final Prototype showing output in the serial monitor.

However, the system developed a continues representation for the collected data from the sensors using ThingSpeak cloud. The results from ThingSpeak can be compared to the results collected from the subsystems individually to ensure the precision and the effective of the system. the following Fig(92) show the representation of the collected data from the motion sensors on the ThingSpeak cloud.

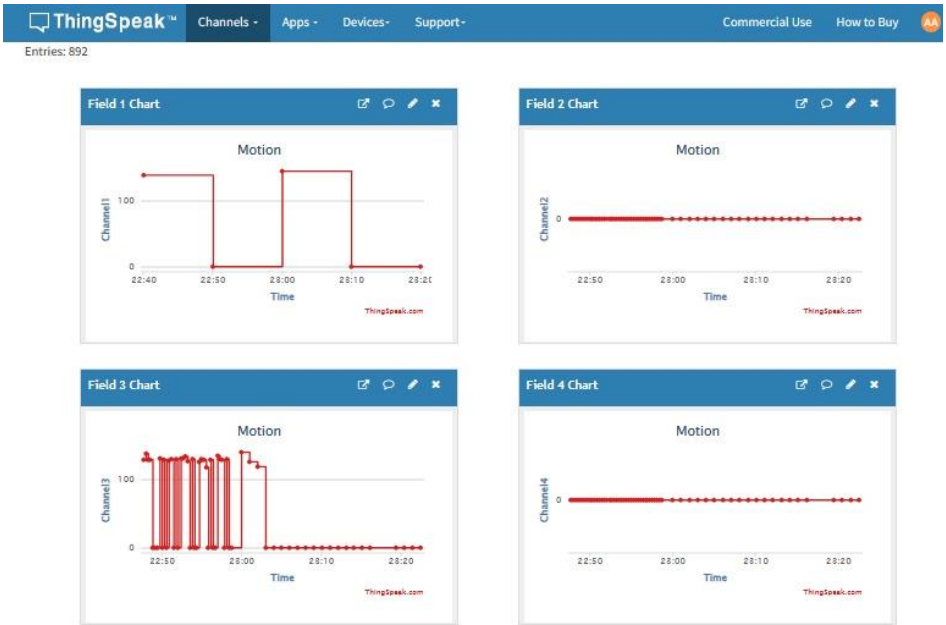

Figure 94: Results of Motion monitoring on ThingSpeak Cloud.

As mentioned in the above Fig(), the fields are representing the channels of the multiplexers. And since there only to motion sensors connected in field 1 and field 3 (Channel 0 and 2), only these fields are giving a response. The other fields are representing nothing since the channels are free and do not have sensors connected to them. The next Fig(93) shows the continues representation of monitoring gases sensors. Each field represents the situation on specific type of gas sensors as connected in the final product.

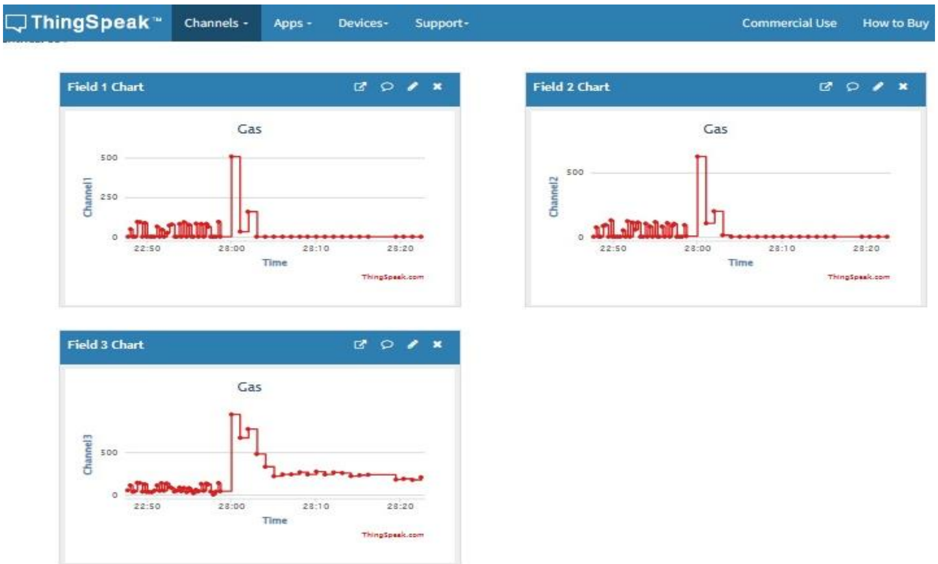

Figure 95: Results of Gases Monitoring on ThingSpeak Cloud.

However, the previous two figures (92,93) were representing the digital sensors from this system. The Following figures (94,95,96) shows the analog sensors which are pressure, temperature, and humidity.

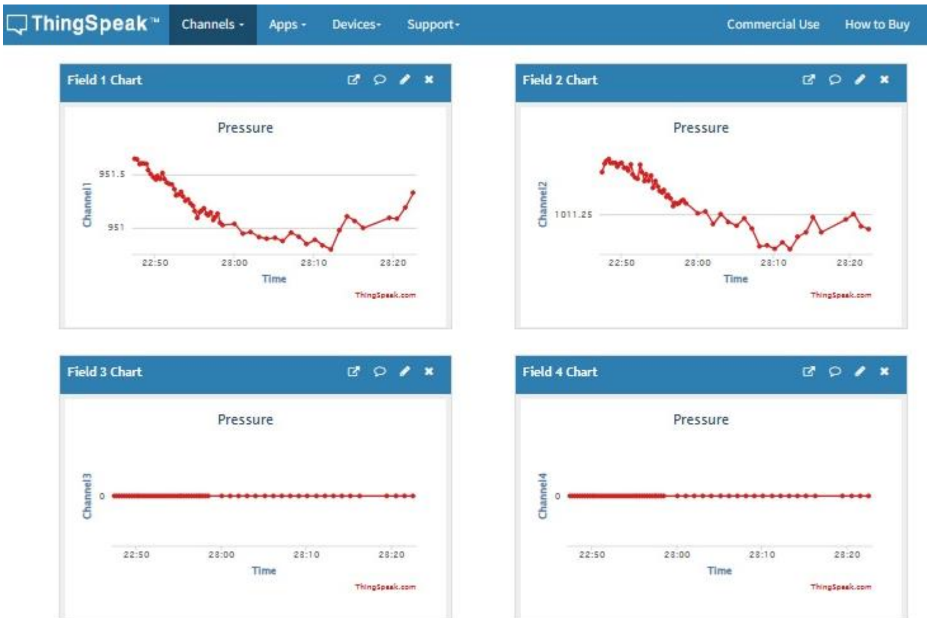

Figure 96: Results of Pressure Monitoring on ThingSpeak Cloud.

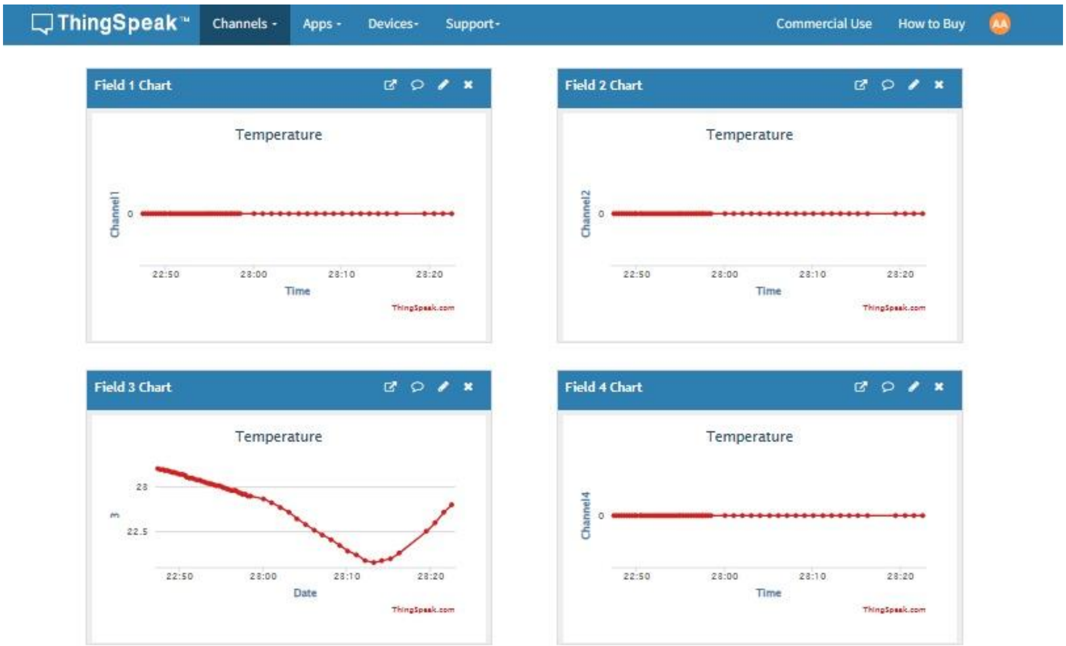

Figure 97: Results of Temperature Monitoring on ThingSpeak Cloud.

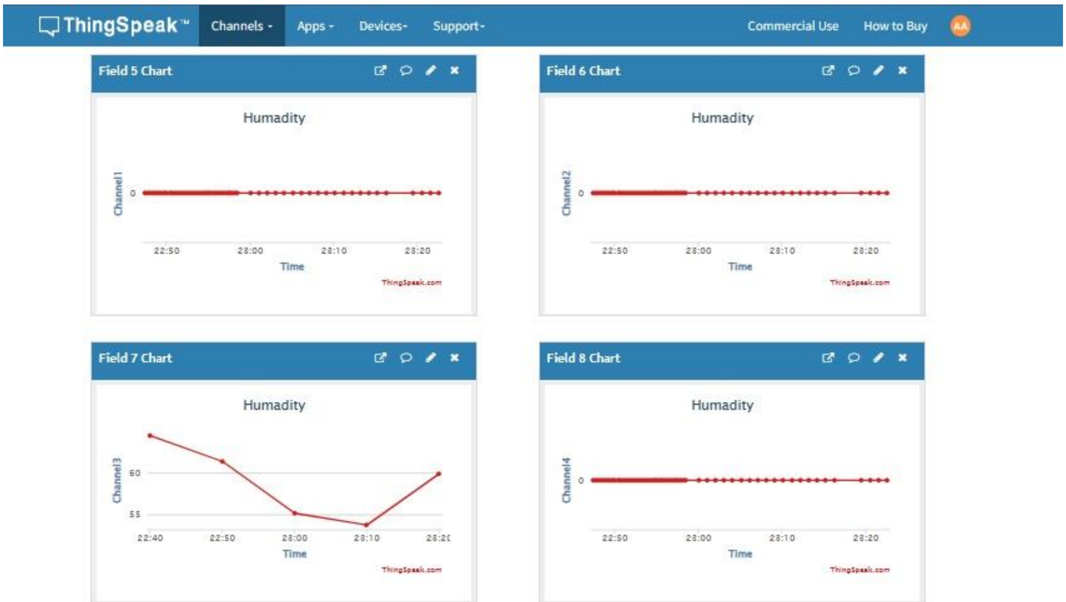

Figure 98: Results of Relative Humidity Monitoring on ThingSpeak Cloud.

Moreover, as similar to the previous results, the fields that doesn't give any response means that there are no sensors connected to them. In addition, the sensors are giving results that are actually comparable to the values from the subsystems individually.

Furthermore, the other part of the output was the SMS alarming system. the results from the alarming system expected to be a warning messages that report for any problem happening in the monitored parameters inside the cleanroom. Therefore, the warning message are different based on the type of the warning. For instance, the warning from the digital sensors like motion and gases sensors are as follows:

1. First message statement:
    a. Ex. "Motion has been detected from channel: 2."
    b. Ex. "Methane Gas Leakage has been detected from channel:3. "
2. Second message statement:
    a. Ex. "motion still detecting from channel:2. "

Once a matter happened, the first warning message will be sent to the user. Then, the second warning message will be sent after 30 seconds if the matter didn't solve within 30 seconds. This short time delay is to ensure the safety and fast response in reporting the situation of the cleanroom. Therefore, after one-minute pass from the time of sending the first message, another message will be sent similar to the first message. Same process will keep continue until solving the occurred problem.

Moreover, the other type of the sensors are the particle detector and the analog sensors such as pressure, temperature, and humidity sensors. Since that these sensors are collecting analog data, the warning messages will be different. The warning messages/message will include the collected value that went out of the permissible range in the specifications of the parameters. The format of the warning messages will be as follows:

1. First message statement:
    a. Ex. "temperature is out of permissible range in channel: 3. Value is: 27.95."
    b. Ex. " Relative Humidity is out of permissible range in channel: 3. Value is: 74.79. "
2. Second message statement:
    a. Ex. " Temperature is still out of permissible range in channel:3. "

However, the process and the time delay between sending first and second message will be similar to the first type. In addition, the time between sending the first message and repeating the process will be similar as well. Therefore, the following Fig(97) represent an example of the warning messages for both types.

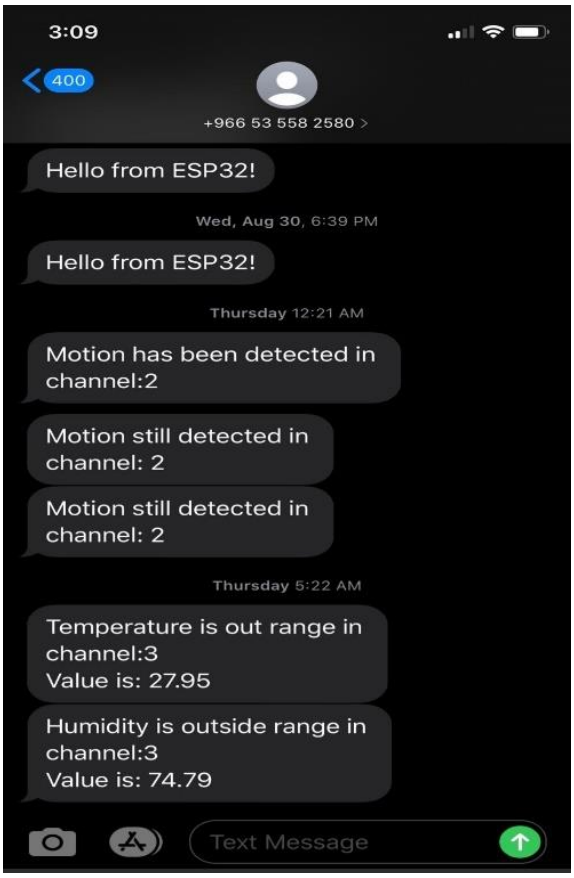

Figure 99: SMS Warning Messages.

Moreover, these were the results from the final product of this design project. Any development and improvements are expected to be listed in the future work of this product.

5.2 EVALUATION OF SOLUTIONS

5.2.1 Technical Aspects

This design will achieve customer requirements in most effective way since it's designing an expandable cost-effective monitoring system that is suitable for several kind of cleanrooms including small laboratory cleanroom and big cleanrooms like in semiconductor factories. In addition, this design includes additional preference that help in informing the user about the situation of the cleanroom continuously. Also, the design includes a backup power system that ensures continuous monitoring without any issue. Furthermore, the system is generic and able to work with additional subsystem. This makes the design adaptable to different kinds of situations and environments.

5.2.2 Environmental Impacts

An important step in ensuring controlled and faultless conditions for fields ranging from healthcare to electronics manufacturing is the development of a clean room monitoring system that is affordable. Although this breakthrough offers improved precision and efficiency, it's important to recognize that introducing any technology into these sensitive environments may potentially present challenges. In order to secure both the operational integrity and environmental sustainability of a clean room, we will examine the main aspects that could have an impact on the environment inside this monitoring system and investigate how these factors can be managed and controlled. Understanding and resolving the environmental aspects of this monitoring system, including electronic components, and power sources, is essential in maintaining the delicate balance of clean room facilities.

5.2.2.1 220 AC to 5 DC converter

A crucial part that enables the conversion of high-voltage alternating current (AC) into low-voltage direct current (DC) is the 220 AC to 5 DC converter. At the end of its life cycle, this converter, like many other electrical equipment, creates risks to the environment. The electronic components contained within it, such as capacitors and semiconductors, can contain hazardous materials, including heavy metals.

These hazardous substances may leak into the environment as a result of improper converter disposal, potentially harming soil and water supplies. To make sure that the converter's parts are handled safely, specialized disposal techniques are required. In order to avoid harm to the environment and human health, this frequently entails recycling and responsible disposal techniques, which should be carried out by licensed organizations with experience in electronic waste management.

Electronic garbage may be handled more sustainably and could help reduce soil contamination when it is recycled and disposed of properly.

5.2.2.2 Power Bank (10 mAh)

While providing a portable power source, the 10 mAh power bank also contains lithium-ion batteries, which can be harmful to the environment if not properly disposed of. These batteries contain chemicals that could harm the environment if they released into the soil or water. To avoid harming the environment, it is important to recycle or dispose the power bank through professional's e-waste recycling facilities.

5.2.3 Safety Aspects

It's crucial to carefully evaluate the safety aspects of the clean room facility monitoring system. For the system to operate correctly and to avoid any danger or damage, safety considerations are essential. This section is discussing some safety issues related to the product, so it can operate without facing any problem.

5.2.3.1 Chemical risk

Chemical exposure restrictions are frequently very severe in cleanrooms. It has been confirmed that the components used to build the product, particularly the sensors and their enclosures, are appropriate for the clean room environment and do not emit any hazardous substances or particles.

5.2.3.2 Electrical risk

Electrical risks could arise from the use of components like the 220 AC to 5 DC converter, power banks, and numerous sensors. These include the possibility of fires, short circuits, and electrical shocks. To reduce these risks, proper insulation, grounding, and adherence to electrical safety standards are made.

5.2.3.3 Radiation Risk

Radiation risks in clean rooms can arise from a variety of sources, and reducing these risks is essential to keeping the environment under control and safe. In a cleanroom, electromagnetic radiation (EMI) can interfere with delicate equipment. It has been confirmed that the product doesn't produce an excessive amount of electromagnetic radiation or is prone to interference from other clean room equipment.

5.2.4 Financial Aspects

This section contains an approximation cost analysis for the design project. The analysis includes the cost of the electrical components and other resources that would be used during working in this project. The following table (13) represent in detail the cost analysis for this design.

Table 21: Project cost analysis

Component name	No. of pieces	Price per each (SR)
220AC – 5DC CONVERTER[54]	1	29
Power Bank[55]	1	99
Relay (5V)[56]	1	25
BMP280[57]	2	27
SHT20[58]	2	133
RCLW-0516[59]	2	15
PMS9003M[60]	1	442
CD74HC4051-EP[61]	2	24
ESP32 SIM800l[62]	1	91
MQ-4[63]	1	24
MQ-2[64]	1	35
MQ-137[65]	1	63
TCA4548A[66]	2	32
SIM card	1	80
Total costs (SR)		1,350

In short, this design is highly effective from the economical side. The main idea of this design was to develop a cost-effective monitoring system. Therefore, this system has some features that make it even more effective design in the market. This system is an expandable system, which mean that the system can work in small cleanrooms that cannot afford the current available monitoring systems in the market due to its expensive cost. In addition, the system is able to expand and suit bigger cleanrooms without any issue since it's expandable and generic.

5.2.5 Social Impacts

As previously stated, cleanrooms are critical for many places, not just hospitals and large, expensive facilities; small cleanrooms, such as laboratory rooms in hospitals and some universities, cannot acquire and handle this monitoring equipment because of how expensive they are. In the future, this product (cost-effective monitoring system) will be able to meet the basic specifications for all types of cleanrooms, which is going to be beneficial to the community.

5.2.6 Global Impacts

If the project succeeds, it is expected to have a global impact in several extensions, most importantly economic. Both large modern and startup firms can manufacture their products in these cleanrooms, it is possible that some of the leading international companies in the field will be dismissed. Also, as consumers for these products most probably the manufacturers and companies will lower prices to enhance the market change.

5.3 CONCLUSION

This Project was about implementing a cost-effective monitoring system for biomedical and cleanroom facilities. Since that most of the available products are expensive and not suitable for small cleanroom facilities, it was required to design a cost-effective monitoring system suits these applications. For instance, the small labs in semiconductors facilities, hospitals, pharmacies, and laboratories in universities. All these can be examples of cleanroom that can't offer expensive cleanroom monitoring system. In addition, the quality required in these small cleanrooms may not be affected by reducing the quality of the system a little to improve the cost of the product.

Moreover, designing a monitoring system that is applicable for these cleanrooms became the main objective of this project. In addition, there were some specific requirements from the customer of this project that need to be achieved as well. For instance, the system has a specific upper limit of cost that shouldn't be exceeded and there some important environmental parameters need to be monitored like temperature, humidity, pressure, and number of particles in air. Also, the system was expected to be generic and expandable to ensure the opportunity for continues developing on the project.

Furthermore, planning and implementing this project after defining the main problem was not an easy project to achieve for sure. In addition, there were many problems occurred continuously during the implementation process. For example, some of the parts were hard to get and the microprocessor was facing hard time following up with collecting the data and take a lot of time in analyzing the inputs. Therefore, most of these problems was solved and the final product was able to achieve the requirements in more effective ways. for example, the microprocessor became to use his dual core in analyzing the data and this made the system much faster than before.

However, this design project achieved the objectives and requirements from the customer. In addition, the design has the ability to be improved more in the future. The solution could have been improved better but, due to lack in time and some resources it wasn't applicable. Therefore, here are some recommended future work that would improve the product performance and economy:

1. Adding UART Multiplexer:

   Since that the particle detector is using serial communication system, it would improve the performance if an UART multiplexer was added to increase number of particle sensor used by the monitoring system.

2. Develop serial communication for long-distance:

   There are some sensors that use I2c communication system. these systems are only applicable for short-distance communication. However, developing long-distance communication for these sensors may improve the performance by covering more area and bigger cleanroom.

3. Monitoring differential and positive pressure:

   Cleanroom has many types of pressure inside it. For instance, there are differential pressure, atmospheric pressure, and positive and negative pressure as well. This product was focusing on measuring the atmospheric pressure which is the most required to be monitored in cleanroom. However, measuring the differential and positive pressure would improve the system for higher class cleanroom in cleanroom classifications that has advanced applications.

4. Improve dual core performance of the ESP32 SIM800l microcontroller:

   Improving the dual core performance of the microcontroller will support in enhancing the performance of the system by reducing the delay in collecting and analyzing the data. It will also help in expanding the system.

To sum up, the final solution faced multiple tests to ensure its quality and reliability to monitor the cleanroom. Therefore, we glad that we were able to finish this project in this effective way. In addition, we hope that monitoring system development and improvement will raise the standard and efficiency of the system in comparison to other monitoring systems available, while ensuring cleanroom safety at a reasonable price.

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APPENDIX – A: VALIDATION PROCEDURES

King Abdulaziz University
Faculty of Engineering
First Semester
2023/2024

EE-499: Senior Design Project

Term-2

<u>Validation Report</u>

SMS Alarming System

Date of Submission: 28/9/2023

Name: Omar Abdulaziz Hussain

Academic ID: 1945955

Advisor: Dr. Nebras Sobahi

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Introduction

To ensure the quality and integrity of delicate processes and products in modern cleanroom environments, it is crucial to maintain precise cleanliness standards and environmental controls. In addition, continuous monitoring, and prompt action in the event of deviations are necessary to sustain these standards. This report focuses on validating an SMS alarming system that is integrated with the ESP32 microcontroller and SIM800L GSM module.

Furthermore, this SMS alarming system designed with the intention of increasing the effectiveness and dependability of notifying users to these variations. Therefore, the system is capable of sending SMS notifications to specified users when some critical circumstances happened using ESP32 and SIM800L, supporting for fast implementation of corrective actions.

However, this validation report provides a thorough examination of the SMS alarming system's functionality, precision, and dependability. Also, it intends to demonstrate the system's efficiency in giving prompt alarms, assuring commitment to cleanroom standards, and contributing to the overall quality assurance of cleanroom operations through precise testing and evaluation.

Objective

This validation experiment's primary objective is to evaluate the efficiency and reliability of the SMS alarming system using the ESP32 and SIM800L for cleanroom monitoring. In addition, its required to insure the specific objectives are as follows:

1. **Functionality Evaluation:**
   Validate the system's ability to monitor key cleanroom parameters and generate SMS alerts when predefined thresholds are exceeded.
2. **Accuracy Assessment:**
   Evaluate the precision of sensor measurements and the system's ability to detect deviations accurately.
3. **Reliability Testing:**

Assess the system's robustness and consistency in delivering SMS notifications under various operating conditions.

Moreover, by accomplishing these objectives, we aim to demonstrate the benefits and the effectiveness of our SMS alarming system for cleanroom monitoring. In addition, improving cleanroom operations and quality assurance procedures.

Background information

In several sectors, including pharmaceuticals, electronics manufacturing, and biotechnology, cleanrooms are essential situations that require strict control over particulate pollution, temperature, humidity, and other crucial parameters. Moreover, these monitored situations were developed in order to ensure product quality, safeguard delicate procedures, and uphold regulatory norms.

One of these innovations is the design of an SMS alarming system using the ESP32 microcontroller and SIM800L GSM module. When crucial cleanroom conditions vary from the set limits, this system's remotely monitoring and alerting abilities provide immediate messages via SMS to the users.

However, the processing power and connectivity required for data capture and transfer are provided by the adaptable microcontroller ESP32. This microcontroller known for its low power consumption and integrated Wi-Fi and Bluetooth capabilities. In addition, this system transforms into an effective device for ensuring the integrity of cleanroom settings when used with the SIM800L GSM module, which makes cellular connection possible.

The aim of this validation report is to comprehensively assess the functionality, accuracy, and reliability of the SMS alarming system built around the ESP32 and SIM800L. By providing an in-depth evaluation of the system's performance under various conditions, this report seeks to demonstrate the practicality and effectiveness of this technology in cleanroom monitoring. Additionally, it highlights the potential benefits of wireless monitoring solutions in enhancing operational efficiency and quality assurance in cleanroom environments.

Assumptions

The successful validation of the SMS alarming system using ESP32 and SIM800L is based on several key assumptions, which serve as the foundation for the testing and evaluation conducted in this report. These assumptions include:

1. **Stable Cellular Network:**

   It is assumed that the cellular network infrastructure in the testing environment and the cleanroom facility is stable and capable of providing reliable connectivity for the SIM800L GSM module. Any interruptions or signal weaknesses in the cellular network could affect the system's ability to send SMS alerts promptly.

2. **Sensor Calibration:**

The sensors used in the cleanroom monitoring system are assumed to be accurately calibrated and capable of providing precise measurements of temperature, humidity, and particle levels. Any sensor inaccuracies could impact the system's ability to detect and alert to deviations effectively.

3. **Cleanroom Operating Conditions:**

   The cleanroom environment is assumed to be properly established and maintained within defined operating parameters. Deviations from specified cleanroom conditions are generated artificially during testing to evaluate the system's response.

4. **SMS Gateway:**

   The SMS alarming system relies on an external SMS gateway service, which is assumed to be operational and capable of delivering SMS notifications to designated recipients without significant delays or errors.

5. **Power Supply:**

   It is assumed that the ESP32 and SIM800L are powered continuously during testing without any power interruptions. Battery or power supply issues that could disrupt system operation are not considered in this validation.

6. **Functional Sensor Hardware:**

   The sensors integrated into the system are assumed to be free from hardware malfunctions or defects that might hinder their ability to generate accurate readings.

7. **Proper Configuration:**

   The ESP32 and SIM800L modules are assumed to be correctly configured and programmed with the necessary firmware to facilitate data acquisition, processing, and SMS alert generation.

8. **Testing Environment:**

   Testing is conducted in a controlled environment that mimics cleanroom conditions to evaluate the system's functionality. It is assumed that the test environment accurately represents real-world cleanroom scenarios.

9. **Testing Period:**

   The testing duration is assumed to be sufficient to capture a range of deviations and scenarios that may occur in the cleanroom. Long-term reliability and performance assessments may not be included in this validation report.

These assumptions provide the basis for the testing and evaluation conducted in this report. It is important to note that any deviations or issues arising from these assumptions will be addressed and discussed in the respective sections of the report to ensure a comprehensive assessment of the SMS alarming system's performance and reliability.

Variables and Constans

There are some variables and constants will be considered in this experiment which are listed as follow:

- Constant Power source with 5V.
- Variable number of pressed on pushbutton.

Caution / Precaution

1. Electrical Safety:
    a. Ensure that all electrical connections and components, including the ESP32 and SIM800L, are properly installed and insulated to prevent electrical hazards.
    b. Avoid exposing the system to water or moisture to prevent electrical shorts and potential damage.
2. Battery Use (If Applicable):
    a. Do not short-circuit or puncture batteries, as this can lead to chemical leakage and safety risks.
3. Environmental Impact:
    a. Properly dispose of electronic components, batteries, and other system-related materials in accordance with local environmental regulations.
    b. Minimize electronic waste by recycling or reusing components where possible.
4. Radio Frequency (RF) Safety:
    a. Keep antennas and RF equipment away from individuals to prevent potential exposure to RF radiation.
5. Installation and Mounting:
    a. Securely mount and install the system to prevent it from falling or becoming a tripping hazard.

    b. Avoid blocking ventilation or air circulation around the ESP32 or SIM800L to prevent overheating.
6. Testing Environment:
    a. Conduct testing in a controlled environment, such as a testing chamber or controlled cleanroom area, to prevent contamination or damage to the cleanroom and its equipment.
    b. Ensure that all testing equipment and procedures comply with cleanroom protocols to maintain the integrity of the controlled environment.
7. Fire Safety:
    a. Ensure that the system and its components are not located near flammable materials or potential ignition sources.
    b. Have fire extinguishing equipment readily accessible during system installation and testing.
8. Security:
    a. Protect access to the SMS alarming system to prevent unauthorized configuration changes or tampering.
    b. Use secure communication protocols for data transmission to safeguard sensitive information.
9. Emergency Procedures:
    a. Establish clear emergency procedures for addressing system failures or false alarms to prevent unnecessary disruptions in the cleanroom.

By adhering to these precautions and safety measures, you can help ensure the safe and responsible deployment of the SMS alarming system while minimizing potential risks to both personnel and the environment. Additionally, it's advisable to consult with safety experts or regulatory authorities if you have specific concerns or questions regarding safety and environmental compliance in your project.

Equipment

- ESP32sim800L

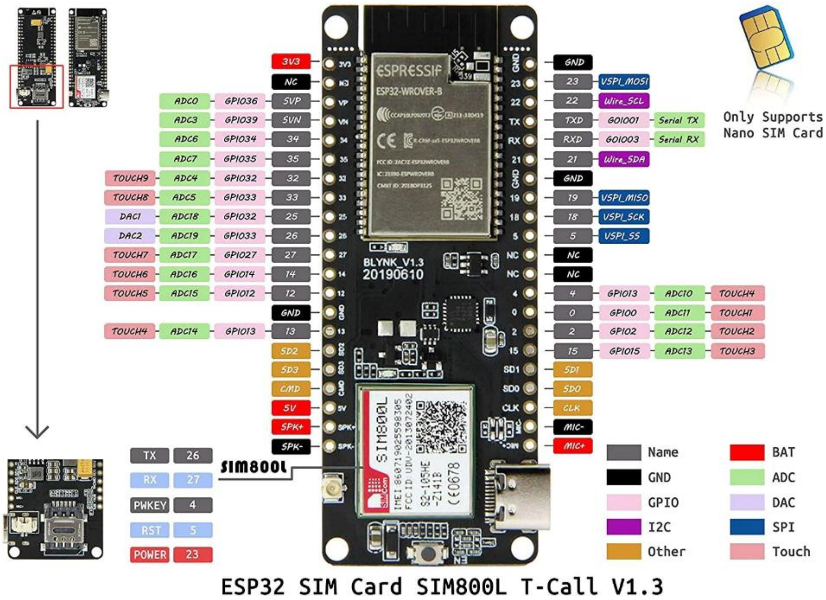

Figure 1: ESP32sim800l

- Power Supply (5V)
- Jumpers
- Breadboard
- Resistor (1k Ω)
- Cables
- pushbutton
- Antenna

Circuit Schematics

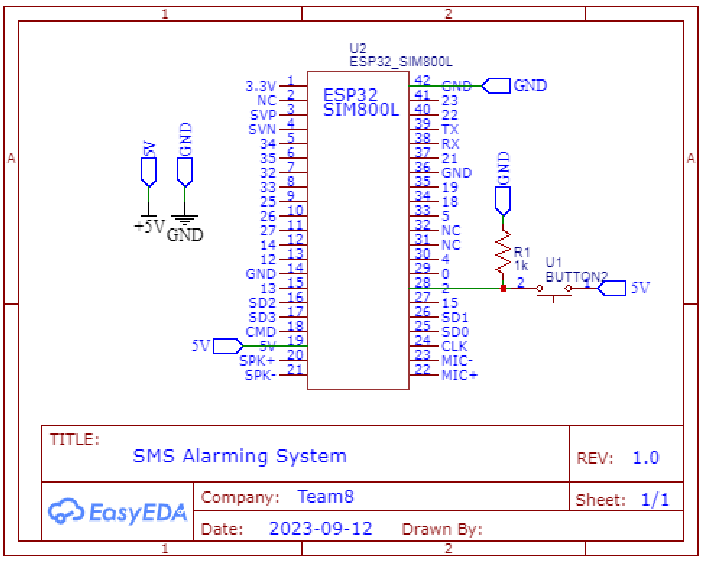

Figure 2: Circuit Schematic[1]

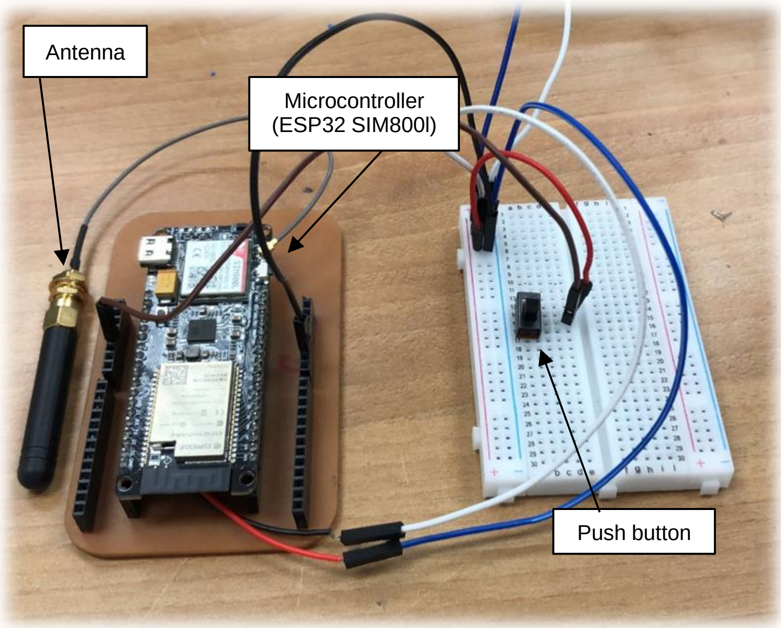

Figure 3: Hardware Connection

Work plan

1- Prepare the code of the program and the required libraries in Arduino IDE software.
2- Connect the type-c input of ESP32SIM800l on your device to upload the program from Arduino IDE in the microcontroller.
3- Type-c input will work as a power supply and feed the microcontroller with 5V.
4- Connect the power supply with 5V to the button and connect the button to pin 28 in the ESP32SIM800l.
5- Connect a pulldown resistor (1k Ω) between the button and the microcontroller.
6- Press the button to send the SMS message.
7- Once the button pressed the message will be sent one time and stop until another press happened.
8- Check the determined phone number to see the message.

Data Collection and Analysis

The collected data from this experiment is weather getting an SMS message in the determined phone or not. Therefore, the pushbutton used in this experiment was the controller of sending the messages. The system was expected to send a message whenever the pushbutton pressed. However, the following fig(4) represent the statue of the system before and after pressing the pushbutton multiple time.

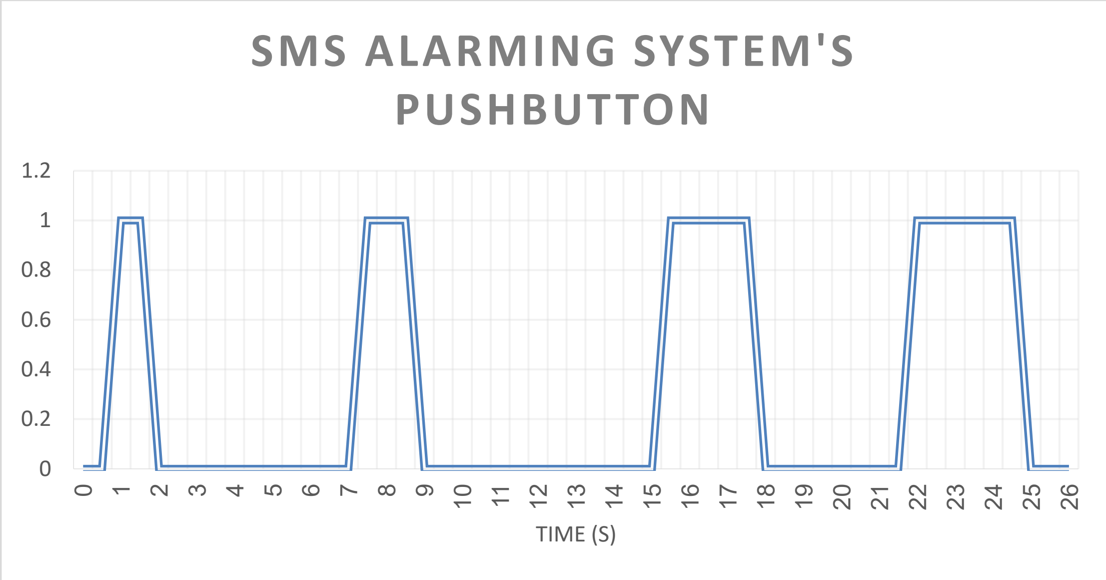

Figure 4: SMS alarming system's Pushbutton

The above fig (4) reflects the situation of the system. When the output is 1 (high) this means that the pushbutton pressed. The system will automatically send the message and return in the low mode (0). Then, it will remain in low mode until another press happened in the pushbutton. Note that, the system sends an SMS message one time when the pushbutton pressed. In addition, the system will not send a message again until the pushbutton released and pressed again.

Results

The output from this validation experiment is an SMS message sent to a determined phone number in specific conditions. the experiment has been successfully achieved by receiving the message when the pushbutton pressed. In addition, the following fig (5) represents an example of the output from this experiment.

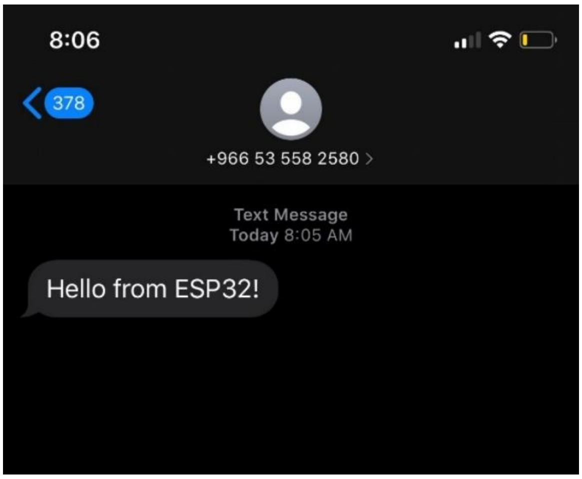

Figure 5: SMS Alarming system result

Discussion

The objective of this experiment was to validate an SMS alarming system. The main system, which is cleanroom monitoring system, required an alarming subsystem to report any failing happened in the cleanroom. Therefore, we tested our developed SMS alarming system to check whether it is reliable to be used in the cleanroom monitoring system or not. However, the system has been tested using pushbutton as an example of problem happened in the measured parameters of the cleanroom. It was supposed to send an alarming message when the pushbutton pressed.

Moreover, the experiment was efficient since that the system was reliable in sending messages when pushbutton pressed. This means the system will be able to warn in case of single or multiple problems happened in cleanroom's parameters. For instance, the system is expected to be able to warn when an out of range temperature degree detected and so on.

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Appendix

```
// SMS Alarming system
// Team: 08

const char simPIN[]   = "";

#define SMS_TARGET  "+966508393281"

#define TINY_GSM_MODEM_SIM800
#define TINY_GSM_RX_BUFFER   1024

#include <Wire.h>
#include <TinyGsmClient.h>

#define MODEM_RST            5
#define MODEM_PWKEY          4
#define MODEM_POWER_ON       23
#define MODEM_TX             27
#define MODEM_RX             26
#define I2C_SDA              21
#define I2C_SCL              22

#define SerialMon Serial
#define SerialAT  Serial1

#ifdef DUMP_AT_COMMANDS
  #include <StreamDebugger.h>
  StreamDebugger debugger(SerialAT, SerialMon);
  TinyGsm modem(debugger);
#else
  TinyGsm modem(SerialAT);
#endif

#define IP5306_ADDR          0x75
#define IP5306_REG_SYS_CTL0  0x00

bool setPowerBoostKeepOn(int en){
  Wire.beginTransmission(IP5306_ADDR);
  Wire.write(IP5306_REG_SYS_CTL0);
  if (en) {
    Wire.write(0x37);
  } else {
    Wire.write(0x35);
  }
  return Wire.endTransmission() == 0;
}

void setup() {
  SerialMon.begin(9600);
```

```
  Wire.begin(I2C_SDA, I2C_SCL);
  bool isOk = setPowerBoostKeepOn(1);
  SerialMon.println(String("IP5306 KeepOn ") + (isOk ? "OK" : "FAIL"));

  pinMode(MODEM_PWKEY, OUTPUT);
  pinMode(MODEM_RST, OUTPUT);
  pinMode(MODEM_POWER_ON, OUTPUT);
  digitalWrite(MODEM_PWKEY, LOW);
  digitalWrite(MODEM_RST, HIGH);
  digitalWrite(MODEM_POWER_ON, HIGH);

  SerialAT.begin(9600, SERIAL_8N1, MODEM_RX, MODEM_TX);
  delay(3000);

  SerialMon.println("Initializing modem...");
  modem.restart();

  if (strlen(simPIN) && modem.getSimStatus() != 3 ) {
    modem.simUnlock(simPIN);
  }

  String smsMessage = "int";
  if(modem.sendSMS(SMS_TARGET, smsMessage)){
    SerialMon.println(smsMessage);
  }
  else{
    SerialMon.println("SMS failed to send");
  }
}

void loop() {
  delay(1);
}
```

King Abdulaziz University
Faculty of Engineering
First Semester
2023/2024

EE-499: Senior Design Project

Term-2

Validation Report

Temperature and humidity monitoring system

Date of Submission: 28/9/2023

Name: Ibrahim Ahmed

Academic ID: 1945968

Advisor: Dr. Nebras Sobahi

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Introduction

Across a variety of industries, precise monitoring of the environment, including of temperature and humidity, is essential. In addition, product quality, equipment reliability, and the safety of users can all be affected by changes in these characteristics[1]. The idea of this validation experiment is the examination of an innovative temperature and humidity monitoring system that utilizes the SHT20 sensor.

Moreover, the SHT20 sensor is one of the innovative components of this system, which also provides real-time monitoring, record of information, and alarms for instantaneous reactions to environmental changes. Our goal is to assess its reliability, precision, and ability to maintain the appropriate conditions.

Objective

The objective of this experiment is to evaluate the performance and reliability of the SHT20 sensor-based Temperature and Humidity Monitoring System. Therefore, in order to make sure it meets the requirements of this project, it's required to evaluate its ability to precisely monitor and maintain temperature and humidity parameters in real-time.

Background information

In fields including medicines, electronics, and food production, the importance of maintaining accurate humidity and temperature measurements cannot be denied[1]. In addition, Humidity affects product quality, and energy efficiency while temperature affects chemical reactions, material qualities, and equipment performance.

Moreover, SHT20 sensor has become more common in recent years due to its precision and reliability in monitoring temperature and humidity. In addition, this sensor provides real-time data collecting and remote accessibility and has been integrated into comprehensive monitoring systems.

However, SHT20 sensor is used by our cleanroom monitoring system to provide continuous monitoring and reporting for humidity and temperature levels. Furthermore, in order to ensure that variations from the ideal conditions are rapidly handled, it provides recording of data and immediate response. In addition, environmental control procedures and facilities might get benefits from this technology.

Assumptions

These assumptions provide the fundamental basis for the experiment's testing and evaluation.

1. **Sensor Reliability:**
   Assume the SHT20 sensor provides accurate temperature and humidity measurements.
2. **Continuous Power:**
   The system is powered continuously without interruptions.
3. **Sensor Placement:**
   The SHT20 sensor is appropriately positioned.
4. **Security:**
   Assume that adequate security measures have been implemented to protect the system from unauthorized access or tampering.
5. **Environmental Stability:**
   The cleanroom or testing environment is assumed to be stable and maintained within specified temperature and humidity ranges during testing. Artificial deviations from these conditions are introduced for testing purposes.

Variables

This validation experiment has two main variables that need to be considered.

- Temperature degree
- The percentage of relative humidity

However, these two variables need to be considered inside the cleanroom to ensure the safety and efficient performance for workers and stored materials.

Constants

- Constant Power source with 5V.

Caution / Precaution

1. Electrical Safety: Ensure proper insulation and connections to prevent electrical hazards. Avoid exposure to moisture to prevent short-circuits.
2. SHT20 Sensor Handling: Handle the SHT20 sensor with care to avoid damage. Ensure it is properly positioned for accurate readings.
3. Testing Environment:
   a. Conduct testing in a controlled environment, such as a testing chamber or controlled cleanroom area, to prevent contamination or damage to the cleanroom and its equipment.

b. Ensure that all testing equipment and procedures comply with cleanroom protocols to maintain the integrity of the controlled environment.

4. Installation and Mounting: Securely install the system to prevent falls or hazards. Avoid blocking ventilation to prevent overheating.

Equipment

- SHT20 Temperature and Humidity Sensor
- Arduino Uno
- Breadboard
- Connection Wires
- TCA9548A I2C Multiplexer
- Power Supply 5V
- Jumpers
- DC converter (5V- 3.3V)

Circuit Schematics:

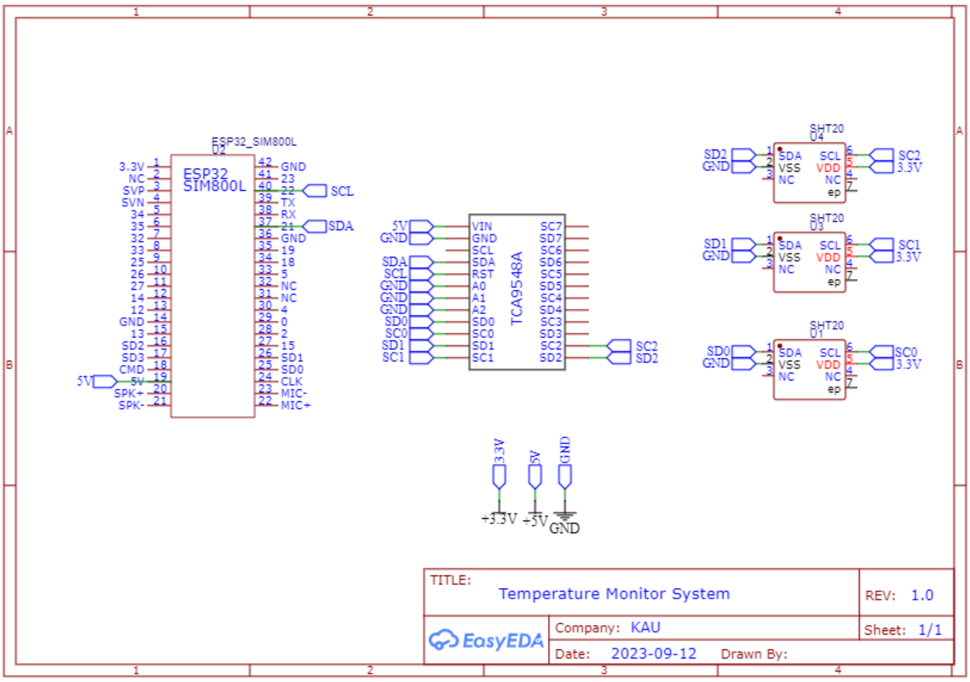

Figure 1: Temp & Humidity monitoring Schematic

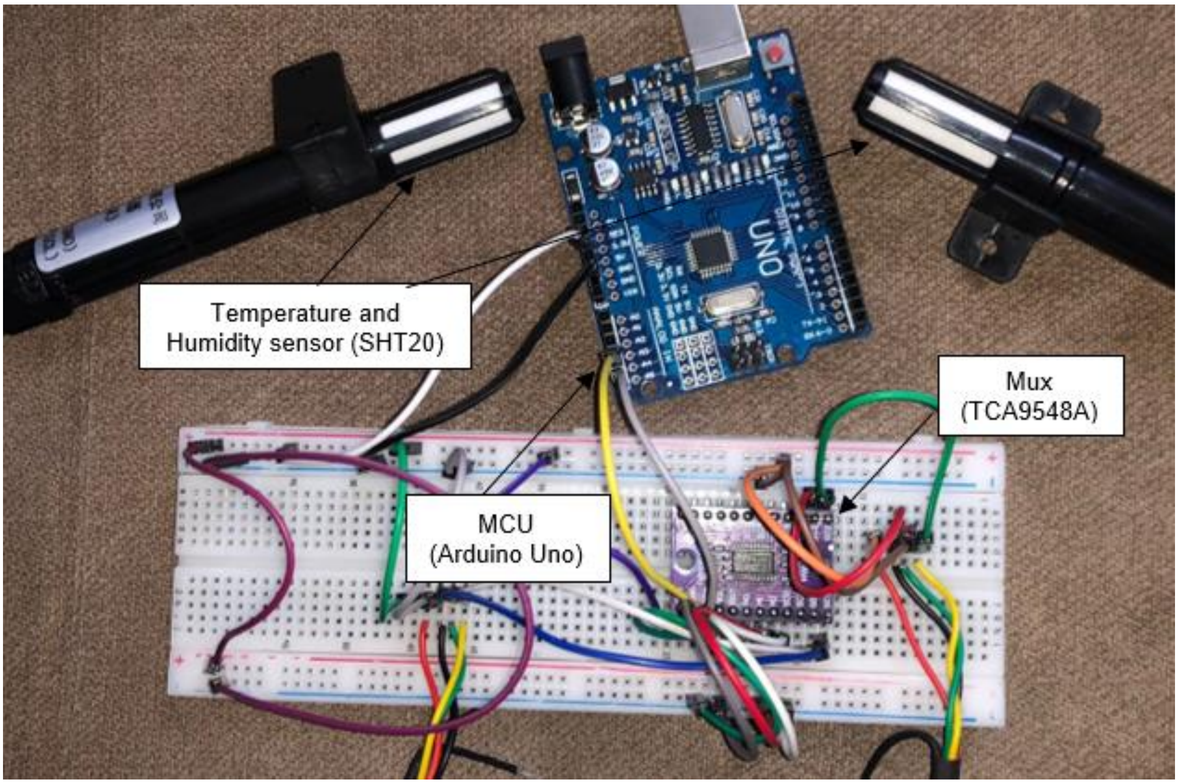

Figure 2: Temp & Humidity monitoring Hardware connection

Work plan:

1. Prepare the code of the program and the required libraries in Arduino IDE software.
2. Connect the input of Arduino Uno on your device to upload the program from Arduino IDE in the microcontroller.
3. Connect the pins SDA, SCL of the multiplexer to the serial input pins of the microcontroller.
4. Connect 5v from power supply into the microcontroller power pin.
5. Connect the first SHT20 sensor to the multiplexer by connecting SDA of the sensor into the SD0 pin in the mux.
6. Connect SCL of the sensor into pin SC0 in the mux.
7. Repeat the same steps 6,7 of the second sensor with pins SD1, SC1 in the mux.
8. Connect 3.3 V power supply to the sensors VDD pin using the DC converter.
9. Connect VSS pins of the sensor into the ground.

Data Collection and Analysis

The figures below show the data collected by SHT20 sensor. The data includes the humidity measured by the sensor and the temperature around its area. We can see from fig (3) that the temperature is changing between 29.1C and 29.2C.

Moreover, the second figure which is fig (4) shows the humidity around the sensor and we can see from the graph that the humidity is changing between 54.20% and 54.70%.

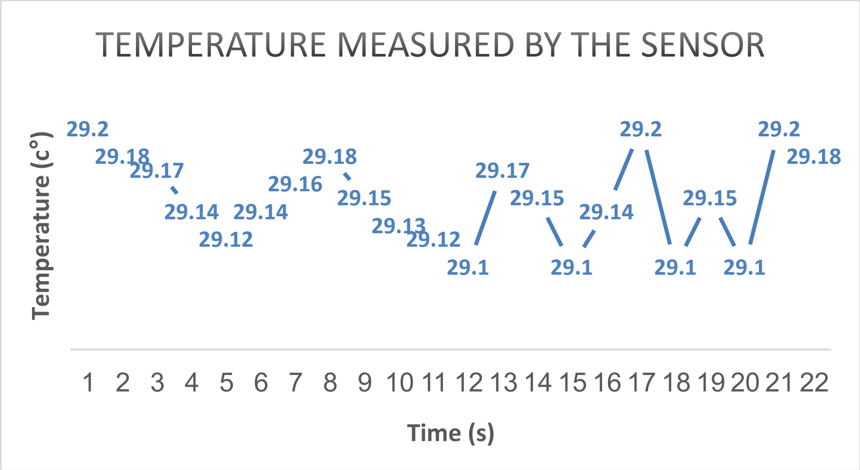

Figure 3: Temperature degrees measred by the sensor

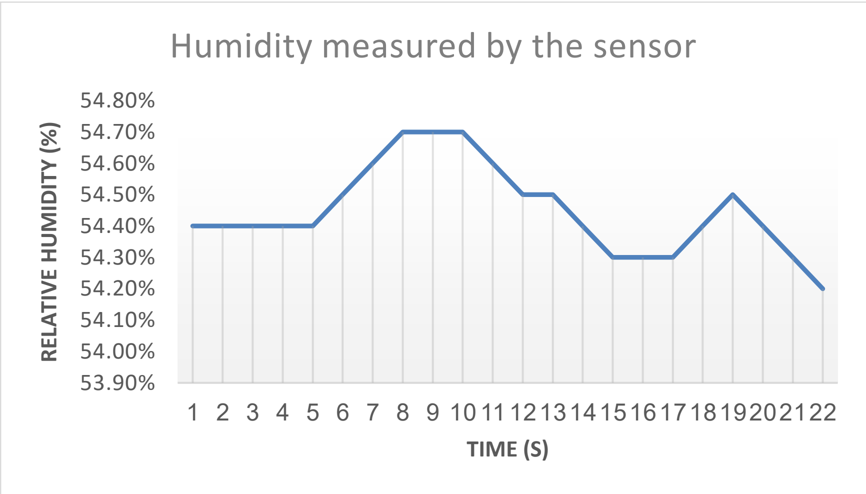

Figure 4: Relative Humidity measred by the sensor

However, the data presented in the above figures shows that the sensor used in this experiment are precise enough to be used in reliable system. In addition, this performance will help in monitoring temperature and humidity in effective way.

Results

Since the outputs from the sensors was analog values, it can be represented by serial monitor and determine the required actions based on the measured values. In addition, the results from this experiment were efficient since it was precise and reliable. It also adapted to the changes in the environment in an efficient way. In addition, the following fig (5) shows the output in the serial monitor for relative humidity and temperature values.

```
04:49:21.470 -> Sensor number on bus0
04:49:21.470 ->  Temperature:nanC Humidity:nan%
04:49:21.509 ->
04:49:24.480 -> Sensor number on bus1
04:49:24.571 ->  Temperature:29.2C Humidity:42.2%
04:49:24.571 ->
04:49:27.575 -> Sensor number on bus2
04:49:27.688 ->  Temperature:28.2C Humidity:42.7%
04:49:27.688 ->
04:49:30.679 -> Sensor number on bus3
04:49:30.679 ->  Temperature:nanC Humidity:nan%
04:49:30.717 ->
04:49:33.679 -> Sensor number on bus4
04:49:33.679 ->  Temperature:nanC Humidity:nan%
04:49:33.713 ->
04:49:36.674 -> Sensor number on bus5
04:49:36.674 ->  Temperature:nanC Humidity:nan%
04:49:36.714 ->
04:49:39.692 -> Sensor number on bus6
04:49:39.692 ->  Temperature:nanC Humidity:nan%
04:49:39.692 ->
04:49:42.700 -> Sensor number on bus7
04:49:42.700 ->  Temperature:nanC Humidity:nan%
```

Figure 5: Temp & Humidity serial monitor output.

As represented in the serial monitor, there were some nan values on some buses. These values represent the situation where no sensor is connected to that bus. In addition, it's showing the values of the temperature and relative humidity continuously when there is a sensor connected.

However, the results from this validation experiment achieved the desired objective which is, having a reliable and precise temperature and humidity monitoring system. This will help in developing a monitoring system for the environment in the cleanroom.

Discussion

To sum up, the main objective of this validation experiment is to validate a temperature and humidity monitoring system. Measuring the humidity and temperature in the cleanroom is important to ensure offering safety and efficient environment for the process and stored materials inside the cleanroom. In addition, this validation experiment gave an efficient performance. The results were precise enough to be reliable in an environment monitoring system for cleanroom. The measured temperature degrees had high accuracy in various values. However, the relative humidity percentage was also accurate values which is reflect the efficient performance of the sensor SHT20.

Furthermore, this experiment results will be used and analyzed in more experiments in developing the monitoring system for cleanroom environment. For instance, the results should be filtered to determine whether it's accepted values in the cleanroom or dangerous. In addition, based on the collected results, there are some required actions to be considered.

References

[1] Melo, C. (2023). Cleanroom temperature & humidity control. *Air Innovations*. https://airinnovations.com/our-areas-of-expertise/cleanroom-environmental-control-hvac-systems/cleanroom-temperature-humidity-control/#:~:text=The%20optimum%20temperature%20for%20a,cleanroom%20must%20also%20remain%20stable.

Appendix

```
#include "DFRobot_SHT20.h"


DFRobot_SHT20 sht20(&Wire, SHT20_I2C_ADDR);

// Select I2C BUS
void TCA9548A(uint8_t bus){
  Wire.beginTransmission(0x70);  // TCA9548A address
  Wire.write(1 << bus);          // send byte to select bus
  Wire.endTransmission();
}

void printValues(int bus) {
  TCA9548A (bus);
  Serial.print("Sensor number on bus");
  Serial.println(bus);
  float missing = 998;
  float value = 0.0 / 0.0;
  float humd = sht20.readHumidity();

  float temp = sht20.readTemperature();

  Serial.print(" Temperature:");
  if(temp == missing){
    temp = value;
    Serial.print(temp);
  }
  else{
    Serial.print(temp, 1);
  }
  Serial.print("C");
  Serial.print(" Humidity:");
  if(humd == missing){
    humd = value;
    Serial.print(humd);
  }
  else{
    Serial.print(humd, 1);
  }
  Serial.print("%");
  Serial.println();
  Serial.println();

  delay(3000);
}
void setup()
{
  Serial.begin(9600);
```

```
TCA9548A(0);
// Init SHT20 Sensor0
sht20.initSHT20();
delay(100);
Serial.println("Sensor0 init finish!");
sht20.checkSHT20();

TCA9548A(1);
// Init SHT20 Sensor1
sht20.initSHT20();
delay(100);
Serial.println("Sensor1 init finish!");
sht20.checkSHT20();

TCA9548A(2);
// Init SHT20 Sensor2
sht20.initSHT20();
delay(100);
Serial.println("Sensor2 init finish!");
sht20.checkSHT20();

TCA9548A(3);
// Init SHT20 Sensor3
sht20.initSHT20();
delay(100);
Serial.println("Sensor3 init finish!");
sht20.checkSHT20();

TCA9548A(4);
// Init SHT20 Sensor4
sht20.initSHT20();
delay(100);
Serial.println("Sensor4 init finish!");
sht20.checkSHT20();

TCA9548A(5);
// Init SHT20 Sensor5
sht20.initSHT20();
delay(100);
Serial.println("Sensor5 init finish!");
sht20.checkSHT20();

TCA9548A(6);
// Init SHT20 Sensor6
sht20.initSHT20();
delay(100);
Serial.println("Sensor6 init finish!");
sht20.checkSHT20();

TCA9548A(7);
```

```
  // Init SHT20 Sensor7
  sht20.initSHT20();
  delay(100);
  Serial.println("Sensor7 init finish!");
  sht20.checkSHT20();
}

void loop()
{
   printValues(0);
   printValues(1);
   printValues(2);
   printValues(3);
   printValues(4);
   printValues(5);
   printValues(6);
   printValues(7);

}
```

King Abdulaziz University
Faculty of Engineering
First Semester
2023/2024

EE-499: Senior Design Project

Term-2

Validation Report

Motion Monitoring System

Date of Submission: 28/9/2023

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Academic ID: 1935764

Advisor: Dr. Nebras Sobahi

Table of Content

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Introduction

In the controlled and highly sensitive environments of modern cleanrooms, the maintenance of pristine conditions is paramount. Precise cleanliness standards and environmental controls are essential to safeguard the integrity of delicate processes and products. Moreover, continuous monitoring and rapid response mechanisms are crucial to ensure these standards are consistently upheld [1]. This report centers on the validation of a motion monitoring system, incorporating the RCWL-0516 sensor, within the context of cleanroom environments.

Furthermore, cleanrooms, with their stringent requirements for particle control and environmental stability, demand an advanced monitoring solution to guarantee the preservation of their controlled conditions. The motion monitoring system under scrutiny in this report has been meticulously engineered to meet the unique demands of cleanroom operations[1]. By utilizing the RCWL-0516 sensor in conjunction with a sophisticated control system, this solution enhances security while adhering to the stringent cleanliness and environmental standards of cleanrooms.

This validation Experiment aims to provide a comprehensive assessment of the motion monitoring system's functionality, precision, and dependability within the context of cleanroom environments. It seeks to showcase how this system effectively detects motion deviations and promptly notifies relevant personnel, thereby contributing to the maintenance of cleanroom standards and the overall quality assurance of cleanroom operations. Through rigorous testing and evaluation, this report endeavors to demonstrate the system's ability to safeguard the integrity of cleanroom environments by ensuring swift response to motion events that may compromise their controlled conditions.

Objective

This validation experiment's primary aim is to assess the effectiveness and dependability of the motion monitoring system utilizing the RCWL-0516 sensor, specifically tailored for cleanroom applications. The following objectives have been defined to achieve this goal:

1. **Functionality Validation:**

   Verify the system's capability to continuously monitor motion within cleanroom environments and promptly trigger alerts when unauthorized or unexpected motion events occur.

2. **Precision Analysis:**

   Evaluate the accuracy of the RCWL-0516 sensor's motion detection capabilities within the cleanroom context, ensuring it can discern genuine threats from false positives.

3. **Reliability Examination:**

   Assess the system's resilience and consistency in delivering real-time notifications regarding motion deviations, even when subjected to varying cleanroom conditions, such as temperature, humidity, and airflow.

However, by achieving these objectives, this Experiment seeks to underscore the advantages and practicality of using RCWL-0516 sensor-based motion monitoring system in cleanroom environments. Ultimately, the validation of this system aims to enhance the security, efficiency, and quality assurance protocols within cleanrooms, contributing to the overall success of cleanroom operations.

Background information

Cleanrooms represent critical environments across a spectrum of industries, encompassing pharmaceuticals, electronics manufacturing, and biotechnology[2]. These meticulously controlled spaces are essential for mitigating particulate contamination, and regulating temperature, humidity, and other pivotal parameters. In addition, cleanrooms are instrumental in upholding product quality, safeguarding intricate processes, and ensuring adherence to stringent regulatory standards[2].

The motion monitoring system, featuring the RCWL-0516 sensor, is designed to meet the unique challenges posed by cleanroom environments. These sterile spaces demand a surveillance system capable of distinguishing authorized personnel from unauthorized intrusions without compromising the stringent cleanliness standards in place.

The RCWL-0516 sensor, renowned for its reliability and precision, has been integrated into this motion monitoring system to provide real-time detection and alerting capabilities within cleanrooms. This technology allows cleanroom operators to respond promptly to any motion deviations, safeguarding the integrity of the controlled environment.

This validation Experiment aims to comprehensively assess the functionality, precision, and dependability of the motion monitoring system built around the RCWL-0516 sensor within the context of cleanrooms.

Assumptions

This experiment use RCLW-0516 motion sensor and ESP32SIM800l microcontroller. The RCLW-0516 motion sensor is designed to detect the motions using infrared. This means, it will detect the motion of living organisms like humans and animals. So, this experiment will be assumed to sense live motions for humans inside the cleanroom. Therefore, there are some assumptions that need to be considered during this experiment. Here is a list of the considered assumptions.

1. Sensor Calibration:

   Assume that the motion sensor is accurately calibrated for precise motion detection.
2. Stable Environment:

   The testing environment maintains stable conditions, including lighting and temperature, to minimize external interference.
3. Proper Sensor Placement:

   The motion sensor is appropriately positioned to maximize its field of view for effective motion detection.
4. Microcontroller Configuration:

   The ESP32SIM800l microcontroller is correctly configured to interface with the sensor and record data accurately.
5. Diverse Motion Scenarios:

   Various motion scenarios, including slow and rapid movements, are assumed for comprehensive system assessment.

Variables and Constans

There are some variables and constants will be considered in this experiment which are listed as follow:

Variables:

- Motion Events:
  - i. Frequency: The number of motion events per unit of time.
  - ii. Intensity: The degree or magnitude of motion (0-180°).
  - iii. Duration: The length of time for which motion events occur

Constants:

- Constant Power source with 5V.
- Constant test area up to 10 meters within an angle of 180 degrees.

Caution / Precaution

To insure the safety of environment and materials, there are some issues that need to be considered during this experiment.

1. Electrical Safety:
    a. Ensure that all electrical connections and components, including the ESP32 and SIM800L and RCLW-0516, are properly installed and insulated to prevent electrical hazards.
    b. Avoid exposing the system to water or moisture to prevent electrical shorts and potential damage.
2. Battery Use (If Applicable):
    a. Do not short-circuit or puncture batteries, as this can lead to chemical leakage and safety risks.
3. Environmental Impact:
    a. Properly dispose of electronic components, batteries, and other system-related materials in accordance with local environmental regulations.
    b. Minimize electronic waste by recycling or reusing components where possible.
4. Sensor Handling:
    a. Handle the RCLW-0516 motion sensor with care, avoiding physical stress or shock that could affect its performance.
    b. Do not tamper with the sensor's internal components or attempt to modify it in any way.
5. Regular Inspections:
    a. Routinely check the setup for safety and environmental concerns

Equipment

- ESP32SIM800L Microcontroller
- CD74HC4067 Analog Multiplexer
- RCLW-0516 Motion Sensor
- Power Supply (5V)
- Jumpers
- Breadboard
- Resistor (1k Ω)
- Cables

Circuit Schematic

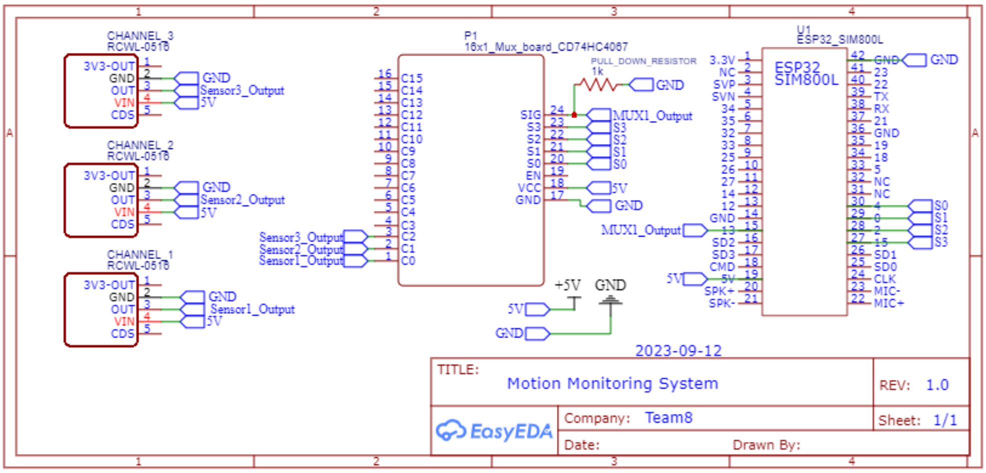

Figure 1: Motion Monitoring System Schematic

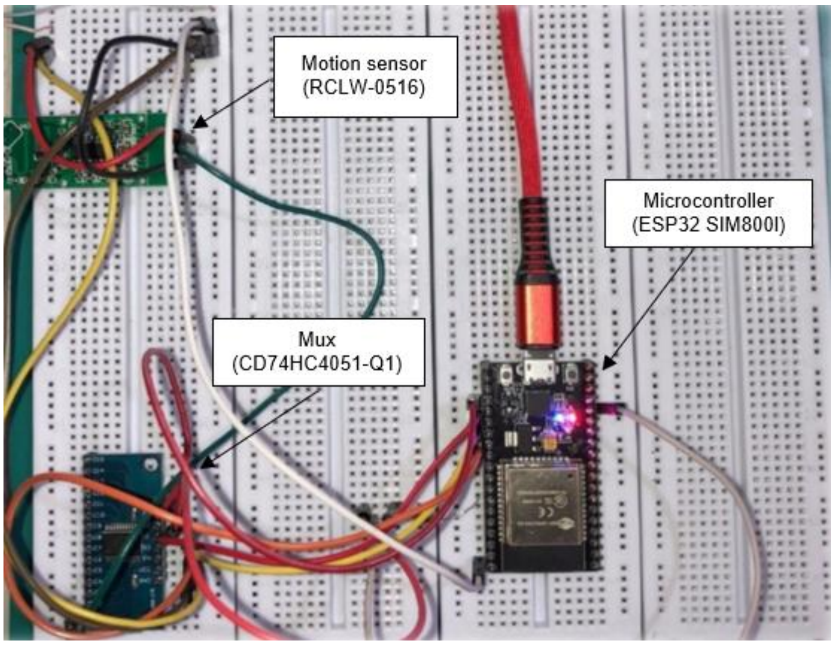

Figure 2: Motion Monitoring System Hardware Connection

Work plan

1- Prepare the code of the program and the required libraries in Arduino IDE software.

2- Connect the type-c input of ESP32SIM800l on your device to upload the program from Arduino IDE in the microcontroller.

3- Type-c input will work as a power supply and feed the microcontroller with 5V.

4- Connect the microcontroller's pins 27,28,29,30 into the pins s0,s1,s2,s3 in the multiplexer to identify the selector value of the multiplexer.

5- Connect the output pin in the multiplexer (SIG) in pin 15 in microcontroller to take the output from the multiplexer.
6- Connect the output of the sensors into the input pins in the multiplexer c0,c1,c2 to take the input from the sensor to the multiplexer.
7- The values from the multiple sensors will be sent to the microcontroller through the multiplexer based on the selector's value.
8- The microcontroller will identify each output based on the number of selector to determine which sensor send the signal in case of motion detection.

Data Collection and Analysis

RCLW-0516 motion sensor is a digital sensor. this digital sensor sends a signal when the motion detection happened using infrared. In addition, the signal will keep in high mode while there is a motion detection. Then, it will go back to low mode and no signal will be sent. The following Fig(3) represents the situation of the signal sent from sensor the multiplexer.

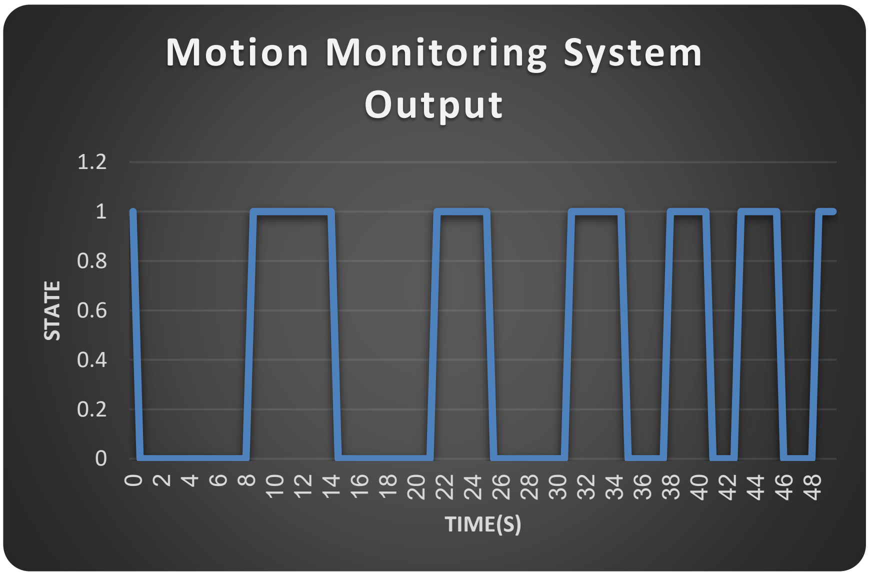

Figure 3: Motion Monitoring System Output graph

Moreover, the signal sent from the sensor will go through the multiplexer to the microcontroller. The microcontroller will identify the signal based on the number of the selector of the multiplexer. This will help in using multiple sensors and addressing each sensor. However, the output from the microcontroller can be represented in the serial monitor to maintain the situation of the signals from each channel of the multiplexer.

Results

The results that come from the serial monitor help in keeping up with the current situation. In addition, it can represent the motion that detected and the time period for that detection. This will help in analyzing the kind of motions that might be detected. Therefore, understanding the type and time period of motion detection will help in determining the required actions to be implemented to ensure the safety for workers in the cleanroom. The following fig(4) represents the output from this experiment in the serial monitor.

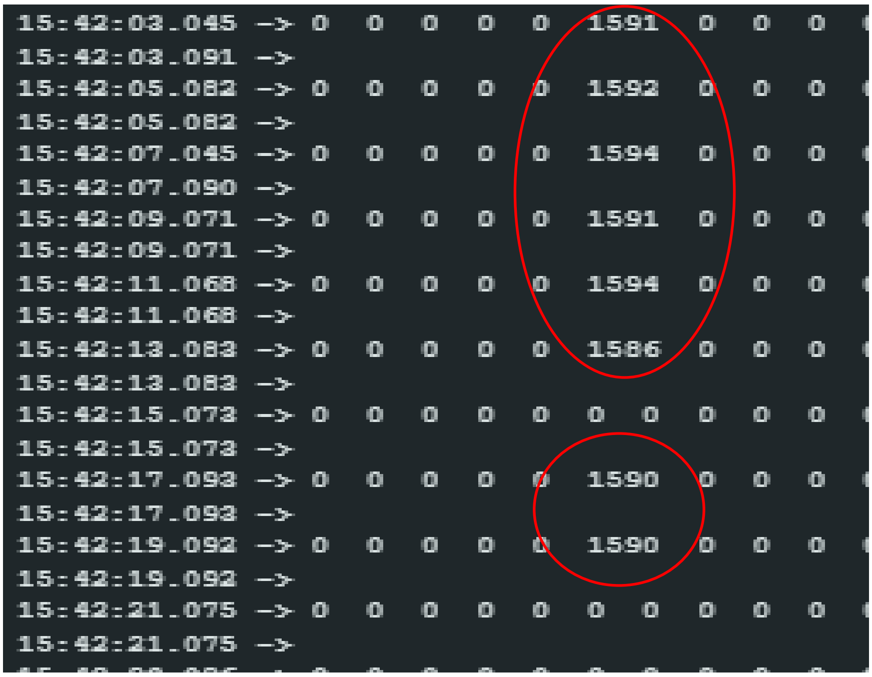
```
15:42:03.045 -> 0  0  0  0  0  1591  0  0  0
15:42:03.091 ->
15:42:05.082 -> 0  0  0  0  0  1592  0  0  0
15:42:05.082 ->
15:42:07.045 -> 0  0  0  0  0  1594  0  0  0
15:42:07.090 ->
15:42:09.071 -> 0  0  0  0  0  1591  0  0  0
15:42:09.071 ->
15:42:11.068 -> 0  0  0  0  0  1594  0  0  0
15:42:11.068 ->
15:42:13.083 -> 0  0  0  0  0  1586  0  0  0
15:42:13.083 ->
15:42:15.073 -> 0  0  0  0  0  0  0  0  0  0
15:42:15.073 ->
15:42:17.093 -> 0  0  0  0  0  1590  0  0  0
15:42:17.093 ->
15:42:19.092 -> 0  0  0  0  0  1590  0  0  0
15:42:19.092 ->
15:42:21.075 -> 0  0  0  0  0  0  0  0  0  0
15:42:21.075 ->
```

Figure 4: Motion Monitoring System Output on Serial Monitor

This output has been collecting from channel 5 of the multiplexer. The motion sensor has been connected to the channel five to test its efficiency and precision in detecting the motions.

Discussion

To sum up, this experiment aimed to validate motion monitoring system in order to help in monitoring the cleanroom. In addition, it was required to have a precise motion monitoring system to ensure the safety for workers inside the cleanroom. However, the experiment shows an efficient results that the RCLW-0516 motion sensor is reliable and has good performance. The results achieved the objectives of this experiment in supporting the cleanroom monitoring system with effective motion monitoring system.

References

[1] Henze-Ludwig, I. (n.d.). *Behaviour rules in a cleanroom*. https://blog.colandis.com/en/behaviour-rules-in-a-cleanroom

[2] Jfischer. (2022). Maintaining cleanrooms and clean manufacturing areas. Plant Engineering. https://www.plantengineering.com/articles/maintaining-cleanrooms-and-clean-manufacturing-areas/

Appendix – A: code of simulation

```
#define S0 4
#define  S1 0
#define  S2 2
#define S3 15

#define  Z 13
int analogVal[16];
void setup()
{
  pinMode(S0, OUTPUT);
  pinMode(S1, OUTPUT);
  pinMode(S2, OUTPUT);
    pinMode(S3, OUTPUT);


  Serial.begin(115200);
}

void loop ()
{

  for (int count=0;count<16;count++)
  {
     // SET THE ADDRESS
     digitalWrite(S0, bitRead(count, 0) );
     digitalWrite(S1, bitRead(count, 1) );
     digitalWrite(S2, bitRead(count, 2) );
          digitalWrite(S3, bitRead(count, 3) );

     // READ THE ANALOG FOR THAT ADDRESS
     int reading = analogRead(Z);
     int channel = count;
     // SERIAL OUTPUT
     Serial.print("CHANNEL_");
     Serial.print(count);
     Serial.print("=");
     Serial.print(reading);
     Serial.print("  ");
     //delay(100);
   }
   Serial.println();Serial.println();
   delay(2000);

}
```

Appendix – B: PCB Design

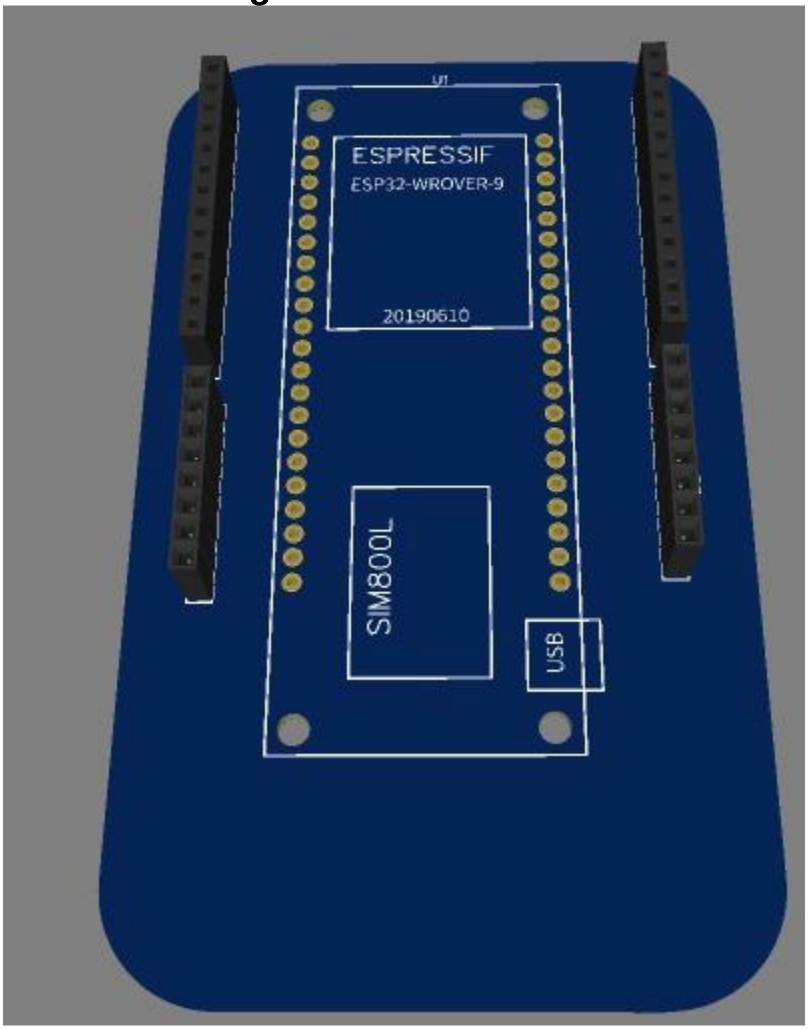

Figure 5: PCB Design 1

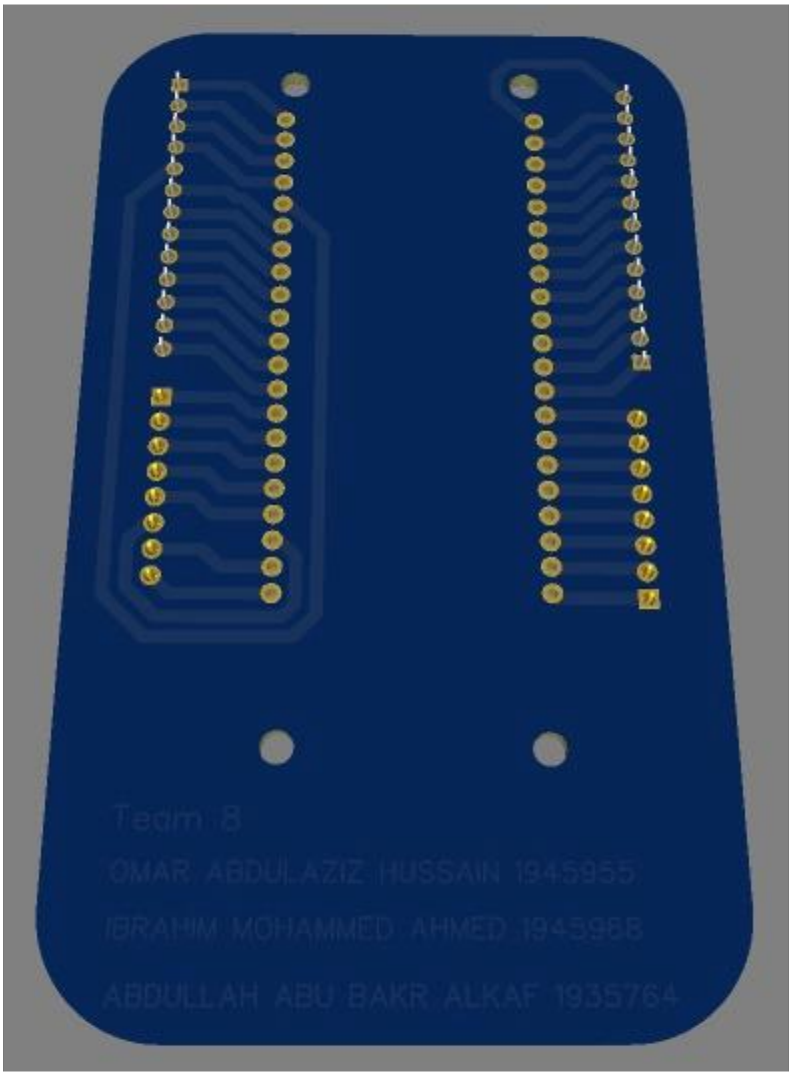

Figure 6:PCB Design 2

Appendix – C: CNC Result

Figure 7: CNC Result

Appendix – D: Final Board(SHIELD)

Figure 8: Final Board 1

Figure 9: Final Board 2

APPENDIX – B: SELF ASSESSMENT CHECKLIST

Use student outcomes (SOs 1 - 7) rubrics to fill the following table. Each member needs to fill in this table; it is important to enable the department to know to what degree the EE programs have been able to achieve the required KPIs of each SO. Please use the following grading letters:

E: Exemplary, **S:** Satisfactory, **D:** Developing, and **U:** Unsatisfactory.

Student Outcome (SO)	Key Performance Index (KPI)	Self-assessment (E, S, D, or U)		
		M1	M2	M3
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	1.1. Problem Identification	E	E	E
	1.2. Problem formulation	E	S	S
	1.3. Problem solving	S	S	E
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	2.1. Design Problem Definition	E	S	E
	2.2. Design Strategy	S	S	E
	2.3. Conceptual Design	D	S	D
3. an ability to communicate effectively with a range of audiences	3.1. Effective Written Communication	S	S	D
	3.2. Effective Oral Communication	E	S	S
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	4.1. Recognition of Ethical and Professional Responsibility	S	E	E
	4.2. Consideration of Impact of Engineering Solutions	D	S	E
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	5.1. Effective Team Interactions	S	E	E
	5.2. Use of Project Management Techniques	E	S	S
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	6.1. Developing Appropriate Experiment	D	S	E
	6.2. Conducting Appropriate Experiment	S	E	D
	6.3. Analysis and interpretation of Experiment Data and Drawing Conclusions	D	S	S
	7.1. Effective Access of information	S	S	D

7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	7.2. Ability to learn and apply new knowledge independently	E	E	E