

KRISTIANIA UNIVERSITY COLLEGE

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MASTER OF APPLIED COMPUTER SCIENCE -
SOFTWARE INTEGRATION

**INTERNET OF THINGS (IOT) ECOSYSTEM
AND INDOOR CLIMATE DASHBOARD FOR
VISUALIZATION IN DOMESTIC HOMES**

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Restricted: Yes No

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I certify that the work presented in this thesis is my own unless referenced.

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Abstract

Internet of Things (IoT) has become a ubiquitous "thing" that we are not aware of. It fits right into daily life as we do our chores, making it simpler without us knowing it in the background. IoT is a "thing" that digitalizes everyday objects and generates a huge amount of data at our disposal. If the data are not handled with analytics or visualization to give meaningful insights it can be wasted. Design theory is a cornerstone in the process of designing a good dashboard. This thesis aims to validate the current design theory by applying it to a dashboard using an IoT ecosystem as its data source. This was done through iterative prototyping and user testing. The results show that some design theory elements are prevalent, while others are not so important. Having the human-in-the-loop approach and design theory combined is a necessity for creating good design. The final prototype reflects the results of the user testing and can be seen as an indicator of good design.

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Motivation

The motivation for doing this research project started with the interest of the Internet of Things (IoT) and my background knowledge for this area of technology. Before starting doing this master thesis I've been thinking of creating some sort of indoor climate monitoring system in my apartment. Looking at research already conducted I found there are many contributions to this area of research. There are many different IoT solutions out there today gathering data for different purposes. For example, collecting data from machines to monitor the behaviors and whether they need maintenance. As a result, this reduces costs because people are not sent out needlessly to fix the machines when you already know the state of the machines is good. IoT is producing a huge amount of data and data scientists are becoming an attractive job position. Data scientists are needed because they can analyze these data which are hard to analyze by others. They also make visualization of the data to be understood by other people without the same background. I believe this is an interesting area as it is hard to visualize big amounts of data using various graphs, colors, shapes, positions, etc. to fit on a single page dashboard. Often these attributes are used wrong and can make it difficult to understand the data because the colors and shapes are making more noise than being helpful. Many of the research reviewed has been helpful in how to gather data and how to use machine learning to e.g. predict air quality, but there was little research showing the visualization process and user testing to better improve the presentation of the data. I got an interest in indoor climate data because today with the advance of technology we spend most of our time indoors and I've also felt the effect of poor indoor climate on my body. My motivation is driven by these factors to further create a dashboard visualizing indoor climate data in an understandable way to people in domestic homes. Hopefully, they can get a better awareness of their indoor climate and maybe take certain actions to improve their indoor climate.

Chapter 1

Introduction

The popularity of the Internet of Things (IoT) is increasing around the world in different sectors, such as in healthcare, smart cities, smart homes, etc. IoT makes it possible for physical objects to be connected to the internet generating a huge amount of data through different sensors that can help us improve the way we live. IoT sensors and microcontrollers are cheap, small, and can be placed on any object to monitor or control its surroundings. It can for example be placed in any machine to monitor how it works and if it needs repair.

We spend more time indoor today than ever before, where most of us work inside, we live indoor and many do their workout in the local fitness gym. A good indoor climate is important to maintain good health and prevent a lack of concentration and headaches. The United States Environmental Protection Agency (US EPA) states that indoor air pollution has been ranked in the top five most risks to human health and studies show that the level of air pollution indoor can be ten times higher than outdoors [1]. According to Wood et al. [2] people in urban areas spend up to 90% of their time indoors. The air is mostly polluted from vehicles and the indoor climate is further polluted by chemicals added by human activities, e.g. from cooking, fireplaces, and cleaning products which causes the indoor air to become a major health concern.

Visualizing data from IoT sensors can be a challenge as there are data that needs to be sorted and dealt with, often by an expert in visual analytics, also known as a data scientist. However, visual analytics can be hard to understand by the user, therefore, by having the user in the loop is important to understand their needs. If the data is not used in analytics and visualization to give meaningful insights to businesses or the user, the data will be wasted [3]. In this research project, the focus is to create a

visualization based on design theory and conducting user testing to gain feedback on the design created and further use that feedback to do changes for better visualization that reflects the users' needs.

An IoT ecosystem has been developed containing three microcontrollers controlling the behavior of different pollutant sensors in three different rooms in an apartment in the city of Oslo. This was to generate a dataset for the realtime dashboard to monitor and visualize the indoor climate. The data was sent from the microcontrollers to a cloud that temporarily stored the data and further sent it to a realtime database. The realtime database pushed the data to a web application containing the visualization of the dashboard and was updated every time new data was received by the realtime database. The system was in operation for several weeks monitoring indoor air and the data was used to create the visualization based on several iterations using design theory and interviews with potential users for the system. The design was made creating a dashboard visualization as an application using ReactJS which is programmed in Javascript and a chart library that helped create different graphs to visualize the data.

1.1 Research Question

In this research project, the goal was to create an ecosystem with IoT, from hardware to software and a monitoring dashboard as a web application displaying data collected from indoor air in an apartment. It's challenging to create good visualization of data and using different attributes such as color, shape, and position to enhance the design for better understanding by the users. IoT generates a huge amount of data that can create dashboards with a lot of clutter and noise rather than being useful. Using previous research, design theory and principles with multiple iterations and user testing to create the design of the dashboard, I hope to give awareness to the user and that they will gain more knowledge of their indoor climate. The purpose of this research project is to answer the following research question:

- *How can design theory be applied to dashboards based on Internet of Things (IoT) ecosystems? A study to validate the design theory of monitoring dashboards by creating an IoT ecosystem and conducting user testing of a dashboard prototype for domestic homes.*

The following steps were performed to answering the research question:

1. A literature search to find relevant research papers within the area of the Internet of Things (IoT) and dashboard visualization.
2. Create a tentative design of the artifact using research and design theory.
3. Creating an ecosystem of IoT devices in real-world scenarios to gather realtime data.
4. First iteration of implementing and developing the dashboard application on the web.
5. Conducting user testing of the dashboard design and collect feedback.
6. Second iterations of developing the dashboard design using feedback from user testing.

1.2 Thesis Structure

- **Chapter 1 - Introduction:** The introduction describes some of the facts about indoor climate and IoT. Further, the thesis is presented and what the goal is for the research project. Then I explain the purpose and the research question I've found through related research and present the structure of this thesis.
- **Chapter 2 - Related Work:** Contains various research papers relevant to this research project and starts with introducing the Internet of Things (IoT). We go into air pollution and describe some of the gases and particulate matter. Then we review some of the air monitoring systems already developed. Lastly, we go into the visualization of the dashboard and design theory to follow for data visualization.
- **Chapter 3 - Research Work:** Describes the research method and why the method was chosen compared to others. I also explain the process of the literature search and data collection method mixed with the main method.
- **Chapter 4 - Development:** Explains the development of a process that is part of the research method chapter, it's placed in a separate chapter for better structure. It describes the process of tentative design and the implementation of the artifact in detail.

- **Chapter 5 - Findings and Results:** Presents the feedback from user testing, the final design of the dashboard, and data reliability.
- **Chapter 6 - Discussion:** Evaluates the results and findings presented in the previous chapter and discuss the answers to the research question.
- **Chapter 7 - Conclusion:** Provides the conclusion of the research project, final remarks, and suggestions for further research.

Chapter 2

Related Work

This chapter introduces the background research for the project. This research project is based on already existing Internet of Things (IoT) air quality monitoring systems. There was little research stating how to best visualize the data collected from the various air quality sensors indoor to the end-user and whether design theory for dashboards, in general, can be used as a tool for IoT visualization. The chapter is divided into four different sections that are relevant for this project. Section one presents the Internet of things (IoT), cloud computing, and various microcontrollers and sensors. Section two air pollution, health, hazardous gases, and particulate matter are reviewed. Section three studies the different systems that have been done on air quality and the differences between indoor and outdoor systems. Section four reviews the visualization made in the different systems already mentioned and data visualized in other research papers about dashboards and section five gives a summary of the theory and the final focus of this research.

2.1 Internet of Things (IoT)

Kevin Ashton in 1999 [4] was the first man to use the term Internet of Things (IoT) and it became popular through related market analysis and publications. Radiofrequency identification (RFID) tags, sensors, actuators, and mobile phones are seen as the building blocks of IoT. IoT makes it possible to transform everyday objects into internet-connected objects that can be aware of their surroundings. It's an ecosystem and consists of several building blocks, these blocks or objects that are connected to the internet can observe, understand, react, and provide information about their environ-

ment [5]. E.g. IoT works as an ecosystem in homes where the fridge can communicate with your phone or the lights with the alarm clock. This can scale up to more homes and further create a smart city where traffic lights, LCD screens in shopping malls, lights in the street, etc. are connected. IoT monitoring systems have become very popular in recent years, with low-cost sensors and simpler data collecting methods and sharing. For example, placing devices in a factory to monitor working machines and the device would give alerts to the user's phone when malfunctioning is detected [6]. These devices are game-changing and report data in real-time which can prevent e.g. machines or other objects from breaking and the cost of repair decreases. Another example is in the health-care sector, IoT is used to give important health information about patients and can save lives if warnings are received in time [5].

IoT has become important in environmental monitoring in areas that require consistent monitoring, analysis, and decision making. E.g. in agriculture where crops are equipped with sensors to give feedback on the health of the crops, to prevent crops dying from diseases or poor watering. In recent years the focus of monitoring air pollution in big cities has become increasingly popular due to the major health problems fine dust particles can cause. [7]

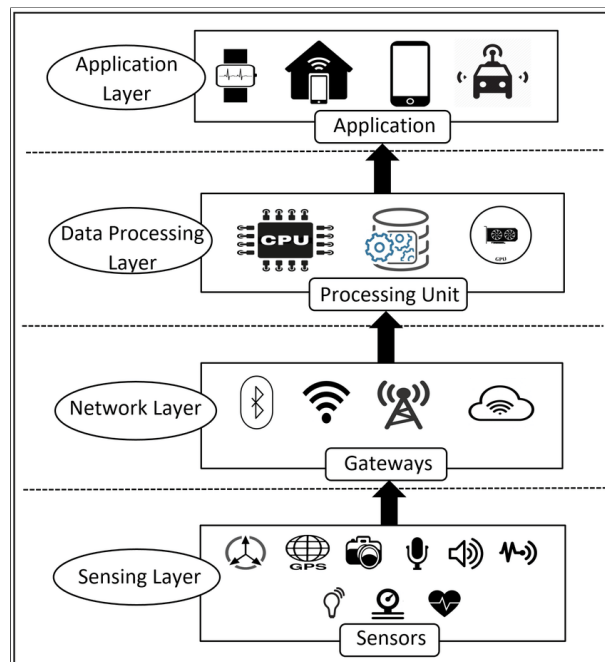


Figure 2.1: An Example of Architecture of Internet of Things [8]

The architecture of IoT consists of four layers with different goals as visualized in figure 2.1. The Perception layer is where the physical object captures data such as temperature, humidity, air particles, etc. and process and transmit the data through a wire-

less transmission module to a network gateway. Wireless sensors, Radio-frequency identification (RFID), smartphones, smart homes, etc. are in this layer. The Network layer transmits the data from the perception layer further in analog format to a network gateway. Bluetooth, LoRaWAN, WiFi, Zigbee, etc. are examples of network layers. The Middle-ware layer makes it possible for different IoT devices to communicate and translates the data. The Application layer is the interface/visualization of the data collected from the perception layer and lets users manipulate them. [9]

2.1.1 IoT in Cloud Computing

The development of IoT would not have become a reality this fast without the advance of cloud computing and wide application of wireless sensor networks (WSN) [4]. Today, there are more IoT devices connected to the internet than smartphones per person. These devices generate a huge amount of data and need a place to be stored. This is where cloud computing has become very important for IoT today. Data storing, sharing, analysis, and communication are some functions of cloud computing. The heterogeneity and complexity of data collected from different sources of measurements make it important to sort the data in a good way to better visualize, control, and analysis for better decision making. Cloud computing is often used in air monitoring systems because of quick deployment and low-cost handling of data. [7]

Microsoft Azure, Amazon Web services, IBM Cloud, and Google cloud platform are some examples of public clouds where the user can deploy applications, services, store data, data analytics and visualize the data. IoT is an inevitable feature in any of these cloud platforms, due to rapid growth and popularity. A cloud platform gives flexibility to the user by not having to build the infrastructure and platform with high costs of maintenance. Users can also scale up as much as they want without having to worry about full disks and high reliability and disaster recovery is a promise to the customer. Through the cloud, the user can also access their data from anywhere with internet access. [10]

2.1.2 IoT Microcontrollers and Sensors

The development of indoor small size, low cost, and high sensitivity sensors have become very popular for indoor environmental monitoring [11]. E.g. Firdhous et al. [12] says that for measuring ozone (O_3), semiconductor sensors are low cost, higher

responsiveness to low levels of O_3 , better repeatability, accuracy and long sensor life. From most research read, when creating a monitoring system for air quality using IoT, the focus is to make it affordable and low cost. E.g. microcontrollers like Arduino makes this possible as sensors can be connected to it and the data collected is converted to be readable by other software.

Different sensors and microcontrollers are used for different purposes. E.g. MQ-7 is an analog sensor sensitive to carbon monoxide (CO) and it detects by cycle high and low temperature, at low temperatures it detects the CO. MQ series gas sensors are sensitive to more than one gas and to get accurate readings it's important to calibrate it to be sensitive to one particular gas, it senses the gas better when air is blowing directly at the sensors [13]. DHT-22 measures humidity and temperature in the air and is a digital sensor which makes it easier to read by computers. Since many sensors are analog we need an analog-to-digital converter (ADC). The ADC converts the analog current into a digital signal for easier readings by the computer or processing unit. The Arduino Microcontroller can perform this and also works as a processing unit. Arduino is a physical open-source I/O board with a development IDE for programming the behaviors of sensors. It's capable of controlling lights, motors, and other physical elements [14]. [15]

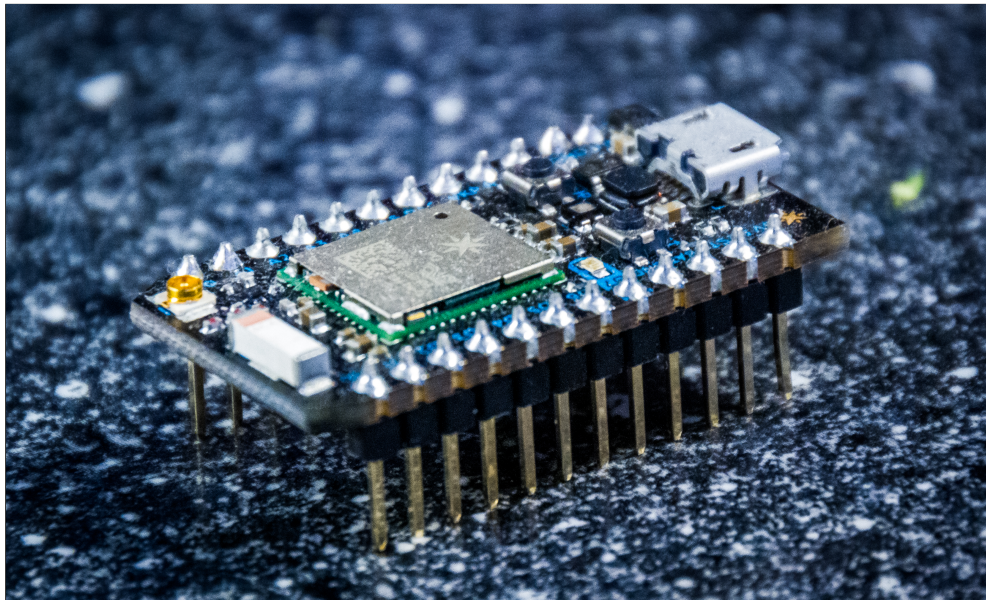


Figure 2.2: Particle Photon IoT Prototyping Board

Another microcontroller used by Munsadwala et al. [13] called Particle Photon provides a fully integrated secure IoT platform that connects software and hardware to the internet. The Particle combines an ARM Cortex M3 microcontroller with a Broad-

com Wi-Fi chip and has the size of a thumb [16]. It's easy to use and all the data is temporarily stored in Particle's Device Cloud where you can also attach webhooks to send data to e.g. Azure IoT Hub or Google Sheets to further visualize and analyze the data. The Particle Photon can be viewed in figure 2.2.

As mentioned earlier, sensors are created for different purposes and are used in different scenarios. The MQ series sensors are made to be sensitive to different gases in the air, both indoor and outdoor. They can help us to find sources of bad pollution and give us data that can help us in creating a better indoor environment.

2.2 Air Pollution

Air pollution is not only harmful air that we breathe in, but bad particulates in the air that are man-made. There are two kinds of air pollution; visible and invisible, both are harmful, but the particulates that you cannot see are the ones that we are not aware of can harm us daily. The Air Quality Index (AQI) is measured by calculating the average of sub-indices of the pollutant during 24 hours, which also gives the health breaking point concentration range [5]. It's the concentration of the gases that makes them harmful, the lower the concentration of the gas in the air the better the air is to breathe [17].

2.2.1 Health Issues from Air Pollution

According to AbdulWahhab [18], 5.5 million people worldwide are dying as a result of air pollution. Immediate health issues such as fatigue, dizziness, nose, and throat can occur from short-time exposure to air pollution. This is often treatable by just removing the patient from the polluted air. Longer exposure to air pollution can give health problems that are much more permanent. These health effects may occur years after exposure or from repeated exposure over time. E.g. respiratory diseases, heart disease, and cancer which are fatal. The immediate symptoms are often misinterpreted with symptoms from colds or other viral diseases and it's difficult to find whether the cause is from indoor pollution. It's important to create a system that monitors the particles in the indoor air to easily find a correlation between symptoms and air quality. Fine particles such as Particulate Matter_{2.5} are very small and can go deep into the lungs and bloodstream without us knowing it [17]. The effects of air pollution vary

from person to person. Some are more sensitive than others, also age and historical health issues can determine the severity of the health problems. [19]

In the article written by Dockery et al. [20] they did a study on the link between mortality and particulate matter in the air in six U.S. cities. They found out that air pollution mostly from fine particles is positively connected with death from lung cancer and cardiopulmonary disease or shortened lifespan. They also controlled for sex, age, smoking, education, exposure to dust, gases, and fumes.

2.2.2 Hazardous Gases

The most common types of air pollutants found indoors are particulate matter, gases such as ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), chemical volatile organic compounds (VOCs), passive smoke, and outdoor ambient air [21]. Some of the main causes of air pollution are listed by US EPA [17]. The burning of fossil fuels is one of the main factors causes of air pollution. Sulfur dioxide (SO_2) is emitted by fossil fuel-driven cars and factories. E.g. 70% of air pollution in the major cities in China is from vehicles [13]. Also, carbon monoxide (CO) is released when incomplete combustion occurs and Nitrogen oxide (NO_x) is also an example of a man-made pollutant, it occurs during agricultural, industrial activities, the combustion of solid waste and fossil fuels [22]. In table 2.1 below the most important pollutants are described.

In agricultural activities, ammonia (NH_3) is one of the most dangerous pollutants to humans. It's used in pesticides, insecticides, and fertilizers. NH_3 can also cause water pollution if e.g. fertilizer is leaked into local streams and rivers. Mining is also a big cause of air pollution because the energy it takes to extract materials is so great and the dust particles formed from the extraction are a risk to human health. Indoor air pollution is the most important topic for this research project because the goal is to visualize the data collected from indoor sensors onto a dashboard. The Environmental Protection Agency says that indoor air is 2-5 times more polluted than outdoors, due to chemicals released from household cleaning products, materials from the walls, electronic appliances, and cooking. Especially oil-based cooking generates great amounts of Particulate Matter (PM) which will be discussed in the next subsection [26]. [17]

The release of pollutants from electronics is also a fact. We have more than one electronic device per person and as technology has grown a lot in the past years, many

Gases from air pollution	Description
Carbon Monoxide (CO)	CO is a colorless, tasteless and odorless gas that is formed when combustion is incomplete. E.g the combustion of petrol in vehicles [23]. Through the body's bloodstream and the lungs it reduces the oxygen O ₂ delivered to the rest of the organs. [24]
Carbon Dioxide (CO₂)	While CO is incomplete combustion CO ₂ is complete combustion. Humans release CO ₂ through the respiratory process. [23]
Sulfur Dioxide (SO₂)	SO ₂ comes from burning of fossil fuels and industries. It also reacts easily with other substances in the air to form other harmful compounds. When inhaled SO ₂ can irritate nose and throat which leads to coughing and other respiratory problems. [25]
Nitrogen Dioxide (NO₂)	NO ₂ is a poisonous gas created from burning of fossil fuels, vehicles, power plants etc. Mainly affects human respiratory system. NO ₂ combined with other sources of gas can form acid rain. [25]
Ammonia (NH₃)	NH ₃ has a strong odor and is produced by decomposition of organic matter, and from human and animal waste. NH ₃ is used in agricultur fertilizer and various biological processes. Acidification is a cause of NH ₃ and gives irritations to the human body. [17] [25]
Ozone (O₃)	O ₃ is a gas formed by three atoms of O ₂ that protects us from poisonous ultraviolet rays in the atmosphere. It's when the gas is on the ground it can cause harm to humans. [25]

Table 2.1: Different Types of Air Pollution Gases Described

offices are full of automated devices to make are our workday simpler. These devices have found to be emitting gases along with low and radio frequency electromagnet waves that are harmful to humans [12]. E.g. in the article written by Firdhous et al. [12] the toner of a copy machine is a fine powder that may leak from the machine from careless handling of the toner or damage to the machine. These fine particles may give a respiratory problem to humans. Photocopy machines are also found to release several gases such as O₃, NO₂, CO, CO₂, and volatile and semi-volatile compounds [12].

2.2.3 Particulate Matter (PM_{2.5} and PM₁₀)

Particulate Matter (PM) is airborne dust which has two size ranges PM_{2.5} and PM₁₀. PM can be found in indoor and outdoor air and comes in different sizes, some you need a powerful microscope to see. PM_{2.5} are particles that have aerodynamic diameters equal to or less than 2.5 μm. These are the most dangerous compared to PM₁₀ because of their small size they can stay airborne for long periods and can travel hundreds of miles in the air. PM₁₀ are particles less than or equal to 10 μm, approximately

equal to one-seventh the diameter of human hair. These particles do not stay in the air as long as $PM_{2.5}$ and do not cause as much harm since it falls to the ground as dust faster. [27]

PM is either formed in the atmosphere or released directly as "Primary" particles from roads and combustion sources. PM formed in the atmosphere from chemical reactions involving primary gaseous emission are called "Secondary" particles. These are often found in fine $PM_{2.5}$. The National Emissions Inventory (NEI) focusing on measuring the gases that contribute to the formation of secondary particles and not the secondary particles directly. The gases include NO_x , SO_2 , NH_3 , and other gases. [27]

2.3 Air Monitoring Systems

There has been much research on monitoring outdoor and indoor climate in the past years. Most of the research found for this project on air monitoring systems using the Internet of Things (IoT) is from 2015 and later. The focus of monitoring the climate has grown drastically due to climate change and the rising temperatures of our planet. The focus of indoor air has also become an important research area. According to US EPA [28], Americans spend 90% of their time indoors. This is not surprising when most of us work indoor. Training centers are buildings with indoor climate, our homes where we spend a lot of time resting and sleeping, shopping centers, and etc. Most of our Activities occur indoor and therefor indoor air is so crucial to monitor and take action upon when bad pollutants are present.

2.3.1 Outdoor Systems

Fuertes et al. [14] created an air monitoring system using the Arduino platform, which comes with a microcontroller and an IDE to program commands to the sensors to react on. The data was collected from the outdoor air in three cities in Ecuador; Quito, Amaguana, and Tena. The device is equipped with three different sensors. Their goal was to develop a low-cost solution for measuring CO, CO_2 , and the density of dust in real-time. The data collected is compared with the standard values from the World Health Organization (WHO) and US EPA. The author's main challenge was to achieve good communication of data between the Arduino and the Web applica-

tion. The sensors capture the data in an analog format, therefore they had to create an API to convert the data into JSON for the web application to read using HTTP as shown in figure 2.3. The results from the experiment were positive and they achieved to create a low-cost device to monitor pollution levels in the three locations. Future work was to apply the analysis of data to create a prediction and behavior models for better decision-making. Kim et al. [29] created a similar device but used Long Term Evolution (LTE) a mobile communication network to solve restriction with installation placement. They also created an atmospheric environment analyzer to look for errors in the data received from the sensors. [14]

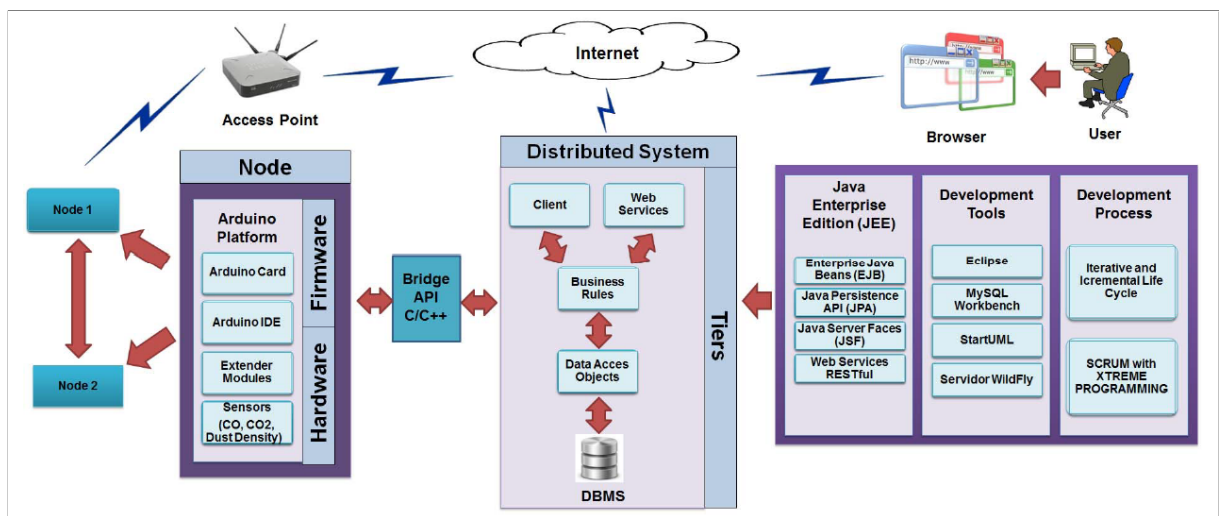


Figure 2.3: An Overview of the Whole System Architecture [14]

Cheng et al. [30] proposed a cloud-based air quality monitoring system. Two types of monitoring systems were deployed, called AQM and miniAQM. The AQM was big and stationary placed in different regions in a city with 20 million people. It connected to their backend via Ethernet and General Packet Radio Service (GPRS). The miniAQM was portable, small, and connected to smartphones using Bluetooth. The whole architecture overview of the system is presented in figure 2.4. The cloud side of the system worked as an analytic engine with a machine learning model. The analytics engine consisted of a signal reconstruction model to denoise corrupted signals, an Artificial Neural Network (ANN) based calibration model to create more accurate readings and an online inference model that further improved the $PM_{2.5}$ accuracy and estimation for places where data were not collected. The new calibration was sent to the AQM and miniAQM in real-time through the cloud. The system was tested for 2 months and they also collected data from public air quality stations placed in the city,

this provided them with training data they needed for the machine learning model. The system had a set of application programming interfaces (APIs) to provide developers with sensor data to create web sites and mobile applications. The article written by Kumar and Jasuja [31] tested their system in Delhi and compared the data with the local environment control authority. The authors say researchers have created systems that mostly monitor temperature, humidity, barometric air pressure, carbon monoxide, and sulfur dioxide, but have paid little attention to measuring particulate matter (PM). Pu'ad et al. [32] focused on measuring PM smaller than 10 and 2.5 because most fixed air stations in Malaysia did not measure below $PM_{2.5}$. They used Raspberry Pi3, two Arduino Nano, three gas sensors, and a GPS module and achieved to measure $PM_{2.5}$ with an error rate of 3.23%. [30][31][32]

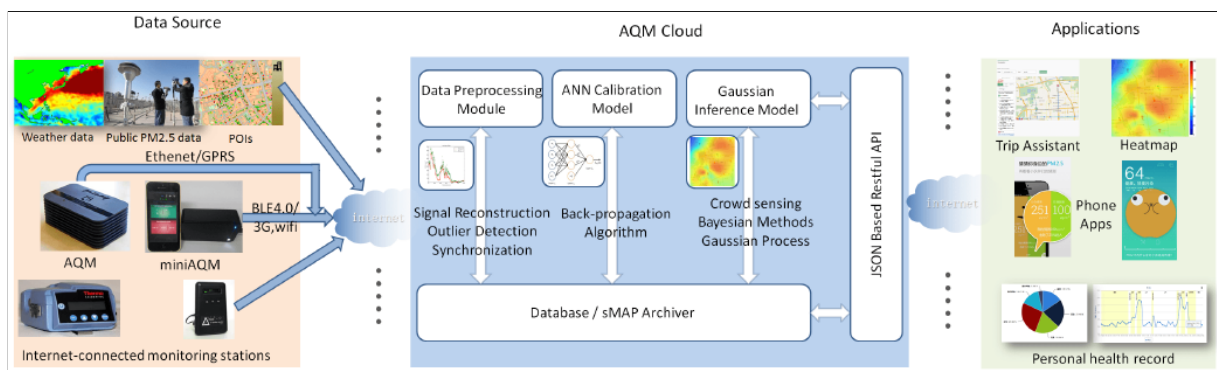


Figure 2.4: Architecture of AirCloud System. [30]

Kodali and Sarjerao [33] used Message Queue Telemetry Transport (MQTT) protocol to communicate between the microcontroller and the cloud where the data was stored and processed. The advantage of using the MQTT protocol is to prevent ambiguous data is stored with the required data. They used a sharp dust sensor (GP2Y1010AU0F) to measure dust particles in the environment and a microcontroller that was ESP8266 based. The focus was to make the system portable instead of the fixed stations around in cities in India, therefore they placed the portable stations onto various vehicles. The user could then login to a web application on their phone to track the vehicle and find out the pollution level of that area. Munsadwala et al. [13] also created an air monitoring system using the MQTT protocol called Atmospheric Air Surveil System (AASS). The device was portable and the data collected from the device could be reached and controlled by authorized users remotely from web-based monitoring of CO and CO_2 gases outdoor. [33][13]

Lampe et al. [34] has found $PM_{2.5}$ to be an extreme risk to human health. $PM_{2.5}$



Figure 2.5: The iOS Application of the Halo System. [34]

is smaller than $2.5 \mu\text{m}$ in diameter and can easily penetrate deep into the lungs and bloodstream. They created a system called Halo, that costs less than \$100 and is powered by solar energy. The $\text{PM}_{2.5}$ concentration in the air was measured using IR light and the data was sent to the user's phone via Bluetooth Low Energy (BLE). Halo was made up of four modules; $\text{PM}_{2.5}$ sensor, data acquisition, and transmission (DAT) using a microcontroller to send the data to the smartphone, solar panel, and web and mobile application for visualization. An example of the iOS application is represented in figure 2.5. $\text{PM}_{2.5}$ sensors are expensive, energy-consuming, and not accurate, therefore the authors chose to use IR light to measure the intensity of light the $\text{PM}_{2.5}$ gives to find the concentration in the air. Halo also had to be powered by renewable sources to eliminate the disadvantage of replacing batteries or to have the devices plugged at a fixed location. [34]

Mahajan et al. [35] created a personal air monitoring assistant using a chatbot to alert the user of abnormal pollution levels. The chatbot monitors the $\text{PM}_{2.5}$ in the air, temperature, humidity and the user could also subscribe to different nodes at which were placed in different locations in Taiwan. Chatbots are capable of acting upon natural language input from humans and to engage upon these. Chatbots have become

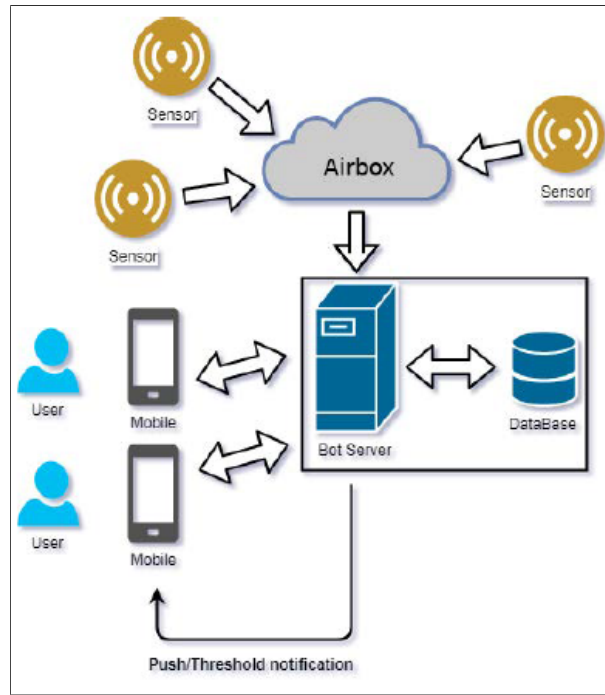


Figure 2.6: IoT-Chatbot System. [35]

very common today and are used by millions due to the internet and smart devices, e.g. you can create a bot using google assistant which already has a built-in Artificial Intelligent (AI). The chatbot from the article was created on an instant messaging application in real-time and analyzed the data that is stored on the server and sends it to the user. The system overview of the chatbot is presented in figure 2.6. They aimed to create a system that works as an assistant to the user by just using the phone and reading the $PM_{2.5}$ levels from any location and any area the user would like to know the air quality. E.g. if the user would go for a run outside the system would alert the user that the pollution levels are too high and it would recommend the user to stay inside. [35]

2.3.2 Indoor Systems

Pradhayini et al. [36] created a climate monitoring system in 2009 using IoT. The main goal was to control the temperature in operation theatres in hospitals. They created the system using a PCI microcontroller (PCI16F877) with five I/O ports and an analog-to-digital converter (ADC). The authors chose to use this microcontroller due to its low cost and easy use. They implemented a temperature sensor and the system could give warnings to the user when temperature levels were too high or low. There were also three buttons and an LCD screen for the user to perform different settings

and commands to the system. The system was designed to control a chilling value as the data from the temperature was received. Kim et al. [37] also created a system that could control the ventilation, but they also monitored and controlled air pollutants, such as CO, CO₂, VOC, O₃ and airborne particles indoor. The authors used a Zigbee module that has a communication range of 30m that works as a transceiver and as an ADC. They aimed to keep the indoor climate balanced, avoiding over-cooling or heating and automatically adjust windows, fans, the ventilation system, etc. to get rid of bad pollutants in the air in buildings. In another article done later by Lee and Lee [38] also created an indoor system with the use of a Zigbee module. Their system could control the ventilation system with a simple implemented fan, but the focus was more on the user experience and how they would control and perceive the pollution levels handed to them on their smartphones. The users only needed access to the internet and a link to a specific website. Lee and Lee used an Arduino UNO board (translates the data from the sensors) that included CO, CO₂, PM_{2.5}, and a temperature and humidity sensors. In figure 2.7 the Zigbee functions as a transmitter between the Arduino board and the website so the data can be visualized from any device with an operating system. [36][37][38]

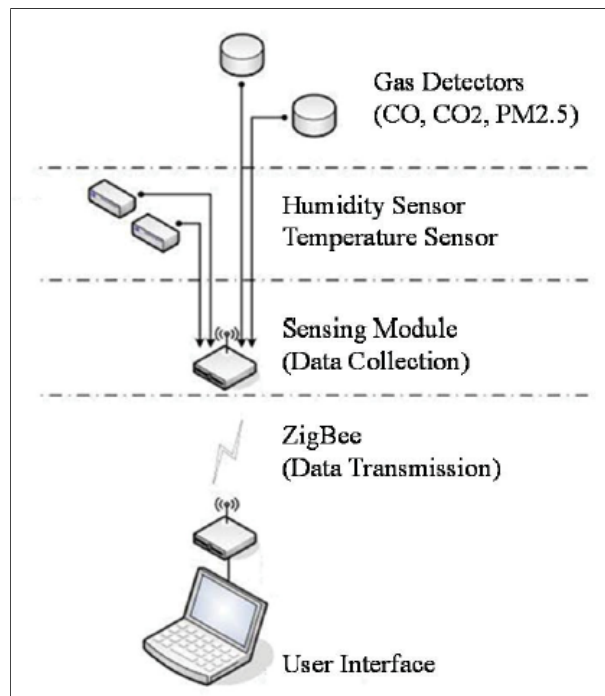


Figure 2.7: Proposed Supervision System [38]

Saad et al. [39] created a system to monitor the air and climate inside a tech lab in Malaysia. They monitored temperature and humidity, particulate matter (PM₁₀), car-

bon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), volatile organic compound (VOC), methane (CH_4) and chlorofluorocarbons (CFC). They used sensing modules which consisted of one microcontroller, temperature and humidity sensor, a dust sensor, various gas sensors, and a wireless sensor network (WSN) node which was connected through wire-based connection. The data collected from the sensor module was sent through the WSN node and to the web through a wireless connected computer where the data was stored. They placed eight sensor nodes in different locations in the building and one base station which collected all the data. The placement of the sensor nodes was not random, they placed them between 75 cm and 120 cm above the floor. This was to get a more precise measurement of the air that we breathe, also called the breathing zone. [39]

Fang et al. [26] believed there was a lack of information about the pollution sources and that people are ignorant of the danger of bad air quality in their homes. The authors proposed a system of monitoring indoor air, called AirSense that could automatically detect pollutions, its source, and give people suggestions on how to lower air pollutions levels at home. The system was tested in a controlled environment at two homes for ten weeks and in an uncontrolled environment in the real world at three homes for nine weeks. AirSense can monitor temperature, humidity, particulate matter ($\text{PM}_{2.5}$) and volatile organic compound (VOC) which are the two most common air pollutants indoor according to the authors. The different climate sensors sent the data to a cloud continuously and were displayed on a smartphone application in real-time and its goal was to alert users and inform them of how the different household activities affected the indoor air quality (IAQ). AirSense could also predict the pollution levels in near future using a non-parametric regression scheme, which is a huge advantage to lower pollution levels before the levels rise too high and is a risk to health. Jangid and Sharma [15] focused on creating an air monitoring system for people struggling with allergies. They wanted the system to inform the users early so they could secure themselves without experiencing the risk factors. Indication or alert message was sent to the concerned person if levels collected by the sensors exceeded the level of pollution that was suitable for his/her health. [26][15]

Firdhous et al. [12] raised the awareness of the electronics release of air pollutants in indoor air. They created an IAQ system to monitor the levels of air pollution next to a photocopy machine in an office. They built a sensing node using the Arduino BT prototype board with an ozone (O_3) sensor (input), speaker (output), microcontroller

(ATmega328P), and a Bluetooth module. They used Raspberry Pi-3 with built-in Bluetooth as a gateway and a computer to process the data with a web application to plot a graph. The system they created could scale up by adding more sensing nodes at different locations and more sensors to measure more types of pollutants. Their system architecture is presented in figure 2.8. [12]

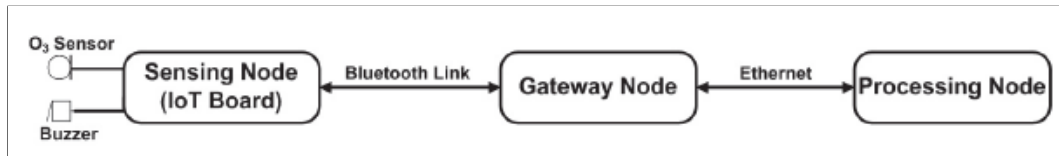


Figure 2.8: Architecture of the Monitoring System [12]

The IAQ systems presented so far were fixed at one location unless they were moved manually. Peng et al. [11] proposed an IAQ system that was movable by installing the system on a small autonomous car based on Arduino's control. The smart car was installed with tracking, obstacle avoidance, and gas sensors. The sensors made it capable to track the user's walking routes indoor and collect real-time data from the air that we breathe in. The obstacle avoidance sensor was placed on the car so it would not collide with objects in the indoor environment. They had the car tested out in a controlled environment in three different enclosed indoor laboratories of different area sizes. Another example of a movable IAQ system was created by Zhi et al. [40]. They focused on a system that could reach difficult places indoor. The solution was to use an unmanned aerial vehicle (UAV) also called a drone. To control clean air and ventilators, a fuzzy control algorithm was presented to overcome the challenges of pollution in the air from the collected data from the sensors. After testing the UAV the authors found it suitable for monitoring where installed stations could not reach. The UAV was also able to monitor the outdoor air around the aimed building and give the data to the indoor air quality controller. This was important data to collect since indoor air is highly affected by outdoor sources. [11][40]

Internet of Things (IoT) as mentioned earlier, helps objects get connected to the internet and provide us with useful data of our surroundings. In Aryal et al's [41] article this had been greatly presented by creating a smart IoT desk for personal indoor air quality conditions. According to the authors, 40% of energy is consumed by buildings in the U.S., where half is from adequate thermal and lighting conditions. Despite the amount of energy spent in buildings, occupants are not satisfied, due to different preferences on e.g. temperature levels. The goal of the smart IoT desk was to collect data

from the individuals and create a personal environment that was satisfying to their preferences. The system could also give alerts when the user should stand up from too much sitting or open windows when air pollution levels were too high. The system is represented visually in figure 2.9. Their main focus differs from other solutions by utilizing a human-in-the-loop approach when testing the system and go beyond the phrase "one size fits all" to address the user's needs. [41]

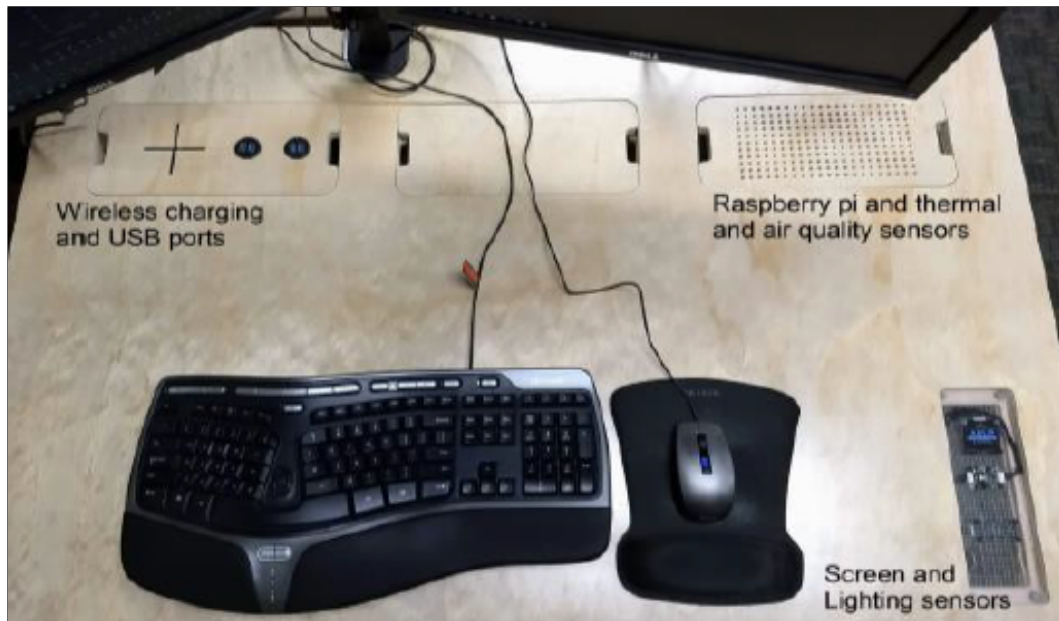


Figure 2.9: The Finale Version of the Smart IoT Desk [41]

Aforementioned, Fang et al. [26] used a prediction scheme to predict the values of air pollution. AbdulWahhab [18] and Xiahou et al. [42] went even deeper into the field of machine learning and data analysis to predict pollution levels in the air. AbdulWahhab addresses the problem of a huge amount of data that is gathered by the sensors from IAQ monitoring. The author used data mining which automatically collects, analysis, and discovers useful information in large datasets to find hidden patterns and hidden information. The new prediction model used was called Compact Prediction Tree (CPT+) which according to the author was proved by other researchers to be more effective and precise in its algorithm calculations. In the IAQ system created by Xiahou et al. [42], the server-side of the system was where the data is stored, analyzed, and further pushed to the web site as visualized data to the end-user. To cope with the huge amount of data they'd built a data center network that was well-loaded. The prediction model used was called Autoregressive Integrated Moving Average Model (ARIMA). ARIMA looks at the sequential data sets for predicted events over time as random events. This was done to "forecast" or predict future events, such as the num-

ber of particles present in the future. With a prediction model, users can take action before the air is getting harmful to breathe. [18][42]

2.4 Visualization

The research presented so far have had some focus on visualization, but their main focus has been on the IoT equipment and the system as a whole. I've found a gap between the system and user involvement in the decision of visualization of data collected from various systems monitoring indoor air. Other researches present some good and bad visualization, both web and mobile application and also the use of a chatbot. This section will present visualization examples from monitoring systems already discussed earlier in this chapter and other research papers that specifically talk about dashboard visualization.

Visualization presented by Fang et al. [26] was mostly simple graphs and no study on why they chose the design. They also had it tested in a real-world scenario with three families and interviewed them after the experiment. Most of the participants agreed on seeing actual numbers on their phones helped them be more aware of the air quality. They also got suggestions on their phones when levels were too high, which guided them to lower the air pollution levels.

Forkan et al. [43] presents a visualization tool for people in smart cities that combines personalized awareness with generalized needs and an overview over air pollution levels using heatmap with the use of color shade green to red, green is good and red is bad. Other researches have also used the same colors and range numbers to visualize the pollution severity, e.g. Enigella and Shahnasser [44]. A heatmap of China with different colors is represented in figure 2.10. They have also visualized a route planner to recommend users to avoid locations with high pollution and a real-time weather tool which gives information about humidity, temperature, wind speed, and rainfall. The authors have used historical open-source data from China, Australia, and EPA Victoria. They have not tested the visualization on users for better knowing if the data is presented in a good way for understanding and usefulness, but have stated in their future work that they would like to do user studies to evaluate the effectiveness of their system. [43]

Several authors have chosen to use ThingSpeak [45] as visualization because it has easy to use interface that plots simple graphs and is well known by developers to

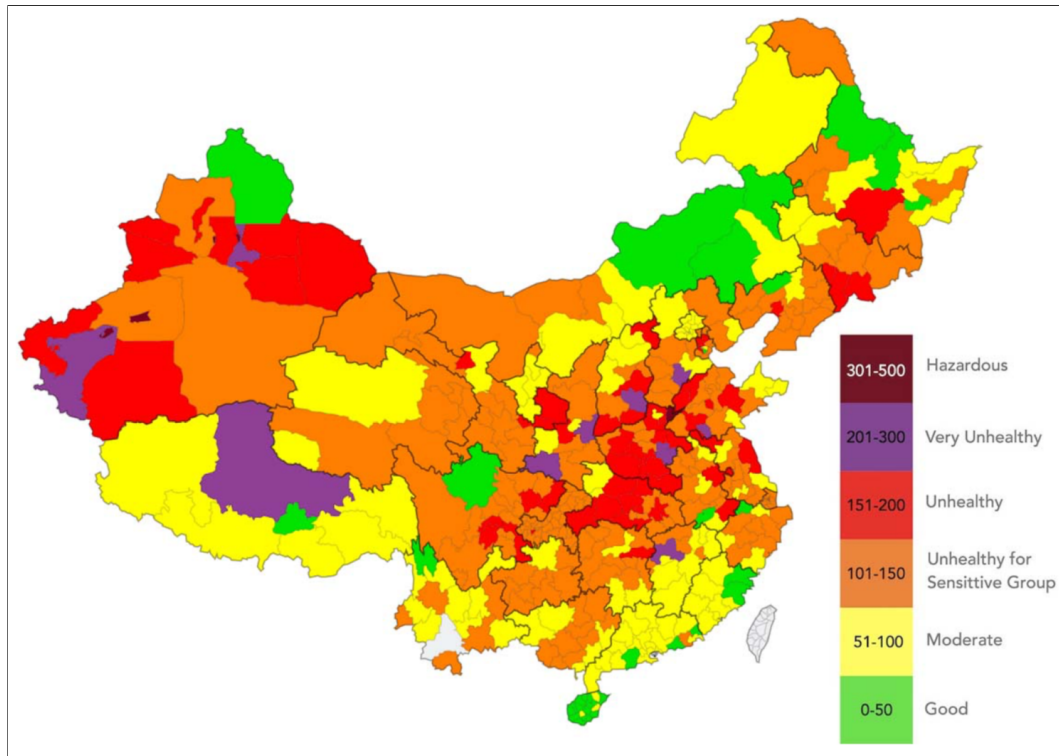


Figure 2.10: Heatmap of China in 2014 [43]

visualize data quickly. ThingSpeak also supports a web and application server and the API supports programming languages like Python, Ruby, and Node.js [6]. A disadvantage of using ThingSpeak is that you have little room to personalize your graphs and is mostly used to show quantitative data to people that are within the field. Other researches have chosen to create their own simple dashboard using different frameworks/software like Dreamweaver [46], Django with Azure web application service [10], Android application [7], IOS application [34], Chatbot [35], etc. Cheng et al. [30] created the system to be an open cloud platform for storing, accessing, and sharing air quality data. They provided third-party developers with APIs to develop visualization on top of their system. This resulted in 8 different application which can give competition for better visualization to the end-user.

AbdulWahhab [18] created a dashboard visualizing the indoor air quality data. The author used curve and gauge charts which were displayed on a web site in real-time. AbdulWahhab says the visualization of the dashboard that they created enhanced the understanding by occupants and made them aware of their environment conditions at home. This is not proven in any user testing in their research and no study on dashboard/design theory has been followed or referenced. The charts are color-coded and represent the different degrees of air pollution levels. The system

alerts the user with a short message when levels are too high. The curved charts show historical data; daily, weekly, monthly, and yearly data for the user to evaluate their indoor environment. [18]

2.4.1 Dashboards

The research paper authored by Khalid et al. [3] gives an overview of research done on the Internet of Things (IoT) data visualization and the use of deep learning in IoT. The author highlights the challenges with visualization in IoT and big data with the 6Vs (Volume, Velocity, Variety, Veracity, Variability, and Value). The author says there is still a need for data scientists to resolve issues like choosing the best visualization options of a large dataset, over-plotting, finding suitable data abstraction, and customizability of the visualization to adapt it to different domains. IoT data can be solved with visual analytics but it will not cover good visualization use because IoT domains have many different use cases. Also, visual analytics is understood by data scientists but not by non-technical stakeholders. Data generated from IoT is expected to grow more than other devices, figure 2.11 shows connected IoT devices within five years. If the data is not used in analytics and visualization to give meaningful insights to businesses, the data will be wasted. However, visualizing the huge amount of data is not easy as it results in over-plotting and not fitting the data to one screen. Data scientists over the years have come up with new techniques to handle big data, such as data reduction, hierarchical exploration, etc. The authors of this paper also discussed that there are little resources on machine learning in data visualization and many examples of it in data analytics. Many resources online focus on different techniques, workarounds, and issues related to big data that are done by humans. Human error and oversimplification is also a problem and therefore the authors propose to use machine learning. [3]

Sarikaya et al. [47] looked at the general scope of how dashboards are designed and used in different areas. Their framework and literature review proposed directions to better create dashboard design, implementation, and use. Visualization dashboards are ubiquitous and are built and used by nearly every industry to support data-driven decision making. They are used by students to track learning, hospitals to track the health of patients, energy consumption, monitoring several systems in infrastructure, etc. An example of a social dashboard for private use is shown in figure 2.12. Dash-

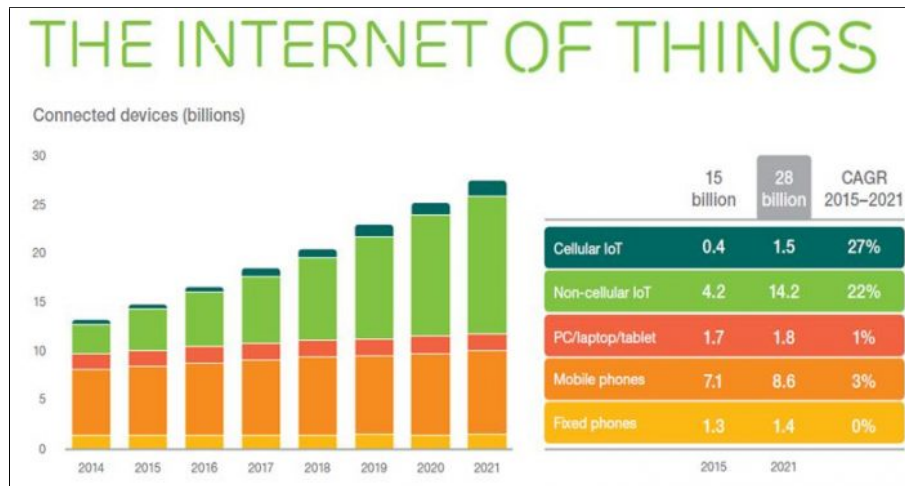


Figure 2.11: The Rise of IoT Devices within 2021 [3]

boards are made for at-a-glance reading, coordinated views, and tracking future and historical data. The authors identify dashboards as a visualization that offers directions for future research. It's important to know your audience when designing a dashboard. E.g. people with different backgrounds and needs see the dashboard differently. It's important to design dashboards after what is needed and what the audience can understand from the data. Dashboards are met with new challenges such as data choice, whether the quality of data is good (completeness, provenance, accountability, uncertainty), representation of dashboard use (design), and understanding the social impact of dashboards. The authors conclude that designers struggle with one-size-fits-all tools that do not reflect the different goals and needs of the user. They want deeper analytics, customization, adaptability, and flexibility when handling the data. [47]

2.4.2 Designing Dashboards

Dashboards and other data related visualizations have different guidelines for the designer to follow before doing user testing. Creating a simple graph requires skills, Few [48] lists 21 different preattentive attributes that can be used when creating a graph, but only a few works well. This is because different techniques work for different cases and too many attributes in one graph give visual clutter (messy appearance). E.g. using both line length (length of a bar in a bar graph) and line width (width of a line in a line graph) for separate variables is a bad combination because these attributes are integral and can be perceived as an area instead of independent attributes when combined. Few have a long list of combination that does not work well with



Figure 2.12: An Example of a Social Dashboard [47]

each other. E.g. attributes of color and hue, size and color, shape and size, shape and curvature (changes the shape) and shape and line orientation. The author says that it's human nature to break free from our limitations to be better and do more, but we do not accomplish this by ignoring our limitations, we must rather try to understand our limitations and find solutions. [48]

Dasgupta et al. [49] says it's important to determine the effectiveness of tools and techniques used in visualization, but most research has been on how well tools and techniques work with analytic needs for the user. Creating visualizations demands time, effort, and knowledge about design principles and user perspective. The authors have found a lack of research on judging and classifying design problems of domain experts and their design in visualizations of data. The authors of this paper are design experts and their focus area is on climate data modeling and have conducted interviews with scientists within that field on design use. The study is a taxonomy to categorize the cause, problems, and consequences in design visualizations created by domain experts. They wanted to gain insight into people outside the visualizations community on how they use, design, and reason about visualizations. The table created by Dasgupta et al. [49] is presented in figure 2.13 which sums up the design problems to the consequences evaluated in the scientists' visualizations. After looking at the problems and consequences the authors created guidelines for the scientists to avoid design problems, especially in data visualizations such as maps, scatter plots, and line charts. First, keeping the audience in mind is important, and creating a visual-

ization for not only within the field but also for external use. The visualization should be expressive enough to give enough information without too much detail. Second, guide users' attention to the salient patterns which let them find similarities and dissimilarities. If done wrong it can cause visual clutter and the audience is left confused. Third, in complex visualizations, it's wise to use text, size, color, or highlights to give support to the data visualized for further explanation. Fourth, scientists happen to use grey color on data that should have been highlighted, different colors should be used for different data types. E.g. grey can be used to de-emphasize data that is not as important. Lastly, be careful of defaults, such as the rainbow color map in many visualization tools. This requires to manually configure visualizations to prevent default settings. The scientists found the guidelines to be useful and for future work, the authors plan to build an automated system to detect design problems to give recommendations. [49]

Causes of Problem	Consequence
Visual variable problem: <i>ambiguity</i> Distortion: <i>scale inconsistency</i>	Misinterpretation
Distortion: <i>projection error</i> Distortion: <i>scale inconsistency</i> Color map: <i>quantitative mapping</i>	Inaccuracy
Chart appropriateness: <i>mismatch</i> Chart appropriateness: <i>configuration</i> Visual variable problem: <i>choice</i> Level-of-detail: <i>jaggedness</i>	Lack of expressiveness
Visual variable problem: <i>choice</i> Level-of-detail: <i>granularity</i> Color map choice: <i>qualitative mapping</i> Clutter: <i>color mixing</i> Clutter: <i>overlap</i>	Inefficiency
Comparison complexity: <i>superposition overload</i> Comparison complexity: <i>lack of explicit encoding</i> Communication gap: <i>grids</i>	
Comparison complexity: <i>lack of explicit encoding</i> Communication gap: <i>grids, legend</i> Communication gap: <i>annotation</i>	Lack of emphasis

Figure 2.13: Connecting Design Problems to Problem Consequences Sorted by Severity [49]

2.5 Summary of Theory

In this chapter of related work, we've gone through how the Internet of Things is an ecosystem of "things" and how it works with cloud computing and microcontrollers and sensors. As sensors can monitor gases in the air we have further looked at Air Pollution and how it affects human health. we've also described some of the most important hazardous gases in both outdoor and indoor air. Further, we looked through research on Air Monitoring Systems, first outdoor to give an idea of the general systems that have been made. Second, we looked at indoor systems which were more related to this project. In the last section, we went into the research gap which is creating a dashboard based on design theory using IoT ecosystem sensor data from the indoor climate. We presented some research examples with air monitoring systems which had good visualization, but was not complete with either user testing or had user testing but did not show related research in designing the visualization of data. We also discussed some research only based on dashboards and design theories that are used within the data visualization community as this is what the dashboard is based on.

Chapter 3

Research Methodology

The research process for collecting data started with gathering articles and documents already conducted in the research area from different research databases online. From the research articles reviewed there was a lack of good visualization of the Internet of Things (IoT) sensor data. There was little explanation on how the researcher got to their conclusion for design and little user testing was conducted. The purpose of this research project was to create an IoT artifact that would generate and visualize data. The artifact was placed in a real-world environment where the collection of indoor air data was generated from the air inside an apartment. Further, the data was analyzed and visualized on a dashboard application. The dashboard was presented for user testing with interviews online. This chapter will discuss the research method used and how it's implemented in this project. Section one discusses the research process and why it was chosen. Section two explains how the literature search was done for the related work chapter. Section four explains how user testing was conducted as interviews. The last section draws upon the limitations of the methods used and other important factors.

3.1 Research Process

In the research of computer science, more than one research method is preferred to get valuable results. The design science research method has been followed as a guideline to this project combined with other common data collecting methods such as literature review and interviews for user testing of the dashboard design. The first section evaluates some of the other methods not used. The second section explains the

different phases of the chosen method and how it's used in this research project.

3.1.1 Other Research Methods

There were other research methods to be considered when choosing the right method for the research project. This section will go through some of the other methods that were not chosen. Experimental research is a method where the researcher tries something out and observes what happens. E.g. testing software for errors or testing user's movement on a website with different factors involved, but using the same factors for all participants. Experiments investigate the cause and effect to prove a link between factors and outcomes. It's normal to create a hypothesis that is to be proven or disproven by doing an experiment. The researcher has to consider all possible factors or else the experiment is not viable, therefore researchers do not conclude their experiments before they have repeated them many times to themselves and others. The goal for this project was to create good visualization of IoT data and it does not contain any hypothesis to prove or disprove. There are no linked causes and effects to investigate and the variables cannot be controlled. [50]

Case study research focuses on one thing to investigate such as an information system, a system developer, or a development project. Choosing a case means to choose a thing to study in-depth to obtain detailed information of that thing. The researcher in case studies must address all factors available, unlike in experimental research where the researcher tries to simplify the real-world by finding one factor. The case is studied in a natural setting and the researcher aims to disturb as little as possible because it usually exists after the researcher has moved on. This method would not have fit into this project because we worked with more than one specific thing. According to Oates [51] the project could have been a case study along with the design science method after the artifact was completed to see it in use, but that can be discussed for future work. [51]

Action research is a method often used by professionals who want to investigate their work. E.g. teachers investigating different strategies for discipline or psychologist trying out different technics on their patients. It's research put into action. It focuses on complex problems expressed by people in the real world. Researchers are concerned with making a difference and learn how they affected the results. If the artifact was implemented in a real-world scenario using participants to make use of the dashboard

in their everyday life it could be considered doing action research. The only process from the real-world was the gathering of data and interviewing potential users for the dashboard. The improvements of the dashboard were not investigated to give practical improvements, rather theoretical from other academic research. [52]

3.1.2 Design Science Research Model

Design science research is the process of learning through building, first, you design an artifact then you evaluate your work [53]. It's important to distinguish design and creation research from "normal" design and creation. For "normal" design and creation projects it's more valuable to create something without learning something new using already existing technics and technology. For research design and creation, it's important to gain new knowledge and try to use a path that is riskier in terms of unknown skills and knowledge on how to develop or implement an artifact [54]. According to Oates [54] the design and creation process is a problem-solving approach involving five steps; awareness, suggestion, development, evaluation, and conclusion. Figure 3.1 represents the design science model of the five steps to follow during the research process.

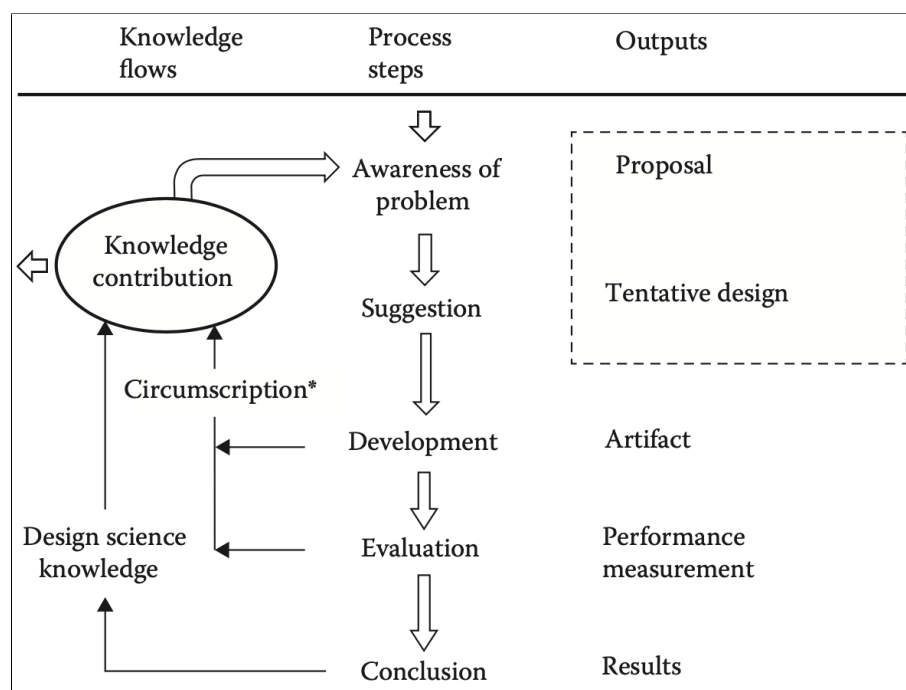


Figure 3.1: Design Science Research Process Model [53]

Awareness

Awareness is the starting phase of the research project where we propose a new research effort. It's the recognition of a problem that can come from multiple sources. It can come from future work stated in research papers, missing research gaps, clients expressing the need for something, from new developments in technology or something that can contribute to already existing knowledge. For this research project, the awareness of the problem was found through research papers and the identification of a gap in the visualization process in various research papers. There was more focus on how to handle the data in the Internet of Things projects for indoor and outdoor climate monitoring. There were also none or some use of user testing. [54][53]

Suggestion

The suggestion phase is connected with the first phase as the proposal should come with a tentative design as shown in figure 3.1 to give weight to the proposal. A tentative design can be existing literature or a prototype to provide suggestions on the artifact developed. It's a suggestion of the solution to the proposed problem if the researcher cannot find a solution, the proposal is thrown away. I've used existing literature and presented them in the related work chapter and I've sketched different designs by hand for brainstorming. Further, a tentative design was created as a prototype and a suggestion to the artifact, it's further explained in detail in the development chapter. [53]

Development

The development phase is where the tentative design is implemented into an artifact. How the implementation is done depends on the proposed IT artifact. E.g. creating an algorithm needs proof to give valuable results, a new user interface needs software development, etc. The development process and the implementation of the artifact are explained in detail in the next chapter of this thesis. The visualization of the artifact is created in multiple interactions. First, the tentative design was created using various design theories and related research. Further, the tentative design was used as a guideline for further implementations and development of the dashboard application. After developing the functioning prototype of the dashboard, it was used for the interviews and the feedback was used to do final changes to the same prototype.

[53]

Evaluation

Evaluation of the artifact is an important phase where we evaluate the worth and expectations according to the proposal in phase one. There is an analytic process where the hypothesis is made about the artifact which the analysis either confirms or contradicts. The design science researcher has not finished the research effort once the artifact is done and evaluated. This phase gives the researcher more information to use in future work and for another round of suggestions. The evaluation process is done after the data from the interviews has been collected. The data is studied with various data analysis methods and finally, they were discussed against the research question and related work. [53]

Conclusion

The concluding phase is the end of the research cycle where the project is summed up and concluded with the results from the artifact. The knowledge gained, results that can not be explained, and further research gaps are also identified in this phase. [53][54]

3.2 Literature Search

The literature search was done using the search engines IEEE, ACM, Taylor and Francis, and Google Scholar was used for further searching references within the related papers. Some of the literature search keywords are listed in figure 3.1. The list is much larger but only the most important are represented for understanding the search process. For every search word, they were noted down with names, hits, and which engine was used. The same keywords were tested in all search engines to see if any important papers were not missed. The keywords 'IoT AND Air AND Quality' in the IEEE search engine gave many good results and most of the papers used were taken from there. The search was shortened down to only looking for conferences and journals and year range from 2000 to 2020, but IEEE then only listed papers from 2012 to 2020. ACM and Taylor and Francis did give either the same results with the same research papers or did not have relevant papers. Taylor and Francis's search hits were

based on the same criteria but resulted in low hit numbers because of limited access. Changing the keyword from 'Air' to 'Climate' surprisingly gave results hits of 10 on IEEE while it gave 80 results on ACM. Further using the keyword 'Visualization', gave too many hits and had to be shortened down to 'Visualization AND IoT' but IEEE and ACM only gave papers ranging from the year 2010-2020 even though the range was set from 2000-2020. It clearly shows that the field IoT is new technology and before the year 2010 there were little to no research papers online. Searching for visual analytics within IoT did not give any relevant papers. Using keywords such as 'IoT AND Monitoring AND Dashboard' gave useful papers and some were already found using the first search query; 'IoT AND Air AND Quality'. After searching for literature the abstract and conclusion were read to eliminate some papers and then, the whole paper was read and more papers were eliminated. The papers were chosen according to relevance, citations, references and to cover different categories. E.g. Some IoT systems that were created for outside purposes and some for indoor purposes. Also, papers that had no relevance to IoT and only focusing on the visualization of dashboards were looked at.

3.3 Interview

For this project, the user testing was done in the form of interviews to gather data for further improvement of the dashboard visualization. Interviews are used as a data generation method which normally results in qualitative data analysis. It's a conversation between people where one person has a purpose and a goal for the interview. It's usually well-planned beforehand and with the person/people that are going to be interviewed. The interviewer guides and controls the topic of the interview to gain the information he/she is looking for. The interview questions can either be complex or open-ended, they can also trigger different emotions by the subject which is to consider in further discussion of the results. [55]

The Interviews were carried out one-to-one over the internet using video calls through different platforms. The interview was planned carefully before it took place along with the functioning prototype of the dashboard which was created after the tentative design. Brooke's System Usability Scale (SUS) was used as part one of the interviews, where the user indicates the degree of agreement or disagreement on different statements on a 5 point scale [56]. This was to get an average of the overall usability of

Search Engine	Search Number	Search Query	Hits
IEEE	1	IoT AND Air AND Quality	306
ACM	2	IoT AND Air AND Quality	1086
Taylor and Francis	3	IoT AND Air AND Quality	289
IEEE	4	IoT AND Indoor AND Climate	10
ACM	5	IoT AND Indoor AND Climate	80
Taylor and Francis	6	IoT AND Indoor AND Climate	33
IEEE	7	IoT AND Indoor AND Particulate Matter	9
ACM	8	IoT AND Indoor AND Particulate Matter	157
IEEE	9	IoT AND Monitoring AND Dashboard	66
ACM	10	IoT AND Monitoring AND Dashboard	348
Taylor and Francis	11	IoT AND Monitoring AND Dashboard	78
IEEE	12	IoT AND Home AND Ecosystem	79
IEEE	14	IoT AND Visual Analytics	40
IEEE	15	Visualization	79,210
IEEE	16	Visualization AND IoT	612

Table 3.1: A Part of the Literature Search Keywords Used

the dashboard. In appendix A we find the document sent to the user by email before the interview started. Since SUS is normally used after the user has used the system, but before instruction takes place, a more detailed interview with questions was done after the user had graded the statements as part two. Five interviewees were chosen with age ranging from 22 to 64 and with different background experiences within technology. According to Nielsen and Landauer [57] using more than five participants for user testing will not give more valuable data when testing the functionality of a system's interface, especially compared to the time it takes to get new feedback not already established by the first five.

3.3.1 System Usability Scale

The System Usability Scale (SUS) is a standardized tool created by Brooke [56] to quickly get feedback on the usability of a system from the user's perspective. SUS is very easy to use and provides a single score which ranges from 0 to 100, the higher the score, the better the usability of the system is. It's based on 10 statements which are

	SUS Statements
1.	I think that I would like to use this system frequently.
2.	I found the system unnecessarily complex.
3.	I thought the system was easy to use.
4.	I think that I would need the support of a technical person to be able to use this system.
5.	I found the various functions in this system were well integrated.
6.	I thought there was too much inconsistency in this system.
7.	I would imagine that most people would learn to use this system very quickly.
8.	I found the system very cumbersome to use.
9.	I felt very confident using the system.
10.	I needed to learn a lot of things before I could get going with this system.

Table 3.2: System Usability Scale (SUS) Statements [58]

graded on a scale from 1-5, where 5 strongly agrees and 1 is strong disagreement. The 10 original statements from Brooke [56] were chosen to use in the interviews which are listed in table 3.2. All odd-numbered statements are positive while all the even-numbered statements are negative and they are calculated differently. The odd numbers 1,3,5,7 and 9 are calculated using the scale position from 1-5 minus 1. The even numbers 2,4,6,8 and 10 are calculated using 5 minus the scale position. Then the sum of all even and odd numbers is multiplied by 2.5 to get the SUS score. The mean of all the SUS scores from the individual interviews was calculated to find the overall score of the system. The meaning of the score values is listed in figure 3.2. [56][58]

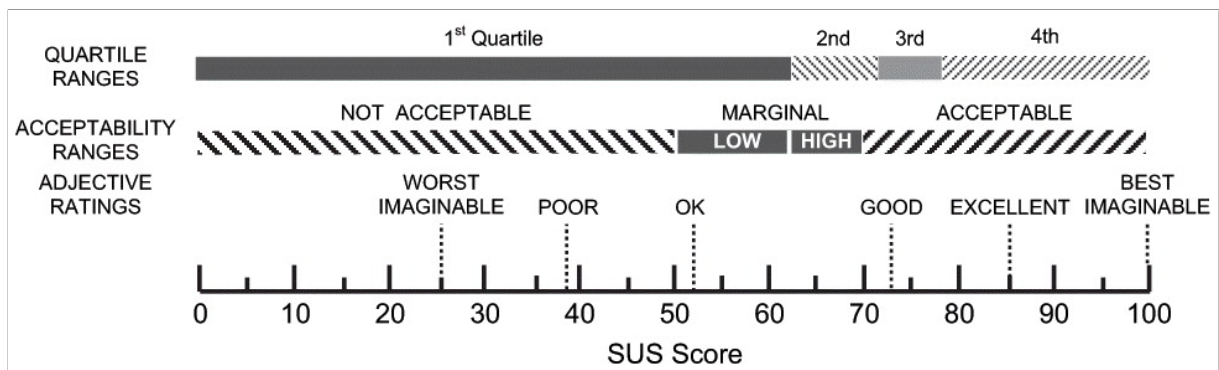


Figure 3.2: Meaning of System Usability Scale (SUS) Scores [58]

3.3.2 Interview Questions

The interview was based on a semi-structured approach where the questions were not necessarily followed by order and there was room for additional questions as unforeseen issues or topics were discovered. The structured approach was not chosen

since I did not want the same answer to the questions from the interviewees. I was interested in some detailed answers and further ideas to the design. The unstructured approach would have given too unique and different answers from the interviewees, I wanted to have some control of the feedback on the design presented. Semi-structured interviews allow the interviewee to speak more freely and give feedback on the design which was the goal for conducting the interviews. There was no personal data collected nor questions requiring personal data. The questions were only asked towards the design of the prototype and the interviewee's opinion and feedback data were used for further development of the final prototype. The interview started with giving the interviewee a link to a webpage displaying the functioning prototype of the dashboard and a document including an introduction with a consent form and 10 statements by e-mail which can be seen in appendix A. They were asked to grade from 1-5 on the 10 statements as explained in the section above. Lastly, they answered around 20 questions asked by the researcher about the design and their experience in more detail. [55]

The questions are listed in appendix B and were planned after how the tentative design was designed which is described in the next chapter. I wanted the interviewee to get an opinion about the dashboard on their own and started off asking questions that were more general and open. Further, I asked more detailed questions that were created based on the design theory found in research to find out what the interviewee thought of the choices that were made. The focus was on the small details such as color choice, shapes and the text size to find out whether it was clearly displayed to the interviewee. Then questions on what they would like to be presented if they were to use this at home were asked. This was asked to see whether the design was successful and to get new ideas for further iterations. Lastly, a more general question about any thoughts or something missing in the design was asked to end the interview.

3.4 Data Analysis

In this research project, there have been used different methods to analyze the data that were either quantitative or qualitative. The data was gathered through user testing in the form of interviews and two different methods was used; System Usability Scale and in-depth interview questions to improve the artifact design. During the interviews, the answers were written in a structured way in Microsoft Excel to easier

analyze the data later. Microsoft Excel was also used to do calculations with quantitative data and to group the qualitative data in columns for better overview.

3.4.1 Quantitative Data

According to Oates [59] there are different kinds of quantitative data and the process of preparing, using visual aids, statistics, and how to evaluate the data analysis are important factors to make the reader understand the data presented. Quantitative data are data in the form of numbers that we can calculate and measure using tables, charts, graphs, and other statistical analysis methods. The data that was collected from the System Usability Scale (SUS) method was ratio data according to Oates [59]. Ratio data has a true zero which means the dataset can contain zeros. We can use addition, subtraction, multiplication, and division to find trends and analyze the data. The data is also continuous which means some numbers are not whole, they have decimals for better accuracy. The data was prepared in Microsoft Excel in tables to create functions to calculate the grades gathered from the SUS. From the data calculated a bar graph was made to show the SUS score per candidate combined with a line graph showing the mean. For the grades gathered from each candidate on their 10 statements, several statistical methods were used to evaluate key points and conclusions. The grades were put into a table to show mean, standard deviation (SD), standard error of the mean (SEM), and also SEM in percentage to show the error range more clearly to the reader. The mean was calculated to find an overall average of the SUS scores collected from the interviews. the SD was found to give the reader an average distance each data value is from the mean, to find whether the different candidates agreed or disagreed with each other. The SEM was calculated to show the error range of the mean calculated, it gives an idea of how much the mean score would change with a higher number of candidates. These calculations gave an idea about the spread and distribution in the dataset and if there was an association between the values. [59]

3.4.2 Qualitative Data

Qualitative data are based on words, images, recordings, etc. Part two of the interview contains questions and answers which are qualitative data. The answers contain detailed texts written down during the interview. The qualitative data generated were important to find detailed and rich feedback to help change the prototype

design for the user's best interest. We've tried to explain the data analysis in detail as the researcher is often accused of not providing enough information about the process. According to Oates [60] the conclusions taken from qualitative data often appear by magic to other readers because the analysis process is not described correctly. Compared to quantitative data, qualitative data do not have any fixed rules to guide the process, it's up to the researcher to find themes and patterns. I decided not to record the qualitative data as the process of transcribing audio takes time. I transcribed as the candidate spoke during the interview and felt I understood what the candidate wished to convey. Using the notes that were taken during the interview I prepared them in Microsoft Excel and had each answer for each question in the same row. The same file was used but separated into a sheet for each candidate. Next to each answer, I used a column next to it for personal comments to the answers. When the answers were ready for analyzing, all the answers from each candidate were placed in the same Excel sheet. They were also placed next to the questions on the same row. This made it easier to analyze the comparison between each answer to the same question asked during the interview. The interview was done in Norwegian and all the answers had to be translated to English when writing the thesis. Placing the text in Microsoft Excel made it easier to analyze when the text had the same formatting and better overview to potentially find themes and patterns in the text. The text was also categorized into relevance to the research question and the type of questions that were asked during the interview. [60]

3.5 Limitations with Applied Methods

The Design Science research method can be risky as we must have some necessary technical skills. I had some of the technical skills, but not necessarily for this type of programming. I had to learn a lot within frontend programming and I used sensors that had to be calibrated. The calibration process had to be learned through research papers and online tutorials. It was difficult to generalize the settings as the artifact was only tested in a single situation. The success of the artifact can also be dependent on the researcher's presence, but in this case, the research project is hopefully well documented as the focus was the visualization of the artifact. Lastly, using this research method could result in perishable research as technology rapidly advances can invalidate the results before being published or tried out in real-life. [54]

During the literature search process, I had to be critical of the research papers found. I mostly used known databases online and looked at whether the authors were known within the topic area to find out the reliability of the papers. I only used webpages where it was necessary to cite products or other companies from their official webpages. I've found many research papers within the research topic and I had to select the most relevant, which means I have not discussed every research paper out there. There might be research papers I have not found due to restrictions with payment or papers not published online.

The major cause of concern when I organized the interviews for the dashboard design was the outbreak of the Covid-19. The school had to shut down physically and all information had to go through the internet. It caused problems when gathering data from the interviews as I could not invite candidates to meeting rooms physically. I had to take all the interviews over the internet and use video-calls. This was a limitation because it affected how I perceived emotions and feelings when doing interviews online rather than physically. Some candidates had a video camera and some did not and I had to rely just on the answers and how they gave the answers through voice. There might be misunderstandings as social cues are difficult to understand over the internet. The interview notes were written and can be less detailed as questions and answers were traded between the researcher and the candidate. [61]

I used both quantitative and qualitative data analysis methods to understand the data that was generated. When analyzing the quantitative dataset I did not have a big amount of values to use to give a good indication of what the population would think of the artifact's usability. However, as mentioned in the chapter earlier by Nielsen and Landauer [57], five is enough to find most of the important usability issues with a system. The analysis can only be as good as the data generated and every decision I've taken can influence the results of the data analysis. For the qualitative analysis method, I did not generate these data using a recorder which could have been easier to find more details in the sentences after the interview process was done that I was not aware of during the interview. I wrote down all the answers on the computer while interviewing the candidate and I could have misunderstood some of the answers. The qualitative method can be overwhelming by the volume of data it generates and it can be difficult to identify themes and patterns if there is too much information. The conclusion taken from the results of the data in qualitative analysis can be affected by the researcher's identity and background rather in quantitative analysis. This is why I

also chose to do a quantitative data analysis method in the interview process. [59][60]

Chapter 4

Development

To accomplish good results from designing visualizations for the Internet of Things (IoT) data I've decided to collect the dataset by creating an artifact that will gather data over a few weeks to create enough data to further visualize historical and real-time charts. Section one explains the visualization process of the tentative design. Section two describes the hardware implementation and section three, the software implementation. The final section draws upon the different limitations to the implementation and components used.

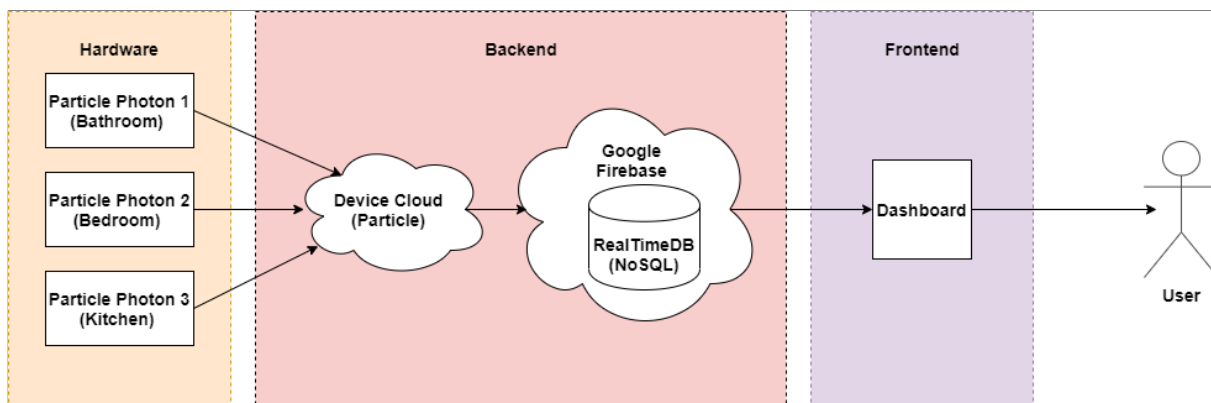


Figure 4.1: Architecture Overview over IoT Ecosystem

The overall overview of the system is presented in figure 4.1. The hardware side of the system collects the data from different sensors which communicates with a microcontroller, the Particle Photon placed in three different rooms; Bathroom, Bedroom, and Kitchen. The backend side receives the data from the microcontrollers which works as an analog to digital converter (ADC), the ADC sends the data to Particle's Device Cloud [62] where the data is further sent to a real-time database. The frontend side of the application visualizes the data received on a dashboard application in the

browser for the end-user to interact with from anywhere.

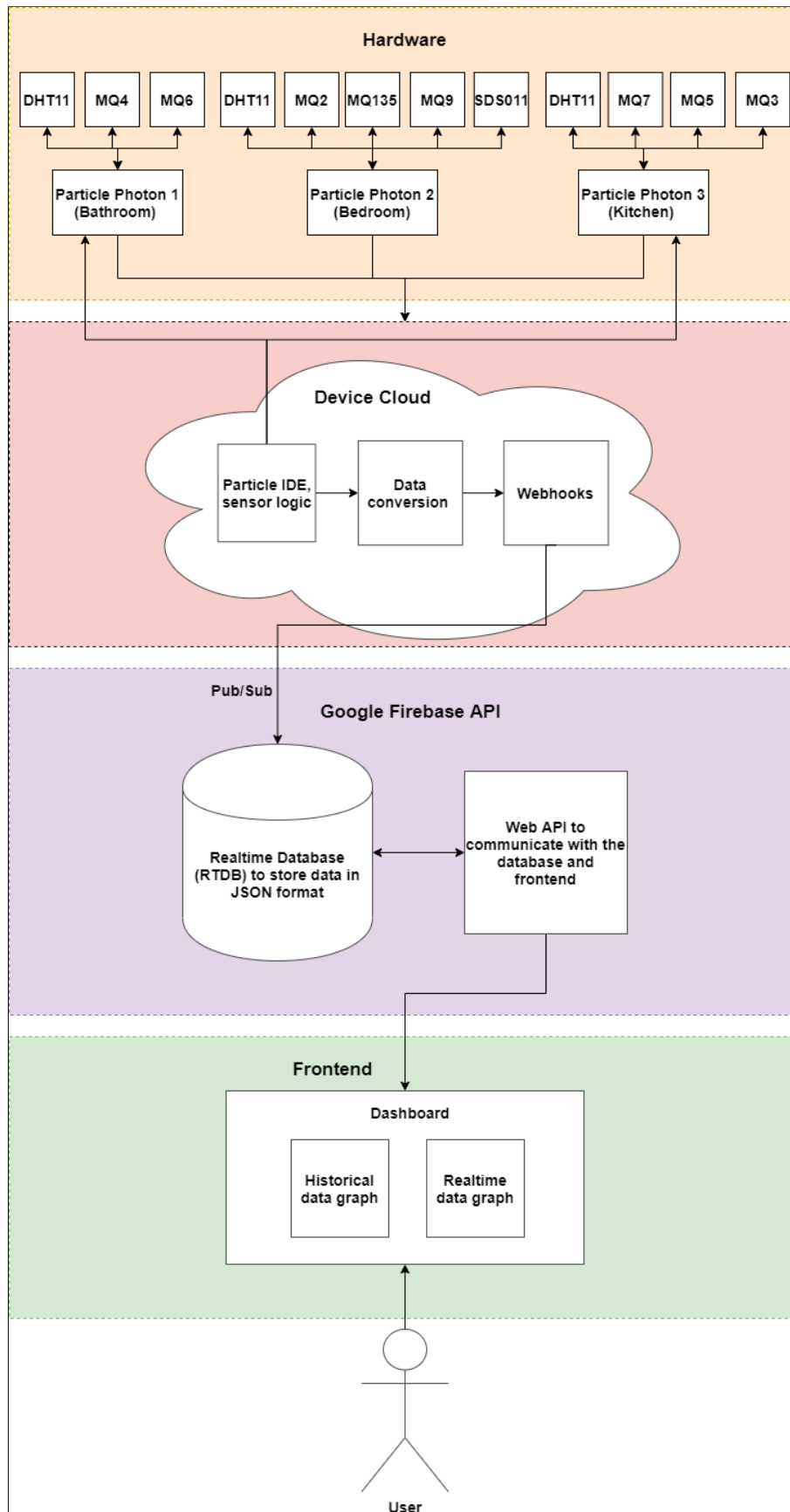


Figure 4.2: Detailed Architecture over the IoT Ecosystem

Figure 4.2 shows an in-depth overview of data flow and components used. It shows the three microcontrollers placed in each room with different gas sensors. The Particle Photon placed in the bathroom was installed with a temperature and humidity sensor named DHT11, an MQ-4 gas sensor calibrated to detect methane (CH_4) and an MQ-6 gas sensor calibrated to detect Liquefied Petroleum Gas (LPG). The Particle Photon placed in the bedroom had a DHT11 sensor and an MQ-2 gas sensor calibrated to detect LPG, MQ-135 gas sensor calibrated to detect Carbon Dioxide (CO_2), MQ-9 gas sensor to detect Carbon Monoxide (CO) and a dust sensor which could detect particulate matter (PM) with the size range of $\text{PM}_{2.5}$ and PM_{10} . The third Particle Photon was placed in the kitchen with a DHT11 sensor, an MQ-7 gas sensor calibrated to detect CO, MQ-5 gas sensor to detect LPG and an MQ-3 gas sensor to detect Alcohol. The calibration process and sensor description are explained in more detail in the hardware section. The Particle Photon microcontrollers downloaded the logic programming code from its Web IDE where the sensors behaved accordingly. The data received from the sensors were stored temporarily in Particle's Device Cloud as events. Webhooks created for each room listened to those events and sent the data further to a NoSQL real-time database in JSON format. This was done with publishing and subscribe protocol. The data was then sent with an application programming interface (API) which communicated between the backend database and the application on the frontend side of the system. The frontend application visualized the data as a dashboard with historical and real-time charts and this was where the user could interact with the data.

4.1 Tentative Design

This section will explain how I designed the tentative design of the dashboard and why the specific objects, colors, shapes, and positions were chosen. The visualization of the tentative design was chosen according to different design theories and dashboard research papers reviewed in the related work chapter. First, we go through different attributes in visual perception, then we go through the choices and meaning of color, further we discuss Gestalt principles [63] of visual perception and lastly the different chart types. The tentative design is presented in figure 4.3 and was the first draft of the visual presentation of the dashboard. The purpose of having more than one iteration was to have a plan to the design before the dashboard was developed as an application.

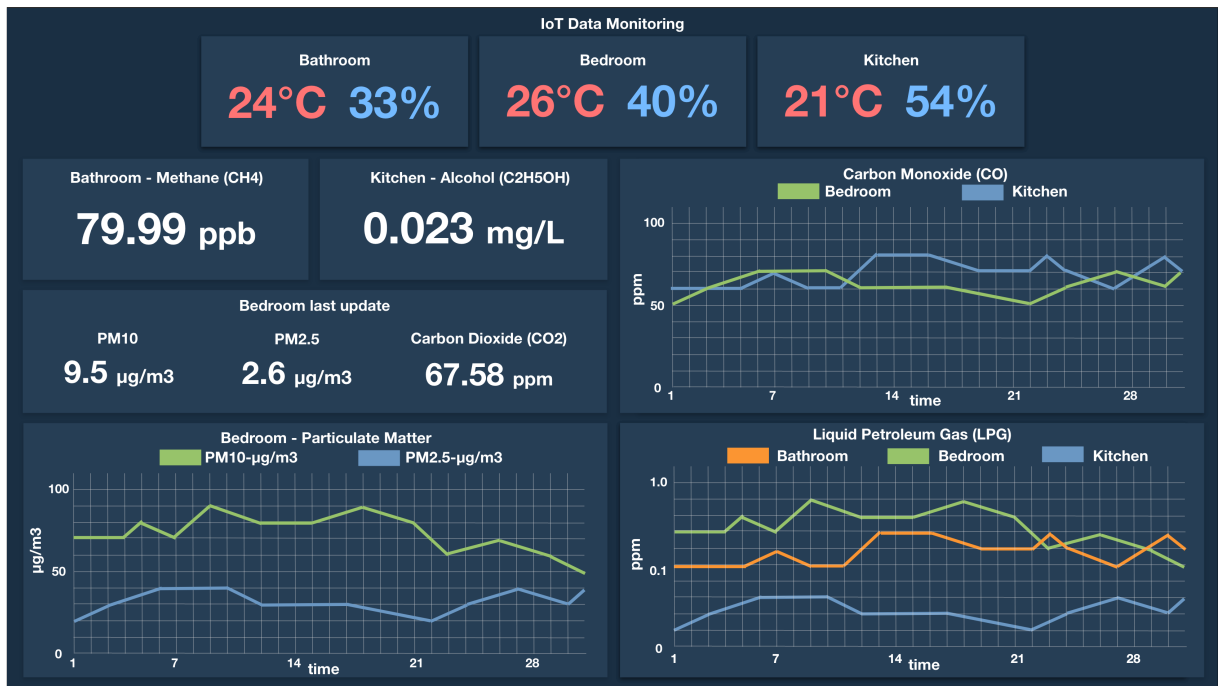


Figure 4.3: Tentative Design of the dashboard

4.1.1 Visual Perception

I looked into how to visually encode data for rapid perception to guide the design process of the dashboard to best understand how people would perceive the data presented. I wanted to create a design that triggers preattentive processing which occurs below the level of consciousness rather than attentive processing which is much slower. For example, by using different color intensities we can perceive data much quicker. I will discuss only some of the many preattentive attributes that were most relevant to this research project. The attribute color is an important tool to help us highlight different data and is described with three attributes; hue, saturation, and brightness. Hue is just another name for the different colors we know, saturation is the degree of the full essence of each hue, and brightness is whether the hue appears dark or light. In figure 4.3, I've used color with lighter brightness when the user hovers over the data to make it come forward on the screen. Certain colors were reused e.g. the color blue was used in both graphs to represent the room kitchen. The y-axis and x-axis unit numbers had full saturation of the color white while the lines behind the data points had lower saturation and were less visible. Colors are also influenced by their surroundings and I've therefore used bright and high saturated colors to prevent data from disappearing into the dark blue background. The attribute form can be the size of an object or the thickness of a line in a line graph. I've used form to separate

and group data in different sizes of squares. The use of positioning can be e.g. using shades to make an object come more forward and 2D positioning. The boxes or squares in the tentative design had shades for this purpose. The attributes of motion are e.g. the flickering of the mouse cursor or any other movement in the dashboard. The only motion present was the change of numbers when new values were collected from the database. The graphs changed their shape depending on what new data point was added. [64][65]

4.1.2 Meaning of Colors

The choice of color was an important process as colors can easily misguide and create noise rather than being helpful. I've given some examples of color choice in the first section but wanted to go more in-depth here. To prevent clutter I've only used five colors (blue, red, green, orange, and white) in the dashboard, according to Few [64] short-term memory cannot retain more than nine colors simultaneously. I've looked into some of the meanings of color and found that it was important to understand how humans perceive them. As seen in figure 4.3 the color blue is dominant in terms of the amount used. According to Cerrato [66], the color blue has a calming effect on humans and gives stability. It's also the most universally favored color in the world and it's a safe choice. A brighter blue was used to represent humidity as blue is also associated with water and sea. The color red is represented with energy, war, danger, strength, power, as well as passion, desire, and love. It's a good color to choose e.g. for alarming values of air pollution which I've not demonstrated in the tentative design but was used in the final result. Red was primarily used for the temperature values because only indoor air was measured where values below zero would rarely occur. In most cases, temperature values below zero are represented with the color blue but have already been used for humidity and the different values would be less clear if used for temperature as well. Green is said to improve vision as it is a very restful color for human eyes. It's also used to represent safety and is the opposite of red. I did not want to stress the user with too alarming colors, I wanted them to understand and become more aware of their indoor climate. Orange is a fun, optimistic, and youthful color, most used by travel agencies. I chose orange to distinguish from the blue and green, yellow would have been too bright compared to the green and blue lines. White is also a calm color and is often used to show simplicity in high-tech products. It's also

a neutral color and I've simply chosen the color due to the dark background color. [66]

4.1.3 Gestalt Principles of Visual Perception

I followed Gestalt six principles of visual perception; proximity, similarity, enclosure, closure, continuity, and connection. These six principles helped to decide how to arrange the different boxes containing either numbers, text, or graphs. They are made to guide us with how people visually connect and separate objects. The principle of proximity guides us to place objects close to each other to form a group and separate the groups by simply using whitespace. I've separated each group using whitespaces as shown in figure 4.3. At the top of the dashboard where we have three of the same size of boxes for temperature and humidity, I've distinguished between the different rooms using whitespaces. The principle of similarity means we group objects after color, shape, size, and orientation. I've used the color blue and red for temperature and humidity to link that they are the same data but in different boxes to visualize that there is a small difference to which room the data belongs to. The principle of enclosure groups together objects by creating a visual border. The border does not have to be strong, I simply used a brighter color to create borders to visualize boxes. The principle of closure says that humans visualize open structures as closed whenever it's reasonable. The different line graphs are a good representation of closure as only the y-axis and x-axis were closed with lines that are required to show the space where the data appears. The principle of continuity explains how humans perceive objects belonging together or is an extension of one another using individual lines to form e.g. a dashed line. I did not have any representation of this principle in the design. The principle of connection is connecting objects using lines to tie them together. There are several round data points in the charts that are connected with a line to separate more than one variable with the same shape. [63][67]

4.1.4 Chart Types

When designing the dashboard, I wanted to show the users changes over time and I looked into different ways to do that by using charts. Line charts are well represented in figure 4.3 and according to Kirk [68], line charts are a good option to show changing trends and patterns over time. They are well known to most people and therefore no need to use the time to educate the users. The x-axis on a line chart com-

compares a continuous quantitative variable while the y-axis shows the values' size. The data points are joined together using lines to visualize a slope to present a story from the past to now. The y-axis does not have to start at zero as we are looking at the relative pattern of the data. Sparklines takes advantage of the visual perception to show changes in low resolution, where display space is limited. It's very useful for single-page dashboards as it highlights the most important spikes in the line and bar chart. The chart type was not used in the design, this could be considered in later iterations or future work. The area chart is similar to the line chart, but the area underneath the line is filled with color to show the progression of values over time. In these types of graphs, starting at zero is important compared to regular line charts because the area must be interpreted correctly. Horizon chart is similar to area charts, but are modified to include both positive and negative values using different color brightness and saturation. The results show a chart that only needs a row of space for both negative and positive values. A stacked area chart shows a compositional view of categories over time and uses different colors to distinguish the categories. They present either absolute values or percentage values. The stream graph is similar to the stacked area chart but does not have any x-axis, so there are no negative and positive values. The purpose is to highlight peaks and usually, the user can interact with the graph to explore the different layers. The different area charts presented cannot be used in this case as we are monitoring gas values and not e.g. amount of customers in a shop during a week which can be counted. I've used some of the attributes from the horizon charts, not to distinguish the negative and positive values, but to highlight data the user wishes to see clearer. [68]

4.2 Hardware

I decided to use the Particle Photon microcontroller because it's small and has a Wifi chip which makes it easy to send data to other software components over the internet. The Particle Photon comes with great documentation, tutorials, and tools that can be found at their website particle.io [69]. It has a cloud called Device Cloud where data is stored in real-time temporarily and a Web IDE [70] where the logic to the microcontrollers was programmed and how the sensors should respond. Particle also has webhooks [71] which makes it possible to connect Particle events to other third party services online.

4.2.1 Components

The most important component for the hardware setup was the Particle Photon which controlled the sensors' behaviors, the layout is shown in 4.4. The Particle Photon has 12-bit Analog-to-Digital converter (ADC) inputs (0-4095), and also digital GPIOs and comes with a wifi chip. Once it's powered to a micro-USB it gives 5V from the pin VIN and 3V3 from the pin 3V3. It has several digital and analog pins and as shown in 4.5 the digital pins tolerate 5V, while the analog pins tolerate max 3V3 unless they are used as digital pins.

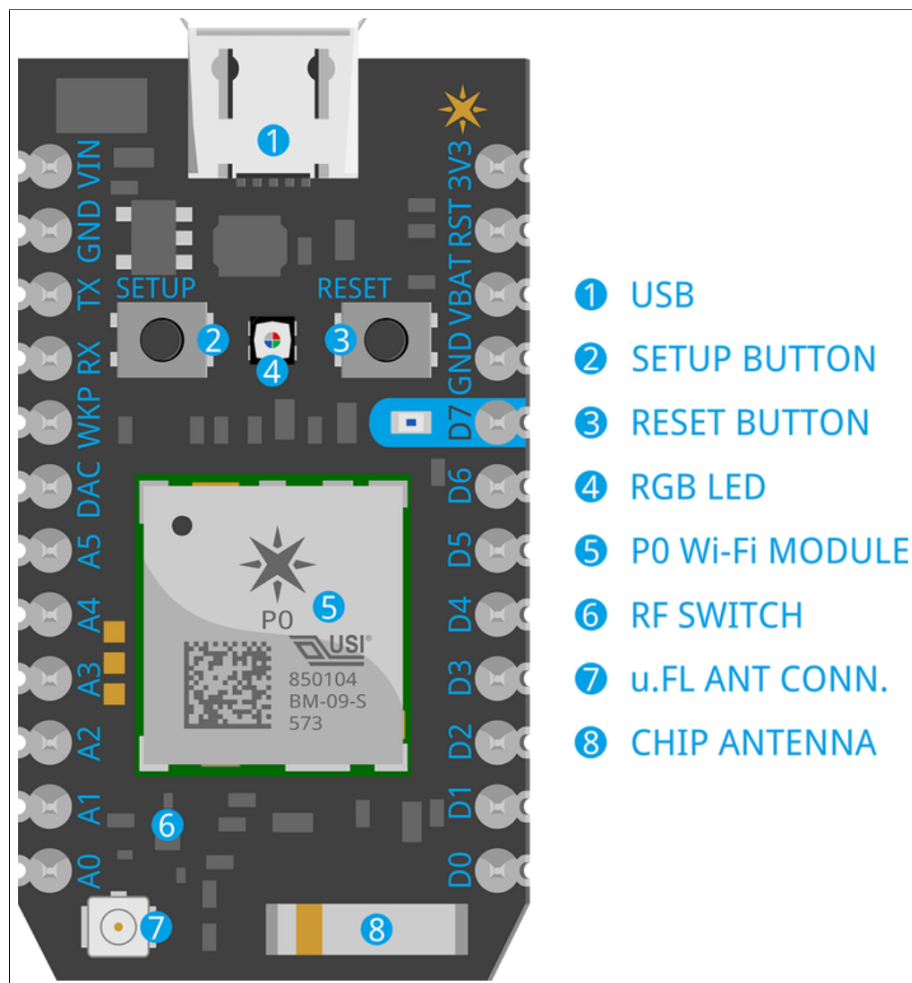


Figure 4.4: Image of the Particle Photon and its Pins [72]

The temperature and humidity sensor named DHT11 is a sensor with a calibrated digital signal output which is easy to read by the microcontroller. It has long-term stability, high reliability, cost-effectiveness, and fast responses. It has low power consumption and up-to-20 meter signal transmission. Humidity measuring ranges from 20-90% and a temperature measuring range from 0-50°C. It can be powered with 5V or 3V3 and to pass the unstable status for wrong reading, it needs around 2 seconds

Peripheral Type	Qty	Input(I) / Output(O)	FT ^[1] / 3V3 ^[2]
Digital	18	I/O	FT/3V3
Analog (ADC)	8	I	3V3
Analog (DAC)	2	O	3V3
SPI	2	I/O	3V3
I2S	1	I/O	3V3
I2C	1	I/O	FT
CAN	1	I/O	3V3 ^[4]
USB	1	I/O	3V3
PWM	9 ^[3]	O	3V3

Figure 4.5: Overview of the Particle Photon's Peripherals and GPIO [72]

delay before measuring. The DHT11 datasheet is in appendix C for further detailed information about the sensor.

The MQ-series sensors are gas sensors sensitive to multiple gases. They have a built-in heater that needs preheating for 24 hours or more depending on the MQ sensor. This means it needs to be powered to 5 Volt for the given time stated in the datasheet to give the best readings. E.g. following the datasheet for the MQ-2 gas sensor in appendix D is sensitive to LPG, i-butane, propane, methane, alcohol, hydrogen, and smoke. Sensitivity adjustments and calibrations are important to distinguish the different types of gases. It needs a preheat time of 24 hours and the resistor is adjustable according to how sensitive you want the sensor to be. The higher the resistor, the more sensitive the sensor is in high concentrations of gases. The datasheets for the different MQ gas sensors are listed in the appendices; D, E, F, G, H, I, J and K. They contain specific information needed for the MQ sensor to work properly and a graph over the typical sensitivity characteristics for several gases.

I decided to use a dust sensor as well to monitor the particulate matter as mentioned in the related work. These particles are very small, airborne and can go through our respiratory system and further to our lungs. The dust sensor is only connected to the set up in the bedroom because there was the only one available and dust particles can be more important to monitor in the air where sleeping takes place. The sensor

is called SSD011 and its datasheet is in appendix L. It can detect particulate matter at two size ranges $PM_{2.5}$ and PM_{10} with the principle of laser scattering which measures the number and diameter of particles by analysis, the signal waveform has certain relations with the diameter of the particles. It can get particle concentration between 0.3 to 10 μm in the air. The response time is less than 10 seconds when the scene changes. Compared to the MQ gas sensors, the SDS011 is more expensive and bigger in size but gives more reliable readings.

4.2.2 Architecture

The architecture of the hardware components wired connection is presented in fritzing diagrams in figures 4.6, 4.7, and 4.8. These diagrams are easy to understand and gives an understandable overview of the wires and connection of the different pins from the sensors to the microcontroller. Black wires were connected to ground, red wires were connected to the power supply and yellow wires were the digital or analog output value to the microcontroller.

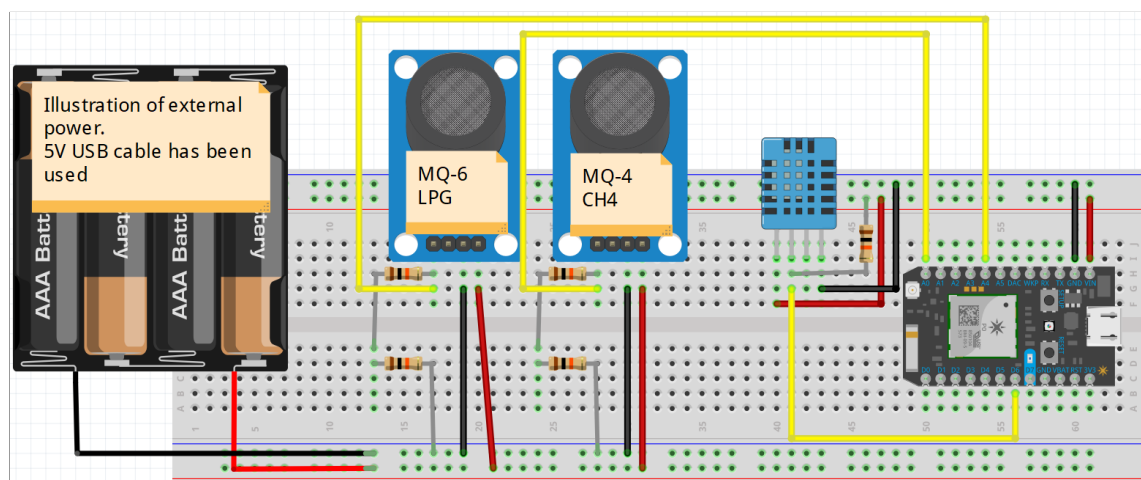


Figure 4.6: Fritzing Diagram of Setup and Components Installed in the Bathroom

The fritzing diagram of the bathroom setup is presented in figure 4.6. The MQ-4 and MQ-6 gas sensors have four pins; Ground (GND), Voltage Common Collector (VCC), Digital Output (DO), and Analog Output (AO) found in appendices F and H. The VIN from the Particle Photon did not manage to send out 5V to all the sensors, this was tested using a voltage multimeter. I had to use 5V from an external source as the MQ gas sensors heater needs 5V to properly work to give better readings. I simply used a USB cable and cut off the end of the micro-USB and taped the GND and VCC onto the solderless breadboard. As stated in the datasheet for both the MQ-4 and

MQ-6, they need a $20k\Omega$ resistor to work properly, I used two $10k\Omega$ for each placed between the analog output and GND. The DHT11 sensor was connected to the Volt IN (VIN) of the Particle Photon as it can use either 3V3 or 5V and had a $10k\Omega$ placed between the digital output and VCC. When the Particle Photon was connected with a micro-USB the VIN pin worked as a Volt Output (VOUT) and should have sent out 5V, but in practice, it was less due to voltage loss on the way to the sensor's pins, caused by the length of the wires and the travel distance on the breadboard.

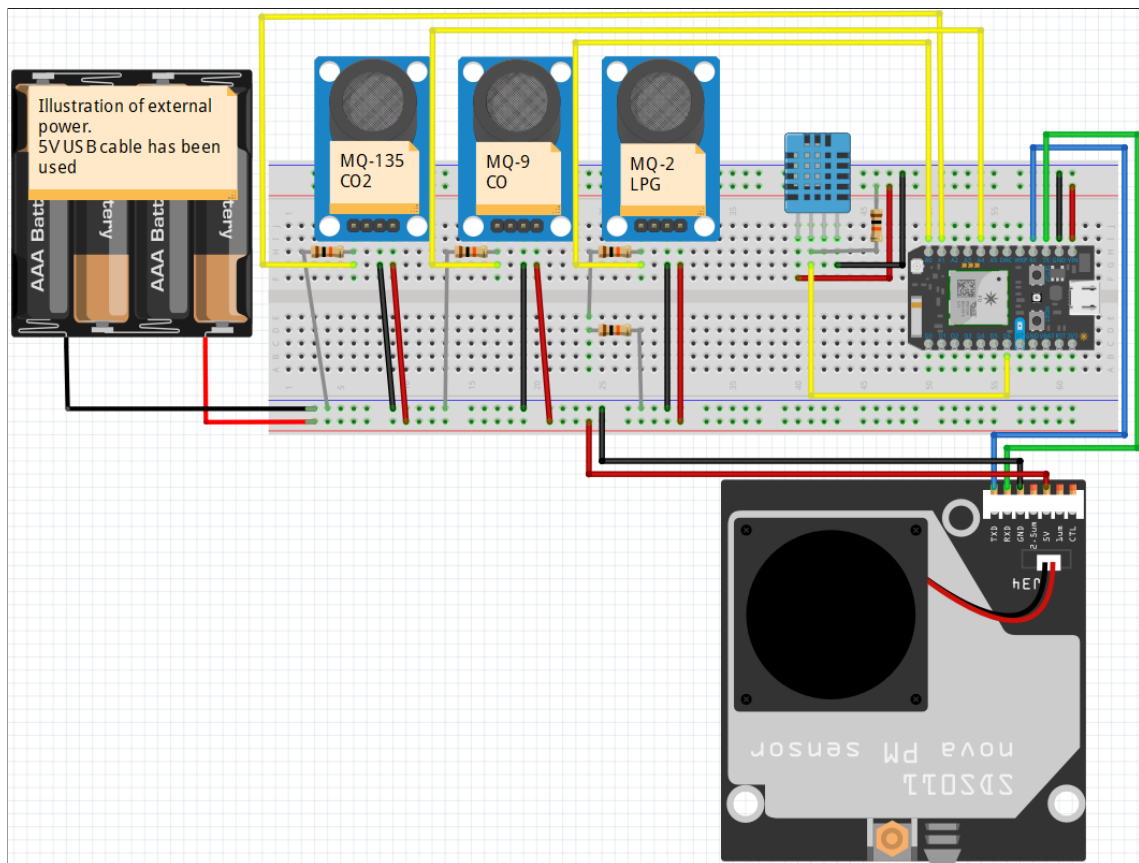


Figure 4.7: Fritzing Diagram of Setup and Components Installed in the Bedroom

The setup in the bedroom had a similar installation as bathroom shown in figure 4.7. MQ-135, MQ-9, MQ-2 were connected in the same way as the sensors in the bathroom setup, the only difference is the load resistance. The temperature and humidity sensor was connected in the same way as in the bathroom and kitchen setup. The MQ-135 and the MQ-9 were connected with one $10k\Omega$ while the MQ-2 was connected with two $10k\Omega$ which is a load resistance of $20k\Omega$ found in appendices D, K and J. The load resistance was chosen according to the datasheets and how each MQ sensor had responded to its environment and the analog values obtained during testing of the sensors. There were many different tutorials online stating different things, but sensors

are unique and behave slightly differently, therefore testing the sensors was important to achieve accurate readings. An addition to the bedroom setup was the SDS011 sensor, which was also connected to the external 5V. The sensor has seven different pins, but only needed to use four of them; GND, VCC, RX, and TX. The RX pin on the sensor was connected to the TX pin on the particle photon and opposite for the TX pin.

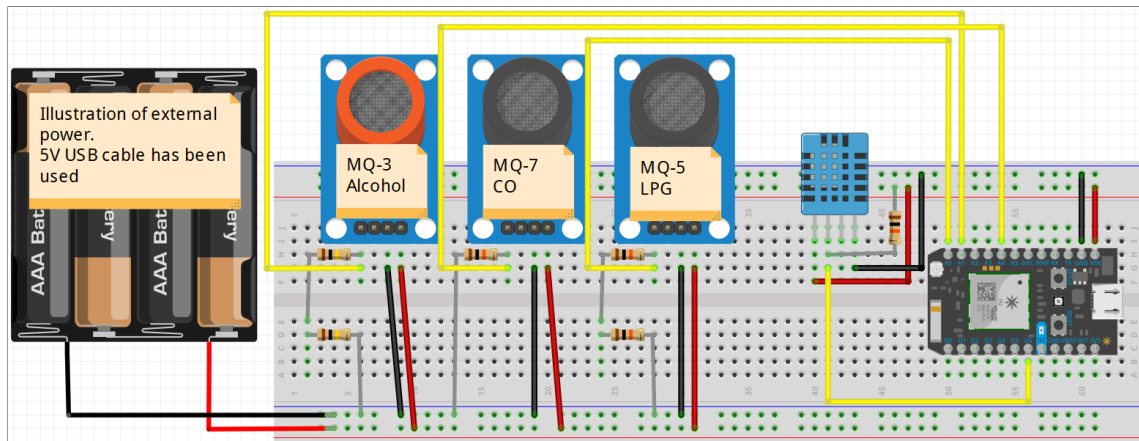


Figure 4.8: Fritzing Diagram of Setup and Components Installed in the Kitchen

In figure 4.8 I've used MQ-3, MQ-7, MQ-5, and a DHT11 sensor in this setup. The DHT11 as mentioned earlier was connected in the same way as in the other two setups. The MQ-3 gas sensor was connected to the external power supply and with two 100kΩ load resistors as recommended in the appendix E. The MQ-7 was also connected as recommended from the appendix I to a 10kΩ resistor and the MQ-5 as recommended with 20kΩ resistor from appendix G.

4.2.3 Sensor Calibrations

The Particle Photon is a 12 bit (ADC/DAC) which means it can read analog values from 0 to 4095. This means the MQ gas sensor will return a value between 0 and 4095 depending on the concentration of gas. The higher the analog value gets the higher the concentration of gas is detected. The MQ sensors need to be calibrated into detecting the right type of gas as they are sensitive to multiple gases. After the sensors were calibrated I needed to convert the values to parts per million (ppm) because the MQ gas sensor returns an analog value as default.

To calibrate the sensors I used a linear equation, but with log to log scale, as the graphs of sensitivity characteristics for the different MQ gas sensors are given in a log to log graph. The graph found in the datasheet in appendices shows the ppm range of

the different types of gases in clean air for any ratio. The equation of a line in Eq. 4.1 and the log to log scale version of it's Eq. 4.2.

$$y = mx + b \quad (4.1)$$

$$\log(y) = m * \log(x) + b \quad (4.2)$$

The y in the equation 4.2 is the Y value on the graph which is the ratio of R_S to R_0 and x is the X value on the graph which is the ppm value. The unknown m is the slope of the line and b is the Y-intercept.

First I needed to find m and b which I calculated manually. To find the slope of the line I used Eq. 4.3 and chose two points from the graph. I chose the point from the start of the line and the point at the end of the line from the gas I wanted to detect.

$$m = \frac{\log(\frac{y}{y_0})}{\log(\frac{x}{x_0})} \quad (4.3)$$

When I had found m I could then calculate the Y-intercept using Eq. 4.4.

$$b = \log(y) - m * \log(x) \quad (4.4)$$

I also needed to find the ratio of the gas concentration which is the R_S and R_0 on the y axes on the graph. R_0 needs to be found in clean air and I could use Eq. 4.5 by looking at the y value of air, which is constant as seen from the graph. k is the value of air and R_{S-air} is found by the recommended calibration of gas on the x axis stated in the datasheet. E.g. for the MQ-2 gas sensor the recommended calibrations for LPG are at 1000ppm and by looking at the y axis we found that the ratio was 1 for 1000ppm. I could then calculate R_0 by using the value of k and R_{S-air} .

$$R_0 = \frac{R_{S-air}}{k} \quad (4.5)$$

After I'd found R_{S-air} I could find R_{S-gas} by using Ohm's Law. First I converted the analog value read from the sensor to voltage using Eq. 4.6 in the code which is represented in figure 4.9.

$$V_{RL} = \frac{AnalogValue - V_{CC}}{4095} \quad (4.6)$$

To find R_{S-gas} I used the already calculated value from V_{RL} shown in Eq. 4.7.

$$R_{S-gas} = \frac{V_{CC} - V_{RL}}{V_{RL}} \quad (4.7)$$

Once I had the unknowns I used them in the final equation calculated in the code shown in Eq. 4.8 and figure 4.9 to find the ppm value of the gas I wanted. The y in the log equation is the ratio R_S/R_0 . [13]

$$ppm = 10^{\frac{\log(y)-b}{m}} \quad (4.8)$$

```
void loop() {
  /*---MQ-4 sensor calculations-----*/
  float sensor_volt4;           //Define variable for sensor voltage
  float RS_gas4;               //Define variable for sensor resistance
  float ratio4;                //Define variable for ratio
  float mq4Value = analogRead(A0); //Read analog values of sensor

  sensor_volt4 = (mq4Value * 5.0) / 4095.0; //Convert analog values to voltage, Form
  RS_gas4 = ((5.0 - sensor_volt4) / sensor_volt4); //RS = [(VC - VRL) / VRL]
  ratio4 = RS_gas4/R04;        //Get ratio RS_gas/RS_air

  float ppm_log4 = (log10 (ratio4) - b4) / m4; //Get ppm value in linear scale accordin
  float ppm4 = pow(10, ppm_log4); //Convert ppm value to log scale
  float methane = ppm4*1000; //Convert to PPB (parts per billion)
  /*-----*/
}
```

Figure 4.9: Example taken from Bathroom Setup of the Logic Programmed in the Web IDE

4.3 Software

This section goes through the software used in the artifact and how it was implemented. Different methods were used for backend and frontend and they were divided into two different sections. The backend software between the hardware and the frontend was mostly handled by a third party and most of the functions developed were in the frontend application of the artifact.

4.3.1 Backend

As mentioned earlier in the hardware description section, I've used Particle Photon's web IDE for programming the logic for the sensors' behaviors, and the data was sent to the Device cloud for further transportation by webhooks. Webhooks read the event name from the particle publish function in the code and if it had the same event name the webhook was triggered. Figure 4.10 is an example of how it was written in the code. The webhook was configured to receive the data as body type since the JSON type reads numbers as strings and not numbers [71].

```

// Publish data to IOT Hub
Particle.publish("temperature", String(temperature) + " °C", PRIVATE);
delay(2000);
Particle.publish("humidity", String(humidity) + " %", PRIVATE);
delay(2000);
Particle.publish("methane", String(methane) + " ppb", PRIVATE);
delay(2000);
Particle.publish("LPG", String(LPG) + " ppm", PRIVATE);

//Information to Webhook
String data = String::format("{\"temperature\": %.2f, \"humidity\": %.2f, \"methane\": %.3f, \"LPG\": %.3f}", temperature, humidity, methane, LPG);
Particle.publish("bathroom", data, PRIVATE);
delay(400000);

```

Figure 4.10: Example taken from Bathroom Setup of how to Send the Data to Firebase from the Web IDE

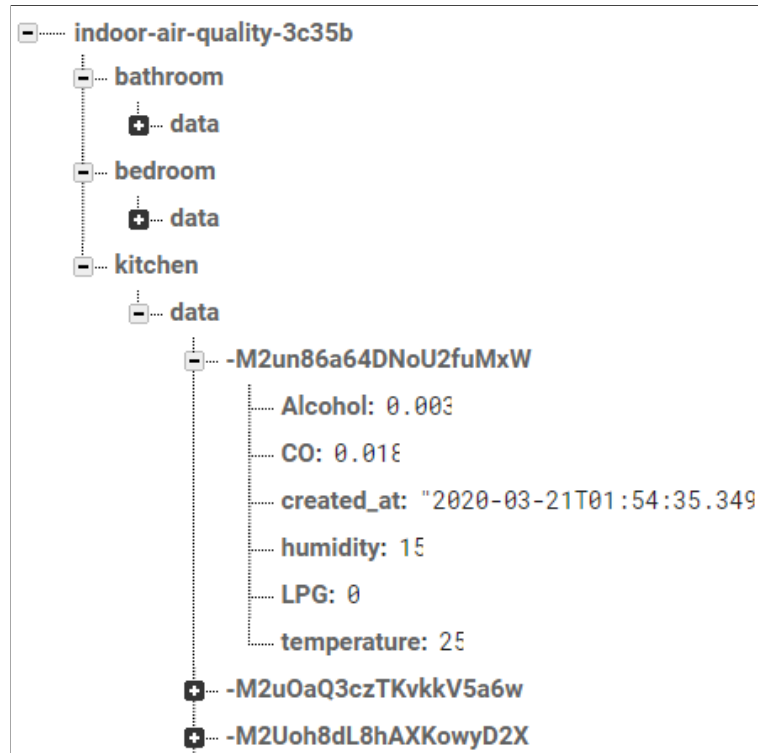


Figure 4.11: Firebase Realtime Database Table Structure

I decided to use Google’s Firebase Realtime Database to store the data since the Particle’s Device Cloud does not store the values retrieved from the sensors in the long term. Firebase works as Backend as a Service (BaaS) and I chose this approach to not focus on implementing the backend myself as the focus was the frontend dashboard design. The realtime database listened on the webhook through an auth key and the data was created under data.json added at the end of the Firebase URL in the config file of the webhook. Figure 4.11 represents the final table structure of the database after receiving data from the three webhooks for each room labeled; bathroom, bedroom, and kitchen.

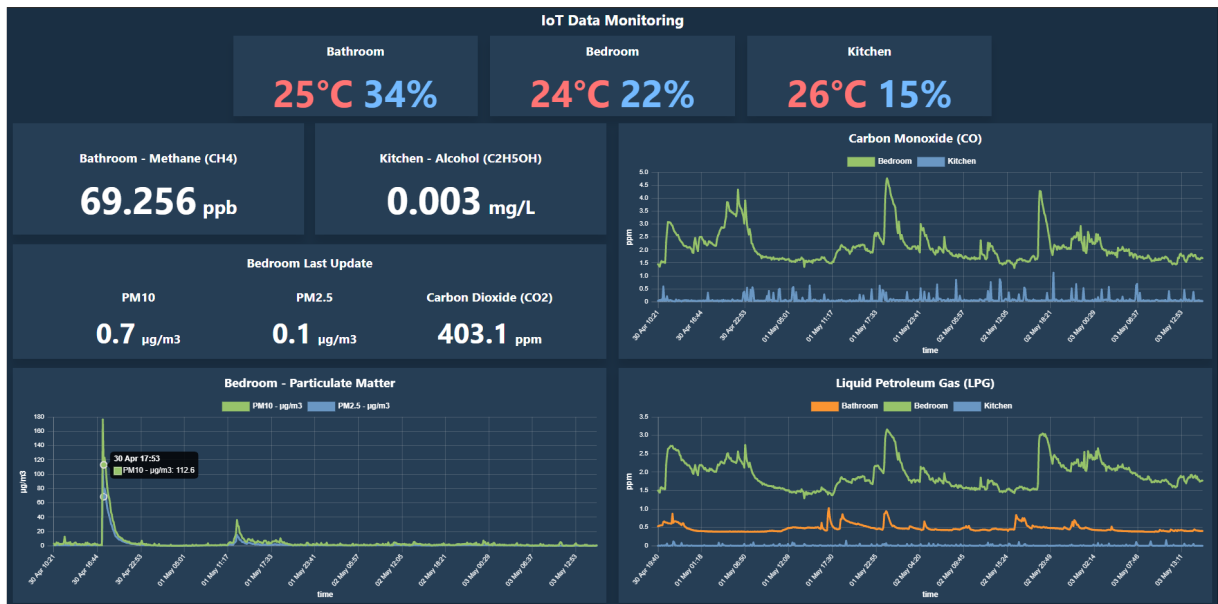


Figure 4.12: Design of the Dashboard as an Application

4.3.2 Frontend

The dashboard was created as a single page webpage using ReactJS [73]. The first step was to create a tentative design of the dashboard before implementing it in ReactJS. Adobe XD was used to create the tentative design with different user experience functions such as hovering over objects to change colors [74]. I did not want to implement the dashboard on the web before I'd looked into design theory and other dashboard visualization research to create the tentative design for the dashboard. After having a plan using the tentative design the design was implemented in the frontend application using ReactJS and react-chartjs-2 library shown in figure 4.12. I used the react-chartjs-2 library to create charts as it already had some finished functions but it still gave the freedom to design the charts how I wanted without any restrictions. The data points in the graph were interactable and gave the user information about that specific time and value. The data values change according to new updates from the sensors and Firebase sent them further to the dashboard application. The lines on the graphs changed form as a new data point was updated in realtime. The code's structure is presented as a UML diagram shown in figure 4.13 and shows how each class was created as a representation of each box group in figure 4.12. For further testing of the design user testing was conducted using interviews and used the answers to further do changes to the dashboard as the final result of the prototype presented in chapter five.

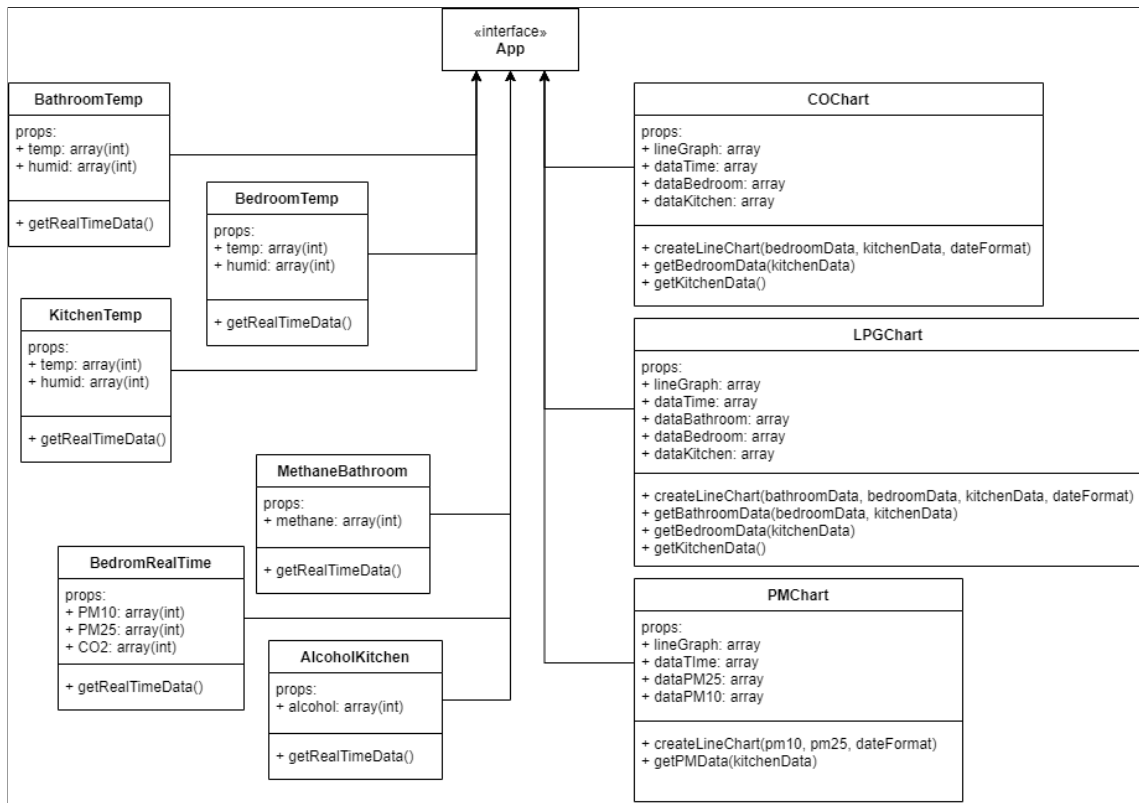


Figure 4.13: UML Diagram of the ReactJS Components

4.4 Limitations with the Artifact

There were some limitations to the implementation of the artifact and the data collected that are important to consider and discuss. The data from the IoT sensors were not demonstrated in a controlled environment, where I could have changed the temperature etc. to show lower or higher values. The various MQ-gas sensors are not reliable to show accurate data values when it comes to one particular gas type. Each of them is sensitive to multiple gases, but the calibrations that were done helped to a certain degree to distinguish the gases from each other. If another type of gas concentration rises it would have affected the sensor and given false values of the type of gas that was monitored. As I'm not skilled in ReactJS, the structure of the application could be poorly set up and there might be many duplicates in the code which could have been avoided with a better experience. This could have affected the user experience with slow loading of data the first time the user opens the application in the browser. I've worked with data that were collected in a real-world scenario and therefore I had no control over the data. The data were not the best to show the potential of the design of the dashboard as I would in a controlled environment, where I could have demonstrated different value spikes in the visualization.

Chapter 5

Findings and Results

This chapter discusses the findings and results from the interviews and the final creation of the prototype in this research project. I analyzed the data from the interviews as they are the groundwork for the further design improvements on the prototype. First, I introduce the findings from the interviews with SUS score as quantitative data analysis and the responses from the interview questions as qualitative data analysis. The second section presents the final prototype design of the dashboard and the analysis that was done during the changes from the last prototype.

5.1 Findings from Interviews

The results from the interviews are divided into two sections. Section one contains findings from the System Usability Scale (SUS) with calculations using tables and graphs. Section two analysis part two of the interview with questions and answers about the system's design in more detail.

5.1.1 System Usability Scale

The results from the System Usability Scale (SUS) gave a quick identification of the system usability from the user's perspective. I used the raw responses before the calculation of the SUS score from the interviews to find mean, standard deviation (SD), standard error of the mean (SEM), and SEM in percentage shown in table 5.1. I found for statement 1 whether the users would like to use the system frequently a mean of 3.4 which indicated most candidates answered with more agreement than disagreement. According to the standard deviation calculated from the mean, statement one had an

<i>nr.</i>	<i>Statement</i>	<i>Mean</i>	<i>SD</i>	<i>SEM</i>	<i>SEM %</i>
1.	I think that I would like to use this system frequently.	3.4	0.490	0.219	6.44%
2.	I found the system unnecessarily complex.	2.8	1.166	0.522	18.63%
3.	I thought the system was easy to use.	3	1.265	0.566	18.86%
4.	I think that I would need the support of a technical person to be able to use this system.	2.4	1.020	0.456	19.00%
5.	I found the various functions in this system were well integrated.	3.6	1.200	0.537	14.91%
6.	I thought there was too much inconsistency in this system.	2	1.095	0.490	24.49%
7.	I would imagine that most people would learn to use this system very quickly.	4	0.632	0.283	7.07%
8.	I found the system very cumbersome to use.	2.4	1.200	0.537	22.36%
9.	I felt very confident using the system.	3	1.414	0.632	21.08%
10.	I needed to learn a lot of things before I could get going with this system.	3	1.095	0.490	16.33%

Table 5.1: Responses to Individual System Usability Scale Statements

SD of 0.490 which means most candidates answered the same. For the standard error of the mean, I got an error range of 6.44% which means with a bigger sample from the population the error of the mean would vary 6.44% lower or higher from the 3.4 mean. The candidates' answer to whether the system was unnecessarily complex got a mean of 2.8 which is close to a neutral response as an average from all candidates, also for statements 3, 4, 8, 9, and 10 had a mean around 2 to 3. The SD for these statements is above 1 so there were more different answers from the candidates for these statements than for statement 1. The SEM was slightly different from each statement with a range of 16% to 22%, meaning the error range for these results was 10% to 15% higher compared to statement 1. The candidates' results for statement 7, all had a strong agreement whether the system would be easy to learn with a mean of 4 and an SD of 0.632 which is close to how the candidates felt for statement 1. The SEM was also as low as statement 1 with 7.07% in error range with a bigger population sample. Most candidates disagreed with statement 6, whether there was too much inconsistency in the system with a mean of 2, but according to the SD of 1.095, there was one candidate that was an outlier compared to the rest. The SEM was 16.33% which indicated a bigger error value than for statements 7 and 1.

Table 5.2 presents the values after the calculations of each grade response from the candidates. This shows roughly how the SUS score was calculated with the results from the calculation of the grade responses, with every odd-numbered statement sub-

tracted by 1 and 5 subtracted from every even-numbered statement. The difference from the calculation from each statement in table 5.1 were the mean, the SEM in percentage, the score from each candidate, and the average SUS score results with mean, SD, SEM and SEM in percentage. The SD and SEM were the same for the score results as the original raw data had not changed with the calculation of the SUS score. The SEM in percentage was not the same as it uses the mean to calculate SEM in percentage to easier show the error variation for a bigger sample from the population.

<i>Statement nr.</i>	<i>C.A</i>	<i>C.B</i>	<i>C.C</i>	<i>C.D</i>	<i>C.E</i>	<i>Mean</i>	<i>SD</i>	<i>SEM</i>	<i>SEM %</i>
1.	3	2	3	2	2	2.4	0.490	0.219	9.13%
2.	2	3	4	1	1	2.2	1.166	0.522	23.71%
3.	3	1	4	1	1	2	1.265	0.566	28.28%
4.	4	1	3	3	2	2.6	1.020	0.456	17.54%
5.	2	1	4	2	4	2.6	1.200	0.537	20.63%
6.	3	3	4	1	4	3	1.095	0.490	16.33%
7.	4	2	3	3	3	3	0.632	0.283	9.43%
8.	4	2	4	1	2	2.6	1.200	0.537	20.64%
9.	3	0	4	2	1	2	1.414	0.632	31.62%
10.	1	1	4	2	2	2	1.095	0.490	24.49%
Final Score out of 100	72.5	40	92.5	45	55	61	19.274	8.620	14.13%

Table 5.2: Individual SUS Score for each Candidate

Statistics for the Calculated Scores

The score calculated for each response per candidate was between 0 to 4, where 4 is a better score than 0. For statement 1, candidate A and C both scored 3, while candidate B, D, and E scored 2 and together gave a mean of 2.4 which is overall a score result higher than the median, most candidates would like to use the system, but with different degree of frequency. Statement 2 gave mixed scores about the complexity of the system. The mean was 2.2 and both candidates D and E gave 1 as score and thought the system was unnecessarily complex. For statement 3 whether the system was easy to use, candidate A gave 3 and candidate C gave a 4, while B, D, and E gave a score of 1. The majority that thought the system was difficult to use, were the same ones saying the system was unnecessarily complex. Statement 4 asked whether they felt like they needed technical support to use the system. Candidate A gave a score of 4 which meant the candidate would not need technical support and gave full score. Candidate B and E gave 1 and 2 and felt like they needed some support before using the system. Whether the candidates thought the system's functions were well

integrated in statement 5 was a bit unclear and needed an explanation of what the functions were as this was a dashboard with little functionality. There was only the moving timeline for every new data received by the dashboard from the database in the graphs and the numbered values changed according to new values. There were also hover functionality where the candidates could view the time and value of the point they hovered over on the line graphs. This had to be explained before the candidates gave their score. Candidate E gave full score on this statement compared to earlier scores which have been 1 or 2. Candidate C also gave a 4 but shows a trend of giving either 3 or 4.

Statement 6 asked about whether the system had much inconsistency, there was one candidate, D giving 1 as score while the others gave 3 or 4 and ended up with one of the highest means of 3. Also statement 7 gave positive responses and a mean of 3, whether the candidates thought this system would be quick to learn by others. Candidates A gave full score while C, D, and E gave a 3. The error value showed a 9.43% which was low compared to the other statements. Statement 8 asked whether the system was cumbersome to use, and between the candidates, there was either a positive score that it was not cumbersome to use giving a 4 from candidates A and C. Candidate B, D and E gave a 1 or a 2 which had been their trend during the interviews. Statement 9 was about whether the candidates felt confident using the system. Again A and C gave either a 3 or a 4, while D and E gave 1 or 2 and B gave a 0. Statement 10 was a similar statement about whether the candidates believed they needed to learn a lot of things before using the system. Candidate C answered with a 4, while A, B, D, and E gave a 1 or 2, giving a mean of 2. It shows that candidate A increased the mean by giving a full score. Finally, the score was calculated for each candidate which was out of 100. Candidate A's scores were mostly 3 and 4 and ended up with a final score of 72.5. Candidate B's scores had many 1 and 2 scores and the only one with a 0, giving a 40 in a score out of 100. Candidate C had an overall score of 92.5 with many scores of 4 and 3, overall very happy with the system, and increased the mean score of the SUS score. Candidate D ended up with 45 as a score, similar to candidate B. Candidate E ended up with 55 as a score showing a roughly 50% satisfaction about the system's usability. The calculated mean from the individual SUS scores ended up with a score of 61 out of 100 and a standard deviation of 19.274. According to Bangor's [58] figure in 3.2, a SUS score of 61 is not bad, it's above average-acceptance.

The graph in figure 5.1 was created to visually show the different candidates A

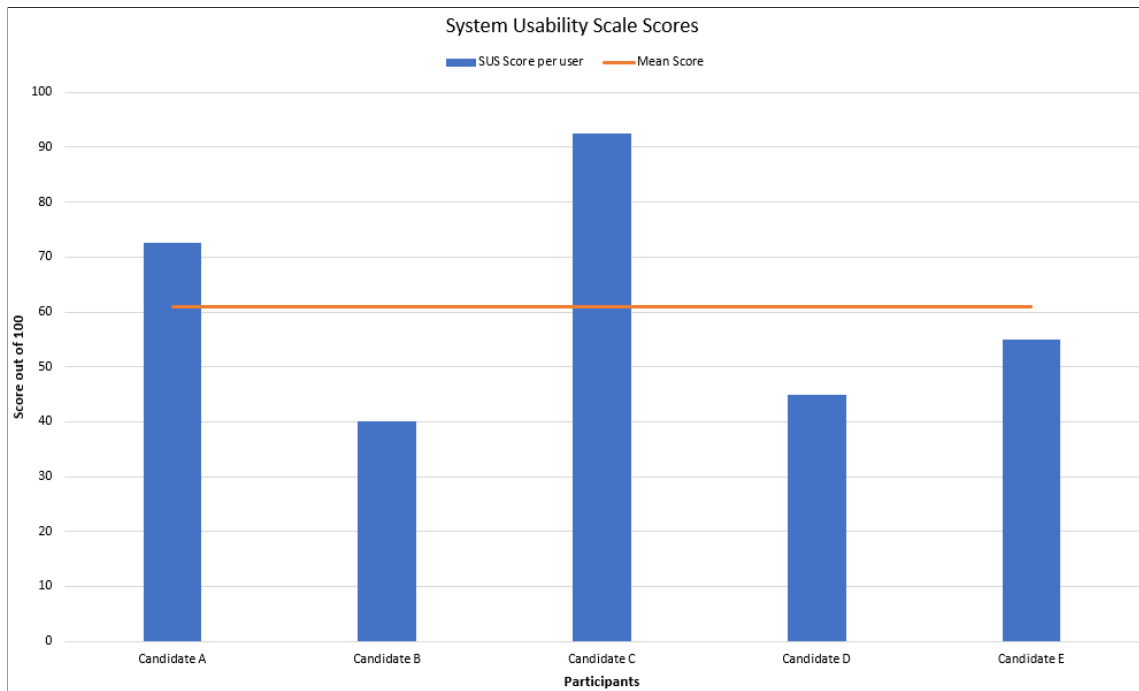


Figure 5.1: System Usability Scale Scores Graph

to E and their SUS score with a lined graph showing the mean of these scores. It shows more clearly how candidate A and especially candidate C increased the SUS score mean from the three other candidates. It's worth mentioning that candidates B and D were both over 50 years old and candidates A, C, and E were in their 20s.

5.1.2 Interview Feedback

The interview questions can be seen in table 5.3, around 19 questions with some subquestions were asked and some added information to the original questions if there was anything unclear to the candidates. This was part two of the interview and the questions were only visible to the interviewer. Question 1 was about the candidates' initial thoughts about the dashboard design. Candidate A said "a lot of information, first I noticed the temperature and humidity had much clearer numbers and colors and after that, I noticed the LPG graph at the bottom right. The last thing I noticed was the white-colored values at the middle left." Candidates C and E also mentioned the same noticeable charts, especially the LPG graph. Candidates B and D thought the dashboard was confusing by first looking at it, but understood quickly what it was about after some explanation. Candidate D mentioned there should be some background knowledge of what they are looking at and thought the chart for "bedroom last update" was confusing. Question 2 asked about the candidates' understanding of the

data presented. Candidate D answered "I had to use some time in the beginning, but then I got used to the data. I do not know what PM2.5 is. I can not read everything at once due to different colors and positioning and the dates on the graphs are not the same, it's inconsistent". Candidate B said they needed a dictionary to understand the data and candidate E could understand how warm it was but not all the gases. Candidate A said the data was clear and when you hovered over the line on the graphs it was easy to compare the different lines with data points. Candidate A also understood the various gas terms but not PM10 and PM2.5 and had no reference if the values were good or bad. Candidate C answered "yes" and had no further feedback or comments to question 2.

Color Choice

Questions 3, 4, and 5 were about the color choice and whether it was visually easy to read. All the candidates agreed that the colored lines and numbers were easy to read, only candidate D mentioned the inconsistency with the dates on the graphs. The candidates liked the dark blue color theme and thought it went well with the other colors as they had enough contrasts to visually come forward from the dark background. Next, I asked about the color choice for temperature and humidity and whether it gave meaning. Candidates C, D, and E said the color red made sense to be temperature as the color red represents warmth. They also agreed with the color blue as it reminded them of water which represents humidity but candidates A and B mentioned it was not clear at first that the values were representing humidity had no text or sign visualized this.

Visual Separation of Data

Questions 6 and 7 was about the candidates' thoughts on whether it was easy to distinguish the different data with the boxes created around each group chart. Question 6 was about the top three boxes and all the candidates thought they were easy to distinguish which room the values belonged to. Question 7 asked about all the other boxes and the gas values, candidates C and D thought it was confusing having the graph for bedroom representing two different variables and the other graphs representing different rooms. Candidate C said it was not clear having liquid petroleum gas (LPG) monitoring in the bedroom, while candidates A and E thought it was clear and

answered "yes" to the question. Question 8 asked whether the different gas units were understandable and candidates B, D, and E understood some of the values or not at all. They wanted more information about what is the normal values of the different gases. Candidates A and C understood all of them except for PM10 and PM2.5. Question 9 asked which graph or box stood more out and all candidates mentioned the LPG graph because it visualized all three rooms and had the strongest contrast color orange.

<i>Interview Questions</i>	
1.	What is your first thought when looking at this dashboard?
2.	Can you see what kind of data is presented? if not? Why?
3.	Are the colored lines and numbers easy to read?
4.	What do you think of the dark blue background and the lighter blue boxes?
5.	What do you think of the color choice for temperature and humidity? Does the red and blue color make sense to you?
6.	Can you distinguish between the different rooms, their temperature and humidity easily by looking at the squared boxes?
7.	Can you distinguish between the different gases in each room by looking at the squared boxes?
8.	Do you understand the different gas units?
9.	Which graph or boxes stand out more to you?
10.	How do you feel about the order and grouping of the square boxes and their values?
11.	What do you think of the blue and green colored line graphs? Blue and green lines are also used in the other graphs but with different variables, is this clear or more confusing?
12.	Can you clearly see the orange line in the right bottom graph?
13.	What do you think about the dates on the x axis of the different graphs? Are they clear?
14.	Do you miss any information on the y axis of the graphs? Are the numbers clear?
15.	What data would you be most interested in when monitoring the air at home?
16.	What sort of warning would you like to see if the values were above normal?
17.	Do you think this dashboard is useful? If yes? What is useful?
18.	If you were going to use this dashboard at home would you be more aware of your indoor climate? If yes? Can you elaborate how?
19.	Is there anything you would like to add to the design? Or something that is not clear?

Table 5.3: Questions Asked to the Candidates During the Interview

Visual Grouping of Data

Questions 10, 11, and 12 was about the grouping of the boxes and the color choice on the different graphs. Candidates A, D, and E thought the grouping of the temperature and humidity boxes were well placed and it made sense that the graphs were at the bottom of the page. They did not like the left side with the white values, there was too much noise as they did not follow any color rule like the other values in the dashboard. Candidate C thought the right side was displayed clearly and had a nice overall

view while the left side was not as clear. Candidate B did not understand why there had to be many boxes to group the values instead of having one box. Question 11, regarding the color choice for the graphs, candidates A, B, C, and D liked the green and blue colors but thought it was confusing having one graph with the same colors representing other values. Candidate E thought it was clear with the color choices and that it was comforting with the color blue, while candidate A mentioned that a lighter blue was not enough contrast compared with the dark blue background. The 12th question was about whether the candidates could see the orange color and they all answered "yes". This was to test whether they were color blind, as some have difficulties seeing this color.

Graph Visualization

Questions 13 and 14 was about the information displayed on the y-axis and x-axis of the graphs. All the candidates thought the dates on the x-axis were well displayed but candidate D mentioned that the dates were inconsistent with the other graphs. The y-axis was not as clear to the candidates and most of them wanted a line showing dangerous levels of the gas and better explanation for the number values. Question 15 asked the candidates about what preferences of air quality data they would like to view at home. Candidate A answered "temperature, humidity, and dust. Dangerous gases when they reach certain high levels, but not that important". Candidates B, C, D, and E also answered temperature, humidity, and dust, they were not that interested in the other gases. Question 16 asked the candidates about which type of warning they would like to see if values were above normal. Candidate A suggested red-colored border around the graphs and that the white values in the other boxes turned red. Questions 17 and 18 were about whether the candidates thought the dashboard was useful and if they would be more aware of their indoor climate using this system. All candidates thought the dashboard was useful to a certain extent, candidate A liked that I managed to have so much information on one page. Candidate B answered, "Yes when you think of temperature, humidity, and dust, but I manage without as well". Candidate E agreed that it was useful if the indoor air quality was unhealthy. The candidates also answered "yes" to question 18 as they did care about having healthy air indoor. The last question 19 asked about whether the candidates had something to add or if there was anything unclear. Candidate C would like the same types of data

from each room, candidate D wanted more control to interact with the dashboard, e.g. being able to change the timeline on the graphs from one week to the last 24 hours. Candidates B and E wanted more explanation to the values, e.g a manual.

5.2 Final Design

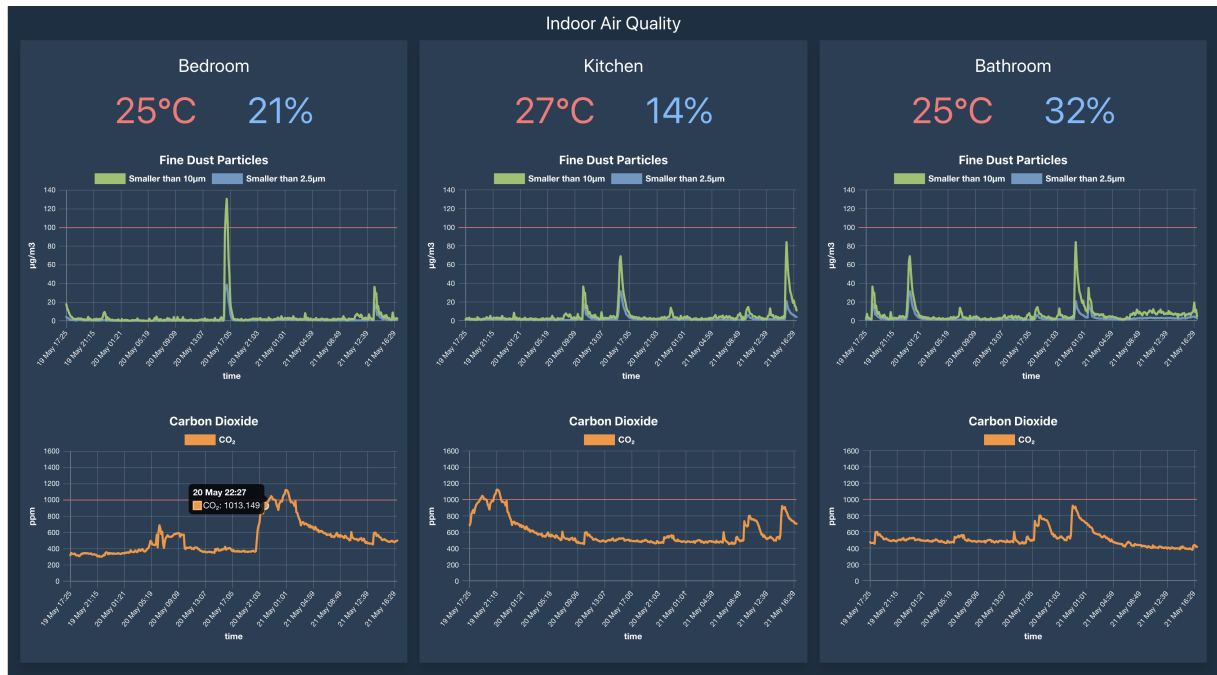


Figure 5.2: The Finale Design of the Dashboard

I used the feedback gathered from the interviews to change the existing prototype for better visualization of the dashboard. The whole layout is changed and some unnecessary data sources have been removed in the new design presented in figure 5.2. Six of the lightly shaded boxes were removed which was used to group the different values into three boxes representing each room in the apartment instead. Each room now only monitors the temperature, humidity, carbon dioxide (CO₂), and particulate matter (PM). I found that after conducting the user testing, the candidates did not bother or knew anything about the other gases represented in the previous prototype. There was too much unknown data and gave more clutter than information to the candidates. I simply chose the most important air quality factors and gave the particulate matter a different name for easier understanding; Finale Dust Particles. The candidates mentioned that the same gases were not represented in each room, due to limited sensors I used the real data of CO₂ and PM from the setup in the bedroom as a reference to display mock data for kitchen and bathroom as they did not have the

same sensors. The CO₂ data has been displayed as a lined graph for each room box and the same for PM. Some of the candidates' behavior was to look for trends in the different graphs and therefore I created the same graphs for each room. I also added a red line for a given y value to show the user the above normal threshold. Since PM has two different sizes but PM₁₀ is classified as a core pollutant according to the European CAQI Air Quality Index [75], I chose to focus on visualizing the PM₁₀ threshold which was set at 100. I did the same for the carbon dioxide graph [76]. I will discuss further why I did the changes in the next chapter.

Chapter 6

Discussion

This chapter discusses the implementation of the generated dataset used to visualize the dashboard. I believe this is an important part of the research project because creating the data myself gave more knowledge about the Internet of Things (IoT) data. Further, the results from the interviews are discussed, both the SUS scores and the answers to the interview questions. Then the final design is discussed and why the design was chosen with the feedback from the candidates. Lastly, the reliability of the data presented in the findings and results chapter is discussed.

6.1 Result of the Internet of Things Ecosystem

The development process was important to the results for the research project as it was the groundwork for the dataset used in the visualization for the dashboard. The indoor systems reviewed in the related works used microcontrollers with sensors and a backend that stored data and further sent it to an application for visualization. The Particle Photon made it simple to set up the ecosystem in the apartment and I got inspired by Munsadwala et al. [13] who also used it. The authors also used an MQ-7 and MQ-135 gas sensor for detecting carbon monoxide and carbon dioxide, the calibrations they did help to further calibrate the different MQ-gas sensors I had implemented. Many of the researchers mentioned in the related work chapter for indoor and outdoor air monitoring systems have used the MQ-gas sensors because they are small and cheap. I experienced them as hard to work with when it came to detecting a specific type of gas. If there were other gases in the room the sensor would have been affected by this and given fault readings. The more expensive and bigger sensor which

I ended up buying for detecting dust particles, scientifically called particulate matter gave great readings and was very precise of what could be seen from the graphs during e.g. cooking. The DHT11 sensor worked well as it gave the right temperature and humidity values and I could see this especially after taking showers in the bathroom. Overall the embedded system worked well for the months while I had it running and only had a few errors during the day due to wifi interruption to the microcontroller shown in figure 6.1.

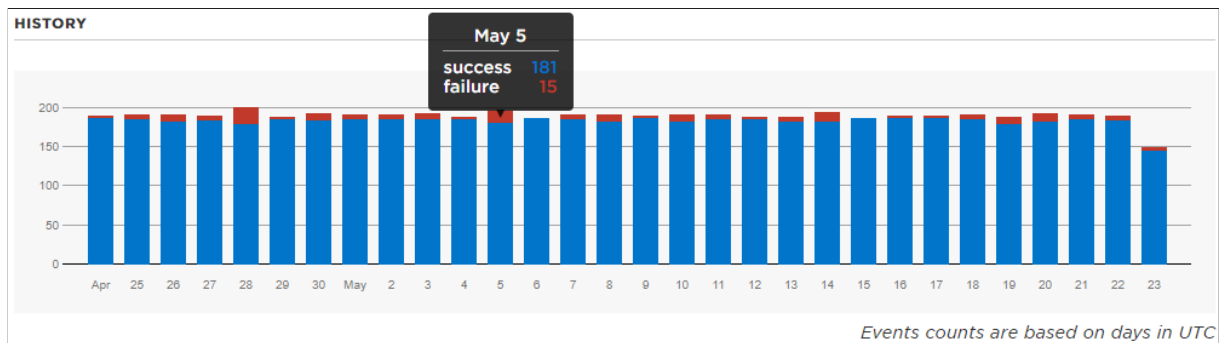


Figure 6.1: Error Data per Day from the Bedroom Webhook Displayed by the Device Cloud

6.1.1 Utilized Software

Google’s Firebase Realtime Database was practical to use as a backend service to the dashboard because the values had to be updated every time new data was received by the microcontrollers detected through the sensor readings. This worked well and I did not have to worry about using too much time on the implementation and rather focus on the dataset and the visualization. The only thing I found difficult with the use of Google’s Firebase Realtime Database was that I could not look into all the data properly in the console as there were too many data entries. When reaching too many entries I could only see parts of the data in the database at once but could reach all of it through the API communicating with the frontend application. The dashboard was created in Javascript using the framework ReactJS and the library react-chartjs-2 for creating the charts. I’ve had some experience with the framework and it was simple to use with the component structure ReactJS has. Several authors such as Gupta et al. [6] have used ThingSpeak as a visualization tool for statistical data in their monitoring system. It’s well known by developers to visualize the data quickly but gives little room to personalize the design and is mostly used in quantitative data methods to

people within the field.

6.2 User Feedback from Interviews

The feedback and results from the System Usability Scale (SUS) and the interview questions gave useful information and teaching for further development of the artifact. The implemented dashboard was based on a tentative design that helped to brainstorm the design choices made. The original plan was to use the tentative design for the interviews and then implement the dashboard using ReactJS. This would not have given the same acceptable answers, the candidates might not have found the design intuitive if only an image was presented with no interactions. There was also one candidate saying there were too few interactions. I've learned that creating visualization for sensor data is not easy, especially when using different gas units which were hard to understand by the candidates. In some of the visualizations presented I got blinded by how pleasing the design would look to the user and not focus on the understanding of the data. I've learned that the understanding of the visualization is as important as how pleasing it looks to the user. This shows how important it's to have a human-in-the-loop approach which Aryal et al. [41] also mentioned with their personalized IoT desk system.

6.2.1 System Usability Scale

I decided not to have an interview process based only on questions but also incorporate the System Usability Scale (SUS) tool to prevent any bias from the researcher. The final score from the SUS score was 61 out of 100, which gave a good indication for further iterations that changes had to be made to the design. It was an "OK" result but not good enough to not do any major changes to the design. There was one candidate that gave really good grades for each statement presented and increased the final score drastically. There were three out of five candidates that gave a score of 40-55 and that is more than half of the participants from the interviews. I focused on their needs and challenges when the final changes were made to the dashboard design as their background and age are quite different. I wanted the design to fit all but were aware that it's hard to do that for people with different backgrounds and needs. Sarikaya et al. [47] says it's important to design dashboards after what is needed and what the

audience can understand from the data. Statement 4 which asked about whether the system would be learned quickly by others, resulted in a 4 out of 5. This means that even though most of the candidates had a hard time understanding the design at first, they only needed some information to understand all the data presented. I believe that was due to lack of understanding at the beginning of the SUS process the candidates gave bad grades and would have given a much higher grade with fewer gas units, which are mostly understood by scientists within chemistry or other areas involving gases.

Candidates Score Results

Most of the candidates already had many questions before they started grading the statements. The goal was to create a design that was easy to understand without the need for learning something new, so I had to keep this in mind for the finale prototype design. For most of the statements, the candidates' answers gave a mean of 3 which is an average satisfaction to the usability of the system. The standard deviation was often above 1 so the mean could vary accordingly towards a higher or lower mean result. I believe with this high SD there is a very big variation in the answers. The 10 statements used from Bangor et al. [58] created by Brooke [56] are quite similar to each other switching between negative and positive statements. When the candidates graded statement 2 about the complexity of the system with a low grade, the trend shows that for the following statements the answers would be the same, same for the candidates grading a higher number. As Brooke [56] mentions this is a "quick and dirty" way to map out the usability of a system. For this research project, this was a tool to quickly find trends and find out whether the candidates could understand something without being told any background information other than the system is monitoring indoor air.

The Error Range

Statement 1 and 7 had the lowest Standard Error of the Mean (SEM) while statements 3 and 9 had the highest. When I looked into what the candidates answered they were in more agreement with each other on statement 1 and 7 compared with 3 and 9. Statement 1 was about whether they thought they would use the system often and 7 was about whether they thought others would learn to use it quickly. I believe that since statement 3 and 9 was about whether the candidates thought the system was easy

to use and whether they felt confident using it was more directed to their background experience than in statement 1 and 7, the candidates were more in disagreement.

The SEM was quite high on most of the statements, around 16-25%. I believe it was because I had few participants, but when I started asking the more detailed question in part two of the interview, I learned quickly as Nielsen and Landauer [57] said that having more than 5 participants would not give more answers than what I had already gathered compared with the extra time it takes to gather more user data. The fifth candidate gave the same answers as I had already collected from the other candidates. I could have used the SUS tool for a larger amount of participants as the results are quantitative data and would have given better calculations and then done part two for only five users to gather more in-depth feedback. For further iterations, I could have a bigger amount of test candidates which will give better SUS calculations for statistical analysis and score results.

6.2.2 Interview Questions

The questions I chose were created based on the SUS statements where usability was important and the visualization process I did with the tentative design. By basing the questions on the knowledge acquired from the visualization process, I could find out if the choices I made were correct according to other research within the area I had studied. The candidates answered according to what grades they gave on the SUS statements, which means the detailed questions and the SUS tool worked well together. The candidates answered there was a lot of clutter when they first saw the dashboard and could not understand the data at first. With some help, they quickly got more confident but this was something I wanted to avoid having to explain the data visualized.

Understanding the Data

At the end of the questions I asked the candidates what data they preferred to monitor at home and they all agreed on temperature, humidity, and dust particles. I found out that most of the candidates did not understand the gases presented, it gave more clutter and noise than being helpful. This could have resulted in giving poor feedback for the rest of the questions in the interview. Having to explain the data presented in the dashboard occurred often during the interviews. This was something I

wanted to avoid as I wanted the dashboard to be understandable without any manual. AbduWahhab [18] says that computing sensory data of an indoor environment assists people with their health and increases their productivity. I've not tested the system in a real scenario but would like to do that when I'm closer to a finished product in further iterations to see if this is correct.

I got positive feedback on the lined graphs which I found out from Kirk [68] is the best way of showing the story of data. People tend to look for trends that I discovered during the interviews after one candidate mentioned inconsistency on the dates on the timeline from the graphs and when looking at them together tried to compare the data. I've programmed the code to get a certain number of data points from Google Firebase and therefore it was hard getting the same date because the events in Particle's Device Cloud set a timestamp when a new event is received by the microcontroller and could not display them at the same time when there are three different webhooks listening on those events to further send it to Google Firebase. I think it was because the bathroom only had three sensors without any heat time cycle and they read the values much faster than the setup in the bedroom and kitchen.

Temperature and Humidity

Two candidates did not understand the humidity values because they did not have a sign such as temperature values have with celsius. Humidity was given a percentage sign next to its value and most monitoring systems I've looked at had the same, e.g. Fang et al. [26] have done in their visualization. Except for Lampe et al. [34] where they used a droplet sign in front of the value to visualize the humidity but they also had the percentage sign behind the value. I believe this is a minor issue as the candidates quickly understood that it was humidity since it was placed next to the temperature and had the color blue representing water.

Reference to Gas Values

I did not have any kind of reference to normal values of pollutants in the design and got many questions from the candidates about this. I should have focused more on this when creating a tentative design for the dashboard application. This resulted in less understanding and gave mixed results, but good feedback for future iterations. I would have been concerned if the candidates were not critical to the design and could

have lied if the feedback was too positive. Overall I found out that the candidates showed an average satisfaction with the dashboard. They all thought it was useful, but for some, it was just another gimmick to have at home for fun. They also mentioned quite often they wanted to see what was bad air quality in the design and I think that with more information towards that could give them more interest in using the dashboard. Many of the related works reviewed presented their reference data in different colors such as Forkan et al. [43] did with their heatmap, but I wanted to find out if this was something the candidates appreciated by conducting interviews.

6.3 Final Dashboard Design

The final design of the dashboard application had many changes after collecting feedback from the candidates who participated in the interviews. I focused on what the candidates answered and they were most positive about the temperature and humidity boxes representing each room. It was clearly displayed as they had a title of which room they were looking at and the color red for temperature and blue for humidity was clear to the candidates. I used these boxes to place all the data from each room into one box and made them bigger and longer so they were placed next to each other as shown in the bottom design in figure 6.2. Since we read from left to right I placed the rooms based on the importance of where pollution in the air often occurs and the normal amount of time spent in a particular room. We spend more time in the bedroom than anywhere else at home, due to sleeping, therefore I thought it was important to place the bedroom box to the far left side of the dashboard. The kitchen is placed in the middle and shows often high levels of particulate matter due to cooking. Finally, I placed the bathroom to the right as I believe it's the least used room, mostly high levels of humidity, and the temperature was important to monitor here. I agree with Khalid et al. [3] that we still need data scientists to choose the best visualization options to avoid dashboards with clutter and noise but data scientists who are experts in visual analytics are only understood by them, conducting user testing is important to understand the needs of the user. Dasgupta et al. [49] mentions that creating visualization demands time, effort, and knowledge about design principles and user perspective.

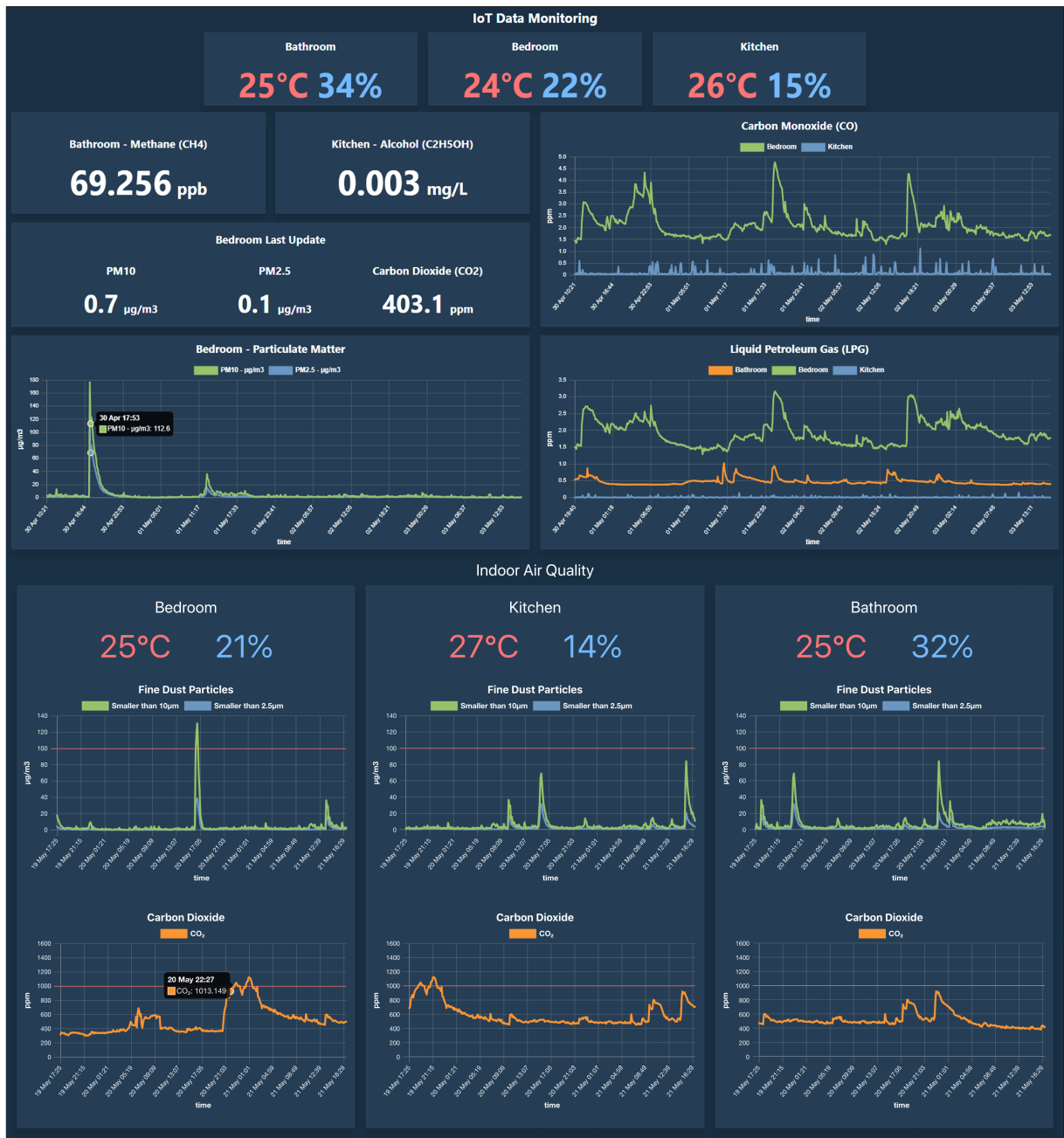


Figure 6.2: The Old and New Design of the Dashboard

6.3.1 Color and Graph Changes

I created a dark-themed dashboard and worried it might not be visually pleasing to view the data for all candidates. The candidates mentioned there were good contrast colors and therefore this was not an issue. I had no text or numbers in black, they were all in white or a contrast color to blue. I also asked if they preferred the theme in white, but was difficult to answer as this was not presented. For further iterations, I could present the test candidates with two different dashboard design to compare themes or to have this as an option in the functionality.

The orange color that was chosen was a success as several of the candidates answered that the LPG graph at the bottom of the page was the first thing that was noticeable on the dashboard. With the new design, I used the color for the carbon dioxide graph and placed it at the bottom because I did not want the user to miss the data at the bottom as this is the last place they read. The color rule I had was inconsistent and was the main reason the candidates struggled to distinguish some data. There were two graphs with different variables and the candidates thought it represented the same values but for different rooms. This shows how important the color choice is and following a rule to categories the same variables with the same color. I focused on not having too many different color hues, according to Few [64] it's not good as humans can only remember a few colors in short memory. Unfortunately, this was challenging when having more than one data point in the graphs and ended up using the same colors for two different variables as shown at the top in figure 6.2 where bedroom has a green and blue color for particulate matter and the other graphs had the same colors but for different rooms. This gave negative feedback from the candidates not understanding the differences in the data. I solved this by placing the different rooms in individual boxes, instead of using one graph for all the rooms we know had a graph for each room.

I changed the graphs so they would be placed next to each for comparison in the final design. I believe that with the use of similar graphs placed next to each other with the same values and dates, the candidates can easily look for trends in the data. The candidates tried to look for changes and similarities between the rooms, and how the graphs and data were presented did not give that overview. As there are different stages of bad air quality as we can see in Enigella and Shanasser's [44] paper, different value ranges are given different colors according to the severity of the air pollution level of the gases. For further iterations, this type of color-coding could be visualized on the graphs presented as a background color or on the data points depending on where the line is on the y-axis.

6.3.2 Changes to the Type of Data Presented

As mentioned earlier from the evaluation of the interview results the candidates were overwhelmed by the number of unknown gas units. Figure 6.2 presents the old versus the new design, where the old design is at the top and the new is below. I

removed the unnecessary gases that were not important for indoor climate. Liquid petroleum gas is not often used indoor in domestic homes, it has a better use at factories where the potential of gas leakage or other dangerous chemicals gas leaks is higher. I also removed carbon monoxide because none of the candidates understood what it was and replaced it with carbon dioxide which is more common as this is the air we breathe out. Even though many of the candidates had trouble understanding the particulate matter values, they quickly found it interesting that it represented dust particles that are airborne and can be dangerous to the human respiratory system. I believe that it's important to teach the users of particulate matter because according to Dockery et al. [20] there is a positive link between particulate matter with death from lung cancer and cardiopulmonary disease or shortened lifespan in six U.S. cities where the study was done. I replaced the name from "particulate matter" to "fine dust particles" and "PM10" and "PM2.5" were replaced with e.g. "smaller than $2.5\mu\text{m}$ ". This was how I explained it to the candidates, and they found it more understandable. I believe that the candidates do not look into the data in detail unless they are particularly interested in the chemicals. I tried to create a design that fit most people living in domestic homes and had to do some sacrifices to the design to make everyone understand what was presented according to the feedback.

6.3.3 Warnings and Alarms

The final change was the red line in the graphs showing when the values are above normal. Since the dust sensor gives two different size values I chose the value of PM_{10} as it's classified as a core pollutant instead of having two different red lines which could be hard to distinguish. The reference to what values are above normal was based on the European CAQI Air Quality Index [75]. The carbon dioxide graph was also given the same red line at 1000 ppm according to acceptable values indoor [76]. In the interview, I specifically asked about what type of warning the candidates would like to see if gas values were above normal. I had already received feedback that there was not any reference to the normal values of the data presented. The candidates came with different ideas such as borders around the graphs, a line splitting good and bad values, and values turning from white to red. All the values presented already had a color, therefore it was hard making the last option work. I thought the idea of having a red line showing the reference point at any time was a good option for the values of

the graph. For further iterations, I would like to add more alarms in the form of push notifications to the users' phones when they are not at home.

6.4 Data Reliability

The grade score used in the SUS method might have been too small as I used scale range from 1 to 5 and 5 participants. Calculating the mean and the standard deviation for such a small dataset might give unreliable answers than with a larger dataset. I chose to calculate the Standard Error of Mean (SEM) to give some idea of the data reliability when having such a small dataset. Looking at the SEM I found how reliable the data I had collected from the SUS method. For most statements in table 5.2 they had an SEM calculated in percentage of 20 to 30% and a few with 10 to 20%. The data between 10 and 20% are considered to be good enough, while some reaching above 30% was not good and this was due to inconsistent answers from the candidates. The overall result from the SUS score of the system had a mean of 61 with a Standard Deviation (SD) of 19.274 which means the score could vary up or down according to the SD. The data collected from the interview questions could have been in more detail if done in a physical environment rather through video calls. Candidates could easily have lied to the questions asked or not answered the questions at all. I did not know what background knowledge the candidates had, one candidate understood the gas units perfectly and this can be due to the candidates' background. As I've not gathered personal data I can not look into the answers on why the candidates understood something or did not.

Chapter 7

Conclusion

In this thesis, I've reviewed different research papers on several indoor and outdoor air monitoring systems and also design theory of visualization of dashboards. I found out that design theory was useful to start creating a visualization of the Internet of Things (IoT) data before conducting user testing. Next, I implemented the artifact with sensors and microcontrollers as hardware, Firebase realtime database as backend, and a web application containing the dashboard with the use of ReactJS as frontend. I placed the IoT devices in three different rooms and waited for a few weeks to gather a good dataset. Then I conducted two-part interviews with five different candidates using the System Usability Score (SUS) tool in the first part and 19 detailed questions for them to answer in the second part. The questions for the second part were made according to design theory knowledge I used in the tentative design and I believe this helped giving thorough feedback on the dashboard presented. Further, I used the feedback to evaluate the dashboard design in another iteration and ended up with a much cleaner visualization containing the same type of data for all three rooms. This hopefully gives the user a better overview of the data, which can be verified by another iteration of user testing.

I discussed the implementation process and found that for better visualization it was important to have sensors that were more reliable than the ones used. The use of Particle Photon was a success as they had a small error value per day and worked well during the period of data collection without major interruptions. The Backend as a Service (BaaS) I used, Google's Firebase realtime database, worked without any problems and the web application received the data every time new data was updated. I found that using ReactJS and the chart library (react-chartjs-2) worked well as a tool to

visualize IoT data. From the interviews, I learned to have users in the loop during the process was important for finding the optimal level of complexity of the dashboards, this was because the users had a different level of understanding of the technical aspects of the system. I also found that by having five candidates were enough as the fifth candidate did not bring anything new to the results.

The Final design of the dashboard was changed from a page containing too many boxes with groups of non-relevant data to a design that was cleaner, where only the most important indoor gases were represented; Temperature, Humidity, Carbon Dioxide, and Particulate Matter. These were the four most mentioned pollutants the candidates wanted to monitor at home if they could choose. I found out that the color choice was important to the candidates and it was important to follow a color rule and not use the same color for different variables.

This research project aimed to find out how design theory can be applied to dashboards based on IoT by creating an IoT ecosystem and conducting user testing of a dashboard prototype for domestic homes. Based on a quantitative and qualitative analysis through interviews with potential users of the dashboard, it can be concluded that creating IoT data visually pleasing and understandable by everyone is challenging. The interviews resulted in a SUS score of 61 out of 100 and that reflected the answers received from the questions, this gave good knowledge for future iterations. I learned that it was important to give the user reference to what the values meant, what values were good or bad, and to have reliable and consistent data for the different rooms. The users looked for trends in the graphs and across the rooms, therefore having the same sensors for comparison was important.

Using both a quantitative and qualitative method for user testing was successful. It resulted in both statistical answers for a quick overview, a summary of the usability of the dashboard, and useful answers on how the dashboard could be further improved. Comparing the old and new design, we see that clutter and noise have been removed and it's visually cleaner with a better overview of the data.

For future work and further iterations of the dashboard, visualization using IoT data can be further improved with another round of interviews and evaluations. I believe I've gained experience that can improve the visualization even further as long as I use the human-in-the-loop approach. For further iterations I would also work more on warnings, alarms, and when values reach too high levels using the right colors and possibly push notification to the user. Some of the users wanted more interactions

and was disappointed there was none besides the realtime data and hovering over the graphs to view specific data points. I wanted to prevent that in a single page dashboard because I believe by giving the user more functionality will make the system more complex to use. The balance between user interaction and the complexity level is something that should be explored in future work and iterations.

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Appendices

Appendix A

Interview Consent Form and SUS statements

Introduction for the interviewee:

Link to dashboard application: "linktodashboard.com"

This is a dashboard showing temperature, humidity, and different gases in three different rooms in an apartment. This dashboard is created to give you as a user easy understanding of the air climate indoor. The purpose of this interview is to collect feedback and user experience of the presented design. First you will get 10 statements where you grade from 1-5. Next you will be asked around 20 questions and the interview will take around 30 to 40 minutes to complete. You are encouraged to be critical about the design and can speak freely. There are no questions directed to your personal data and you will be anonymous during and after the interview process. The only data collected will be the answers you give to the questions asked and other information you wish to give. By participating in this user test, you are agreeing to participate in the research study. You understand the purpose and nature of this study and you are participating voluntarily. You understand that you can withdraw from the study at any time, without any penalty or consequences.

Statements for the System Usability Scale

Give each statement a grade ranging from 1-5 where 1 is strongly disagree and 5 is strongly agree.

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Appendix B

Interview Questions

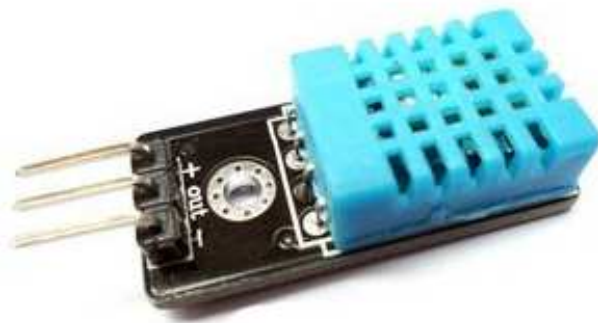
Interview Questions:

1. What is your first thought when looking at this dashboard?
2. Can you see what kind of data is presented? if not? Why?
3. Are the colored lines and numbers easy to read?
4. What do you think of the dark blue background and the lighter blue boxes?
5. What do you think of the color choice for temperature and humidity?
 - a. Does the red and blue color make sense to you?
6. Can you distinguish between the different rooms, their temperature and humidity easily by looking at the squared boxes?
7. Can you distinguish between the different gases in each room by looking at the squared boxes?
8. Do you understand the different gas units?
9. Which graph or boxes stand out more to you?
10. How do you feel about the order and grouping of the square boxes and their values?
11. What do you think of the blue and green colored line graphs?
 - a. Blue and green lines are also used in the other graphs but with different variables, is this clear or more confusing?
12. Can you clearly see the orange line in the right bottom graph?
13. What do you think about the dates on the x axis of the different graphs? Are they clear?
14. Do you miss any information on the y axis of the graphs? Are the numbers clear?
15. What data would you be most interested in when monitoring the air at home?
16. What sort of warning would you like to see if the values were above normal?
17. Do you think this dashboard is useful? If yes? What is useful?
18. If you were going to use this dashboard at home would you be more aware of your indoor climate? If yes? Can you elaborate how?
19. Is there anything you would like to add to the design? Or something that is not clear?

Appendix C

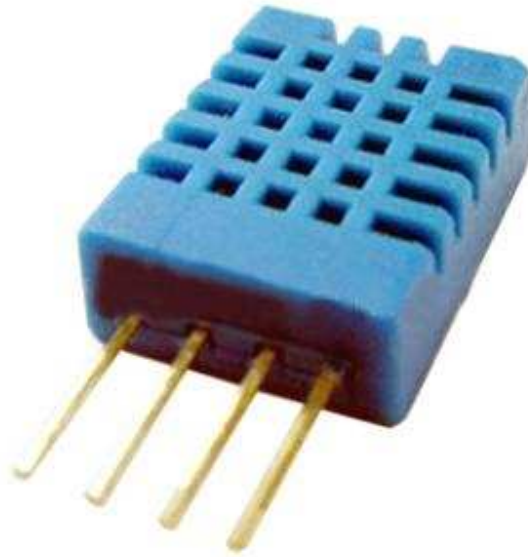
Datasheet: DHT11 - Humidity and Temperature Sensor

DHT 11 Humidity & Temperature Sensor



1. Introduction

The DHT11 Temperature & Humidity Sensor features a temperature & humidity sensor complex with a calibrated digital signal output. By using the exclusive digital-signal-acquisition technique and temperature & humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement component, and connects to a high-performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability and cost-effectiveness.



Each DHT11 sensor is strictly calibrated in the laboratory that is extremely accurate on humidity calibration. The calibration coefficients are stored as programmes in the OTP memory, which are used by the sensor's internal signal detecting process. The single-wire serial interface makes system integration quick and easy. Its small size, low power consumption and up-to-20 meter signal transmission making it the best choice for various applications, including those most demanding ones. The component is 4-pin single row pin package. It is convenient to connect and special packages can be provided according to users' request.

2. Technical Specifications:

Overview:

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 °C	± 5 RH	± 2°C	1	4 Pin Single Row

Detailed Specifications:

Parameters	Conditions	Minimum	Typical	Maximum
Humidity				
Resolution		1%RH	1%RH	1%RH
			8 Bit	
Repeatability			± 1%RH	
Accuracy	25°C		± 4%RH	
	0-50°C			± 5%RH
Interchangeability	Fully Interchangeable			
Measurement Range	0°C	30%RH		90%RH
	25°C	20%RH		90%RH
	50°C	20%RH		80%RH
Response Time (Seconds)	1/e(63%)@25°C 1m/s Air	6 S	10 S	15 S
Hysteresis			± 1%RH	
Long-Term Stability	Typical		± 1%RH/year	
Temperature				
Resolution		1°C	1°C	1°C
		8 Bit	8 Bit	8 Bit
Repeatability			± 1°C	
Accuracy		± 1°C		± 2°C
Measurement Range		0°C		50°C
Response Time (Seconds)	1/e(63%)	6 S		30 S

3. Typical Application (Figure 1)

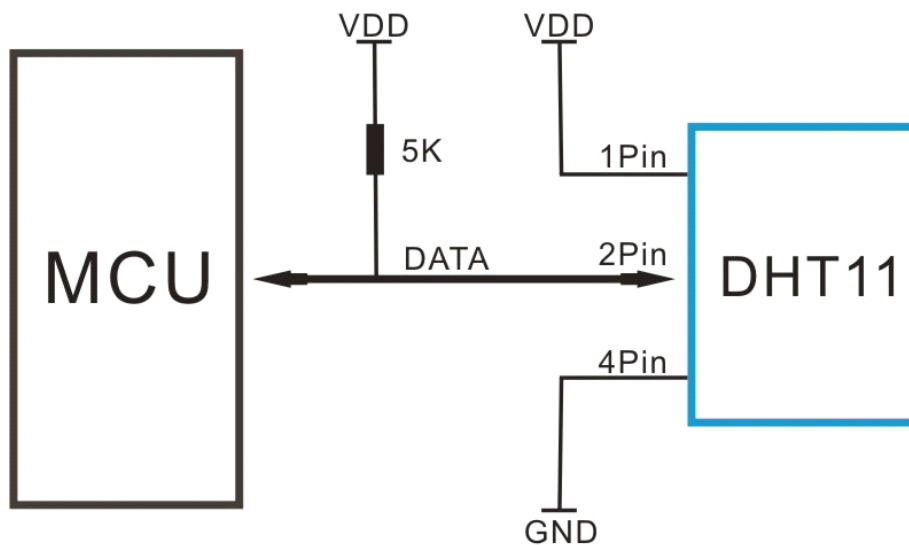


Figure 1 Typical Application

Note: 3Pin – Null; MCU =Micro-computer Unite or single chip Computer

When the connecting cable is shorter than 20 metres, a 5K pull-up resistor is recommended; when the connecting cable is longer than 20 metres, choose a appropriate pull-up resistor as needed.

4. Power and Pin

DHT11's power supply is 3-5.5V DC. When power is supplied to the sensor, do not send any instruction to the sensor in within one second in order to pass the unstable status. One capacitor valued 100nF can be added between VDD and GND for power filtering.

5. Communication Process: Serial Interface (Single-Wire Two-Way)

Single-bus data format is used for communication and synchronization between MCU and DHT11 sensor. One communication process is about 4ms.

Data consists of decimal and integral parts. A complete data transmission is **40bit**, and the sensor sends **higher data bit** first.

Data format: 8bit integral RH data +8bit decimal RH data +8bit integral T data +8bit decimal T data +8bit check sum. If the data transmission is right, the check-sum should be the last 8bit of "8bit integral RH data +8bit decimal RH data +8bit integral T data +8bit decimal T data".

Appendix D

Technical Data: MQ-2 Gas Sensor

TECHNICAL DATA

MQ-2 GAS SENSOR

FEATURES

Wide detecting scope
Stable and long life

Fast response and High sensitivity
Simple drive circuit

APPLICATION

They are used in gas leakage detecting equipments in family and industry, are suitable for detecting of LPG, i-butane, propane, methane ,alcohol, Hydrogen, smoke.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
V _c	Circuit voltage	5V±0.1	AC OR DC
V _H	Heating voltage	5V±0.1	AC OR DC
R _L	Load resistance	can adjust	
R _H	Heater resistance	33 Ω ± 5%	Room Tem
P _H	Heating consumption	less than 800mw	

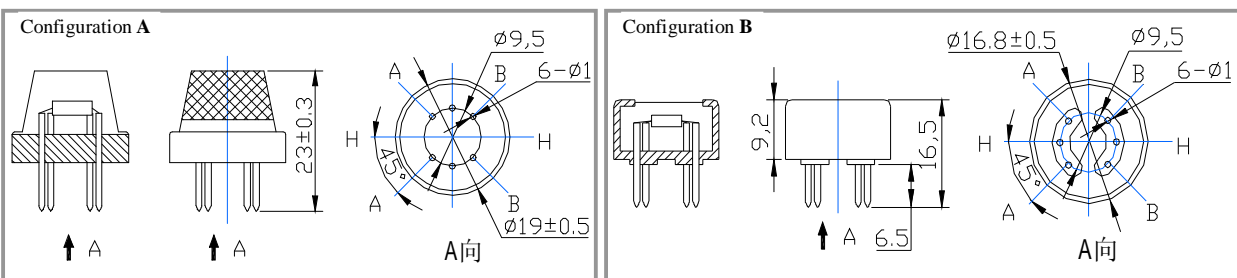
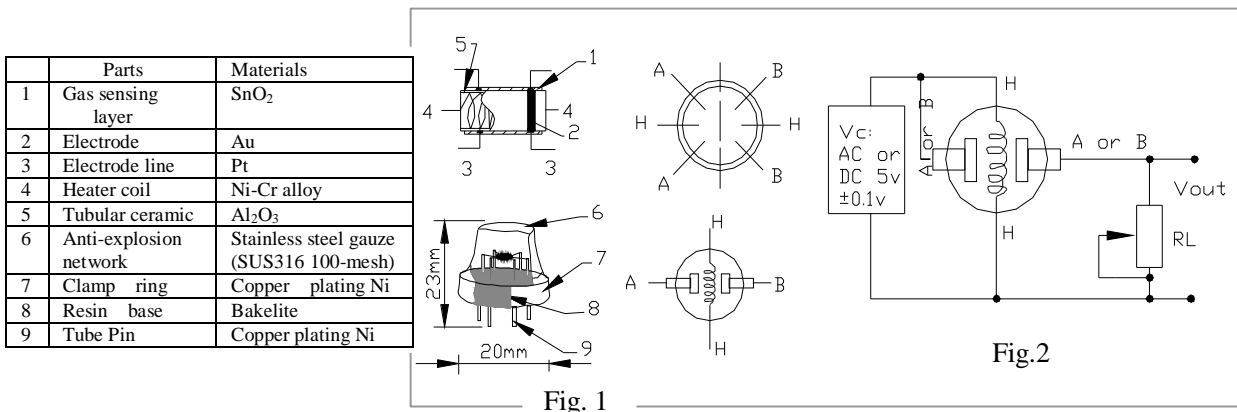
B. Environment condition

Symbol	Parameter name	Technical condition	Remarks
T _{ao}	Using Tem	-20℃-50℃	
T _{as}	Storage Tem	-20℃-70℃	
R _H	Related humidity	less than 95%Rh	
O ₂	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	minimum value is over 2%

C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remarks
R _s	Sensing Resistance	3K Ω -30K Ω (1000ppm iso-butane)	Detecting concentration scope: 200ppm-5000ppm LPG and propane 300ppm-5000ppm butane
α (3000/1000) isobutane	Concentration Slope rate	≤0.6	
Standard Detecting Condition	Temp: 20℃ ± 2℃ Humidity: 65%±5%	V _c :5V±0.1 V _H : 5V±0.1	5000ppm-20000ppm methane 300ppm-5000ppm H ₂ 100ppm-2000ppm Alcohol
Preheat time	Over 24 hour		

D. Structure and configuration, basic measuring circuit



Structure and configuration of MQ-2 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro AL₂O₃ ceramic tube, Tin Dioxide (SnO₂) sensitive layer, measuring electrode and heater are fixed into a

crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-2 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

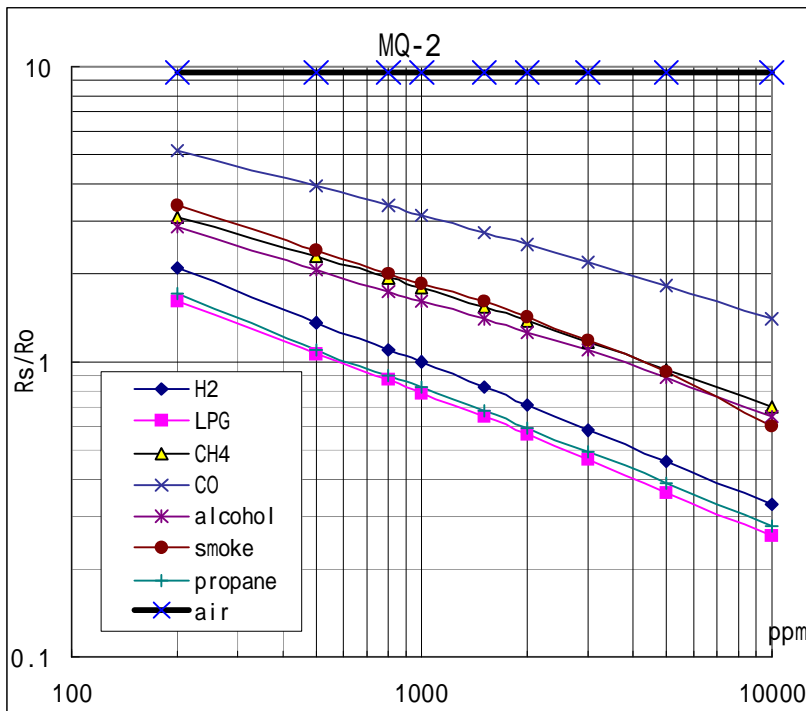


Fig.2 sensitivity characteristics of the MQ-2

Fig.3 is shows the typical sensitivity characteristics of the MQ-2 for several gases.

in their: Temp: 20°C、
Humidity: 65%、
O₂ concentration 21%
RL=5k Ω

Ro: sensor resistance at 1000ppm of H₂ in the clean air.
Rs:sensor resistance at various concentrations of gases.

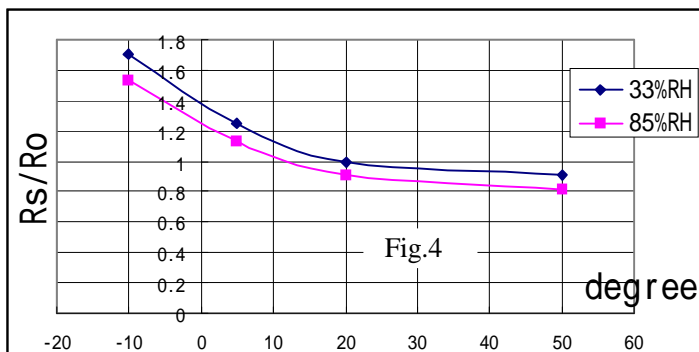


Fig.4 is shows the typical dependence of the MQ-2 on temperature and humidity.

Ro: sensor resistance at 1000ppm of H₂ in air at 33%RH and 20 degree.

Rs: sensor resistance at 1000ppm of H₂ at different temperatures and humidities.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-2 is difference to various kinds and various concentration gases. So,When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000ppm liquified petroleum gas<LPG>,or 1000ppm iso-butane<i-C₄H₁₀>concentration in air and use value of Load resistance that(R_L) about 20 K Ω (5K Ω to 47 K Ω).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

Appendix E

Technical Data: MQ-3 Gas Sensor

TECHNICAL DATA

MQ-3 GAS SENSOR

FEATURES

- * High sensitivity to alcohol and small sensitivity to Benzine .
- * Fast response and High sensitivity
- * Stable and long life
- * Simple drive circuit

APPLICATION

They are suitable for alcohol checker, Breathalyser.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
V _c	Circuit voltage	5V±0.1	AC OR DC
V _H	Heating voltage	5V±0.1	ACOR DC
R _L	Load resistance	200KΩ	
R _H	Heater resistance	33Ω ±5%	Room Tem
P _H	Heating consumption	less than 750mw	

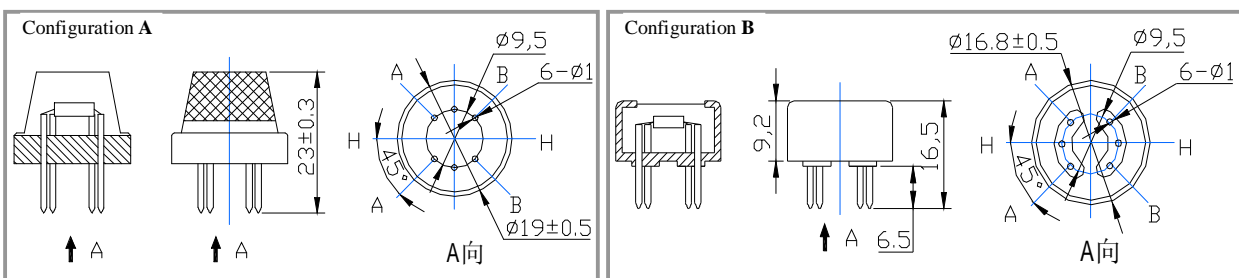
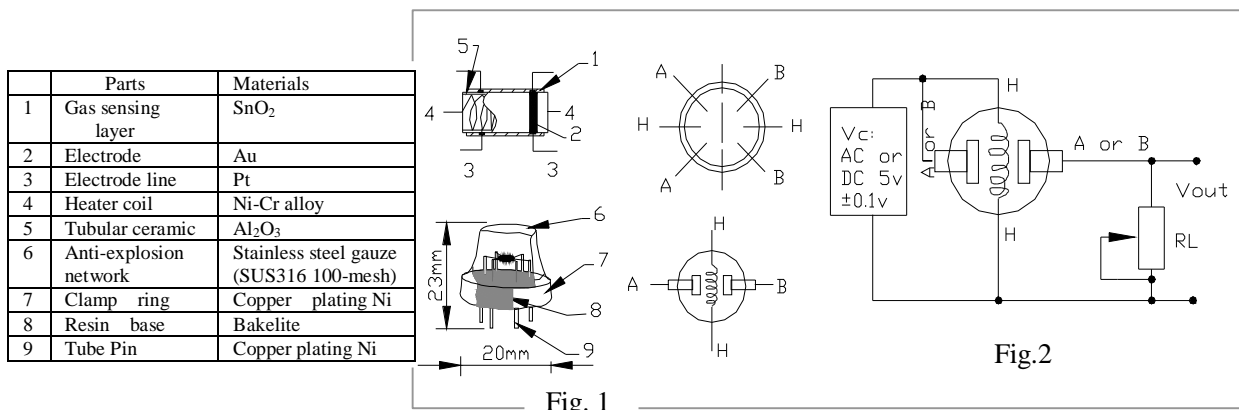
B. Environment condition

Symbol	Parameter name	Technical condition	Remarks
T _{ao}	Using Tem	-10°C-50°C	minimum value is over 2%
T _{as}	Storage Tem	-20°C-70°C	
R _H	Related humidity	less than 95%Rh	
O ₂	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	

C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remarks
R _s	Sensing Resistance	1MΩ - 8 MΩ (0.4mg/L alcohol)	Detecting concentration scope: 0.05mg/L—10mg/L Alcohol
α (0.4/1 mg/L)	Concentration slope rate	≤0.6	
Standard detecting condition	Temp: 20°C ±2°C Humidity: 65%±5%	V _c :5V±0.1 V _h : 5V±0.1	
Preheat time	Over 24 hour		

D. Structure and configuration, basic measuring circuit



Structure and configuration of MQ-3 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro Al_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-3 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

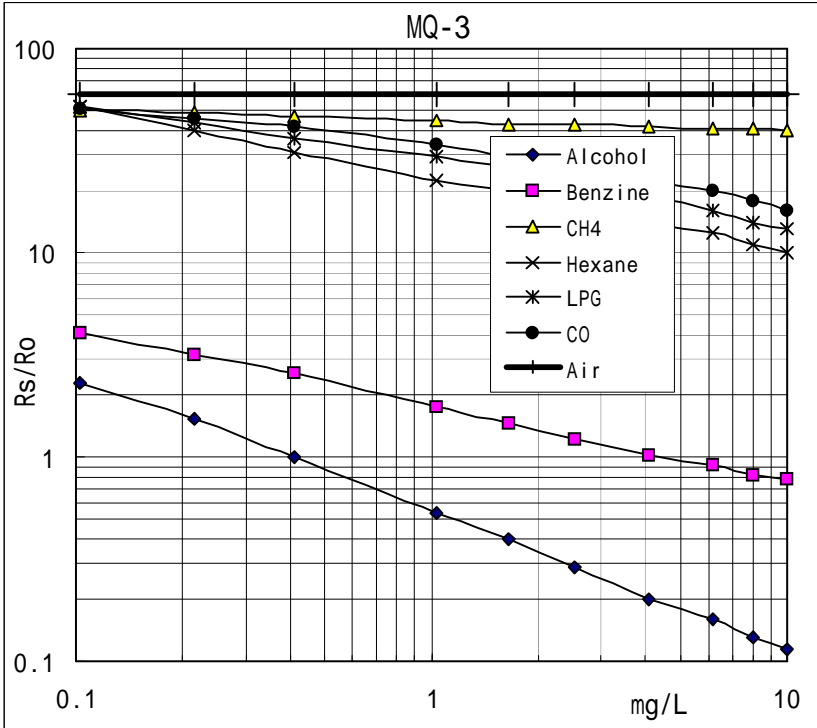


Fig.2 sensitivity characteristics of the MQ-3

Fig.3 is shows the typical sensitivity characteristics of the MQ-3 for several gases.

in their: Temp: 20°C,
Humidity: 65% ,
O₂ concentration 21%
RL=200k Ω

Ro: sensor resistance at 0.4mg/L of Alcohol in the clean air.

Rs:sensor resistance at various concentrations of gases.

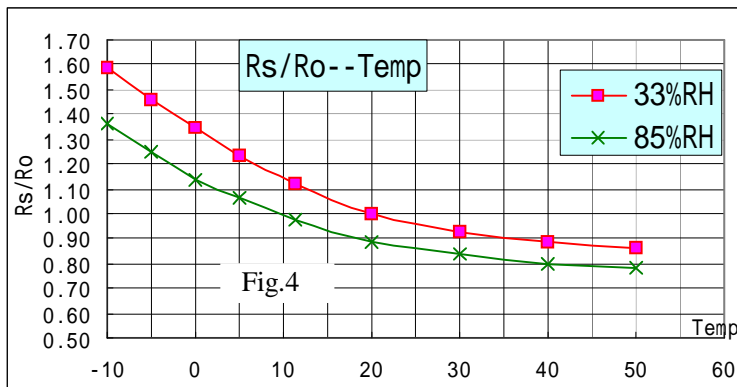


Fig.4 is shows the typical dependence of the MQ-3 on temperature and humidity.

Ro: sensor resistance at 0.4mg/L of Alcohol in air at 33%RH and 20 °C

Rs: sensor resistance at 0.4mg/L of Alcohol at different temperatures and humidities.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-3 is difference to various kinds and various concentration gases. So,When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 0.4mg/L (approximately 200ppm) of Alcohol concentration in air and use value of Load resistancethat(R_L) about 200 K Ω (100K Ω to 470 K Ω).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

Appendix F

Technical Data: MQ-4 Gas Sensor

TECHNICAL DATA

MQ-4 GAS SENSOR

FEATURES

- * High sensitivity to CH₄, Natural gas.
- * Small sensitivity to alcohol, smoke.
- * Fast response . * Stable and long life * Simple drive circuit

APPLICATION

They are used in gas leakage detecting equipments in family and industry, are suitable for detecting of CH₄, Natural gas, LNG, avoid the noise of alcohol and cooking fumes and cigarette smoke.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
V _c	Circuit voltage	5V±0.1	AC OR DC
V _H	Heating voltage	5V±0.1	AC OR DC
P _L	Load resistance	20K Ω	
R _H	Heater resistance	33 Ω ±5%	Room Tem
P _H	Heating consumption	less than 750mw	

B. Environment condition

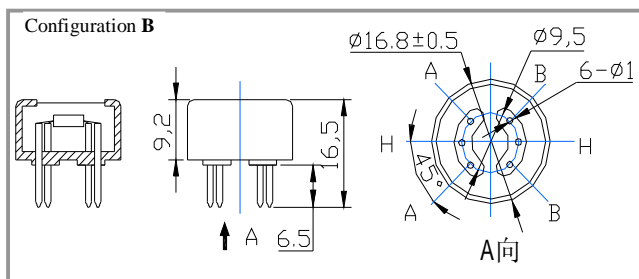
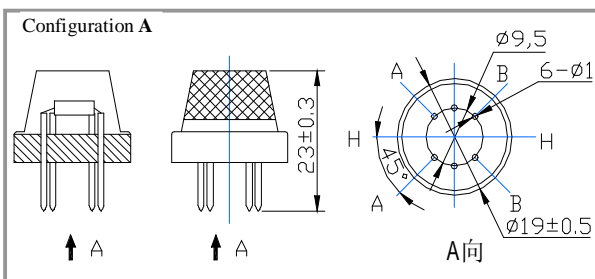
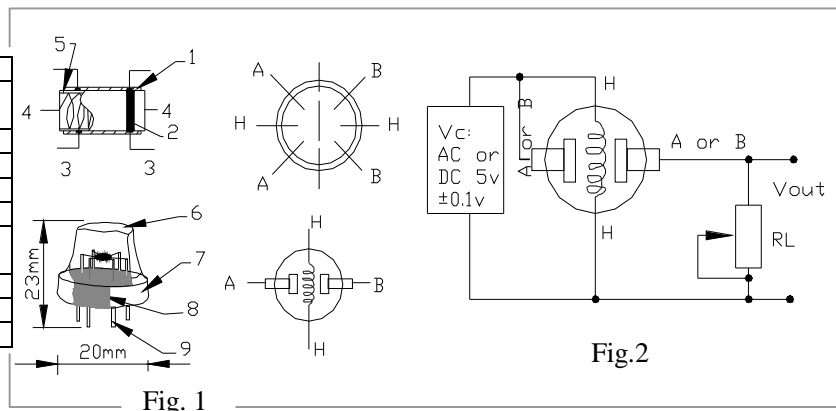
Symbol	Parameter name	Technical condition	Remarks
T _{ao}	Using Tem	-10°C-50°C	minimum value is over 2%
T _{as}	Storage Tem	-20°C-70°C	
R _H	Related humidity	less than 95% Rh	
O ₂	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	

C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remark 2
R _s	Sensing Resistance	10K Ω - 60K Ω (1000ppm CH ₄)	Detecting concentration scope: 200-10000ppm CH ₄ , natural gas
α (1000ppm/ 5000ppm CH ₄)	Concentration slope rate	≤0.6	
Standard detecting condition	Temp: 20°C ±2°C Humidity: 65%±5%	V _c :5V±0.1 V _H : 5V±0.1	
Preheat time	Over 24 hour		

D. Structure and configuration, basic measuring circuit

Parts	Materials
1 Gas sensing layer	SnO ₂
2 Electrode	Au
3 Electrode line	Pt
4 Heater coil	Ni-Cr alloy
5 Tubular ceramic	Al ₂ O ₃
6 Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7 Clamp ring	Copper plating Ni
8 Resin base	Bakelite
9 Tube Pin	Copper plating Ni



Structure and configuration of MQ-4 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro Al_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-4 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2
 E. Sensitivity characteristic curve

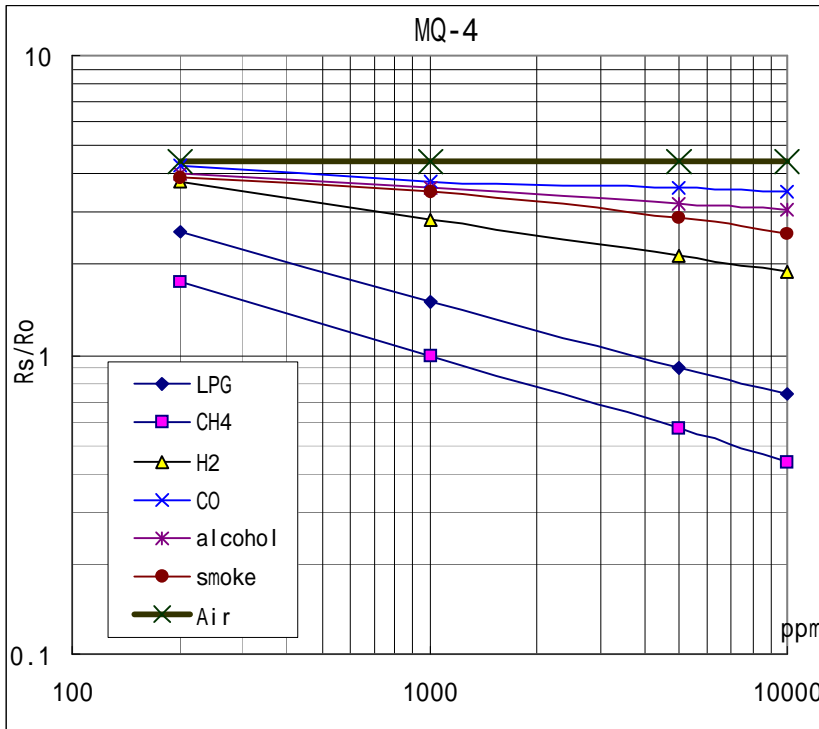


Fig.2 sensitivity characteristics of the MQ-4

Fig.3 is shows the typical sensitivity characteristics of the MQ-4 for several gases. in their: Temp: 20°C、 Humidity: 65%、 O_2 concentration 21% $R_L=20k\ \Omega$

R_o : sensor resistance at 1000ppm of CH_4 in the clean air.
 R_s :sensor resistance at various concentrations of gases.

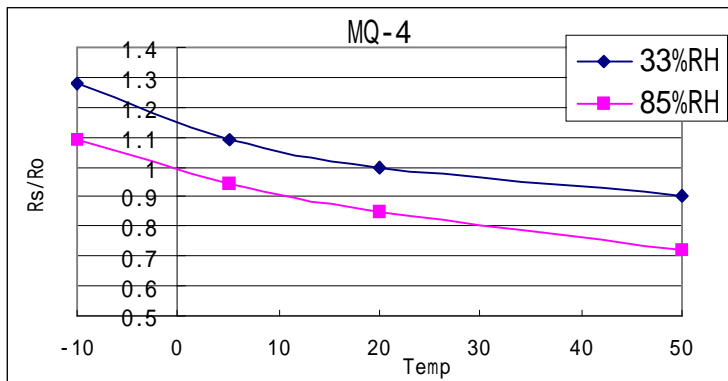


Fig.4 is shows the typical dependence of the MQ-4 on temperature and humidity. R_o : sensor resistance at 1000ppm of CH_4 in air at 33%RH and 20 degree.
 R_s : sensor resistance at 1000ppm of CH_4 in air at different temperatures and humidities.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-4 is difference to various kinds and various concentration gases. So,When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 5000ppm of CH_4 concentration in air and use value of Load resistance (R_L) about $20K\ \Omega$ ($10K\ \Omega$ to $47K\ \Omega$).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

Appendix G

Technical Data: MQ-5 Gas Sensor

TECHNICAL DATA

MQ-5 GAS SENSOR

FEATURES

- * High sensitivity to LPG, natural gas , town gas
- * Small sensitivity to alcohol, smoke.
- * Fast response . * Stable and long life * Simple drive circuit

APPLICATION

They are used in gas leakage detecting equipments in family and industry, are suitable for detecting of LPG, natural gas , town gas, avoid the noise of alcohol and cooking fumes and cigarette smoke.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
V _c	Circuit voltage	5V±0.1	AC OR DC
V _H	Heating voltage	5V±0.1	AC OR DC
P _L	Load resistance	20KΩ	
R _H	Heater resistance	31±10%	Room Tem
P _H	Heating consumption	less than 800mw	

B. Environment condition

Symbol	Parameter name	Technical condition	Remarks
T _{ao}	Using Tem	-10°C-50°C	
T _{as}	Storage Tem	-20°C-70°C	
R _H	Related humidity	less than 95% Rh	
O ₂	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	minimum value is over 2%

C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remarks
R _s	Sensing Resistance	10KΩ - 60KΩ (5000ppm methane)	Detecting concentration scope: 200-10000ppm LPG,LNG Natural gas, iso-butane, propane Town gas
α (5000ppm/1000ppm CH ₄)	Concentration slope rate	≤0.6	
Standard detecting condition	Temp: 20°C ±2°C Humidity: 65%±5%	V _c :5V±0.1 V _H : 5V±0.1	
Preheat time	Over 24 hour		

D. Strucyure and configuration, basic measuring circuit

Parts	Materials
1 Gas sensing layer	SnO ₂
2 Electrode	Au
3 Electrode line	Pt
4 Heater coil	Ni-Cr alloy
5 Tubular ceramic	Al ₂ O ₃
6 Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7 Clamp ring	Copper plating Ni
8 Resin base	Bakelite
9 Tube Pin	Copper plating Ni

Structure and configuration of MQ-5 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by

micro Al_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-5 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

Fig.2 sensitivity characteristics of the MQ-5

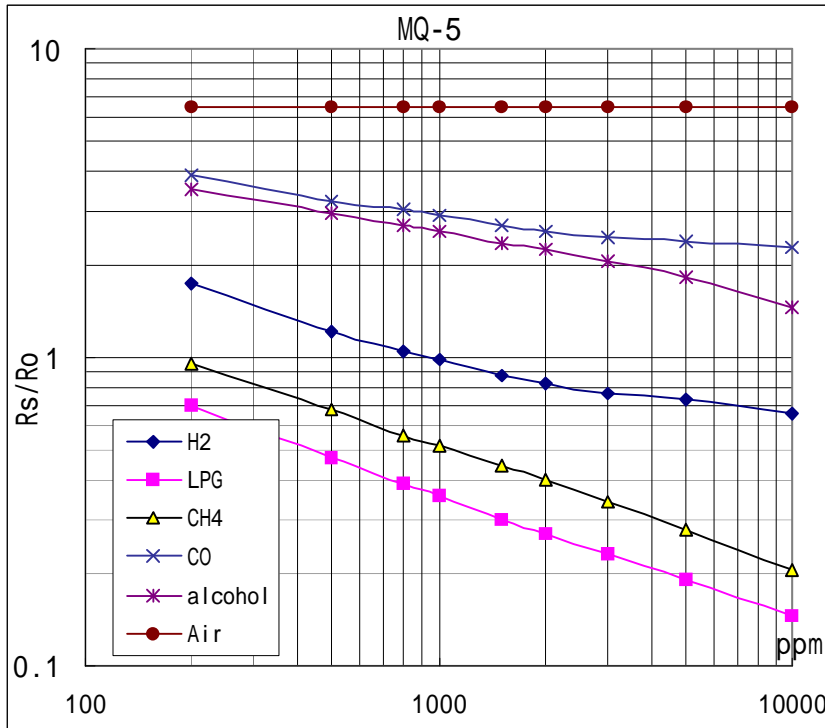


Fig.3 is shows the typical sensitivity characteristics of the MQ-5 for several gases.

in their: Temp: 20°C、
Humidity: 65%、
 O_2 concentration 21%
 $R_L=20k \Omega$
 R_o : sensor resistance at 1000ppm of H_2 in the clean air.
 R_s :sensor resistance at various concentrations of gases.

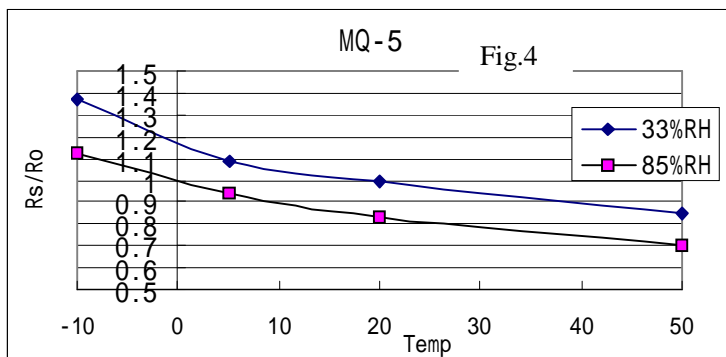


Fig.4 is shows the typical dependence of the MQ-5 on temperature and humidity.

R_o : sensor resistance at 1000ppm of H_2 in air at 33%RH and 20 degree.
 R_s : sensor resistance at different temperatures and humidities.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-5 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000ppm H_2 or LPG concentration in air and use value of Load resistance (R_L) about 20 K Ω (10K Ω to 47K Ω).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

Appendix H

Technical Data: MQ-6 Gas Sensor

TECHNICAL DATA

MQ-6 GAS SENSOR

FEATURES

- * High sensitivity to LPG, iso-butane, propane
- * Small sensitivity to alcohol, smoke.
- * Fast response . * Stable and long life * Simple drive circuit

APPLICATION

They are used in gas leakage detecting equipments in family and industry, are suitable for detecting of LPG, iso-butane, propane, LNG, avoid the noise of alcohol and cooking fumes and cigarette smoke.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
V _c	Circuit voltage	5V±0.1	AC OR DC
V _H	Heating voltage	5V±0.1	ACOR DC
P _L	Load resistance	20K Ω	
R _H	Heater resistance	33 Ω ± 5%	Room Tem
P _H	Heating consumption	less than 750mw	

B. Environment condition

Symbol	Parameter name	Technical condition	Remarks
T _{ao}	Using Tem	-10°C -50°C	
T _{as}	Storage Tem	-20°C -70°C	
R _H	Related humidity	less than 95% Rh	
O ₂	Oxygen concentration	21% (standard condition) Oxygen concentration can affect sensitivity	minimum value is over 2%

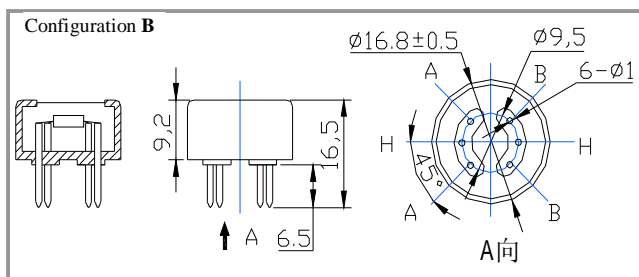
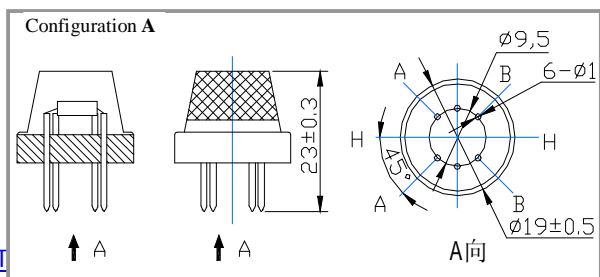
C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remarks
R _s	Sensing Resistance	10K Ω - 60K Ω (1000ppm LPG)	Detecting concentration scope: 200-10000ppm LPG , iso-butane, propane, LNG
α (1000ppm/ 4000ppm LPG)	Concentration slope rate	≤0.6	
Standard detecting condition	Temp: 20°C ± 2°C Humidity: 65% ± 5%	V _c : 5V ± 0.1 V _H : 5V ± 0.1	
Preheat time	Over 24 hour		

D. Strucyure and configuration, basic measuring circuit

Parts	Materials
1 Gas sensing layer	SnO ₂
2 Electrode	Au
3 Electrode line	Pt
4 Heater coil	Ni-Cr alloy
5 Tubular ceramic	Al ₂ O ₃
6 Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7 Clamp ring	Copper plating Ni
8 Resin base	Bakelite
9 Tube Pin	Copper plating Ni

Fig. 1 **Fig. 2**



Structure and configuration of MQ-6 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro Al_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-6 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2
 E. Sensitivity characteristic curve

Fig.2 sensitivity characteristics of the MQ-6

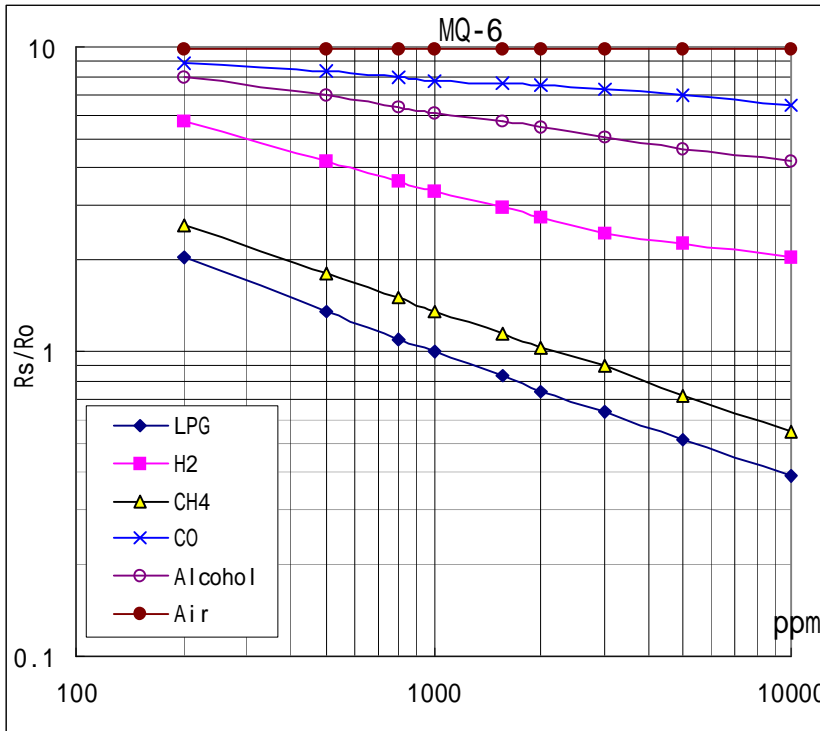


Fig.3 is shows the typical sensitivity characteristics of the MQ-6 for several gases. in their: Temp: 20°C、 Humidity: 65%、 O_2 concentration 21% $R_L=20k \Omega$

R_o : sensor resistance at 1000ppm of LPG in the clean air.
 R_s : sensor resistance at various concentrations of gases.

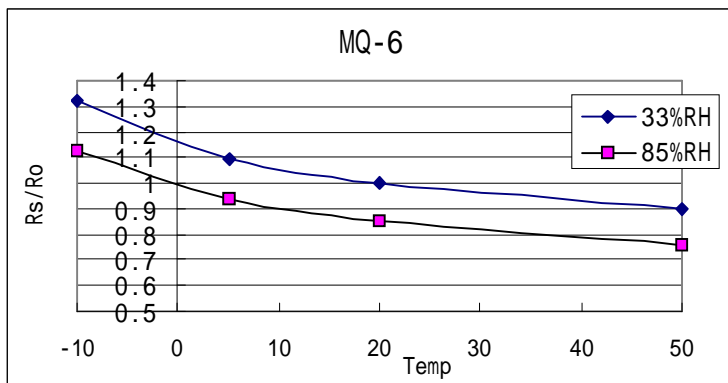


Fig.4 is shows the typical dependence of the MQ-6 on temperature and humidity. R_o : sensor resistance at 1000ppm of LPG in air at 33%RH and 20 degree.
 R_s : sensor resistance at 1000ppm of LPG in air at different temperatures and humidities.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-6 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 1000ppm of LPG concentration in air and use value of Load resistance (R_L) about $20K \Omega$ ($10K \Omega$ to $47K \Omega$).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

Appendix I

Technical Data: MQ-7 Gas Sensor

TECHNICAL DATA**MQ-7 GAS SENSOR****FEATURES**

- * High sensitivity to carbon monoxide
- * Stable and long life

APPLICATION

They are used in gas detecting equipment for carbon monoxide(CO) in family and industry or car.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remark
Vc	circuit voltage	$5V \pm 0.1$	Ac or Dc
V _H (H)	Heating voltage (high)	$5V \pm 0.1$	Ac or Dc
V _H (L)	Heating voltage (low)	$1.4V \pm 0.1$	Ac or Dc
RL	Load resistance	Can adjust	
RH	Heating resistance	$33 \Omega \pm 5\%$	Room temperature
T _H (H)	Heating time (high)	60 ± 1 seconds	
T _H (L)	Heating time (low)	90 ± 1 seconds	
PH	Heating consumption	About 350mW	

b. Environment conditions

Symbol	Parameters	Technical conditions	Remark
Tao	Using temperature	-20°C-50°C	
Tas	Storage temperature	-20°C-50°C	Advice using scope
RH	Relative humidity	Less than 95%RH	
O ₂	Oxygen concentration	21%(stand condition) the oxygen concentration can affect the sensitivity characteristic	Minimum value is over 2%

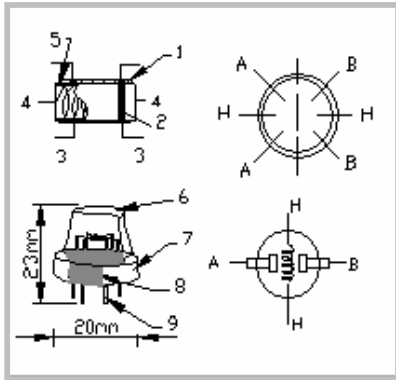
c. Sensitivity characteristic

symbol	Parameters	Technical parameters	Remark
Rs	Surface resistance Of sensitive body	2-20k	In 100ppm Carbon Monoxide
a (300/100ppm)	Concentration slope rate	Less than 0.5	Rs (300ppm)/Rs(100ppm)
Standard working condition	Temperature	$-20^{\circ}\text{C} \pm 2^{\circ}\text{C}$	relative humidity $65\% \pm 5\%$ RL: $10K \Omega \pm 5\%$
	Vc: $5V \pm 0.1V$ VH: $5V \pm 0.1V$ VH: $1.4V \pm 0.1V$		
Preheat time	No less than 48 hours	Detecting range: 20ppm-2000ppm carbon monoxide	

D. Structure and configuration, basic measuring circuit

Structure and configuration of MQ-7 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro AL₂O₃ ceramic tube, Tin Dioxide (SnO₂) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-7 have

6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.



Parts	Materials
1 Gas sensing layer	SnO ₂
2 Electrode	Au
3 Electrode line	Pt
4 Heater coil	Ni-Cr alloy
5 Tubular ceramic	Al ₂ O ₃
6 Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7 Clamp ring	Copper plating Ni
8 Resin base	Bakelite
9 Tube Pin	Copper plating Ni

Fig.1

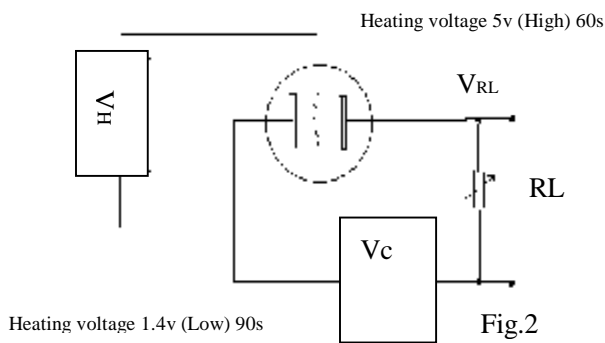
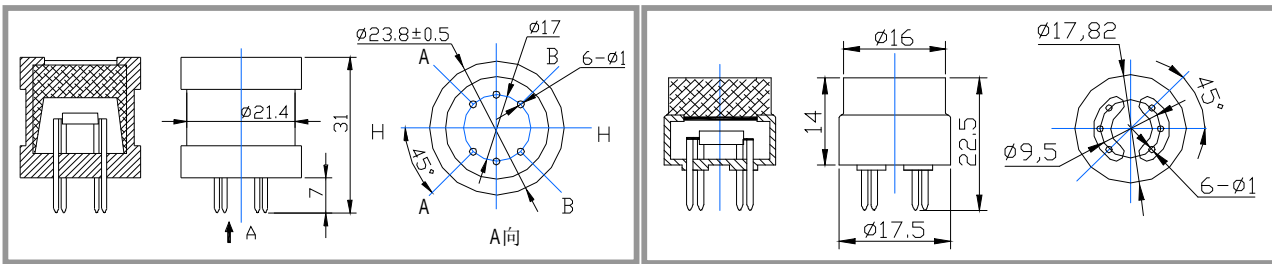


Fig.2

Standard circuit:

As shown in Fig 2, standard measuring circuit of MQ-7 sensitive components consists of 2 parts. one is heating circuit having time control function (the high voltage and the low voltage work circularly). The second is the signal output circuit, it can accurately respond changes of surface resistance of the sensor.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

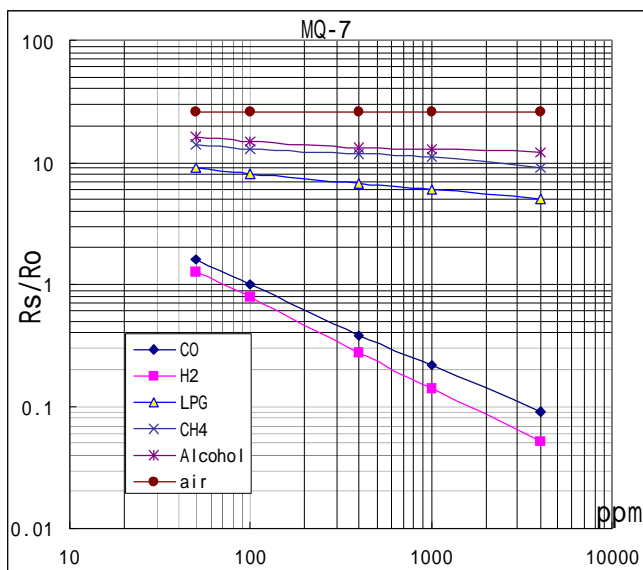


Fig.3 sensitivity characteristics of the MQ-7

Fig.3 is shows the typical sensitivity characteristics of the MQ-7 for several gases.

in their: Temp: 20°C、
Humidity: 65%、
O₂ concentration 21%
RL=10k Ω

Ro: sensor resistance at 100ppm
CO in the clean air.

Rs: sensor resistance at various concentrations of gases.

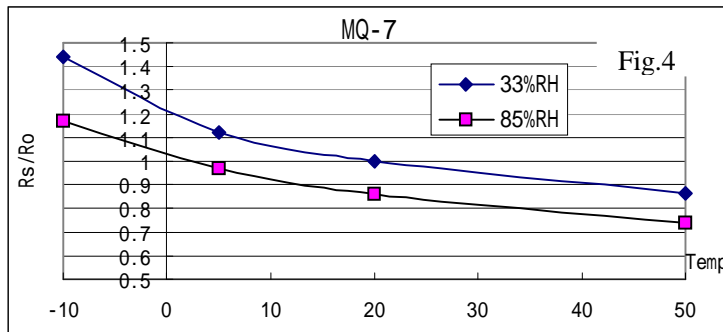


Fig.4 is shows the typical dependence of the MQ-7 on temperature and humidity.

Ro: sensor resistance at 100ppm CO in air at 33%RH and 20degree.

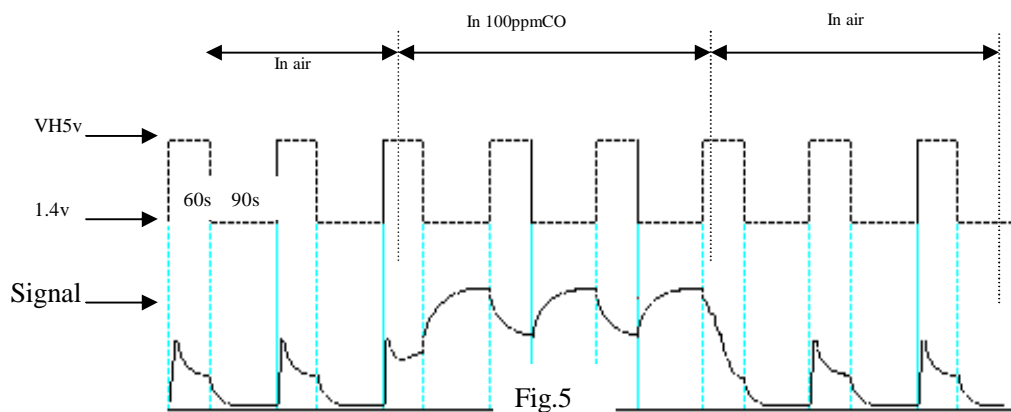
Rs: sensor resistance at 100ppm CO at different temperatures and humidities.

OPERATION PRINCIPLE

. The surface resistance of the sensor R_s is obtained through effected voltage signal output of the load resistance R_L which series-wound. The relationship between them is described:

$$R_s \setminus R_L = (V_c - V_{RL}) / V_{RL}$$

Fig. 5 shows alterable situation of R_L signal output measured by using Fig. 2 circuit output



signal when the sensor is shifted from clean air to carbon monoxide (CO), output signal measurement is made within one or two complete heating period (2.5 minute from high voltage to low voltage).

Sensitive layer of MQ-7 gas sensitive components is made of SnO_2 with stability, So, it has excellent long term stability. Its service life can reach 5 years under using condition.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-7 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 200ppm CO in air and use value of Load resistance that (R_L) about $10 \text{ K } \Omega$ ($5 \text{ K } \Omega$ to $47 \text{ K } \Omega$).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence. The sensitivity adjusting program:

- Connect the sensor to the application circuit.
- Turn on the power, keep preheating through electricity over 48 hours.
- Adjust the load resistance R_L until you get a signal value which is respond to a certain carbon monoxide concentration at the end point of 90 seconds.
- Adjust the another load resistance R_L until you get a signal value which is respond to a CO concentration at the end point of 60 seconds .

[Supplying special IC solutions, More detailed technical information, please contact us.](#)

Appendix J

Technical Data: MQ-9 Gas Sensor

TECHNICAL DATA MQ-9 GAS SENSOR

FEATURES

- * High sensitivity to carbon monoxide and CH₄, LPG.
- * Stable and long life

APPLICATION

They are used in gas detecting equipment for carbon monoxide and CH₄, LPG in family and industry or car.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	technical condition	Remark
V _c	circuit voltage	5V±0.1	AC or DC
V _H (H)	Heating voltage (high)	5V±0.1	AC or DC
V _H (L)	Heating voltage (low)	1.4V±0.1	AC or DC
R _L	Load resistance	Can adjust	
R _H	Heating resistance	33Ω±5%	Room temperature
T _H (H)	Heating time (high)	60±1 seconds	
T _H (L)	Heating time (low)	90±1 seconds	
P _s	Heating consumption	Less than 340mw	

b. Environment conditions

Symbol	Parameters	Technical conditions	Remark
T _{ao}	Using temperature	-20℃ -50℃	
T _{as}	Storage temperature	-20℃ -50℃	Advice using scope
RH	Relative humidity	Less than 95%RH	
O ₂	Oxygen concentration	21%(stand condition) the oxygen concentration can affect the sensitivity characteristic	Minimum value is over 2%

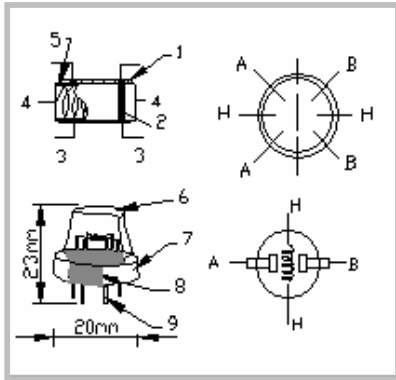
c. Sensitivity characteristic

symbol	Parameters	Technical parameters	Remark
R _s	Surface resistance Of sensitive body	2-20k	In 100ppm Carbon Monoxide
a (300/100ppm)	Concentration slope rate	Less than 0.5	R _s (300ppm)/R _s (100ppm)
Standard working condition	Temperature -20℃±2℃ V _c :5V±0.1V V _H :5V±0.1V V _H :1.4V±0.1V	relative humidity 65%±5%	RL:10KΩ±5%
Preheat time	No less than 48 hours	Detecting range:20ppm-2000ppm carbon monoxide 500ppm-10000ppm CH ₄ 500ppm-10000ppm LPG	

D. Structure and configuration, basic measuring circuit

Structure and configuration of MQ-9 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro AL₂O₃ ceramic tube, Tin Dioxide (SnO₂) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-9 have

6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.



Parts	Materials
1	Gas sensing layer SnO ₂
2	Electrode Au
3	Electrode line Pt
4	Heater coil Ni-Cr alloy
5	Tubular ceramic Al ₂ O ₃
6	Anti-explosion network Stainless steel gauze (SUS316 100-mesh)
7	Clamp ring Copper plating Ni
8	Resin base Bakelite
9	Tube Pin Copper plating Ni

Fig.1

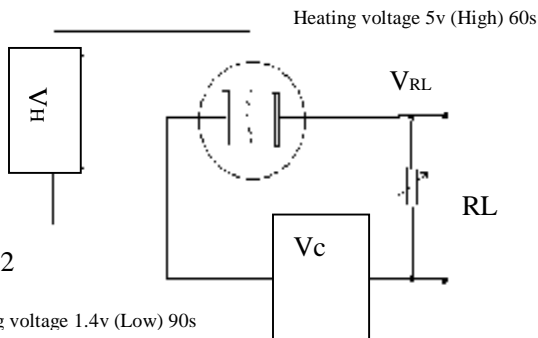
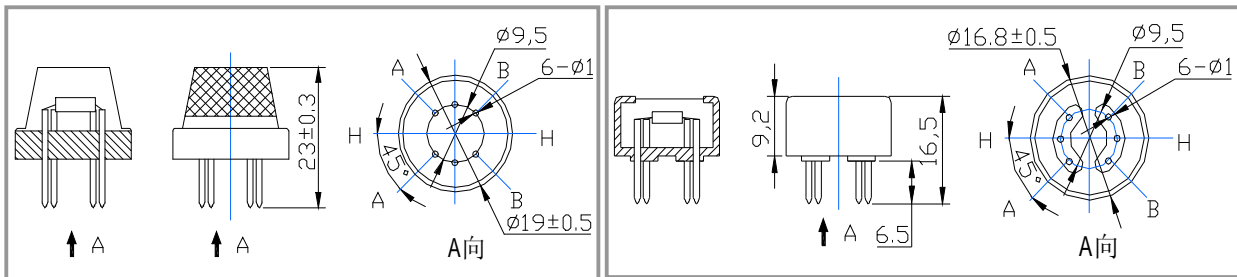


Fig.2

Standard circuit:

As shown in Fig 2, standard measuring circuit of MQ-9 sensitive components consists of 2 parts. one is heating circuit having time control function (the high voltage and the low voltage work circularly). The second is the signal output circuit, it can accurately respond changes of surface resistance of the sensor.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

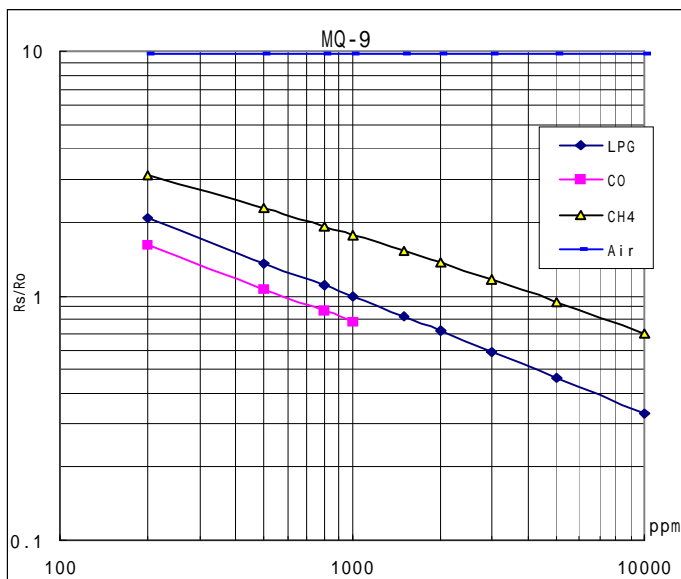


Fig.3 sensitivity characteristics of the MQ-9

Fig.3 shows the typical sensitivity characteristics of the MQ-9 for several gases.

in their: Temp: 20℃、

Humidity: 65%、

O₂ concentration 21%

RL=10k Ω

Ro: sensor resistance at 1000ppm

LPG in the clean air.

Rs: sensor resistance at various concentrations of gases.

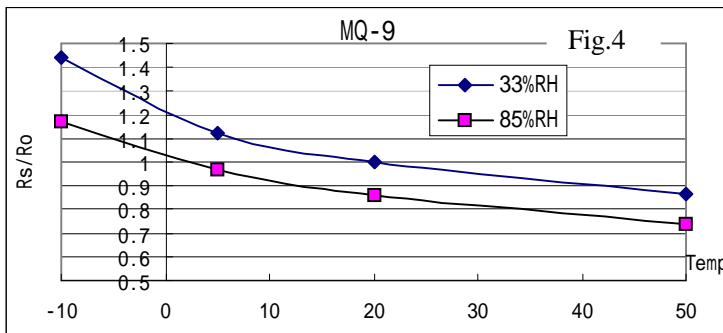


Fig.4 is shows the typical dependence of the MQ-9 on temperature and humidity.

Ro: sensor resistance at 1000ppm LPG in air at 33%RH and 20degree.

Rs: sensor resistance at 1000ppm LPG at different temperatures and humidities.

OPERATION PRINCIPLE

. The surface resistance of the sensor R_s is obtained through effected voltage signal output of the load resistance R_L which series-wound. The relationship between them is described:

$$R_s \setminus R_L = (V_c - V_{RL}) / V_{RL}$$

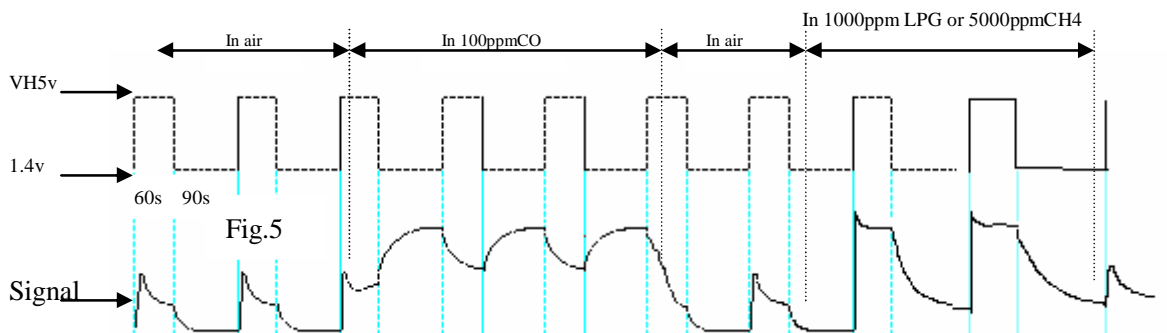


Fig. 5 shows alterable situation of R_L signal output measured by using Fig. 2 circuit output signal when the sensor is shifted from clean air to carbon monoxide (CO) or CH_4 , output signal measurement is made within one or two complete heating period (2.5 minute from high voltage to low voltage).

Sensitive layer of MQ-9 gas sensitive components is made of SnO_2 with stability, So, it has excellent long term stability. Its service life can reach 5 years under using condition.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-9 is difference to various kinds and various concentration gases. So, When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 200ppm and 5000ppm CH_4 or 1000ppm LPG concentration in air and use value of Load resistance that(R_L) about 20 K Ω (10K Ω to 47 K Ω).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

The sensitivity adjusting program:

- Connect the sensor to the application circuit.
- Turn on the power, keep time of preheating through electricity is over 48 hours.
- Adjust the load resistance R_L until you get a signal value which is respond to a certain carbon monoxide concentration at the end point of 90 seconds.
- Adjust the another load resistance R_L until you get a signal value which is respond to a CH_4 or LPG concentration at the end point of 60 seconds .

Appendix K

Technical Data: MQ-135 Gas Sensor

TECHNICAL DATA

MQ-135 GAS SENSOR

FEATURES

- Wide detecting scope
- Stable and long life
- Fast response and High sensitivity
- Simple drive circuit

APPLICATION

They are used in air quality control equipments for buildings/offices, are suitable for detecting of NH₃, NO_x, alcohol, Benzene, smoke, CO₂, etc.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
V _c	Circuit voltage	5V±0.1	AC OR DC
V _H	Heating voltage	5V±0.1	AC OR DC
R _L	Load resistance	can adjust	
R _H	Heater resistance	33Ω±5%	Room Tem
P _H	Heating consumption	less than 800mw	

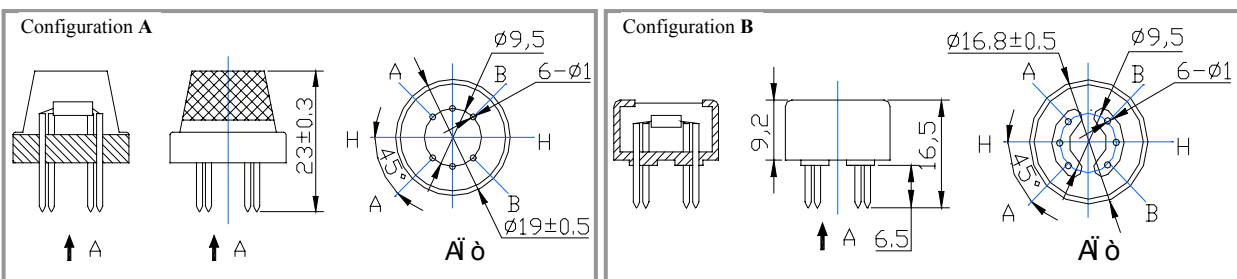
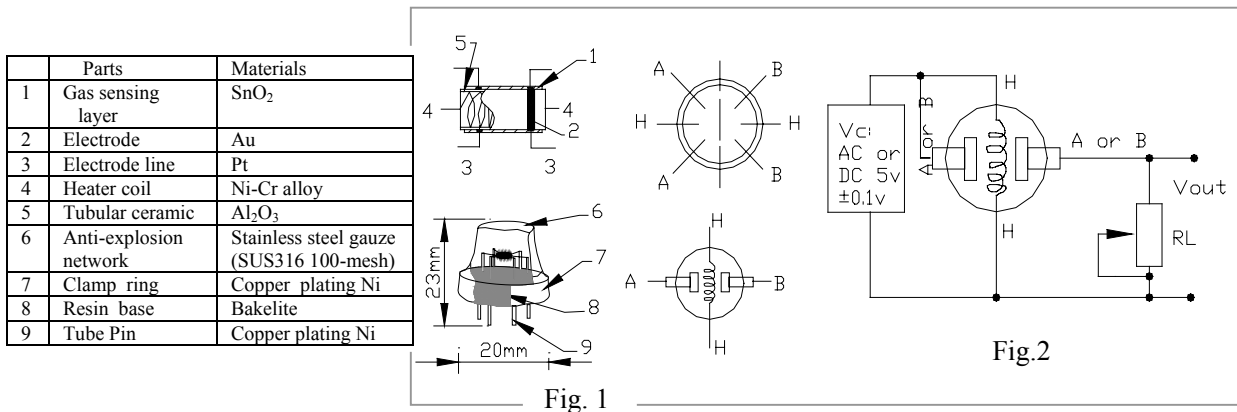
B. Environment condition

Symbol	Parameter name	Technical condition	Remarks
T _{ao}	Using Tem	-10℃-45℃	
T _{as}	Storage Tem	-20℃-70℃	
R _H	Related humidity	less than 95%Rh	
O ₂	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	minimum value is over 2%

C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Remark 2
R _s	Sensing Resistance	30KΩ-200KΩ (100ppm NH ₃)	Detecting concentration scope 10ppm-300ppm NH ₃ 10ppm-1000ppm Benzene 10ppm-300ppm Alcohol
α (200/50) NH ₃	Concentration Slope rate	≤0.65	
Standard Detecting Condition	Temp: 20℃±2℃ V _c :5V±0.1 Humidity: 65%±5% V _H : 5V±0.1		
Preheat time	Over 24 hour		

D. Structure and configuration, basic measuring circuit



Structure and configuration of MQ-135 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro AL₂O₃ ceramic tube, Tin Dioxide (SnO₂) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive

components. The enveloped MQ-135 have 6 pin ,4 of them are used to fetch signals, and other 2 are used for providing heating current.

Electric parameter measurement circuit is shown as Fig.2

E. Sensitivity characteristic curve

Fig.2 sensitivity characteristics of the MQ-135

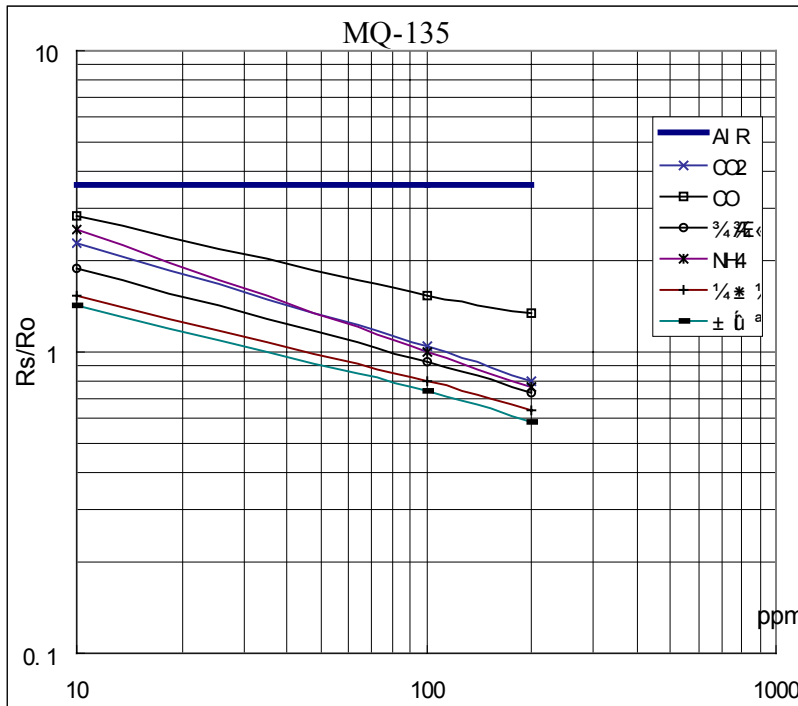


Fig.3 is shows the typical sensitivity characteristics of the MQ-135 for several gases.

in their: Temp: 20 °C
Humidity: 65%
O2 concentration 21%
RL=20kΩ

Ro: sensor resistance at 100ppm of NH3 in the clean air.

Rs:sensor resistance at various concentrations of gases.

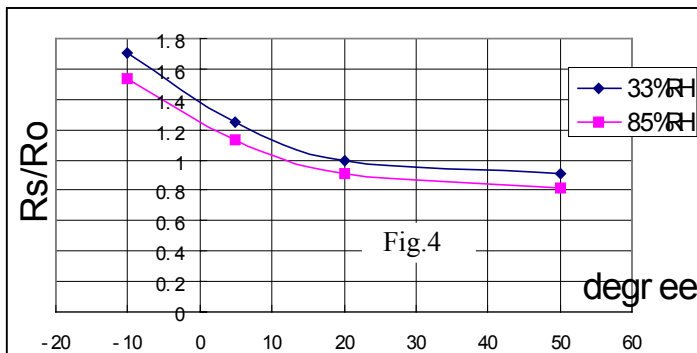


Fig.4 is shows the typical dependence of the MQ-135 on temperature and humidity.

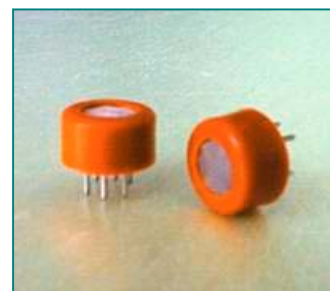
Ro: sensor resistance at 100ppm of NH3 in air at 33%RH and 20 degree.

Rs: sensor resistance at 100ppm of NH3 at different temperatures and humidities.

SENSITIVITY ADJUSTMENT

Resistance value of MQ-135 is difference to various kinds and various concentration gases. So,When using this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 100ppm NH3 or 50ppm Alcohol concentration in air and use value of Load resistancethat(RL) about 20 KΩ(10KΩ to 47 KΩ).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.



Appendix L

Datasheet: SDS011 - Dust Sensor

Overview

The SDS011 using principle of laser scattering, can get the particle concentration between 0.3 to 10 μ m in the air. It with digital output and built-in fan is stable and reliable.



Characteristics

1. Accurate and Reliable: laser detection, stable, good consistency;
2. Quick response: response time is less than 10 seconds when the scene changes;
3. Easy integration: UART output (or IO output can be customized), fan built-in;
4. High resolution: resolution of 0.3 μ g/m³;

5.Certification: products have passed CE/FCC/RoHS certification.

Scope of application

Detector of PM2.5;Purifier.

Working principle

Using laser scattering principle:

Light scattering can be induced when particles go through the detecting area. The scattered light is transformed into electrical signals and these signals will be amplified and processed. The number and diameter of particles can be obtained by analysis because the signal waveform has certain relations with the particles diameter.

Technical Parameters

No	Item	Parameter	Note
1	Measurement parameters	PM2.5,PM10	
2	Range	0.0-999.9 $\mu\text{g} / \text{m}^3$	
3	Rated voltage	5V	
4	Rated current	70mA \pm 10mA	
5	Sleep current	<4 mA	Lase&Fan sleep
6	Temperature range	Storage environment: -20 ~ +60 $^{\circ}\text{C}$	

		Work environment: -10 ~ +50°C	
7	Humidity range	Storage environment: Max 90%	
		Work environment: Max 70%	
8	Air pressure	86KPa~110KPa	
9	Corresponding time	1s	
10	Serial data output frequency	1Hz	
11	Minimum resolution of particle	0.3 μm	
12	Counting yield	70% @0.3μm 98% @0.5μm	
13	Relative error	Maximum of ± 15% and ±10μg/m ³	25°C, 50%RH
14	Product size	71x70x23mm	
15	Certification	CE/FCC/RoHS	

Power requirement

Power Voltage: 4.7~5.3V

Power supply: >1W

Supply voltage ripple: <20mV

About service life

Service life is the key parameter of laser dust sensor. The laser diode in this sensor has high quality and its service life is up to 8000 hours. If you need real-time data (such as detector), you can use the default configuration that measures at the frequency of 1time per second. On the occasion of real-time demand is not high (such as filter, air quality monitoring, etc.), you can use the discontinuous working method to prolong the service life. For example, you can start the sensor for 30 seconds per minutes. If you have any other requirements, please contact us, we are willing to serve for manufacturers and developers.

Product specifications

1.Product size

L*W*H=71*70*23mm

2.Interface specification

No	Name	Comment
1	NC	Not Connect
2	1 μ m	PM2.5: 0-999 μ g/m ³ ;PWM Output
3	5V	5V Input
4	2.5 μ m	PM10: 0-999 μ g/m ³ ;PWM Output
5	GND	Ground

6	R	RX of UART (TTL) @3.3V
7	T	TX of UART (TTL) @3.3V

PS: The distance between each pin is 2.54mm.

The UART communication protocol

Bit rate : 9600

Data bit : 8

Parity bit: NO

Stop bit : 1

Data Packet frequency: 1Hz

The number of bytes	Name	Content
0	Message header	AA
1	Commander No.	C0
2	DATA 1	PM2.5 Low byte
3	DATA 2	PM2.5 High byte
4	DATA 3	PM10 Low byte
5	DATA 4	PM10 High byte
6	DATA 5	ID byte 1
7	DATA 6	ID byte 2
8	Check-sum	Check-sum
9	Message tail	AB

Check-sum: Check-sum=DATA1+DATA2+...+DATA6 。

PM2.5 value: $PM2.5 (\mu g / m^3) = ((PM2.5 \text{ High byte} * 256) + PM2.5 \text{ low byte}) / 10$

PM10 value: $PM10 (\mu g / m^3) = ((PM10 \text{ high byte} * 256) + PM10 \text{ low byte}) / 10$

PWM output description

Range of PM2.5 value	0-999 $\mu g / m^3$
Range of PM10 value	0-999 $\mu g / m^3$
Cycle	1004ms $\pm 1\%$
High level output time at the beginning of the whole cycle	2ms
The middle time of this cycle	1000ms $\pm 1\%$
Low level output time at the end of the whole cycle	2ms