Pneuma

ESE 451 - Senior Design II
Inter-Departmental Senior Design Project

Team 12

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II. Executive Summary

According to the American Lung Association, around 134 million Americans are at risk of disease or premature death due to air pollution. The CDC has identified six main pollutants that affect those with and without lung conditions: carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide[1]. Other air pollutants that cause damage to the lungs include acrolein, asbestos, benzene, carbon disulfide, and others. While metrics such as the Air Quality Index (AQI) attempt to capture a sense of how acceptable the air quality is, the metric is not sufficiently specific to different diseases with different sensitivity thresholds. Moreover, AQI is usually measured for relatively large areas. There is a need for more location-specific and disease-specific metrics.

Our project, Pneuma, is a network of portable devices aimed to prevent respiratory damage for users with pulmonary diseases. Any passersby with medical conditions affected by such pollutants could be at serious risk for further and more severe pulmonary injury. Our physical device consists of a microcontroller attached with various hazardous gas sensors, targeted at common pollutants. A constant stream of sensor and GPS data is uploaded to our cloud data service, generating a granular and real time map of each toxin. Our device alerts the user if they enter an area with significant pollutant concentrations that is specific to each user’s condition. The user would then be able to take the necessary precautions to minimize their health risk. We intended to have a personalization component to Pneuma, in which an application would be able to not only help visualize the air quality surrounding the user but would also allow one to adjust certain weights relative to specific sensitivities to major pollutants.

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[1] CDC: https://www.cdc.gov/air/pollutants.htm#:~:text=These%20six%20pollutants%20are%20carbon,matter)%2C%20and%20sulfur%20oxides.

III. Overview and Project Motivation

People suffering from pulmonary diseases are at major risk of further lung damage due to pollutants surrounding them. Air pollution poses a threat to the prognosis of their disease, so it is of major importance to address these environmental and health issues that affect the lives of millions of Americans.

The idea behind Pneuma is to create a device that tracks air pollution at a granular level for patients suffering from lung complications. It is composed of hardware that senses the presence of pollutants, as well as a front-end software that collects the data and maps it on a visual map for the users to play around with. The idea behind this project came from Ketan Mandava's work at a pulmonary disease research laboratory in Colorado. His principal investigator identified the pressing need to create a portable product that could offer patients information on how much their surrounding air is damaging them.

There are currently available methods of air quality trackers in the market, such as the Air Quality Index, but these tend to provide information at a city-wide level and do not update data in real time on a granular level. Additionally, these indices do not provide specific pollutant concentration data, and it has been scientifically proven that there are some gasses that affect patients with pulmonary diseases more than others. Therefore, we decided to implement all these shortcomings in existing technology to come up with our product, Pneuma. Hopefully, by using our product, patients can freely circulate around while avoiding air that may damage their lungs even more.

IV. Technical Description

Constraints and Specifications

As was stated in the problem statement, our motivation for the project included helping those with pulmonary afflictions navigate heavily polluted areas by providing them granular data that would be more specific to their pulmonary affliction. Our objective was to create a score that would be specific to each affliction. For example, a score for someone with lung cancer might assign different weights to different gases.

The proposed solution to our problem was to design a portable device that people could carry around with them and provide an iOS app that would allow each user to check the data collected by their device as well as the data collected from any surrounding devices carried by other users (Appendix A).

In an ideal scenario with a large budget, one could make enough of these devices to be able to place them on every corner of Philadelphia so that each person with these afflictions could simply check their phone to be able to see the air quality that surrounds them or the places they intend to go to. However, the problem with this alternative solution is that in order to provide quality metrics, one would need to provide a scale that is unfeasible for the scope of this project. Air pollution travels quickly and having a handful of them in street corners provides no real contribution to people with these afflictions. Additionally, having these devices on public property would have the additional difficulty of having to convince public officials to allow the company to place these devices on street corners. While this may be a worthy long-term goal, we sought to provide immediate value for people with these afflictions.

By contrast, having people carry these devices allows us to provide the users data that is relevant to their location, as well as allow them the opportunity to access the data collected by other users in surrounding areas. Our objective was to create a gas quality score that would be specific to each affliction.

<u>Hardware - Sensors</u>

In order to help the largest number of people with pulmonary afflictions, we targeted the 6 major pollutants identified by the CDC. These gasses are carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide.

There is a clear trade-off in the design of our product: the more sensors we include in the design, the heavier and larger our product needs to be, and therefore the less portable it is, which makes it less appealing for people to carry. There is an additional constraint in the cost of the product, as we intended to have a lower price than the static (and less granular) solution other companies were providing.

For these reasons, we decided to include the following sensors in the final design of the product:

- MQ-7: This sensor measures the concentration of carbon monoxide in the air

- MQ2: This sensor measures the concentration of combustible gases in the air
- MQ135: This sensor measures the concentration of ammonia, benzene, and alcohol in the air
- PM2.5: This sensor measures particulate matter. Even though the sensor is relatively large and expensive, we decided to include it in the final design of the product as particulate matter is one of the pollutants that is most harmful for people with these afflictions.

The error rate and power consumption of each of these sensors can be seen in Table 1.

The most expensive of these sensors is the particulate matter sensor, which approximately cost $40. The MQ sensors were acquired in a pack with an approximate cost of $15.

Table 1. Energy efficiency and data accuracy of each of the four sensors used.

	MQ-135	**MQ-2**	**MQ-7**	**PM 2.5 sensor**
Power Consumption	150 mA	88 mA	130 - 150 mA	120 mA
Error	±5% 10 ~ 1000 ppm	±9.7% 300 ~ 1000 ppm	±5% 20 ~ 2000 ppm	±10% 100 ~ 500μg/m^3
Gases Detected	Ammonia, Benzene, Alcohol	Combustible gases	Carbon Monoxide	Particulate matter

Hardware - Microcontroller

The chosen microcontroller for the project was a Bluetooth Low Energy (BLE) Bluefruit board. A major constraint for our project was the battery life of the device. This was another reason why we decided to limit the number of sensors in our device. The advantage the BLE Bluefruit board posed over alternatives we had previously tried (see Outcome 2.2 below) is that battery consumption was much lower.

The approximate battery-life of the device was 4 hours. As is shown later on, the device would collect data every 10 seconds, broadcasting through BLE to the app’s local storage, which would then be uploaded to AWS every minute.

Full Hardware Design

As shown in Figure 1, the full architecture of the hardware included the microcontroller and the four gas sensors, all connected through a small breadboard.

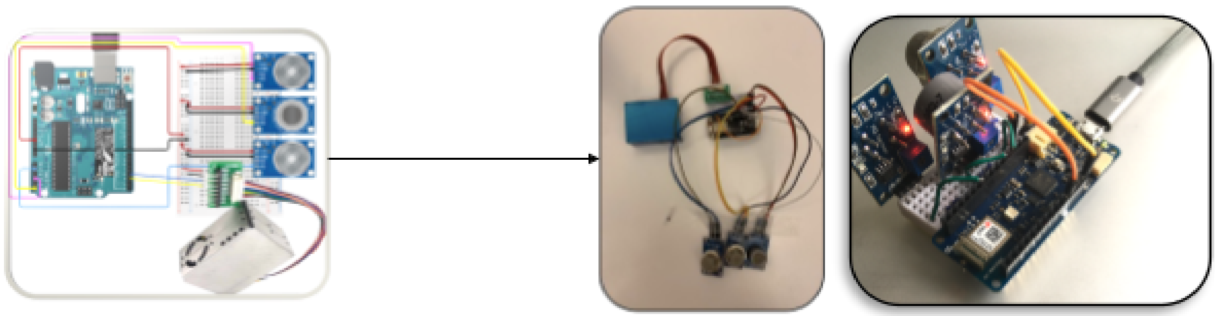

Figure 1. Diagram of the final hardware architecture

Additionally, we designed the container of the Pneuma device to be the following cylinder, as shown in Figure 2. The idea behind this design was to make it attachable to a backpack using Velcro or a magnet as it was unrealistic to ask users to carry around a device of this size. The cylindrical shape of the device was suggested by our advisor. The holes are meant to allow air to flow through the device with the objective of obtaining more precise readings from the sensors. A trade-off we had to consider was between reliability and resiliency. The larger the holes were, the more air the sensors were exposed to, which made them more vulnerable to rain, for example.

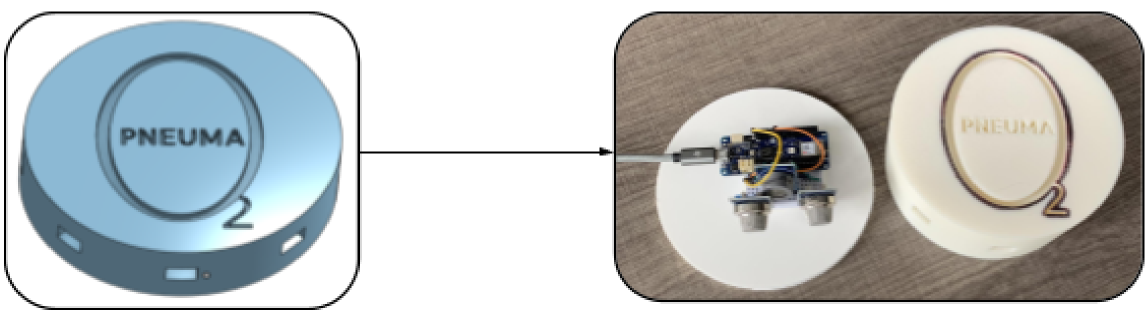

Figure 2. CAD and 3D printed version of casing design for the hardware

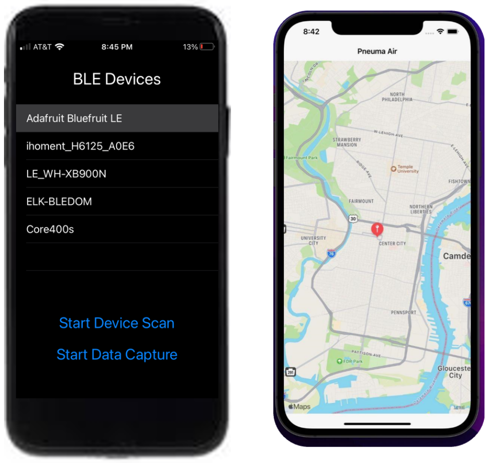

Figure 3. Visual representation of iOS app where the user must connect to the Adafruit Bluefruit BLE out of all listed devices.

Cloud Storage

All data was stored on AWS Simple Storage Service[2] (S3) buckets according to location as well as date of the measurement. AWS S3 is well known for storage, and it is not expensive.

Each data point stored in S3 included the location (latitude and longitude), as well as the readings for each of the four devices and the time the measurement was made at.

The bucket itself was partitioned by date while the objects were stored in JSON format with the time, latitude, longitude, and each of the sensor readings.

The following example object could be located in

Bucket\2022\04\18

{“time”: “18:53:11”, “latitude”: 39.952583, “longitude”: -75.165222, “mq135”: 729, “mq2”: 235, “mq7”: 412}

We noticed that our S3 bucket sizes were appropriate for the purposes of the project, and our account provided sufficient cloud storage space (Appendix B).

Software

The final iOS app we implemented was built using SwiftUI. The app was designed to act as the middleman between the hardware device and AWS S3, as well as to show the data to the user

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[2] AWS S3:https://aws.amazon.com/pm/serv-s3/?trk=fecf68c9-3874-4ae2-a7ed-72b6d19c8034&sc_channel=ps&sc_campaign=acquisition&sc_medium=ACQ-P|PS-GO|Brand|Desktop|SU|Storage|S3|US|EN|Text&s_kwcid=AL!4422!3!488982706719!e!!g!!aws%20s3&ef_id=CjwKCAjwjZmTBhB4EiwAynRmD-RfNQMxwbv0X-vJxHq-6eFEJbHoFbpR_wUkQKAiLDw3OWXFA7XZjBoCjEIQAvD_BwE:G:s&s_kwcid=AL!4422!3!488982706719!e!!g!!aws%20s3

in an appealing way that would enable the user to act based on the readings. After several integrations of the app (see outcome 2.2), the final design of the app mapped the location and readings of all surrounding readings.

To interact with AWS S3, the app uses a framework called AWS Amplify[3]. The readings were sent from the Bluefruit board to the app via Bluetooth in Json format. The files were subsequently uploaded to AWS S3 via AWS Amplify. This same framework was used to pull the data from AWS S3, download it temporarily on the device and plot it in a map centered around the user's location.

The app took less than 15 seconds to boot up and plot the data points once the device was activated. See the pictures below for the specific design of the app

<u>Integration</u>

The full integration of the different components, seen in Figure 4, involved using the Arduino IDE to collect the data from the sensors, and then using Bluetooth to upload the data to Amazon S3 buckets and displaying it in the Swift UI application through an AWS Amplify framework.

Figure 4. Flowchart diagram of the hardware-software integration using different services.

[3] AWS Amplify: https://aws.amazon.com/amplify/?trk=41731cf6-f5eb-4611-81ef-f2914ec706b5&sc_channel=ps&sc_campaign=acquisition&sc_medium=GC-PMM|PS-GO|Brand|All|PA|Mobile%20Services|Amplify|US|EN|Text|PMO22-13306&s_kwcid=AL!4422!3!588971138365!e!!g!!aws%20amplify&ef_id=CjwKCAjwjZmTBhB4EiwAynRmDyHOIZLsNJVUzd4npv-FgmA1e03Iz6ytznGpLDhQVzh33nZa3YpdYRoCDNAQAvD_BwE:G:s&s_kwcid=AL!4422!3!588971138365!e!!g!!aws%20amplify

What iterations or alternative solutions have you considered?

<u>Hardware</u>

With respect to the hardware, the biggest iteration our product went through was in the microcontroller. The first microcontroller we used was a standard Arduino Uno board. Instead of going through the app via Bluetooth, this iteration of the product simply uploaded the data to AWS S3 using Wi-Fi. We decided to pivot to a BLE Bluefruit board for three reasons.

Firstly, Wi-Fi is much more power-intensive than BLE. Since we wanted to maximize the battery life of our design, it was logical to change the design of the product and make it use BLE to send the data to the app via Bluetooth.

The second reason why we decided to move away from this design is that it required the user to turn on the Wi-Fi hotspot on their phone, which added unnecessary friction to the design as well as increased the battery consumption on the user's phone.

Lastly, the BLE Bluefruit board was significantly smaller than the standard Arduino Uno board, which helped us reduce the size of the final device.

<u>Software</u>

Our app went through several iterations before the final version.

The first iteration of the app was built using Python and a library called Kivy[4]. The members of the team that worked on the app did not have Apple laptops, yet we all had iPhones, which is where we would be testing the app. Moreover, none of our team members had experience with Swift. The first iteration of the app was successfully made into what is displayed in Figure 5. However, the app was no longer useful once we pivoted away from using Wi-Fi to send data to AWS S3 as there were some compatibility issues using Bluetooth to send the data.

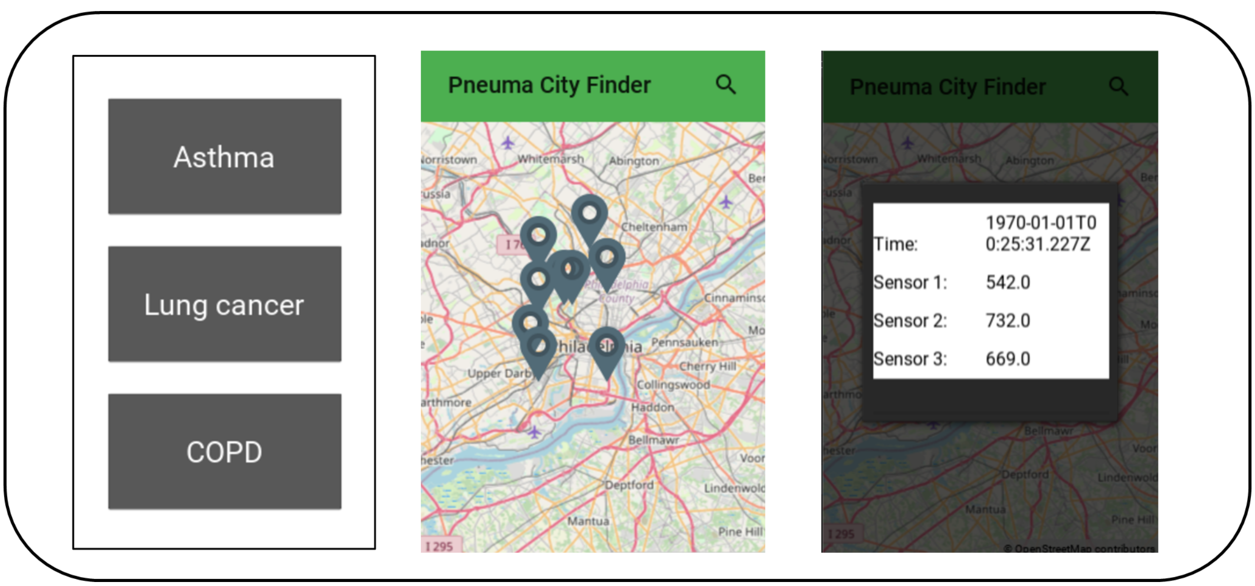


Figure 5. Initial iteration of the front-end application with map visualization.

[4] Kivy: https://kivy.org/#home

The second iteration of the app was made with an SDK made by Google called Flutter[5]. The advantage of using Flutter is that the SDK is compatible for both iOS and Android. The main reason behind this was the difficulty of having to design an iOS app without a Mac. However, the ESE department generously provided a Mac for us to borrow, which is why we finally decided to do the app using SwiftUI (Appendix C-E).

These compatibility issues meant we had to restart the development of the iOS app twice, which had a significant impact on the project. Because of these setbacks, we could not provide each user with the personalized scores we intended to provide when we first started the project.

Societal, Environmental or Economic Considerations

There were two ethical aspects of the product that we were concerned about. The first concern we had that affected the design of the product was user privacy. We knew that, especially at the beginning when few users had acquired the product, tracking live location had some ethical concerns. However, for our design, the identity of the users was not required, which helped with anonymity. In a scalable case, we would have given the users the option to not share the data and have the rest reciprocate (i.e. only if the user agrees to share data does he have access to others' data).

Part of the value of the product lies in the network, and unlike users' agreements with social media platforms, there is a very conscious action by the user when she decides to buy one of these devices, as it is obvious the device tracks location. Furthermore, this device is targeted at a very specific segment of the population (those with pulmonary afflictions). We realize there is a trade-off between utility and privacy, but we would allow the user to choose between them.

The other ethical concern we had was with respect to how the device would be used. We could foresee a scenario where enough data on air quality could negatively affect real estate prices in poorer neighborhoods if the air quality surrounding them was significantly worse. Another concern we had was with respect to insurance companies. If this data were widely known to them, life or medical insurance could become more expensive for those that lived in areas with poor air quality. Unfortunately, apart from not making the data available to non-paying subscribers, there is not much to be done with respect to the design of the product that could prevent these scenarios from happening.

Final status of the project and test results

As was previously shown, the sensors of the device were not very precise. They all have relatively high error rates, and their readings measure relative changes in air concentration of a specific kind of gas. Apart from testing whether the readings changed in different parts of campus, the sensors made it difficult to test their reliability.

[5] Flutter: https://flutter.dev/?gclsrc=ds&gclsrc=ds

Contextualizing Results

The single device we had fulfilled all of its intended purposes. We were able to simulate a network of devices, but without multiple physical devices we were unable to perform extensive stress testing.

Power draw of the device itself including all incorporated sensors and bluetooth transmission equates to less than 600 mA. It is safe to say that a common rechargeable USB power bank (at least 10,000 mAh) will sustain our device for at least 16 hours.

Conclusion

Moving forward, we realize there are a few aspects of the design and the technicality of Pneuma that we will want to alter and improve. First, we would like to find new sensors that are smaller and make the device more portable. One of the judges on demo day recommended the use of spec-sensors. These sensors are the size of a quarter, detect all the necessary information at the same accuracy, but cost $50 each.

During our senior year, we were unable to properly incorporate the personalization and navigation aspect of Pneuma. The personalization aspect can be easily introduced into our existing system by plugging in values into a formula and displaying them. However, we were unable to find sufficient and relevant research to support our intended personalization. Incorporation of a navigation system would require extra systems on both the front and back ends of our app. Our lack of experience with such technologies, specifically in Swift, led to several setbacks which undermined our ability to develop a navigation system.

V. Self-learning

Throughout our senior design, there were several technological features that were unknown to us, but we knew were going to add major value to our product. Therefore, we decided to learn by ourselves the following:

Application Building

None of us had skills building an iOS app that could be connected to Amazon S3 buckets. Therefore, we decided to learn how to navigate around the Kivy library to use it as the platform for our first iteration of the front-end software. Although the application was usable, it was not enough to support the backend data collection aspect. Therefore, we later decided to transition to the Flutter SDK and became knowledgeable with Swift coding to create the final iteration of the iOS application.

Gas Sensors

In terms of the hardware, we had never worked with gas sensors. Although these parts are simplistic in terms of connecting it to the software, we had to revise the documentation of each sensor to understand what each reading meant. We found out that the gas sensors did not provide exact concentration values, but rather relative values that must be converted to concentration units using a calibration curve provided in each documentation. Additionally, we attempted to use different microcontrollers when building the hardware architecture. Although our first idea involved using an MKR WiFi Arduino board to collect and upload data, which some of us had previous experience using, we then changed our board to a BLE Bluefruit. Given that none of us had worked with this board, we had to learn how to use it and how it differed from the MKR WiFi.

Academic Preparation

There were several classes previously taken that gave us a solid foundation towards building the architecture. The course CIS545 taught us the nuances of Amazon Web Services to be able to store such large data into S3 buckets. It also gave us general ideas of the possible ethical standards and compliances for our product in terms of data collection. Also, the foundational courses in computer science were of major help when coding for the iOS application even if the courses were taught in Java rather than Swift. Lastly, our hardware knowledge came from the courses BE309 and BE310, where we had to constantly work with Arduino boards and the Arduino IDE to collect all sorts of medical data.

VI. Ethical and Professional Responsibilities

As previously mentioned, we use the Center for Disease Control as our base when deciding which gasses are the most harmful. We also utilized the American Lung Association to give a contextualization of how large of a problem air pollution and poor air quality are. Overall, we believe that our project serves the purpose of helping the global environment improve its air quality, and gives it a societal component as well considering this will be able to help individuals that have pre-existing lung conditions or are at risk of developing one due to air pollution or poor air quality.

In terms of socio-economic impact, we originally planned to price our product at $149.99 up-front price based on cost and a $4.99 subscription fee to add in order to utilize the customization and data aspect. (The justifications will be discussed in the Business Plan section).We received feedback from judges stating that our price was either (1) too high for people of lower income classes and thus inaccessible to some, or (2) too cheap considering this is a medical product that solves a problem not yet fully addressed. After many more considerations, our Senior Design team believes it is more responsible as engineers to provide a product that is more useful and accessible to all. As a result, we would like to continue our current pricing model. At the same time, we do realize that this does pose a burden to certain groups of people. However, we believe that moving forward, insurance companies would cover the product if the individual deemed it necessary.

From our first resort, we previously have outlined the potential areas where Pneuma could have a negative effect. Three, in particular, come to mind:

- **Data Collection:** Firstly, having data our devices collect publicly available could have a significant impact on real estate prices, which could especially affect poorer neighborhoods. Should a house be found to live in a highly toxic area, we believe its price could drop significantly. As a result, we are not sure if the already biased programs, such as Zillow, will take this information and find another way to manipulate pricing. Beyond this, the issues affecting real estate pricings can lead to further ethical and political problems, as we are unsure whose job it is to help improve real estate prices due to poor neighborhood air quality.
- **Accessibility:** As previously mentioned above, the price for Pneuma, while lower than its competitors, still might impose a burden to certain groups of people that might not have enough discretionary spending. In terms of data collection, we also believe that the data collected from Pneuma could possibly be used by insurance companies to target their customers and charge more for medical insurance to clients who live in areas where air quality is poor, which we think corresponds to lower class neighborhoods. While we have not researched much on the insurance industry, we are unsure if insurance companies will charge higher premiums to those who are in neighborhoods with poor air quality, which tend to be lower-income neighborhoods. This creates a vicious cycle.

- **Accuracy and Durability:** Lastly, on an infrastructure level, it is important to make a device that delivers accurate metrics, and that can be easily maintained. If our objective is to create a network of these devices, the sensors as well as the battery power will have to last a relatively long time. The project will not be sustainable if the sensors need to be replaced every few weeks. Given the concerns we have raised, it is our responsibility to create a product that is precise, so that no misunderstandings occur. We also have to make sure we are accurately recording data, and that our device does not lose its accuracy based on the time of data, battery power, etc.

In terms of attempting to solve the problems posed, we believe that we can implement a method of keeping user data confidential. We believe that live location should not be tracked due to privacy concerns. This is especially important as we pilot the app, where the number of users is low. For this reason, we believe that once scale is achieved, it is best to make the devices send the data periodically throughout the day with a lag, meaning that each device will send the data to the cloud a few minutes after having gathered it. This way, neither we nor any other user can know exactly where each user is and we can preserve anonymity. As for the other problems, we must find a way to help curb any ethical issues, but working with insurance companies and at the local, state, and federal governmental levels are out of our control.

VII. Meetings

We ran weekly meetings to plan and distribute the work for the deliverables. All the team members were able to join either in-person or virtually. This time was also used to discuss challenges faced regarding product design and to make technological decisions as a group. Although most of the meetings were used to brainstorm and set a work plan, we also had four one-hour sessions during Spring 2022 where we worked on the software architecture and installed it to the hardware.

Throughout this semester, we virtually met with our advisor Dr. Cullen to give him an update of our project. At the same time, he gave us feedback on our current status, but also suggested ways on how to design our product in a more user-friendly sense. He also highlighted the limitations of our device and how to possibly overcome these. Dr. Cullen was very excited to envision Pneuma on the market, so he also brainstormed on brand names and logo designs.

Lastly, we also met with some subject matter experts that offered us insight into both the technology and overall demand for a product like ours. Through the help of Dr. Sangeeta Vohra, we got connected to surgeon Dr. Ari Brooks. He shared his thoughts on the possibility of taking this product to the market, and also provided his personal opinion as a doctor who could potentially suggest his patients to use this product. Our team also had multiple discussions with the ESE 451 TA Andrea Yoss about the ethical considerations regarding data collection and the potential features on the application that could enhance user experience.

VIII. Schedule with Milestones

Early on, we decided to create a schedule of the necessary milestones we had to achieve before the end of the semester to consider our device a complete product. Our plan initially involved finishing the hardware first to then work solely on the software. We were trying to have an all-hands-on work on the different components at different times. However, once we began encountering issues with the uploading of the software to the hardware, we had to make several changes to both architectures. By that point, we had to readjust our schedule and milestones. We were able to achieve all but one major milestone: adding weights to the different gas concentrations depending on its damage to patients with different lung diseases. Although this was not achieved, we still completed all other major milestones in the spring semester, as shown in Table 2.

Table 2. Spring semester milestones distributed among team members.

Task	Agustin	Ketan	Longteng	Max	Victor
Add PM 2.5 sensor			15-Feb		15-Feb
Install BLE Bluefruit			28-Feb	28-Feb	
Add GPS component			14-Mar	14-Mar	
Finish user interface through iOS app		22-Mar		22-Mar	
Populate map with randomized readings	30-Mar		30-Mar		
Build casing for hardware	1-Apr				1-Apr

IX. Discussion of Teamwork

Our team decided to divide the work into two categories, hardware and software:

The Systems engineers—Max, Agustin, and Ketan—were primarily involved with the software. This entailed trying out the different software development kits to create the iOS app for the device. Max and Agustin initially attempted to use the Kivy library on Python to create the front-end of the device. However, after creating an application that visually emulated our final product, they found Kivy's latest version did not translate well when converting it to an iOS app. Furthermore, Kivy interacted well with Wifi, but not with Bluetooth. After a second attempt using the SDK made by Google called Flutter, we realized that it would be very difficult to create an iOS app without a Mac. The final iteration of the product in Swift UI was designed by Longteng, Max and Ketan.

The Bioengineers—Victor and Longteng—worked on the hardware aspect of the device. This included choosing the appropriate sensors based on research on the six major pollutants defined by the CDC and the available sensors compatible with Arduino (Appendix F). They outsourced a PM 2.5 sensor that measures particulate matter and included it in our breadboard. Additionally, Longteng added a GPS that tracks time, as well as latitude and longitudinal coordinates to map on the front-end application. Victor designed the casing for the hardware using the Onshape platform and 3-D printing it at Bollinger Digital Fabrication Laboratory (Appendix G).

In terms of administrative duties, Agustin was the one in charge. He coordinated all meetings with the instructors and with other stakeholders that could provide feedback on the product. He also led the creation of the business plan, given that he is a student in the Management & Technology program.

During the last few weeks, our amount of work ramped up. We worked together on integrating all of the project components together. We met and talked about potential limitations, as well as possible enhancements to our technology. Eventually, we all tried playing around with the application to ensure that it was user-friendly, as well as well-designed to display the necessary data.

X. Budget and Justification

Our original budget was set to ~$85.93 for the sensors, given we already had all other required hardware components at our disposal. The most expensive sensor was the PM2.5 sensor, which was $39.95, and the other three were the least expensive. We also had originally budgeted to include the MQ-131 sensor, but opted out of using it, which then decreased our budget for sensors to $55.94. After pivoting to add the Bluefruit Bluetooth Board instead of using wifi, and including the Breadboard cost, we increased our final budget for Pneuma to $77.44.

Additionally, we decided to use AWS in order to help with pushing our data into the cloud. By the end of the project, we had used approximately ~$10 of the $500 given to each group, including some that we funded ourselves while waiting for the AWS credits. As a result, we could update our cost to be ~$87 for the given timeframe. This, however, does change based on the amount of usage of AWS. As a result the $4.99 additional cost each month would be useful to cover that cost.

Table 3. Breakdown of final budget.

Part	Estimated Cost Unit	Quantity	Vendor	Source of Funding	Subtotal
AWS Credits	$10	1	Amazon Web Services	Team	$10
BLE Bluefruit Microcontroller	$17.50	1	Adafruit Industries	ESE	$17.50
MQ Sensors	$15.99	1	Amazon	ESE	$15.99
PM 2.5 Sensor	$39.95	1	Adafruit Industries	ESE	$39.95
Breadboard	$4.00	1	Adafruit Industries	ESE	$4.00
Onshape Account	Free	1	PTC		$0
3D Case	Free	2	Bollinger Digital Fabrication Lab		$0

XI. Standards and Compliance

The intricacies of Pneuma lead it to fall under different categorizations of standards and compliance. The way the team decided to split up these categorizations is under healthcare and data.

Healthcare

Beginning with healthcare, Pneuma can be considered an FDA Class I Medical Device. This due to its lack of risk to the user and non-invasive nature. Staying within the realm of the FDA, we believe that it is important that the Pneuma hardware considers any requirements of the Pre-Market Approval for Medical Devices. However, after doing research, it seems as if Pneuma might not need as rigorous of a pre-approval since it is not a Class III device. Because this is still a medical device, we believe we will still hold a necessary degree of standards before entering the market. Finally, the team looked at the International Organization of Standardization (ISO), which assesses quality, safety and efficiency of products in a business. The three codes that pertain to Pneuma are 11073 (point-of-care medical device communication), 13485 (Design, Production, Installation of Medical Device), and 20417 (Medical Devices). ISO 11073 deals with medical devices that directly exchange data that are networked point-of-care devices. ISO 13485 and 20417 deal directly with medical devices, but 13845 pertains more to the design and the creation of the device, while 20417 pertains to the manufacturing of medical devices. We believe that both of these standards are ones that Pneuma must comply with since we currently are in the stage of being the designer and the manufacturer of the Pneuma device.

Data Collection

When looking at the IEEE standards, we were focused on making sure our classifications were exhaustive of all those pertaining to Pneuma. Because Pneuma is not utilizing the data to make predictions, carry-out decisions or policy (as was originally intended), or to use in collection banks, there were many standards in the IEEE that were not relevant to the current state of the project. IEEE P1752 was one that we found important, which is used for open mobile healthcare, and more specifically for cardiovascular, respiratory, and metabolic health. The purpose of this is to help lower costs of data collection to make biomedically discoveries that help in improving health and disease. Additionally, we believe the IEEE P7002 is also relevant to Pneuma, considering it is the Data Privacy Policy. We have users that are self-reporting data, but at the same time are going outside and collecting data from their surroundings. A few of the important data points that are self-reported by the user in the Pneuma app would be the location of each reading as well as the individual diseases the user suffers from, if they would like to share.

XII. Progress since Fall 2021

By the end of last semester, we had a functioning hardware consisting of an MKR WiFi board connected to three gas sensors: MQ2, MQ7, and MQ135. The board uploaded data to an S3 bucket, and the data was constantly processed in a Colab notebook and displayed in a scatter plot (Appendix H).

This semester, we decided to make several changes to both the hardware and software components of our project once technological hurdles began arising. We restructured the hardware architecture by replacing the microcontroller to one that connected to our software through Bluetooth. This implies that we had to work with new circuitry to connect the sensors to the new board. Additionally, we added the GPS component to the hardware to provide time and position information to plot in the front-end map.

We can definitely conclude that the software was the main bulk of our work for this semester, while we already had the foundation of our hardware since last semester. Our biggest challenge was coding for a completely new iOS app interface that users can log into and have access to the data readings. There were several iterations of the application, therefore taking around 2 months to complete. Lastly, we also worked on the business plan for our project, as well as the design aspect of it by printing a casing for our hardware that can be easily carried by the user.

All of these steps during the spring semester guided us to having a fully functioning hardware that can be carried by the patient and an interactive iOS platform that allows patients to access data in real time and at a granular level.

XIII. Discussion and Conclusion

Throughout the progression of this project, our team faced various challenges and technological problems that we had not yet seen. The first knowledge gap we faced as a group was pertaining to the various particulate matter sensors we needed to achieve the most well rounded and successful product we had envisioned. As none of us come from a strictly pulmonary background, determining what pollutants and pulmonary irritants were most important to consider in our construction was somewhat of a challenge. Given the sheer volume of literature on primary pollutants in worsening pulmonary injury, we found ourselves going in circles at the beginning of the project, with our uncertainty making us hesitant to take a certain path forward due to time constraints. However, through conversations with our Advisor, Dr. Cullen, in addition to continued research, we were able to decide on a core set of irritants that we could base our product around and begin hardware and software development before moving on to testing.

As we continued our development toward a complete product, we faced challenges surrounding both hardware and software implementation. In terms of software, the various frameworks we were using to build our solution were causing issues with compatibility and accessibility across platforms, something we realized was common when utilizing software packages from developers that were intended for all-use-cases. Because of this, switching to a ground up development strategy ended up being the best solution for us, and we believe that we found a software package that suited our needs. In terms of hardware, miniaturization and accuracy were our primary issues. We had determined what needed to be measured and a methodology to make that information accessible, but the sensors we had decided on ended up being suboptimal with accuracy of measurement and were too large for use in our case. Given we wanted to make this device a wearable solution, size was one of our primary concerns and an aspect of Pneuma that we unfortunately could not address in the scope of this project. We did manage to create a portable device, but it was nowhere near the size that we had hoped.

In the future, we intend to address these issues of miniaturization as well as dig deeper into the personalization component of our product. We are proud of our solution as it stands, but there are a couple areas where we expect to make alterations. Beginning with the sensors used and the form factor of our product, we will opt for more accurate sensors with a smaller footprint with the goal of making the device smaller. In this vein, with an adequate budget, a true wearable device is possible, which was our ultimate goal when beginning this project. With better sensors also comes the potential for better individualization. Better measurement of the surrounding environment will allow us to more accurately inform users about their surroundings and whether they are at increased risk for injury given their predispositions. Overall, given the scope of the class and our interdisciplinary approach to Senior Design, we are satisfied with our final product and are considering next steps for the Pneuma device as well as the Pneuma team.

XIV. Business Plan

The business portion of Pneuma consists of two parts: individual consumers and medical consumers. Individual consumers would be able to purchase Pneuma directly from the producers, or in the future through a retail setting, while medical consumers would work with individual patients and insurance companies if the product is recommended through a medical professional.

Value Proposition:

Everyone is vulnerable to lung damage due to harsh chemicals in the atmosphere, and susceptible individuals are likely to encounter complications because of this.

Our goal with Pneuma is to create a physical and cloud based technology solution that accurately tracks and monitors environmental factors that lead to and worsen pulmonary injury. The importance of such an issue stems from a lack of micro-scale air quality measurement systems for individuals with pulmonary disease. Current solutions measure at a very macro level, with AQI being the EPA (Environmental Protection Agency) standard and only having city wide measurements. This solution will be used primarily by individuals with pulmonary diseases, but can also support individuals working in industry jobs with high pollution in the form of a dosimetry device.

Stakeholders:

Pneuma has numerous stakeholders depending on its usage. We have decided to separate them into legislative, medical, and individual stakeholders:

- The legislative stakeholders encompass local, state, and federal lobbiers or politicians that might utilize technology to demonstrate how unsafe the air quality is throughout numerous cities. The device can thus be utilized to lobby for certain bills or as evidence for presence of certain toxic air pollutants in major cities.
- The medical stakeholders include doctors, specialists, insurance companies, and other medical professionals that might prescribe a patient to begin using the Pneuma platform as a way of diagnosing air quality in a person's routine or for preventing lung damage to a patient susceptible to developing certain conditions due to toxins in the air.
- The final portion of stakeholders would consist of users who could purchase the Pneuma platform for themselves or as a gift to use on a daily basis.

Market - Size, Growth, and Opportunities:

According to the American Lung Association, around 37 million Americans suffer from a chronic lung disease. This includes but is not limited to asthma, pulmonary fibrosis, and pneumonia. Globally, 334 million people suffer from asthma and more than 200 million from COPD. The prevalence of these diseases is growing, and the effects of air pollution is becoming a pressing issue for the hundreds of millions of patients affected.

In terms of the SIC system, we are placed under three possible industries: Computer Programming Services (SIC code 7371), Measuring and Controlling Devices (3829), and Orthopedic, Prosthetic, and Surgical Appliances and Supplies (SIC code 3842). However, we largely fall under the first one, as we specialize in hardware plus software solutions driven by data analytics.

The wearable healthcare devices market was USD 16.2 billion in 2021, and it is projected to reach USD 30.1 billion by 2026, at a CAGR of 13.2%. Additionally, the outbreak of COVID-19 has led to an increased awareness of air quality, whether it is from diseases or from air pollutants. Therefore, there has been an increasing adoption of wearable devices to track health data. Also, when analyzing the respiratory disease diagnostics industry, it is expected that the global market will be worth USD 6.7 billion by 2025. There is much demand for health products that can help prevent degrading prognosis of pulmonary diseases, and a lot of capital is going towards solutions worldwide.

Customer Segments

We are primarily targeting people with pulmonary diseases who tend to circulate in outdoor environments. The Pneuma portable device is intended to allow patients to travel around without the fear and risk of hurting their health by inhaling air pollutants. In the presence of toxic pollutants, the Pneuma app automatically advises users to use a mask or potentially provides alternative routes to a desired destination. We are targeting all ages, but expect middle-aged workers to adopt the product the fastest because they are more sensitive to pollution than kids, and they move around more than elders. Another potential customer segment would be governmental and federal institutions that can benefit from such data for regulatory purposes. This includes agencies concerned with air pollution for the health of the community and for the wellbeing of the environment.

Competition

One of our most notable direct competitors is Purple Air, a for-profit company that specializes in air quality monitoring systems, and BreezoMeter, which is the service used by Apple on its weather application.. PurpleAir’s product consists of fixed sensors that measure airborne particulate matter in real time. Its value proposition lies in using laser counters to count the number of particles by sizes ranging from 0.3 to 10 μm and its ability to log data with or without WiFi connection. The majority of its customer base lies in government air districts and commercial organizations. This competitor effectively tracks pollution both outdoor and indoor and builds a comprehensive map with AQI and exposure information. However, it lacks portability and a recurrent revenue stream associated with data services, as its map can be visualized by anyone. As previously mentioned, the Breezometer service used by Apple does not offer a comprehensive look into the air quality beyond the AQI.

Our indirect competitors are companies that specialize in air quality tracking, yet their core product does not rely on a network of sensors. AirNow is a centralized data system for recording air pollution at a local, state, national, and worldwide level. Rather than selling hardware, the company offers air quality reports and forecasts. Although not in the hardware game, AirNow's mapping software still serves as a substitute for the Pneuma device. The company has created strong partnerships with government institutions, including the U.S. Environmental Protection Agency and CDC. However, its mapping algorithm does not provide granular measurements of gasses beyond ozone and particulate matter. AirNow is not limited to only tracking air pollutants, but also tracks wildfires and educates on how these environmental changes affect the community.

Revenue Model

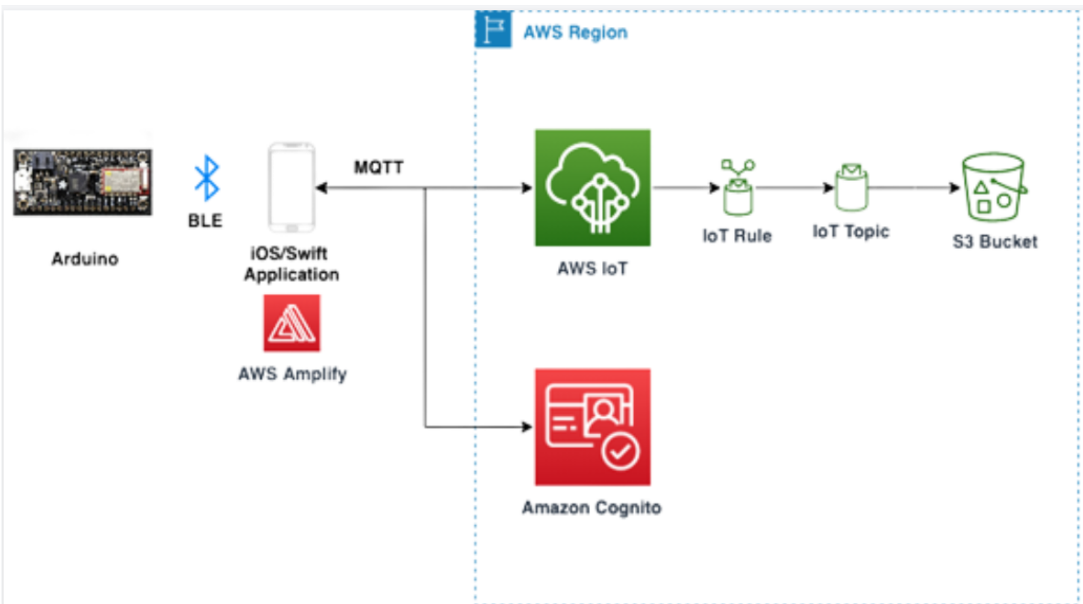
The team has decided that a subscription and cost-based pricing strategy is the best route for Pneuma. We believe our revenue model would follow a razor-razorblade model, where one pays a flat fee for the Pneuma device and then pays a subscription fee to access the data. After exploring our cost model in the previous section, we believe that consumers should pay a maximum of $149.99 for the Pneuma device, and then a $4.99 subscription fee per month.

With the addition of new features into the application and to the Pneuma device, we hope to be able to increase the subscription fee per month.

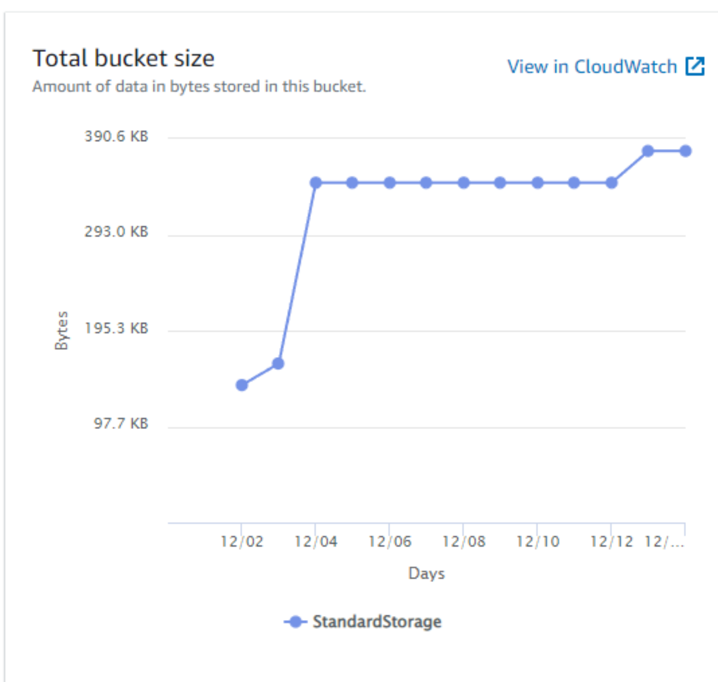
XV. Appendices

place detailed drawings, code, circuits and the like here and refer to them in the body of the report.

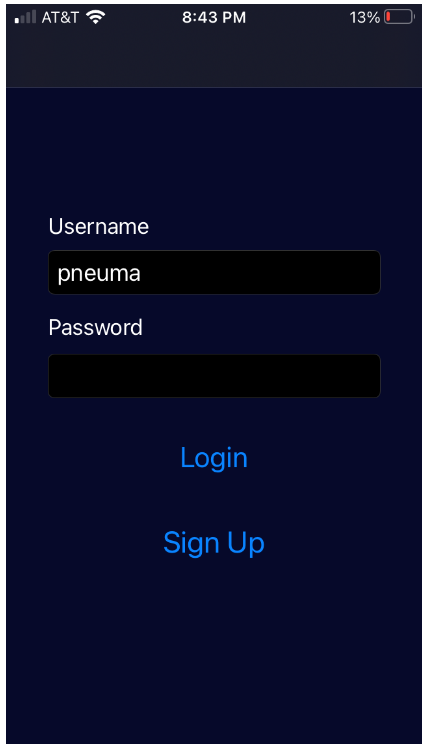
Appendix A: Flowchart of Final Architecture



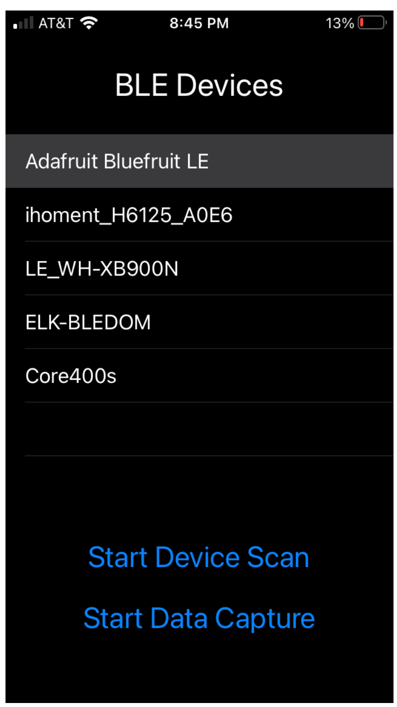
Appendix B: Historical bucket size in Amazon S3 in first demo day



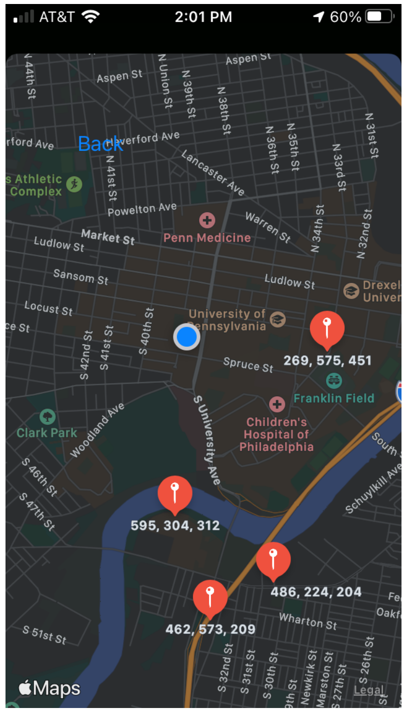
Appendix C: Sign-in Page



Appendix D: Setting up the Bluetooth connection



Appendix E: Interface of the Application

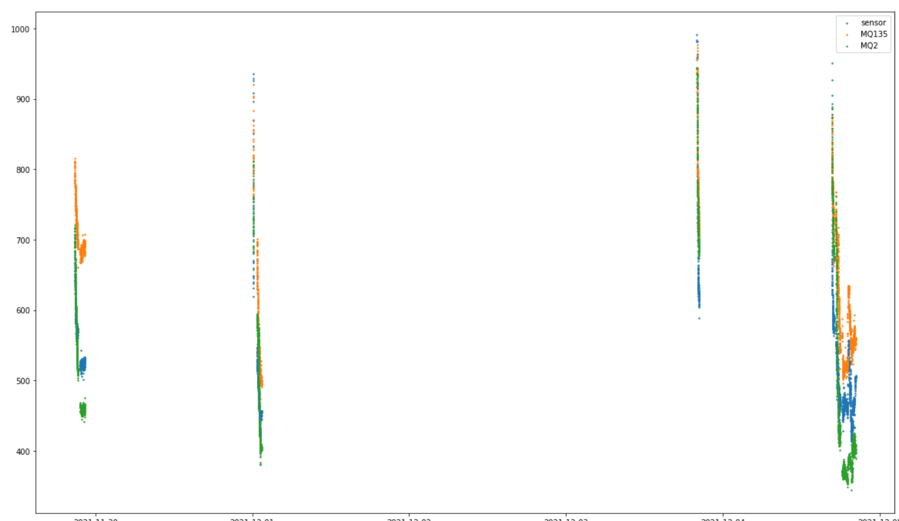


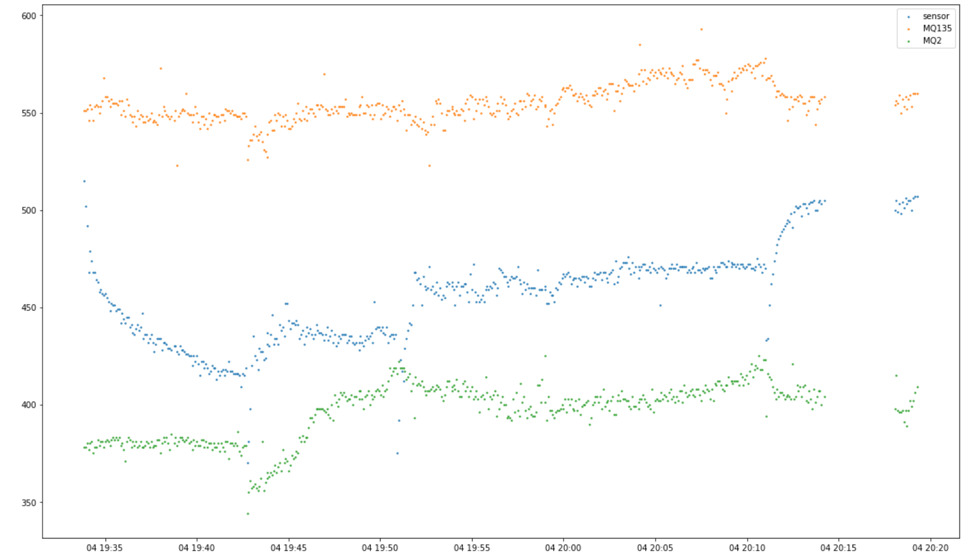
Appendix F: List of potential gas sensors for hardware

Part	Function
MQ2	**H2, LPG, CH4, CO, Alcohol, Smoke or Propane**
MQ3	Alcohol, Benzine
MQ4	Methane, Natural Gas
MQ5	LPG, natural gas, town gas
MQ6	LPG, iso-butane, propane
MQ7	**CO**
MQ8	H2
MQ9	CO, coal, liquefied gas
MQ135	**NH3, NOx, alcohol, Benzene, smoke, CO2**
MQ131	Ozone
PM 2.5	Dust & Particulate Matter

Appendix G: Top of 3-D Case

Appendix H: Data readings represented in plots for the 3 MQ sensors. We later had to interpret this data into benchmarks and map locations with their respective readings.





Appendix I: Link to Kickstarter video

https://www.youtube.com/watch?v=C2V0O1vgovI