Research Proposal for a Low-Cost Portable Air-Quality Sensor System

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ABSTRACT

A low-cost portable sensor system allows users to monitor the different components of the air quality around them. There is a need for a sensor system like this because of the millions of deaths and diseases that occur every year due to air pollution worldwide. My planned contribution is for the prototype sensor system I design and build to be as DIY (do it yourself) and low-cost as possible while still being usable in a theoretical online network for large-scale pollution mapping in real time. I will program the sensors together and investigate the calibration of the sensors because they can fall out of calibration after extended periods of time. I will evaluate the results of my experiment of building and using the sensor system by: the robustness of the system indoors and outdoors, analyzing the repeatability of the experiment, analyzing how the system could further be improved for ease of access to users financially, system portability, and how well the network abilities of the sensor system allow for mapping of data.

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1 INTRODUCTION

The quality of air that we breath directly affects our health, and the majority of the time that poor or harmful air quality is inhaled, we do not realize it. The World Health Organization (WHO) reports that 91% of the world's population (7.18 billion people) live in areas where the air breathed exceeds WHO guideline limits of air pollution, and over 7 million die every year from health issues created or made worse by continuous inhalation of air pollution [13, 18]. Air pollution is linked to one-in-eight deaths world-wide [13]. The vast majority of deaths linked to harmful air quality are from cardio-vascular diseases including ischaemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and acute lower respiratory infections in children [13]. The effects of pollutants are even stronger on children, the elderly, immune compromised people, pregnant women, and those who already have some respiratory illness [19].

The overwhelming majority of people who live within the highest polluted areas are of low or middle income [18]. There is a great need in the world for a low-cost portable air quality sensor system to help people who are affected by dangerous air quality [10]. The system needs to be inexpensive so that as many people as possible are able to afford and make use of the system. Because of the heterogeneous nature of air pollution, especially in areas of increasing urban density, there is a need for a massive increase in the density of stationary sensors, or in this proposal, the need is for a huge increase in the density of portable mobile sensors. If the systems are portable, the sensors can be more of use to the user while still remaining useful for others in the area around them. Stationary sensors are also not able to read the air quality inside buildings, where people spend most of their time, while a personal portable system would be able. Stationary sensors are able to read areas around them in high accuracy, but only up to a certain range. The range depends on where the stationary sensor is located, but is not enough for areas containing hot-spots of high concentrations of pollution under 100m in diameter [6]. These hot-spots can differ from areas nearby them by magnitudes of 1.5 to 8 times the pollution levels than at the stationary sensor within 1 km of the hot-spot [6]. Hot-spots come from rush-hour traffic and, specifically, from medium/heavy-diesel trucks that produce heavy exhaust particles that do not rise into the atmosphere as fast or high as exhaust from gasoline vehicles [6, 27]. The pollution from traffic is not just from exhaust emissions however, but also from brake wear and tire wear on the road that causes a lot of particulate matter to float in the air [6, 7]. The amount of wind or airflow on the roads influences how dense pollution levels are - during peak travel times, cars idle longer in dense urban areas causing pollution density to rise [7, 16].

The system should be made of a number of air quality sensors, each measuring a main quality of the air around to determine if the quality of air is safe, these will include measurements of particulate matter, volatile organic compounds, carbon monoxide/dioxide, temperature, humidity, barometric pressure. The uses for such a system of sensors and network are life-saving for the individual because the user can be alerted if the air surrounding them is harmful, such as high levels of carbon monoxide, or if they have been exposed to high pollution levels over extended periods of time, days or weeks. Additionally, if the sensor systems can be networked through smartphones and servers for visual mapping of air pollution relative to location, they can work to save the lives and health of those that do not have the system themselves as long as they have the app and are near users with sensor systems.

Pollution, sensors, and networks are discussed in the Background section. It lays out what goes into creating a sensor system, what

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the system should be able to detect and why, and how a network of sensor systems is possible.

The Design and Implementation section explains my plan to make a sensor system on an Arduino board using a particulate matter sensor, multiple gaseous sensors, and a sensor for temperature, humidity, and barometric pressure. The system will include a particulate matter sensor for micrometer sized pollutant particles in the air, gaseous sensors that can detect various gaseous pollutants in the air, and a temperature/humidity/barometric sensor that will aid in calibration and data analysis. The system will operate through smartphone connections for users to monitor pollution levels. The system will be accessed in network capabilities as to the plausible future improvements on the system post-CS488. If I am able to create a working physical version of the sensor system, I plan on evaluating it against stationary sensors to determine its accuracy and calibration reliability. If I am not able to create the working physical version of my sensor system design, I will evaluate the system through analyzing the pros and cons of it and its practicality. I will code the system using the tools available online to aid in time efficiency to get the most out of the testing of the system and risk management.

The paper ends with a discussion of risks and a timeline. The Major Risks section outlines the inherent risks that are a part of this research and experiment. In the Major Risks section I also lay out the plausible pitfalls that could happen and what my plans are for them. The timeline I will follow is presented in the Timeline section.

My research question is: what are the strengths and weaknesses of this particular prototype system, as a means for citizens to get a sensor system that can work with a network? This will produce my contribution to science as a form of helping find solutions to our air pollution crisis, specifically:

- A DIY prototype system that can measure air quality and pollution
- Analysis of the prototype system capabilities indoors and outdoors
- Analysis of plausible system network design and system implementation
- Discussion of miniaturization of the system for further prototypes

2 BACKGROUND

There exist many pollutants in the air that we breathe, they mostly come from similar categories of sources, such as industry and transportation. Major pollutants include:

- carbon monoxide from burning of fossil fuels [1]
- volatile organic compounds (VOCs) commonly emitted from industrial areas from the production of paints, pharmaceuticals, and refrigerants. compounds such as oxidants, byproducts of water chlorination, and solvents [5].
- ozone from the mixing of nitrogen oxides and VOCs [2].
- sulphur dioxides, also from burning fossil fuels [4].
- particulate matter of sizes between one and ten micrometers, the majority of the most dangerous being around two and a half micrometers, that come from any sources that produce smoke, dust, aerosol chemicals, or nitrogen oxides which combine in the atmosphere into hundreds of different dangerous aerosols [3].

2.1 Sensors

A variety of sensors would need to go into a system that would be able to detect all of the most common types of air pollutants while remaining portable and wireless.

2.1.1 Particulate Matter Sensors:

There should be a sensor that could detect particulate matter (commonly referred to as PM) of sizes down to 2.5 micrometers or lower. This is due to the fact that particulate matter of this size or smaller enters the lungs and is able to enter the blood stream more easily than larger size particles and the size of the particle makes it impossible to detect by eye [3]. Particulate matter makes up the smog and haze that you see over cities [3]. There are two main types of PM sensors:

(1) **Light Scattering Particle Sensors:** These run off of a small laser or some other light emitting source, such as an LED, and a light receptacle that light beams into. Particulate matter floats through the beam of light, causing the light receptacle to be able to sense the amount and size of particles based on the light blocked and how it is refracted [9, 12, 14, 15, 17].

(2) **Diffusion Size Classifiers:** These use a sensing surface and send electrical signals through the surface to identify changes on the surface. There is a multi-step process that the air goes through when it enters the sensor chamber. The air passes through a chamber called a diffusion charger that uses a corona wire to produce ions that then attach to particles in the air. The charged particles then pass through to an induction stage that measures their charge, which is a direct proportion to their concentration. The particles then pass into a diffusion chamber that precipitates the particles to produce an electrical charge that is proportional to their concentration. Large particles that do not precipitate then are measured for their charge and concentration at the end of the sensors measuring. The way that the particles pass through the sensor allows for their size to be determined [9].

2.1.2 Gaseous Pollutant Sensors:

A gaseous pollutant sensor is another key sensor for the system. This kind of sensor is different than a particulate matter sensor because it is detecting a gas rather than an aerosol, meaning the gas is in a mixture in the air rather than small particles suspended in gases in the air. [9] This causes the gases to not be detectable in the same way as the particulate matter is. There are multiple different sensor techniques when it comes to gaseous sensing:

(1) **Metal Oxide Semiconductor:** Commonly known as MOS or MOX, this kind of sensor works by having a heating element and a metal oxide sensing element contained inside an enclosure that allows it to be carried on a person. The heating element heats up the sensing element to operating temperature (300-500 degrees F) where the gases coming in contact with the sensing element to chemically react. The reaction causes the change in the electrical conductivity on

Particulate Matter Sensors Pros and Cons	
Pros	Cons
Light scattering particle sensors are small, low-cost, and require low power [9, 12, 14, 15, 17]. They are better equipped for outdoor use because, compared to the competitor, it does not have to be cleaned nearly as often.	Temperature and humidity affect the accuracy of the sensor as the sensor detects water vapor as particulate matter [9, 12, 14, 15, 17].
The **diffusion size classifier** has a higher accuracy than its competitor [9].	The sensor has a high production cost and the frequency of having to clean the sensor surface makes it more difficult for users [9].

Table 1: Pros and cons of particulate matter sensor types.

the sensing surface which is read by a external circuit to determine gas levels and type. Usually MOS sensors can detect carbon monoxide (CO), carbon dioxide (CO2), non-methane hydrocarbons (NMHCs), nitrogen oxides (NOx), ozone (O3), and many combination of NOx and O3 [9, 15].

(2) **Electrochemical:** Commonly known as EC, this kind of sensor works by having at least two electrodes near each other. One of the electrodes is working and the other is the counter. As gasses pass by the working electrode, they cause a chemical reaction on the surface of the working electrode that causes an electrical charge to be formed. The charge is directly proportional to the gas concentration. EC sensors usually detect NOx, CO, CO2, O3, and sulphur dioxide (SO2) [9, 15].

(3) **Non-Dispersive Infrared:** Commonly known as NDIR, inside the sensor there is a chamber where infrared light is shined onto a receptacle where gasses pass through the beam. The gasses absorb some of the energy from the light and changes the frequency of the light as it hits the sensor surface. The frequency is sent out in electrical current. This determines the gasses by detecting how much energy has been absorbed and how much gas concentration there is. NDIR sensors usually detect CO2, but can detect other gasses by the wavelength of the light that is received if tuned and calibrated properly [9].

(4) **Photo-Ionization Detector:** Commonly known as PID, UV light shines through the gasses as they pass by, which ionizes the gasses. The gasses can be read as electrical current when they collide with a detecting surface inside the sensor. The resulting current detected measures direct proportional to the amount of gas, the PID sensor can detect any gas whose photo-ionization potential is lower than the UV light hitting it - this means that it is not specific to any particular pollutant [9].

The MOS's con of power-draw, as seen in table 2, will most likely be fixed through future sensor development and better battery technology. Additionally, the accuracy drift can be fixed by regular calibration - which requires the system to have humidity and temperature sensors [9].

Gaseous Sensors Pros and Cons	
Pros	Cons
The **MOS sensor** is the best suited for a low-cost portable air quality sensor system [9, 15]. This is because of its high sensitivity, resistance to environmental effects such as temperature and humidity, and short response time creating high frequency of data [9].	Its power-draw and accuracy drift causing bad data [9].
The **EC sensor** is a sensor that is commonly used because of its high sensitivity and low cost, but it is used less often than the MOS sensor. They have less power-draw and are less affected by humidity and temperature than the MOS [9].	Has a slower reaction speed and other gasses affect the measuring abilities of EC sensors more than MOS sensors [9].
The **NDIR sensor** is a good quality gaseous sensor that is small, reliable, and has little power-draw [9].	They are not sensitive to low concentrations of gas and are very susceptible to water vapor and accuracy drift as well as costing multitudes more than both the MOS and EC sensors [9].
The **PID sensor** is small, has low power-draw, is very sensitive to gas levels and has a fast response time [9].	The sensor needs to be recalibrated more often than the EC sensor, it is prone to accuracy drift, it is susceptible to high humidity and water vapor levels, and it costs multitudes more than the MOS or EC sensors [9].

Table 2: Pros and cons of gaseous pollutant sensor types.

Besides the sensors that are required to detect harmful pollutants in the air, there are needed sensors that can determine qualities of the air in order to better optimize the sensor system's function.

2.1.3 Additional Sensors

Humidity Sensor: A sensor that would be able to detect humidity concentration is another crucial part of the sensor system because humidity has been shown in studies to have a major effect on the accuracy of PM sensors and other air quality sensors in high levels [9, 12, 14, 22]. If calibrated correctly and with a sufficient algorithm, knowing the precise humidity at the sensor system can help the other sensors be more accurate in measurements.

Temperature Sensor: A temperature sensor would be needed for the sensor system. This is due to the temperature having a direct affect on the ability of the sensor system to calibrate and maintain calibration. Extreme temperatures have been shown in studies to have a direct affect on the accuracy of sensors while operating and their ability to re-calibrate. [9, 11, 14, 22, 24].

2.2 Battery and Bluetooth

Battery: The system I plan on building will require a battery that can last for at least 24 hours of constant usage. It will be easiest for users if the battery was rechargeable, and if the system can be used while charging. However, the battery cannot have just a large capacity, but it also needs to be as lightweight as possible for user convenience.

Bluetooth: The Bluetooth transceiver needs to be able to transmit sensor data from the sensor system to a smartphone or laptop, very similar to a smartwatch, and receive calibration updates from the smartphone or laptop. Bluetooth 5.0 is the newest version. It uses the least power and can transmit the most data per second of any Bluetooth version.

2.3 Network and Calibration

The sensor system would not be nearly as effective for users and non-users without a proper connection to a smartphone and server-side network system that recalibrates and gathers air quality data. The network applications will take in data from the smartphone connected to the sensor system and then apply it to a map that would track the location of dangerous air quality levels in real time. The sensors (often referred to as nodes) need to be recalibrated at certain time intervals (weekly, bi-weekly, or monthly). This could be done through varying calibration techniques:

Pairwise Calibration: This calibration technique uses two different sensors, a reference sensor and a node that is going to be calibrated. This technique is also referred to as **collaborative calibration, collaborative multi-hop calibration, rendezvous calibration, and opportunistic calibration**. The node is calibrated using the reference sensor. This technique can use non-reference nodes as reference nodes if they are calibrated accurately off of a reference node, or it can use a stationary sensor that is pre-calibrated to be the reference sensor. Then the mobile nodes that are within close vicinity of the now calibrated mobile reference node calibrate off of that node and become reference nodes themselves [9, 11, 15].

Pairwise Calibration Shortcomings:

(1) Pairwise calibration can propagate errors across nodes. Because of the way that the referencing system works, errors made by one node can propagate to nodes that calibrate off of the erroneous reference. This can cause a wave of errors that would need to be fixed manually through some other calibration form [11, 15].

(2) The last big hurdle for pairwise calibration is for sensors is non-linear calibration. This means that sensors that are not the same build, or have a different environmental interaction, would be more challenging to accurately calibrate using pairwise calibration. This is because of how they differ in interacting with environmental stimuli and could propagate more errors or cause the node calibrating to become less accurate than before calibration [11, 15].

Macro Calibration: For this technique, all sensors on the network are calibrated at once using the same calibration algorithm without the nodes interacting with each other. For example, all sensors in the world would receive the same calibration, whether the sensors were on top of Mt Everest or in the Amazon Rain Forest. This is also referred to as **blind calibration** as the nodes are blind of one another when being calibrated. Macro calibration is not commonly used if the amount of sensor systems is large or if they are spread far apart in different climate areas [9, 11, 15].

Macro Calibration Shortcomings:

(1) One of the main drawbacks to macro calibration is the lack of fidelity due to the environmental differences between sensor nodes if they are spread over a large area. For a macro calibration technique to work, it requires a large amount of data from a large amount of densely populated sensor systems to create the calibration function that would be applied to all sensors equally [9, 11, 15]

(2) In the papers reviewed for this literature review, it is discussed that macro calibration is only really successful using a function that adjusts for data offset in the sensor systems [9, 15]. Although, it should be possible, if combining calibration techniques, to use macro calibration as a distribution form rather than the basis of creating the calibration function [11].

Group Calibration: This calibration technique falls between the pairwise and macro calibration techniques. The sensor nodes are grouped based on categorical qualities, such as location, or if they contain sensors that detect specific things, and then macro calibration would be applied to all nodes in the group. For example, all the sensor systems on Earlham's campus would be one group that would be macro calibrated, and every sensor on campus would have the same calibration algorithm. This is also considered to be **partially blind calibration** because the groups are blind to one another while those nodes inside each group are not blind to each other [11].

Group Calibration Shortcomings:

(1) Because group calibration is a combination of pairwise and macro, the disadvantages of both strategies are taken into account. Group calibration requires sensor systems to be near each other in some form of relatively similar environment for the macro calibration to have a positive effect. However, because the group calibration technique uses interactions between sensor systems to determine the calibration function, it diminishes the disadvantage of small environmental changes between the sensor systems [11]

Transfer Calibration: Transfer calibration is a technique that has been implemented inside factories where electronic noses (e-noses) are used to detect gasses and chemicals in the air and differentiate what gas it is measuring to the user. The technique is to develop a calibration function that uses data from typically one control sensor that is in proximity to the other sensors in a factory to calibrate all nodes [9, 15]. In order to adapt this to for general use, the calibration function would be developed so the nearby nodes are calibrated off of the control sensor calibrated with a neural net function. The neural net functions are built off of years of air quality data from stationary ground sensors to best calibrate the sensor for the area that it is in based on previous years' data. For the continuing neural net function, it would be fed data from in use sensor systems to build and adapt the calibration so that the future systems in a specific area would be more easily calibrated. This would reduce the need for new data moving forward to make changes to the calibration function. This kind of neural net machine learning technique is called transfer learning and it is theorized that it can be adapted to general outdoor use for sensor systems [9, 15]. With a proper calibration technique (most likely using a neural network working with transfer learning/calibration), it is possible for a sensor system to be able to determine the gases and particles that it is sensing in the air from the interactions between all sensors in the system - similar to an electronic nose [15].

Transfer Calibration Shortcomings:

(1) Transfer calibration generally assumes that the accuracy drift in nodes is equal to the accuracy drift of the control sensor. In real world applications, this is most likely not the case for nodes because of the variety of micro-climate shifts [15].
(2) Environmental interactions are assumed to be equal across different nodes. This could be the case if all the sensor system nodes were identical, but most likely there will be some interactions with the environment that are different between the same nodes. This could be due to age of the sensor system, or due to the user not cleaning the sensor if it needs it, or some other standard condition that happens with time [15].

A disadvantage all techniques, with the exception of macro, face is that the nodes need to be in close vicinity in order for the calibration to happen. This can cause nodes that are farther away from the others to go uncalibrated. The disadvantage could be mitigated if there were a large enough amount of nodes for rendezvous points to occur frequently for calibration [11, 15]

From the studies discussing sensor calibration reviewed, it appears that no one technique for calibration accounts for all environmental discrepancies between sensor nodes. I suggest the best way for a low-cost portable air quality sensor system to be implemented and optimized is for a calibration and network technique that uses pairwise, group, and transfer forms of calibration in different situations where the best calibration option can be chosen based on the users environment and the density of systems and reference stations nearby.

3 DESIGN AND IMPLEMENTATION

The sensors for the system will include a gaseous sensor and a PM sensor - these will be used for measuring air pollution. Sensors for humidity, temperature, and air pressure will be needed for calibration purpose and will help with data analysis by allowing data from the PM sensor to be interpreted as water vapor or dangerous particulate matter. A Bluetooth transceiver is needed to send data to a smartphone or laptop to be viewed on an API. This is all subject to change as experimenting will be a part of the research in CS488, but I will spend as much time as I can over winter break learning for the spring semester. The sensor system should be built on a easy DIY platform. I plan on using an Arduino board that can support the three sensors categories (particulate matter, gaseous, and additional) and the Bluetooth transceiver. The specific sensors I plan on using are:

- **Particulate Matter Sensor:** PMS5003. This is a generally low-cost light scattering particle sensor that can be found for under $20 online. It can measure particles of sizes between 1 and 10 micrometers with an accuracy of +/- 10% for extended periods of time, and it is listed as having a long lifespan [8, 23].
- **Gaseous Pollutant Sensor 1:** MQ135. This is a very low-cost MOS sensor that can be found under $10 online. It specializes in detecting multiple gases including: NH3, NOx, alcohol, Benzene, smoke, CO2, and more. It detects most gases with high sensitivity and accuracy, according to the manual, and has a long lifespan in practice [25].
- **Gaseous Pollutant Sensor 2:** MQ131. This is a sensor for detecting ozone in the air. It can be found for under $20 online. It can detect ozone from 10 to 1000 ppm ozone. It is supposed to be reliable and easy to set up [26].
- **Additional Sensors:** BME280. This sensor is for measuring temperature, humidity, and air pressure. It is extremely low-cost, it can be found for under $5 online. It is very easy to incorporate with the Arduino board and should be as accurate as needed for a sensor system [20].

The plan is for the entire sensor system to be as small as possible for convenience for the user. Miniaturization of the system would also serve as a marketing point to get more users for the theoretical pollution-over-land mapping network. The system will have a battery for continuous monitoring that is not too heavy or too large in order to better reach the goal of miniaturization.

- **Battery:** the battery is one of the biggest hurdles in creating a system that is low-cost, lightweight, and small. From my findings, there are two ways of going about this issue: either creating a small rechargeable battery pack using small batteries, or finding a small low-cost portable rechargeable battery pack online. From my findings so far, it seems that battery technology might not be up to par for the system that I am trying to create and will have to remain a theoretical topic for my research.
- **Bluetooth:** DSD TECH HM-19. This is a small Bluetooth 5.0 transceiver that operates with the Arduino platform. It can be found for under $10 online and it will be able to handle the data sending and receiving to a smartphone or laptop. It has encryption capabilities and a large range as well for user security and convienience [21].

The calibration for the sensors on the system will be handled once the system has been constructed. The calibration will be done, when necessary as the sensors come from the factory pre-calibrated, by using measurements from controlled environments against high-quality measuring devices and using documentation provided by the sensors' manufacturers.

The board will be evaluated for accuracy, reliability, battery life, portability, and general robustness in outdoor environments against other similar sensor systems such as stationary sensor monitoring stations that are built to continuously monitor air quality in the location they're built. My sensor system will be evaluated for accuracy by testing pollution levels in a controlled environment against reference sensors that are already proven accurate. The system will be evaluated for reliability by its ability to be carried in the outdoors for extended periods of time (more than one hour) and not have calibration drift or accuracy loss. The system's battery life is pretty straight forward to evaluate as it should be able to be used for over six hours straight. The portability of the system is also straight forward as the smaller and lighter the system is, the better portability it will have. The system's robustness will be a measure of how much of the pollution in the air is actually measured. The data from the stationary sensors is gathered online and stored daily for free access to anyone, making it easy to compare or use if I am not able to physically build the system.

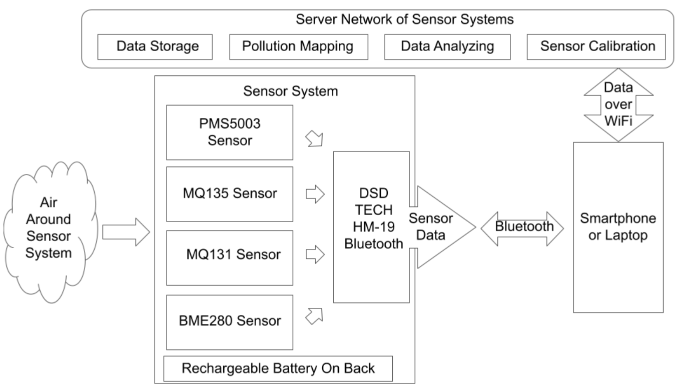

Figure 1: This is a figure of the data transfer path for the sensor system, it does not perfectly represent the physical design of the sensor system but rather the components and how they interact with each other.

4 MAJOR RISKS

There is a plausible chance that I will not have the resources to physically build the sensor system I plan on and therefore not be able to test it. If this is the case, I will design the sensor and talk about its benefits to creating a low-cost air quality sensor system for users. I will also go into how it could theoretically be used in network with similar sensor systems and how such a network would be structured and designed. There is also a major risk that the sensor will not function in the way that I am predicting it will - as in the system not detecting the proper compounds in the air, or not proving the data needed to make judgements about air quality. To help mitigate this, I will continue researching thoroughly the sensors I will use, but the risk of the system not functioning as predicted is still plausible. Another risk is that the sensor will not be practical to be portable for users, this is something that cannot really be mitigated without a industrial factory to create all the necessary components to fit into the sensor system or the advancement of DIY electronics. Another very plausible risk is that the sensor system will not be robust in working outdoors, most air quality sensors designed and sold are built for indoor use and not outdoor. There is no way to mitigate this risk either besides just getting sensors that should work outdoors.

Progress	Point in Time
• Get all hardware necessary	Week 2
• Sensors on Arduino board • As much done on first draft of paper as possible	Week 4
• Work on code for sensors • Work on coding data from sensors to interact for air quality analysis	Week 5
• Sensors coded and working on calibration • Start working on data analysis • Another draft down for paper	Week 6
• Work on getting the sensor system ready for field testing • Do controlled environment tests with sensor system • Make sure calibration for sensors is good • Make optimizations in code for field tests • Keep working on paper	Week 6 - 8
• Start field experiments with sensor system • Analyze data from field tests • As much revisions with paper done as possible	Week 10
• Have enough field experiments done to make conclusions and work on poster • Evaluate network capabilities	Week 12-14
• Finish paper and poster	Week 14 - End

Figure 2: This is a figure of the timeline I am going to follow in CS488.

5 TIMELINE

My timeline for this project is by week two of the spring 2022 semester, I should have gathered all the necessary hardware for the sensor system. I should have the sensors connected to the Arduino board and have as much done as possible on my first draft of my paper within the first four weeks. On week five, I should be working on the code for each sensor and working on getting the data from the sensors to interact for air quality analysis. By week six, I should have the code for all of the sensors complete for them to function and be working on getting the data compiled from the sensors ready for analysis and have another draft down for my paper. Week six through eight I should be working on calibration and optimizing the sensor system for field testing. By week ten, I should have been able to: test the sensors in controlled environments, make sure they are calibrated, and be ready to start field experiments. At this point, I should also have the majority of my paper finished with as many revisions as possible down. Weeks ten through fourteen should all be focused on field experiments and data gathering with analysis for evaluation. By the end of week fourteen, I should have been able to do enough experiments with my sensor system that I can start making conclusions about the practicality of the sensor system and plausible network interactions. The final three weeks of the spring 2022 semester will be revising my paper and finalizing the conclusions of the experiments and plausible network applications.

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