Citizen Air Quality Sensor

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***Abstract*—Finding air quality data on general regions is simple and readily available to the public; however, procuring data for a local area can be challenging. This paper proposes a new device capable of sampling desirable air quality data. The device will be intended for use by local citizens, communities, or researchers with limited electrical engineering knowledge. This paper will also discuss why air pollution should concern the modern world and how its current technology can be used for this project.**

Keywords—Air Quality Sensor, Replicable Sensor Design, Community Atmospheric Science, Air Pollutant Sampling, Modular Sensing System Architecture

I. Introduction

Pollution is a matter that should be fully recognized by society. Air pollution at high levels can cause a variety of adverse health risks. Some examples include heart disease and lung cancer [1]. Even with knowing this, most people don't look into how pollution affects them in their community. The team's goal is to allow people the option to see what pollutants affect them in their communities. The objective is to create an easy-to-use, solar-powered, easily replicable, and low cost modular system that uses multiple sensors to gather data on different pollutants. The data will be easily accessible online for users to decide how to combat pollution in their community..

II. FORMULATING THE PROBLEM

The modern world has sometimes experienced unhealthy or even deadly levels of pollutants in the very air humans breathe [2]. Finding local information on air quality is based on algorithmic calculations [3]. There are plenty of resources to make guesses, but accurate air quality measurements are challenging to come by despite the technology in some forms. Services such as weather apps on phones and PCs (Personal Computer) give information about air quality and primary pollutants; however, this is based on an average of sensors placed around a large area such as a county [4]. It is this averaging that does not allow for true readings from any arbitrary chosen location. These currently used apps and algorithms will not do the job for a single person or community attempting to gain information from a specific location and those who would like only to gain information about certain pollutants that may not be commonly measured. The obstacle for local measurements of very customized intakes is that the technology may exist, but it is not compiled to fulfill this need.

A. Background Information

The background check includes air quality sensors themselves, the effects of contaminated air, and how expected values are obtained.

Air contamination refers to chemicals or particles in the air that can harm the health of humans, animals, or plants [7]. Common qualities to measure are carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide [8]. Particulate matter (PM) is of interest given the area of testing is Cookeville, TN as PM 2.5 is a common type of air pollution found in the area [9]. Knowing this, there are a great many health concerns that could be revealed when testing the air quality. From the National Geographic team, "Long-term health effects from air pollution include heart disease, lung cancer, and respiratory diseases such as emphysema. Air pollution can also cause long-term damage to people's nerves, brains, kidneys, liver, and other organs. Some scientists suspect air pollutants cause birth defects" [1]. If the proposed device can reveal these pollutants in local communities, many could be saved from undesirable health risks or even death.

Air quality sensors are devices used to detect levels of contamination in the air [5]. The inner workings of air sensors vary widely, from lasers that measure the size and number of pollutants to the ultrasonic disruption from sending out sound waves that bounce off pollutants, counting each bounce as another pollutant to add to the total [6]. The sensors take their measurements and then convert them to an electrical signal regardless of the method the data was gathered [6]. It is here where the proposed device comes into play to read this electrical signal to convert it into an easier-to-read format. So, knowing how the sensor functions are essential, but for the interest of the project, the conversion and formatting are the focus.

The U.S. government and some companies provide information on air quality regarding an area through weather apps. These apps source their information from sensors placed around the region being tested. These sensors are placed both systematically across the country and in highly populated locations. Algorithms are then used to average and guess the air quality of regions in between the sensors [4]. Think of it like a vast web with gaps between the strings that are filled in after the web is made. For general use, this is fine, however, for someone wanting to use accurate data in their research, this will not do. Having access to the proper air quality data would allow for a more accurate groundwork for any point trying to be proven. This is whether to prove the air quality around a particular area is harmful or that the expected values are misleading, whatever the case..

B. Specifications and Constraints

The specifications and constraints placed upon the construction and design of the project:

- Shall have a selection of tested and approved sensors to cover a range of pollutants, particulates, air composites, and other qualities. Common qualities to measure are carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide. Other qualities may be selected in the future, but these are definite qualities to look for. These sensors should work independently from each other.

- Shall be easily replicable. The device and additional components shall be mostly, if not entirely, off-the-shelf purchases. This should lower the technical knowledge required to construct the device tremendously. The software should be available for free online on GitHub. Software licenses will be included depending on which software is chosen and used.
- Shall be well documented to answer common questions about the functionality of the device. All questions cannot possibly be answered; however a very strong groundwork for how the device operates and essential functions with limitations shall be documented on GitHub. This should answer common questions that may arise.

- Shall be relatively cost-effective. The device, additional components, and software should remain under $300. The cost of sensors is not taken into account as the sensors are used on a case-by-case basis.

- Shall be protected against the environment. The standard to be followed for water resistance will be IPX4, protecting from all directions against the rain. The standard to be followed for dust and small objects will be IP3X which states protection against hazardous parts, thick wires, or solids of sizes greater than 2.5 mm. The device will operate in a temperature range of 10°F to 90°F. This covers a wide and likely temperature range seen in the U.S. The device will also be staked into the ground and resist wind speeds up to 74 mph.

- Shall be modular. In this instance, modularity refers to the ability to change to a multitude of previously tested and compatible sensors without the need to change any or at most 2 select settings. The change of sensor should be seamless and handled by the board and software.

- Shall utilize sensors that are interchangeable. The sensors will have multiple kinds of Input/Output (I/O) ports, so a list will be made that acknowledges all I/O ports of sensors to be approved and tested. The I/O ports that are shared among a group of sensors should be able to operate seamlessly if swapped out from the same type of I/O port for another sensor in the group using that I/O port. Sensors that do not share this I/O port will have a port of its own grouping that has this same functionality within that group.

- Shall be able to operate with at least 3 sensors sampling independently of each other. Sensors will take samples at set intervals and be read and stored on the device periodically. Samples may be received and outputted one at a time.

- Shall have easily accessible data. The device should be able to take data from storage and send it to a website to be read by the user remotely. This transfer of data will follow Transmission Control Protocol (TCP) and IEEE 802.11. If the user wishes, he/she may also read data from the device directly. Formatting will be basic and leave room for improvement for future development.

- Shall have a set of security measures to protect the device and data. The data shall be encrypted with an undisclosed algorithm. This is during transmission encryption and encryption during the storage of the data on the board. The chassis will be made of a material to be reasonably impact resistant at the standard of IK08. This standard rates the device at 5 Joules of impact. A global positioning system will also be added to aid to reclaiming during loss or theft.

- Shall have an independent power source. The device should be able to be planted somewhere and operate with an onboard power supply. This power supply may include two major components, a solar cell pack and or a rechargeable battery pack. The battery pack should be able to maintain the device for at least 24 hours without recharging. If the solar cell pack is included, the solar cell should allow for charging of the battery pack and prolong the life expectancy.

These are the specifications to be met when constructing and designing the project. They are absolute statements. It should be noted however, that given the status of the team as undergraduate students, the project may falter in regards to certain projections i.e. knowledge, time, and resources. Realistic goals are at present set, but, due to the unpredictability of the future, these goals may change.

C. Surveying Solutions

Research concludes that: air sensors are not typically used in an interchangeable way, but other sensors are, some multi-use air sensors have been made but have limitations, modular microcontrollers can be used to fulfill the project needs when modified, and air quality checks are public information given by companies.

The technology of today already includes a large variety of air quality sensors. The issue with these sensors is their inherent simplicity. One sensor can be used for its particular task, but if the user wanted to use air sensors, these could not be interchanged. The housing unit, or chunk of material the sensor is attached to, will never change or work for another kind of air sensor. This is one issue that needs to be addressed. A core goal for the project is to allow for interchangeable air sensors. This means that the housing unit must accept many different types of air sensors with hand-selected I/O types, implying here that some I/O's will be different than others. The I/O types will be grouped and work interchangeably within its group. The technology to do this exists, but it has not been compiled together in this way. For example, the company Ellab makes vacuum, pressure, and temperature sensors that all use the same connections and may therefore be used interchangeably [10]. These sensors also sport a wireless data logging system, however, with all these advantages comes a high cost with some basic kits being over $750. One of the "Pro Temperature Recording" kits sold for $2900. Their methods may be incorporated for subverting this issue but avoiding the high price will be a priority.

A piece of existing works to consider is the air quality sensors providing regional information for large portions of the world. A big example is the Air Quality Index (AQI) provided by the U.S. Environmental Protection Agency. The AQI takes information from sensors placed in key locations around the United States to make assumptions about the air quality for a certain area using sophisticated algorithms [3]. This may sound like the problem is already solved in this case, but this project seeks to get true local results. The algorithms used can only make guesses. Bypassing the algorithms and jumping straight to the raw data will provide a true local reading for the air quality around a designated region.

Another solution from today sees that air sensors already exist with the ability to measure a range of pollutants, particulates, or compositions in the air. The company Airly Inc. produces a device called Airly PM. [11]. This device is capable of measuring many pollutants and particulate matter all in one easy to use device for $100 to $300 in monthly rent. So, multiple kinds of sensors can be used simultaneously on one device, however, this device comes with a preset of sensors that cannot be altered or customized. If the user wanted to measure something not included in the preset, this would not be possible. This was likely to stay in the realm of "easy to use". Finding a balance of easy to use and having a variety of sensors is one target for the project. More options could inadvertently confound the user and should be avoided. This does limit the user in what can be measured and discovered.

Finally, other works to consider are Arduino and Raspberry Pi which are popular microcontroller boards that allow for modularity[12] [13]. The problem inherently requires modular components, so the existence of these boards does allow for an off the shelf option. This allows for a more simple user interface which ultimately does make the product more accessible to more people. Lowering the knowledge requirement for constructing this device potentially allows more to be built and hopefully improved for future use around the world. The concept of this device being easy to make, easy to use, lower cost, and give sufficient data is a driving factor when making a community-friendly product.

III. Looking for Solutions

The task of having a port designed as input to use a desired sensor interchangeably is difficult to solve. Finding an adapter that can be integrated into the system can solve this issue. Since there are many different pollutants, one goal is to make the air quality device to house 3 different pollutants and receive informative data on each at the same time. Even though it will be able to send current-time data for 3 pollutants, the device shall be able to house sensors for 8 pollutants in total.

Another potential issue that may hinder the replicability is using custom components within the device in order to achieve requirements. It has already been stated that one goal is for the air quality sensor to be easily rebuildable and low cost. Therefore, custom products that may be difficult to remake or design are not to be used during the development of this project. Not every customer is likely to be savvy in electronics and have detailed understanding of making PCB's, soldering connections and devices, coding hardware to assign I/O ports, reading electronic schematics, knowing electrical behavior, and etc. Arduino or Raspberry Pi products can solve interface issues and system user control. Microcontrollers that can communicate using SPI, I2C, or UART to other receiving microcontrollers can be useful for the functionality of this device.

A. Unknowns

Accounting for the future and all hindrances that may follow is not feasible. Best predictions and how to approach them:

1) Certain sensors share an I/O group with approved sensors but still will not work.
   a) In this case, the sensors that are approved have already been grouped and listed. Using a sensor that is not approved but similar will not guarantee a successful sampling of data. This could be fixed with a software update. However, this fix is considered tedious and not long-term.
2) A team member is inhibited from completing designated workload.

a) Other members of the team will divide the designated workload amongst each other.

3) The microcontroller board has an element that hinders progress that was unforeseen.

   a) What this means is that the selected board has a limitation that wasn't discovered or apparent. In this case, the team should do plentiful research on the board to investigate workarounds or modifications. If this does not solve the issue, then another board will have to be chosen.

4) The supply chain industry withholding ordered parts/materials thus stretching the projected timeline.

   a) Members searching for parts to order must judge the quantity present and required.

5) The multi-variant virus called COVID may slow down the design process.

   a) This could not only impact the manufacturers that the team may be interested in buying a product, but also each team member's health has the potential to be compromised if any have the virus.

Predicting the future takes into calculation far more variables than can be accounted for. Knowing this, there are things that can be done to minimize the risk of failure: consistent updates from members, asking for help when it is needed, seeking outside knowledge, performing thorough research, allowing time for sufficient experimentation, and designating one member to allot time for tasks.

During experimentation, the goal should be to find the most effective design regarding costs, effort in construction, and completion following the measures of success. It should be noted that during experimentation, not all effects could be found. This is to say that some effects of the device could be unintentional, although, it is highly unlikely considering the nature of the device, but this is still worthy of mentioning. These effects cannot be specified at this time due to them falling under the unknowns of the project. If these unknowns were to affect the measures of success, then a potential design modification would be required.

B. *Measure of Success*

Measures of success for this project will be the fulfillment of the previously mentioned shall statements to the best of the team's abilities. Failure to complete the shall statements does lower the overall success of the project, however, certain specifications are considered critical. If the device fails to measure three out of the six qualities, it will be considered a critical failure in design and cannot be overlooked. If the device fails to resist wind speeds of 74 mph, that can be considered negligible losses. The case by case nature of this measure will mean that approval by the customer throughout each step of adding/adjusting/removing the shall statements will be necessary.

Seeing as this design is going to be public, seeing the design well-received will prove a successful job. Knowing that there are persons or groups that appreciate the work done and utilize it show that the effort placed into the project is not folly. Even if the project is in the end considered incomplete but still a great foundation for related future projects would still be a success. Seeing teams in the future use this project's documentation and designs as a basis for an improved air quality sensor would be a good sign. Maybe even an app could be created that pairs with the device to allow an easier time reading, receiving, or manipulating the data. Recognition from other projects such as citations or acknowledgements are welcome as well. Although the goals are set and it is desirable to fully realize them, there are alternative investments that are being made for future generations in the completion of this project.

C. *Ethics and Responsibility*

This design team shall follow National Electrical Code safety procedures, associated National Fire Protection Agency procedures, and abide by piracy laws. There are no intentions to break any laws established by the United States of America Government. All patents, licenses, and copyrighted material will be used under legal fair use with citations and credit when appropriate. This product will be designed in such a way to prevent risk and unintended harm to the users, the communities, and the environment.

This product will be designed with the IEEE code of Ethics in mind and follow common electrical concepts/standards: resistor color codes, design schematics, communication between devices, etc.

The only foreseeable harm that could be caused by the proposed device is the ignition of an electrical fire. The risk of this will be minimized during design. A wild fire could prove devastating to an environment and will need to be avoided as responsible engineers would. Hazardous materials and potential harm to the user are otherwise non-existent. Potential negative impacts on communities or persons are negligible, if any exist, given the nature and purpose of the device. In theory, communities will be improved by the use of the proposed device in that they will be able to see if the air quality in their homes, work places, and schools is safe for adults and children alike.

IV. RESOURCES

Resource listings here are speculation for what tools, software, components, testing equipment, and software may potentially be required to complete the project.

- Visual Studios, Notepad++, or some other type of code editing software.

- Microcontroller integration software to program any boards that may be used.
- Microcontroller boards such as the Arduino or Raspberry Pi boards. Currently unknown model.
- Port modules to be added to related microcontroller boards.
- Standard electrical lab equipment: multimeter, oscilloscope, etc.
- Hand selected air quality sensors. This is to be determined later when a standard for I/O ports has been made.

Time is another resource that must be considered. The project is to be completed over the course of two semesters. Estimating the hurdles and objects to pass, the allotted time should be sufficient to create a prototype of the device and allow for future development, because of the scheduled timeline planned within the given time period.

The last resource to consider is the budget. Although the budget for design is much higher, in order to stay in line with the goal of having a low-cost construction, the prototype should be constructed out of materials with a monetary value under $300. Given that Raspberry Pi and Arduino boards can range from $10 to $80, further research into the most cost-effective option will need to be completed. Other resources are for designing the device itself as the software will be available for free online. The sensors themselves are not taken into consideration as the cost changes case by case.

A. Personnel

There are many different aspects of electrical, computer, and mechanical engineering that will be implemented within this project. As such, in order for the specifications to be met and shall statements verified, there is a need to use an ample amount of time in research, design concept, and experimentation. Looking at various sensors and product standards will be some of the things that will be looked into. Finding the correct component/circuit/ or system will be a major factor towards the development process.

All of the members on the team have studied over various circuits and how to implement them to do what the developer wants it to. Alejandro Moore, has had some experience in PCB circuit design, analysis, and manufacturing. Knowing what is the correct component to the system and analyzing how it should be used are things that will be needed in order to understand and record the design process. He has also had some experience in BNC cable installation and other types of wires. Learning these concepts has given a plethora of resources that can be shared with the team if needed. He is aware that the team members have other skills that can also be used within this project. This is beneficial for the functionality of the team, because it can help the others learn the concept and further the process of the project.

Marvo Odds has had many experiences in digital logic projects,circuit design and coding projects. Many of these experiences came in the form of projects from classes at Tennessee tech such as coil gun circuit, digital logic circuit that implemented the game Ship,Captain,Crew, and coding projects in CSC 1300 that used C++. This is beneficial because the design will need knowledge in circuit design and coding to implement the website and databases.

The skills that Cameron Smith brings to the team are familiarity with C, C++, VHDL, and assembly coding languages, programming microcontrollers, digital design, circuit analysis, and client/server communication design.

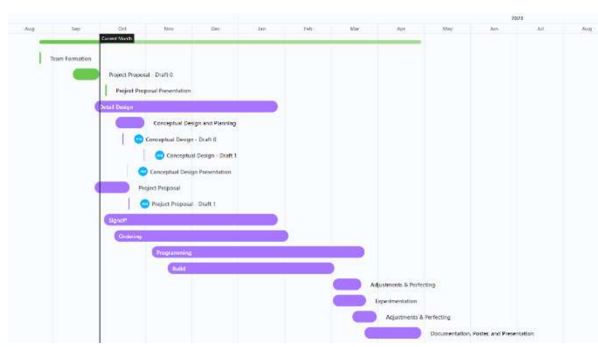
Joshua Egwuatu has had experience in the field of engineering. He understands the design process in its completion from start to finish. He also has experience in C++, Solidworks, Altium, and web design. Due to the need of having to export data collected to a website, web design knowledge will contribute a lot. He also has a strong background in leadership and communication due to the many roles held in his academic career. This skill set should be very beneficial for the team.

Kaleb Irwin has experience in coding primarily in C++, and a little bit in HTML as well. He also has worked with microcontrollers before and designed several small projects throughout school time in engineering at Tennessee Tech from making the game Shut the Box with logic gates to designing and building a coil gun. Almost certainly more skills and experiences will be required during this project and he is looking forward to getting started.

B. Timeline

1) Project Proposal: September 25th, 2022
2) Conceptual Design & Planning Final: October 30th, 2022
3) Detail Design Draft 1: November 10th, 2022
4) Detail Design Draft 2: November 24th, 2022
5) Design 1 Final: December 11th, 2022
   a) Final Presentation for Design 1
6) Design 2 Draft: March 6th, 2023 (Estimate)
   a) Prototype
   b) Website Completion
7) Final Presentation: April TBD, 2023

Team 1 Timeline Gantt Chart:



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