ECE 445

Senior Design Laboratory

Project Proposal

Automated Sensor-Based Filtration System

Team No.68

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Introduction

1.1 Problem

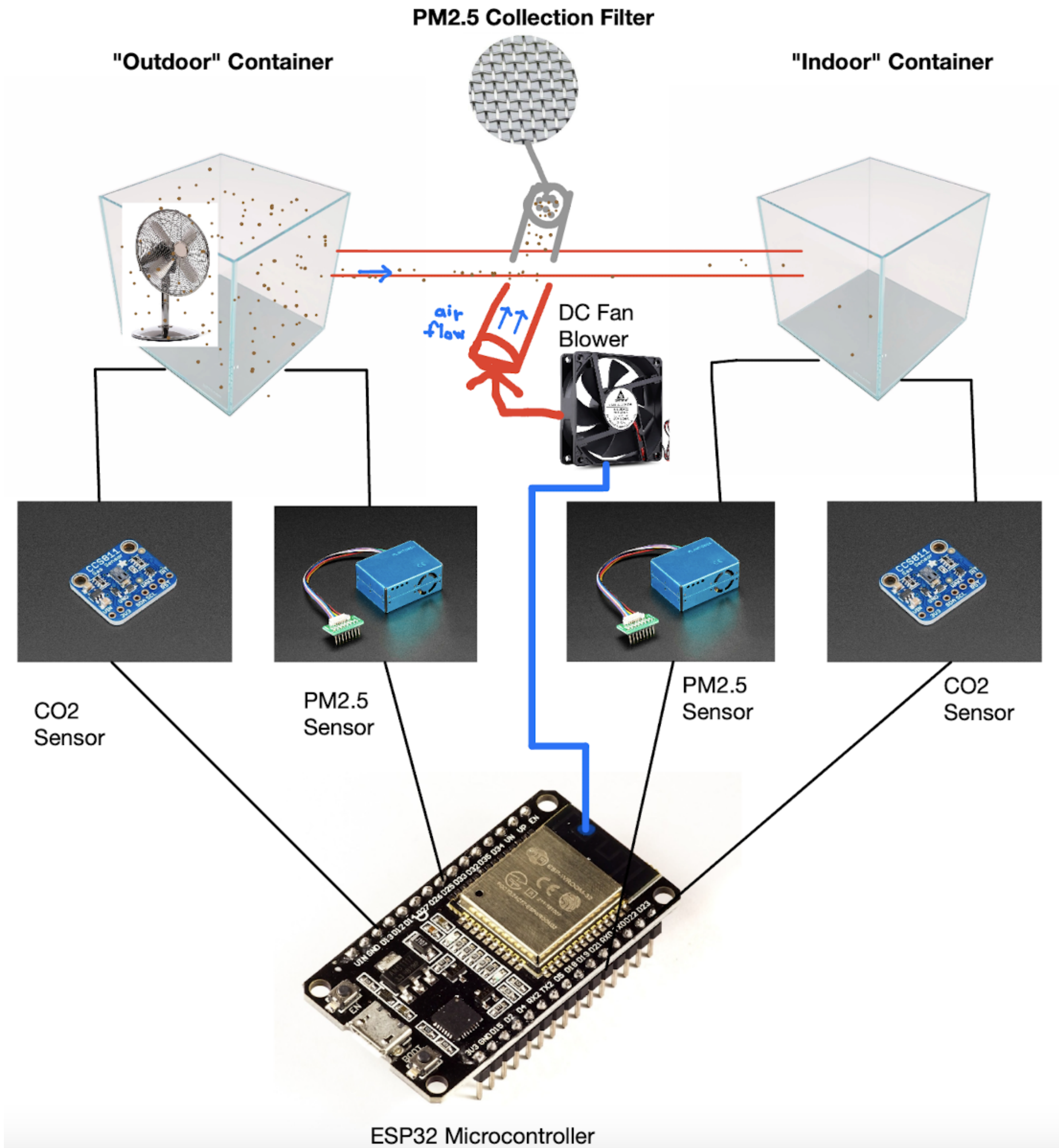
As our environment continues to change for the worse with the presence of global warming and increased human consumption of resources like fossil fuels, the safety associated with breathing clean air is being threatened. In metropolitan areas across the world, there is an increase in the smog and toxic output, leading to increased respiratory problems. Currently, no building filtration systems adapt according to compounds present outside the building, like volatile organic compounds (VOCs), and, as a result, the implementation of a new, different filtration system becomes necessary.

1.2 Solution

The proposed solution to this vast and unending problem is a dynamic filtration system that adjusts according to the concentration of a specific outdoor particle. We have chosen to monitor CO2 and PM2.5 particles commonly found in dust. The goal is to keep the indoor particle concentrations despite any change in composition of the outside air. This will be done using a sensor subsystem, an ESP32 microcontroller, and an air blower for filtration testing. The electrochemical sensor system constantly monitors these factors and provides a reading that will activate the dynamic filtration subsystem to filter out particles in a more accurate manner.

To keep the indoor concentration numbers constant, we must compare data from the outdoor particulate sensor system with one based inside the enclosure. Two separate electron chemical sensor systems will monitor outdoor and indoor particles, and a microcontroller will take the data from these sensors and determine what particles to filter out. The adaptation functionality of changing the directional flow of an external source of air will be implemented according to the results from the data acquisition subsystem and the responses of the microcontroller subsystem.

1.3 Visual Aid



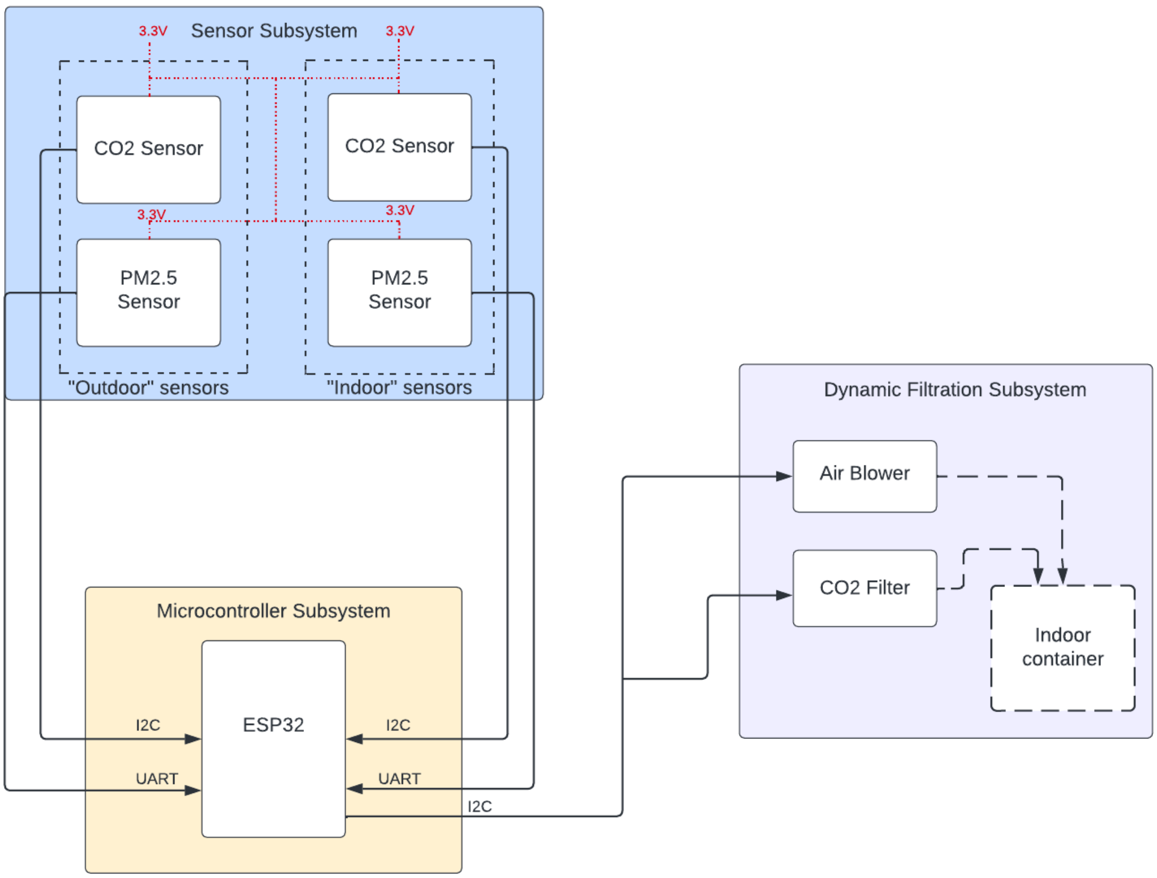
1.4 High Level Requirements

- The concentrations of CO_2 and PM2.5 in the “indoor” enclosure should be lower than those of the “outdoor” by approximately 75-80%.
- The concentration of CO_2 will determine whether air flow will speed up or slow down based on circulation.

- In order to maintain power efficiency, the dynamic filtration mechanism must only start running when the PM2.5 or CO_2 particles reach a certain level.

Design

2.1 Block Diagram



2.2 Subsystem Overview

Data Acquisition Subsystem

The data acquisition subsystem consists of an array of electrochemical sensors that will receive data from the enclosures' concentrations of PM2.5 particles and carbon compounds and transmit that data to the microcontroller subsystem. Its goal is to feed real-time data accurately to the overall system to provide essential information for the correct implementation of the entire project.

Microcontroller Subsystem
The microcontroller subsystem consists of a single microcontroller that will communicate with both the data acquisition subsystem and the dynamic filtration subsystem to provide accurate instructions to the directional air flow about when to activate. Using an external power source with a measured voltage, this subsystem will be the core impetus for the functionality of this entire project.

Dynamic Filtration Subsystem
The filtration subsystem consists of the air blower and the CO_2 removal filter. The air blower is used to control air flow using inertial impaction to filter the PM2.5 particles, while the CO_2 removal is another layer of filtration for carbon dioxide particles. Both of these components are controlled by the ESP32 module, adjusting the velocity of the air or how much CO_2 is removed based on the sensor data collected.

2.3 Subsystem Requirements

Data Acquisition Subsystem

<u>Dust Particles</u>

1. The sensor that will be used to detect dust particles entering the air ducts will be the PMSA003l PM2.5. This sensor is essential with regards to our high-level requirements as it will be used to assess the dust concentration outside and the dust concentration inside, therefore giving us data with regards to how much dust has been successfully filtered out.
2. The PM2.5 sensor utilizes laser scattering, whereby scattering light is collected, to determine the concentration of particles under 2.5 microns in width in the air.
3. I2C protocol will be used to communicate to and from the PM2.5 sensor
4. This particular subsystem will then be connected to the microcontroller subsystem in order for data to be collected and analyzed.
5. If 3.3V or 5V is not provided as power, the sensor will not function.

6. If the microcontroller subsystem fails to take in and read data from the sensor, then it will be of no use.

<u>CO2 Detection</u>

1. The sensor used for detection of C02 levels in the air will be the SGP40, which provides TVOC and CO2 data. The SGP30 will also be an essential piece of our design since it will give us CO2 readings both inside and outside, therefore providing us information with regards to how successful our CO2 filtration really is.
2. The I2C protocol will also be used to read data from the SGP30.
3. The CCS811 supports multiple drive modes to take a measurement every 1 second, every 10 seconds, every 60 seconds, or every 250 milliseconds.
4. Sensor already placed on a PCB with a 3.3V regulator and level shifting.
5. This particular subsystem will be connected to the microcontroller subsystem in order for data to be collected and analyzed.
6. If 3.3V or 5V is not provided as power, the sensor will not function.
7. If the microcontroller subsystem fails to take in and read data from the sensor, then it will be of no use.

Microcontroller Subsystem

1. The microcontroller that we plan on using for this subsystem is the ESP32 microcontroller, a versatile chip that will allow us to both receive data and send signals to the dynamic filtration subsystem.
2. The ESP32 will receive data from the specific CO_2 and PM2.5 particle sensors and communicate with the sensor that is controlling the amount of air received from the external blower.
3. The requirements for the ESP32 are minimal, requiring the basic 3.3V for functionality.
4. This is the fundamental subsystem that would enable us to collect data and then initiate a change based on that information. In order for the other subsystems to work, the microcontroller must be successfully implemented.

5. If 3.3V or 5V is not provided as power, the microprocessor will not function.

Dynamic Filtration Subsystem

1. The system should use the theoretical concept of inertial velocity and impaction to conduct the filtration.
2. The system should respond to readings from the microcontroller and the sensors by initiating the air current of a cross-directional flow to ensure that additional filtration is provided.
3. The air blower must generate enough force to redirect dust particles from the horizontal air flow to the collection pocket of the tube.
4. It should reduce the amount of particulate matter and dangerous compounds significantly by at least 70% between the initial and final enclosures.
5. The speed must adjust according to the PM2.5 and CO_2 concentrations detected by the sensors in the initial container. The program responsible for this dynamic function must run properly on the ESP32.
6. If our data acquisition subsystem is not functioning properly, this would also be an issue as the microprocessor would be collecting false data and giving inaccurate instructions to our filtration subsystem. This means filtration would depend on both data acquisition and microprocessing to be successful.

2.4 Tolerance Analysis

The most critical part of this project is the programmable air blower/DC fan that filters the PM2.5 particles. The rated voltage is 12V, with the operation range being 4.5-13.8 VDC. The speed/airflow of the fan is proportional to the supplied voltage; if the fan VDC decreases, so does the RPM.

ITEM	DESCRIPTION
RATED VOLTAGE	12 VDC
OPERATION VOLTAGE	4.5 – 13.8 VDC
INPUT CURRENT	0.11 (MAX. 0.17) A
INPUT POWER	1.32 (MAX. 2.04) W
SPEED	8000 R.P.M. (REF.)
MAX. AIR FLOW (AT ZERO STATIC PRESSURE)	0.375 (MIN. 0.338) M^3/MIN. 13.24 (MIN. 11.94) CFM
MAX.AIR PRESSURE (AT ZERO AIR FLOW)	9.39 (MIN. 7.61) mmH_2O 0.370 (MIN. 0.300) $inchH_2O$
ACOUSTICAL NOISE (AVG.)	41.0 (MAX. 45.0) dB–A
INSULATION TYPE	UL: CLASS A

Figure 7: DC Fan Datasheet

According to the datasheet, the nominal speed at 12V is 8000 RPM. The tolerance level associated with this value is typically +-10%. The average peak current draw is 0.17 A, which can also be displayed as a periodic waveform of a certain frequency rather than a single value. The applied voltage can never exceed the operation range 4.5-13.8 V, which means the RPM should be 8000 maximum.

Running current is measured using the true root mean square formula:

$$\mathbf{TRMS = (DC^2 + AC^2)^{1/2}}$$

For measuring the current RPM of the fan, we need to monitor the DC ripple current. Using an oscilloscope, we can display the waveform of the current and determine the period of the current graph. This will have some slight uncertainty, since the measurement will not be exact. Then we determine RPM with:

$$f = \frac{1}{T}$$

f = frequency
T = Period

Another critical component is the sensor subsystem, the VOC/CO2 having a very low voltage tolerance of 1.62-1.98 V compared with the PM2.5's 5 V.

Ethics and Safety

There are general risks pertaining to PCB assembly and the use of electronic components. Solder will be used to stick our sensors and microcontroller onto one PCB, therefore we must beware of burn hazards as well as chemical hazards. We aim to proceed cautiously with the use of gloves as well as safety goggles. One main safety hazard related to our project specifically would be excessive inhalation of dust. Our goal is to demo our project by creating an environment filled with dust particles in order to see if our clean environment is capable of filtering all of it out. When creating this dust-infested environment, we must wear masks and control the dispersion of dust particles as the buildup of it in our body can be very dangerous, consequences of which include lung infection and even more serious complications for those with asthma. [1]

In addition, there are IEEE safety regulations associated with the usage of blowers and their application in this project. Blowers are high demanding, high quality machines that require precise measurements and accurate usage to ensure the best possible performance. However, common issues that happen to these blowers are symmetry irregularities, rotor malfunctions, and speed. These can occur given specific instances of a manufacturing issue, a power surge, or even a power failure. Symmetrical variations in the blower may cause either incorrect directional air flow or even an internal issue in the functionality of the device. Voltage dips may cause the blower to function improperly, either at low capacity or turn off, depending on the power input. Power surges may cause the capacitors within the blower to overheat and malfunction, making the entire device worthless. Given the various safety hazards associated with working with blowers, we plan on being very safe when using them. Such actions include using surge protectors to ensure minimal power surges and ensuring a battery supply to provide a constant current into the system. We also plan on purchasing a blower from a well-known manufacturer and running basic tests on the blower to test its performance and its symmetrical properties.

References

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