PARTICULATE MATTER SENSOR NODE

ECE 445 Design Document Check
Team 12
Team Members: Mahip Deora, Zachary Plumley, and David Young

1. Introduction

1.1 Objective

We are building an affordable particulate matter (PM) sensor system for both health and environmental researchers. There exists many areas in the United States in which no PM data is being collected, limiting air quality awareness. This lack of data makes it difficult for researchers to understand the sources and potential effects of PM in those areas. Our product mitigates this issue by providing a cost efficient PM sensor system that can be deployed in areas that lack the equipment to track air quality. Our product can provide the EPA with PM data, such that they can regulate PM emission sources and improve public health.

1.2 Background

Particulate matter is the combination of solid and liquid particles found in the air, some of which are hazardous. PM emissions, particularly particles which are smaller than 2.5 micrometers, have been linked to an array of health complications [3]. Specifically, these health issues include nonfatal heart attacks, decreased lung function, increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing, among others [5]. The majority of these particles are smaller than 10 micrometers. These particles will fit into 3 buckets (1, 2.5, and 10) depending on the size (e.g. particles smaller than 2.5 micrometers will be PM2.5). Common particles in these buckets are smoke, dust, soot, salts, acids, and metals.

The EPA collects data on PM emissions but their data isn't comprehensive and lacks granular data [4]. In addition, the current method of data collection is via using sensor stations that collect data for a large, general area. If the EPA were to have nodes collecting data about smaller regions, they'd better understand sources of PM.

1.3 Solution Overview

Our project aims to get data from a smaller range as compared to current methods by having our sensor be affordable, portable, and mass producible. Our sensor array will measure location, temperature, humidity, wind speed, wind direction, and PM 2.5/10. These data points which will be used to pinpoint the sources of PM pollution and fill in the blank areas in the EPA's map.

In addition, our system should be cost efficient such that it can be used at scale by the EPA and researchers. Furthermore, in order to place our box in various locations autonomously, we will be adding a solar powered battery to power our system.

Finally, in order to store data we will have a local storage device (SD card) in our box to record all of our data points. Once we have obtained the PM data, it will be uploaded to a web dashboard and viewed in a user-friendly UI. This dashboard will be the central source where users can view our data. Allowing a mobile and scalable system will help the EPA fill in missing data and hopefully help regulate PM emission sources.

1.4 High Level Requirements

1. Our system is able to accurately collect (less than 10% loss for each sensor) PM data once per hour for at least 1 month at a given location (e.g. near a wildfire, factory, powerplant, etc.)
2. Our system is able to operate (collect and write PM data) indefinitely using a solar powered battery and autonomously (without the need of human oversight)
3. Our system is able to easily store in an external storage device and output the PM data to a web UI and MySQL database. The web UI will refresh every time it detects new data from the MySQL database.

2. Design

Our design consists of 4 main subsystems which includes a power supply, data processing, sensor array, and a web UI. For information will be given in the following sections.

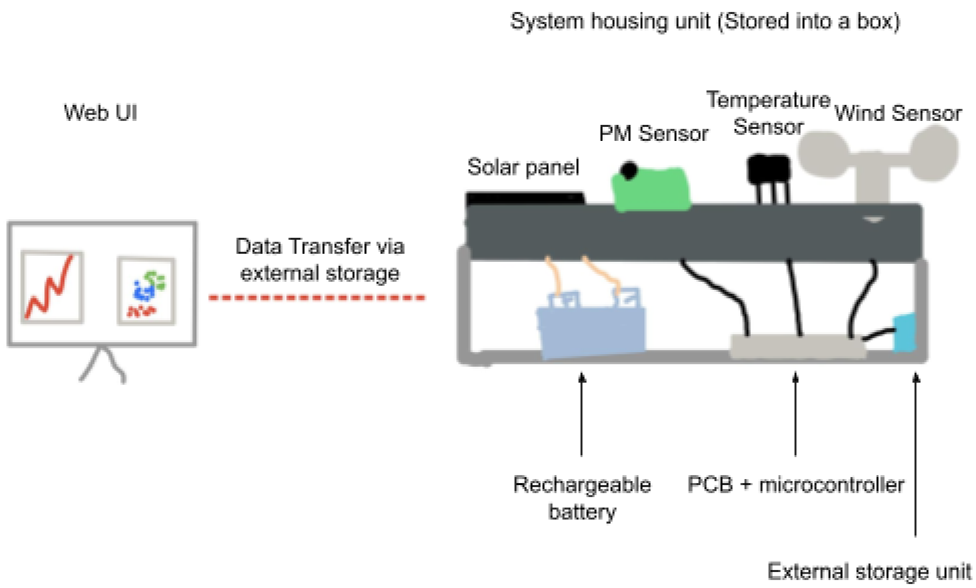

Figure 1. Shows our system from a internal level

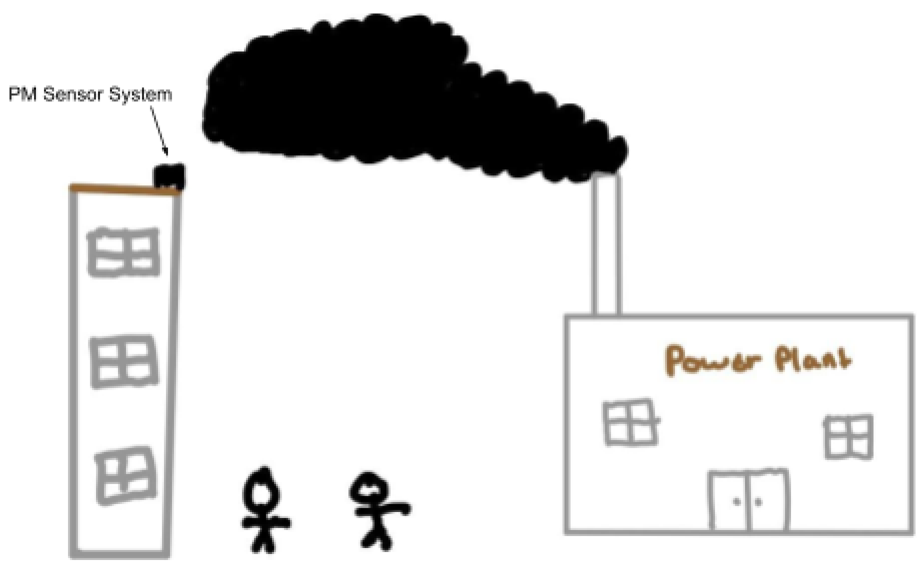

Figure 2. Shows how our system might be deployed. For example, in the figure above we deployed our system next to a power plant

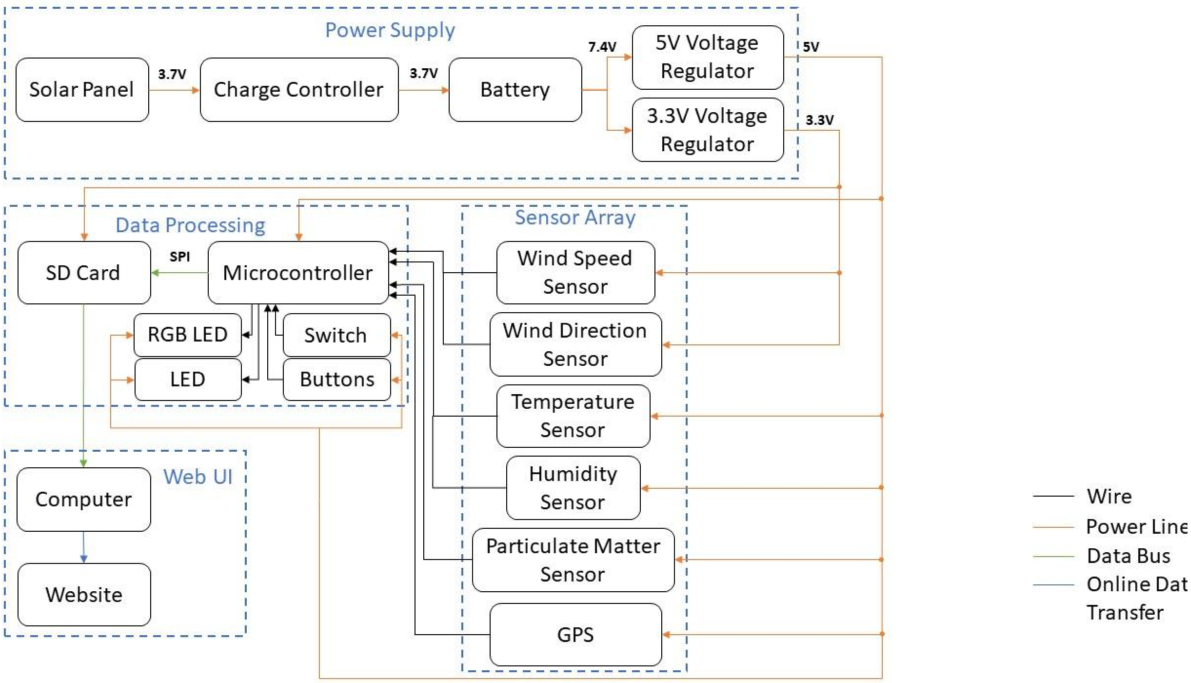

Figure 3. A block diagram showing components and modules

2.1 Data Processing Unit

The Data Processing Unit manages the storage of all sensor data. A microcontroller controls an SD card and communicates to sensors via GPIOs. It also contains a small user interface with an LED, a button, and a 3 position slide switch.

Table 1: Requirements and Verification for the Data Processing Unit

Requirements	Verification
1. The microcontroller must be able to communicate over the SPI at speeds greater than 1Mbps (each). 2. Must sink or source 10mA +/- 5% on each of GPIOs at 5V +/- 5%. 3. The LED must be able to respond within a second of any device errors.	1. Send 1Mb of data to the SD card every second and check if the data written is correct 2. Measure each of the GPIOS using a multimeter to ensure 5V +/- 5% 3. Cause each error and time how long it takes for the LED to react

2.2 Sensor Array

The Sensor Array consists of 5 sensors: a wind speed sensor, a wind direction sensor, a temperature/humidity sensor, a particulate matter sensor, and a GPS module. Each sensor will communicate with the microcontroller via GPIOs. The sensors will be powered by the voltage regulator.

Table 2: Requirements and Verification for the Sensor Array

Requirements	Verification
1. The wind speed, wind direction, temperature, and PM sensor must be able to collect data for a month on end without a significant (greater than 10%) loss in accuracy. 2. The GPS module must be able to identify and communicate to the microcontroller the location of the box while the device is powering on.	1. a. Using historical data and a average range, make sure the sensors are calibrated and collecting data within their range b. Use each sensors data protocol when we perform signal processing 2. a. Test the GPS sensor at various locations to ensure proper functionalities

2.3 Power Supply

The power supply unit produces, stores, and distributes electricity at the correct voltages. A solar panel generates electricity which is routed through a charge controller to safely charge a lithium ion battery. A voltage regulator will step the battery voltage down to 3.3V and 5V for the sensor array and data processing unit.

Table 3: Requirements and Verification for the Power Supply

Requirements	Verification
1. The charge controller will not charge each battery past 4.2V to ensure they do not fail. a. The charge controller must supply 3.7V +/- 10% during charging b. The battery must be able to supply power to the sensor node for a month when the node is making measurements at one hour intervals. 2. The voltage regulators must be able to supply at least 400 mA to ensure	1. a. Measure the open-circuit voltage with a voltmeter, ensuring that it is between 3.33 V and 4.07V b. Measure power consumption over one day, extrapolate that to a month, and ensure that the battery and solar panel can supply that much energy. 2. Using an ammeter to measure the output of the voltage regulators to make sure it is at least 400 mA.

that all components can function properly. 3. The voltage regulators must be able to output 3.3V +/- 10% and 5V +/- 10%	3. Using a Multimeter we probe the voltage regulator to ensure that it can output 3.3V and 5V based on the sensor and other factors

2.4 Web UI

The Web UI will be a simple webpage that enables the user to visualize and interact with the data they've collected. Users will remove the SD card from the box and plug it into their computer in order to extract the data. They can then upload the file to our webpage. The webpage will store the data in a simple MySQL database.

Table 4: Requirements and Verification for the Web UI

Requirements	Verification
1. The website must be able to parse and display the data within 5 seconds of the file being uploaded.	1. Using the date/time library in python, verify that our queries and data upload is within 5 seconds

2.5 Circuit Schematics

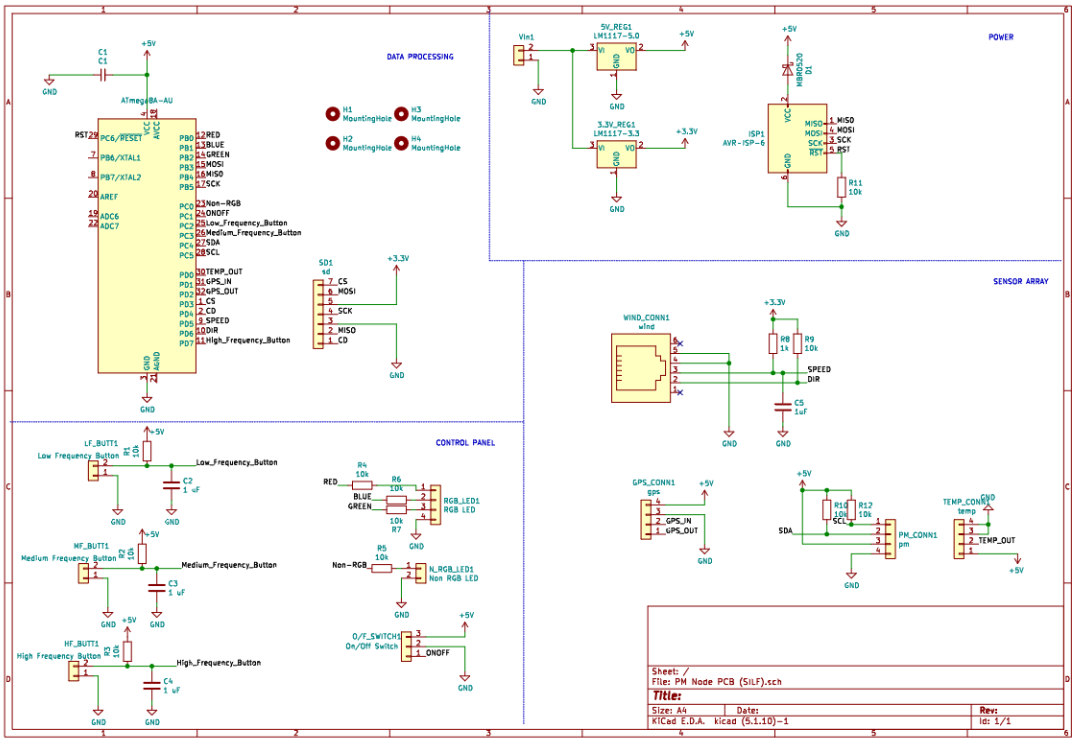

Figure 4. Circuit Schematics

2.6 Tolerance Analysis

The functionality of the data processing module is integral to the success of our system, since this module is in charge of converting all of the sensor's analog signal to a digital signal.

Furthermore, each sensor will have its own sensor protocol that will need to be used by the microcontroller. For example our PM sensor will output a 30 bit signal to our Microcontroller using I2C communication (100kHZ). The first 4 bits are header information, and the other 26 bits correspond to various PM sizes (2.5,5,10) data. The GPS and our temperature sensor will also output a fixed length bit signal. Rest of our sensors will output an analog voltage that will feed into a 10 bit A/D converter. The A/D converter formula is given as:

$$\frac{Resolution\ of\ the\ ADC}{System\ Voltage} = \frac{ADC\ Reading}{Analog\ Voltage\ Measured}$$

Where system voltage is 5V or 3.3V depending on the sensor. The resolution for 5V is 1023 and 512 for 3.3V. Thus our equation simplifies down to a ratio to find the ADC reading, where we have the resolution of the ADC, system voltage, and the analog voltage measured.

One of our goals is to keep the error tolerance for each sensor within 10% of the truth value. One of the biggest factors that can affect our error tolerance is the exposure to the elements. Since our system is meant to be kept outside for an extended period of time, exposure to varying temperatures, rain, etc. can possibly deteriorate our sensors.

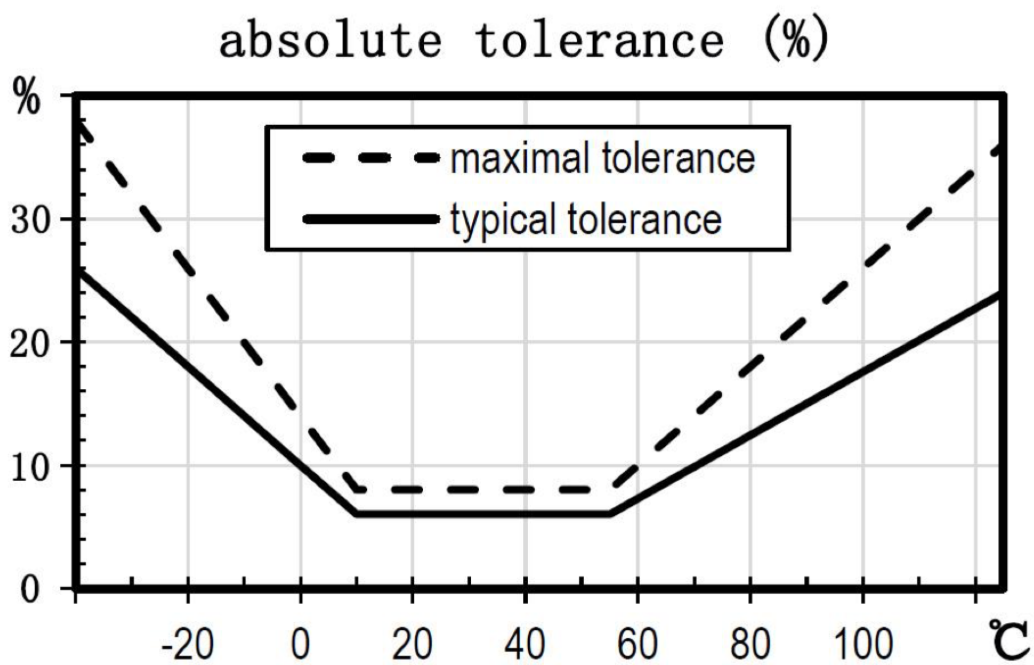

Figure 5. The relationship between consistency deviation and temperature in the Grove Particulate Matter Sensor [2]

As shown in the figure above, different temperatures can impact the tolerance of the PM sensor. This figure highlights the point that exposure to elements can vary/impact our error tolerance for each sensor. To counter this risk, we chose sensors that were capable of withstanding the forces of nature.

The wind speed, wind direction, air temperature, humidity, PM1.0, PM2.5, PM10, latitude, and longitude will be written to the SD card. Storing this data in a .txt file requires 68 bytes per line. Over the course of 30 days, data is written to the device at our maximum frequency of every 5 minutes, the device will have written 8640 lines of data. 8640 lines of data at 68 bytes per line equates to 0.000588 GB of data, much smaller than any SD card sold, mitigating the concern of data being overwritten.

4. Ethics and Safety

Our project is meant to be fully unsupervised when our system is collecting data at a given location. We have identified a few ethical and safety issues that could occur from our system.

4.1 Overheating

Our rechargeable battery could potentially overheat and pose a fire risk. This a particular concern since our box is meant to be placed in a remote location, and could pose a wildfire risk. In accordance with IEEE Code of Ethics #3 [1], “to avoid real or perceived conflicts of interest whenever possible”. To prevent overheating and battery failures, we will charge each of our batteries in parallel using a charge controller to prevent overcharging.

4.2 Box Placement

Our system could be placed in private property without prior approval. This would be in breach of IEEE Code of Ethics #9 [1] which states “to avoid injuring others property”. To counter this, we will provide labeling on the box, as well as documentation which states where a user can/can’t place their box.

4.3 Data Bias

Data collected might be biased against 1 or more potential sources of PM. For example, if our system is placed only near power plants or factories then all the data will point at these locations as sources as major PM sources. This breaches IEEE Code of Ethics #2 [1] “ To improve the understanding by individuals and society”. If the PM data is biased, then it will fail to identify various kinds of PM sources.

Citations

[1] “IEEE Code of Ethics.” *IEEE Code of Ethics*, www.ieee.org/about/corporate/governance/p7-8.html.

[2] “HM-3300/3600 Dust Sensor Data Sheet.” *HM-3300/3600 Dust Sensor Data Sheet*, files.seeedstudio.com/wiki/Grove-Laser_PM2.5_Sensor-HM3301/res/HM-3300%263600_V2.1.pdf.

[3] “Particulate Matter (PM) Basics,” *EPA*, https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM.

[4] *Interactive Map of Air Quality Monitors*, https://epa.maps.arcgis.com/apps/webappviewer/index.html.

[5] “Health and Environmental Effects of Particulate Matter (PM).” *US EPA*, www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm. Accessed 26 Sept. 2021.