Development of a Low-Cost Sensor for Improved Air Quality Data Collection

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Abstract

Increasing particulate matter 2.5 (PM2.5) pollution in the atmosphere is a major concern that continues to bring about adverse societal effects as poor air quality can negatively impact human well-being and the environment. PM2.5, a tiny particle with a diameter of 2.5 micrometers, can travel deep into the respiratory tract and the lungs affecting human health. The pollutant is responsible for increasing the acidity of freshwater streams, harming the organisms that rely on the water. Due to the damaging effects of pollutants, air quality testing and monitoring have become more important. However, the traditional methods and instruments used for air quality monitoring are difficult to come by because of their large size and high cost to deploy and maintain.

Low-cost air quality sensors (LCSs), a relatively new technology, have been recognized as an alternative to the conventional methods of data collection. Compared to equipment costing thousands of dollars to use, the sensors only cost a few hundred dollars. Even so, studies have shown that LCSs lack accuracy in their data collection of air pollutants. Changes in relative humidity (RH) and temperature affect the accuracy of the sensors as they reacted differently to particles based on their sizes.

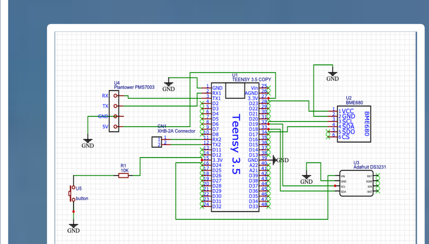
The goal of this research was to determine the processes required to develop and calibrate a LCS that could produce improved measurements of pollutants in the air, specifically PM2.5. A Teensy 3.5 based LCS that could measure the concentration of PM2.5 in a surrounding air environment was used as a basis for the development of a printed circuit board (PCB) to connect each sensor in a compact and organized format. It was assumed that each sensor and component were in working order before being added to the Arduino- based sensor. It was also assumed that the online PCB software, EasyEDA, already had the needed sensors and components in their libraries. As air pollution continues to impact climate change, public health, and the environment, it is one of the biggest issues in the world. This study provides insight into the next steps that could be taken to prevent the effects of air pollution from worsening. LCSs could become so developed that individual citizens could carry them around and use them to measure their daily exposure to pollutants.

Methods

The proper sensors and components were found in the EasyEDA library. Selected devices had a black blueprint, the appropriate number of pins for proper connection, and were similar in look to the physical component. A configuration of each device took place to determine fitting placements that did not interfere with wire connections.

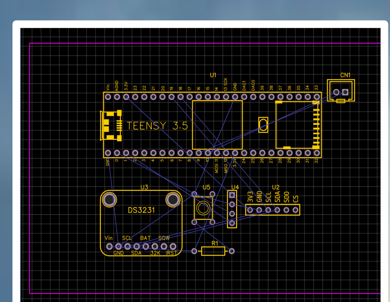
The physical Teensy 3.5 device with a BME680 sensor, PMS7003 sensor, Time Clock, Button, and Resistor.

The layout of the schematic was altered to be closer to the format of the physical Teensy device. Each component was organized into different possible placements until an adequate schematic was created. Unused pins were eliminated, and the blueprint was converted to a more completed PCB schematic.



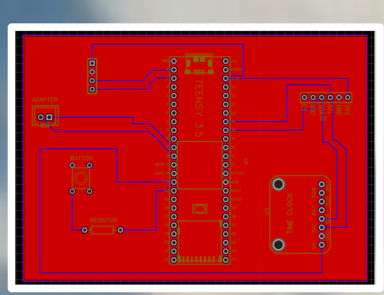
The schematic before conversion to PCB.

Upon the conversion, wire connections that were altered during the process were fixed so that wires were not intersecting. The components were moved around to allow for wires to be organized in a compact format.



The schematic after transfer to PCB.

A copper layer was added in the final stages of the schematic to ensure a functioning and organized PCB. The copper layer was connected to ground connection to remove extra wire connections and make the connections automatic.



The schematic after conversion with organized wire connections and copper layer.

The Effects of Elevated RH Condition

Weather and other physical conditions like humidity, temperature, and wind can affect the function of LCSs. Specifically, when the relative humidity (RH) of an area exceeds a certain percent, some particles can absorb the moisture in the air, leading to what is known as hygroscopic particles. In a study conducted in Maryland, [Citation Here] these particles were found to cause peaks in PM2.5 concentrations when measured by low-cost sensors. Therefore, constraints exist since weather conditions can lead to the presence of hygroscopic particles, affecting LCSs ability to provide accurate measurements of pollutant concentrations.

Correction Equations

The PMS7003 sensor and BME680 sensors would be tested without adjustments or corrections to the data. Then, correction equations linear calibration (LC), inverse calibration (IC), and hygroscopic calibration (HG) would be applied to the data set where the Root Mean Square Error (RMSE) between the reference instrumentation data and the corrected LCS data would be derived. Using the LC technique, ordered pairs would be formed with the LCS device PM measurements being the x-intercept and the reference measurements being the y-intercept. An unweighted linear regression of the data point would be formed and plotted. Based on these plots, a line of best fit would be derived mathematically in the format of a y = f(x) equation. The IC technique would be done by forming ordered pairs with the reference data being the x-intercept and the measured data being the y-intercept. The best linear fit equation would be found then inverted to form the calibration equation. With the HG technique, the equation a+b(RH^2/1-RH) was then applied to the LCS data.

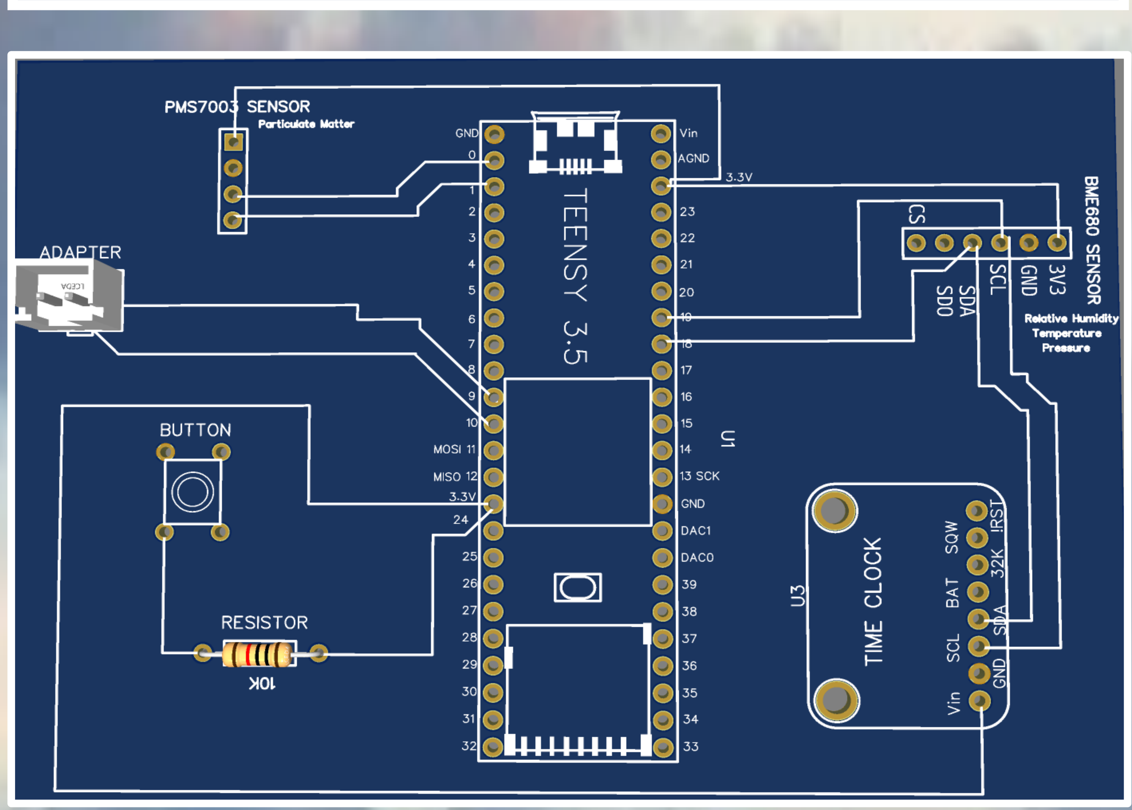
Root Mean Square Errors between Reference Data and PMS3003 Using Various Correction Techniques – March 6-17 and March 18-28, 2019

Technique	March 6-17 RSME (μg/m^3)	March 18-28 RSME (μg/m^3)
Uncalibrated PMS3003	10.8	8.1
Linear Calibration	3.0	2.5
Inverse Calibration	4.0	3.6
Hygroscopic Growth Equation	3.7	4.5

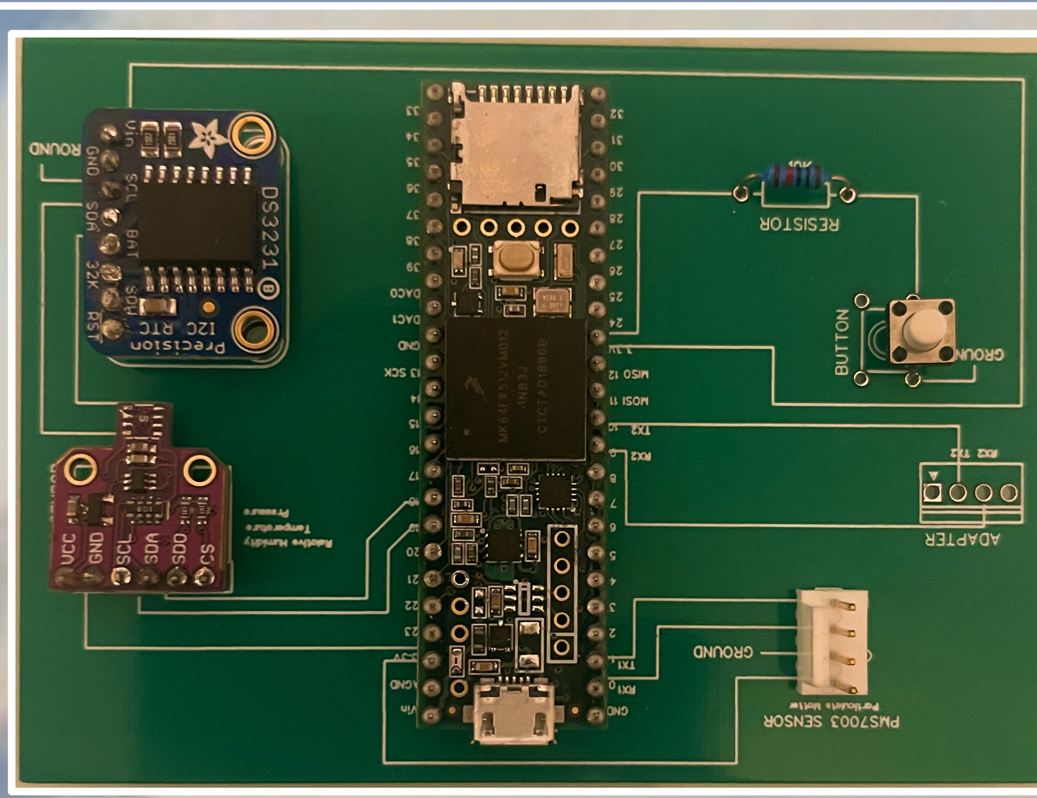
Prospective RMSE table using data collected from the device and reference data. Photo taken from: Breakdown of a Nocturnal Inversion Measured with a Low-Cost Tethersonde System: A High School Student Experiment (2021)

Findings

Throughout the creation of the PCB board, modifications were made to every new design. The components were moved around to make more space for wires to fit without intertwining. At the same time, the board was kept compact to ensure a cohesive, compact device. Compared to the original design, a new button component was added, the SD card module was removed, and an adapter component was added for the successful connection of the iMet-Radiosonde pressure, temperature, and RH sensor.



3D model of the final layout of the PCB board. On the board are all the components along with the copper core for the ground connection. All components are labeled on the board to allow for understanding of where each connection takes place.



Physical PCB with components properly fitted into holes.

Summary and Discussion

After developing the PCB schematic, the conclusion that the wires should not intersect, or touch was quickly drawn. The placement of each component mattered in ensuring this. Analyzing the results and data from the study that was described in "The Breakdown of a Nocturnal Inversion Measured with a Low-Cost Tethersonde System: A High School Student Experiment (2021)", the most ideal calibration technique for a PM data set was determined. The inverse calibration technique was discovered to be the best correction method for the data as it made a good improvement in RMSE values without compromising the data values. For improved comparison of the PCB and the physical Teensy device, the PCB schematic should be developed to exactly match the physical device in terms of layout. This would allow for easier debugging of the entire device as corrections could be made to the physical device then mirrored on the PCB. More research could be done towards an ideal protectant that would not prevent or hinder the device from collecting data but rather protect the components from the outside elements.

Future Research

Based on the conclusion of this study, suggestions for other researchers are to work closer with low-cost sensors to make them more compact. The next step for this research is to begin the transfer and connection of the physical components to the PCB. The PCB device should function in the same way as the breadboard device with the PMS7003, BME680, and iMet-Radiosonde working to collect data. In terms of data collection, the ability to get data in real-time rather than it being saved to an SD card should be explored. Additionally, the device could be tested in different weather conditions to see the correlation and effect of a variety of conditions on PM2.5 concentrations. If possible, the LCSs could run for longer periods to analyze functionality and accuracy over time.

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