Research Report

Aware of Air – Measuring Local Air Quality using Portable Arduino-based Sensors

The aim of this project was to design, prototype, program and calibrate a low cost portable air quality monitor. The research was inspired by poor worldwide air quality and statistics from the World Health Organization (WHO) and United States Environmental Protection Agency (EPA). The results show that low-cost sensors can be used to collect reliable air quality data and that the data can be crowd sourced. The research is significant because it demonstrates that citizens can collect air-quality data, share the data, and become aware of the health hazards that take the lives of millions worldwide yearly. There were two aspects to this project – hardware and software engineering

Hardware Engineering - Sensor Selection, PCB Design and Prototyping

Low-cost Carbon Monoxide (CO), Ozone (O_3), Volatile Organic Compounds (VOCs), and Suspended Particulate Matter (SPM) sensors were chosen. The pollutants were chosen based on the EPA air quality pollutant criteria, which outlined what air pollutants are most significant according to the EPA. The sensors used were the MQ-7 for CO, MQ-131 for O_3, MQ-135 for VOCs, and the GP2Y1010 for SPM.

To begin with, a breadboard connected to an Arduino Uno was used. The data was received from the sensors through the Arduino Serial Monitor on a laptop. For this setup, the Arduino had to be wired to the laptop via a USB cable, and data collection was prompted by the user sending a specific byte to the Arduino via the serial terminal through the computer. The limitation of the system was that data was outputted only as text within the serial monitor and could not be exported in any way.

To circumvent this limitation, a PCB was designed based on the circuit tested on the breadboard. It used an Arduino Pro Micro. The use of a PCB allowed for the air-quality monitor to interface with a smartphone instead of a computer. Furthermore, the data could be read outside of a serial monitor. The first PCB however had a few drawbacks, chief among which was the insufficient space between sensors and lack of contacts for the dust sensor to operate optimally.

All these issues were rectified in the second prototype of the PCB. In addition, it also accommodated a DHT11 temperature/humidity sensor so that the effect of temperature and humidity on the other sensors could be studied. The DHT11 was later replaced with a DHT22 sensor that served the same purpose, but did so with a greater degree of accuracy, albeit at a higher cost. This PCB was housed in an acrylic case, but due to concerns over possible interference of plastic on the gas sensors, the PCB was housed in an aluminum case. The performance of the PCB and sensors met expectations.

Due to their relatively high power consumption, a third prototype of the PCB was developed to mount only the MQ-131, DHT22, and GP2Y1010 sensors. This energy efficient model did not replace the previous prototype and instead served as an alternate.

Software Engineering and Sensor Calibration

The software development went side by side with the development of the hardware. All of the Arduinos were programmed in Arduino C. The monitor code performed the following two functions – i) instructed the Arduinos to collect data from all of the sensors when it received a specific serial message and ii) sent the collected data to the device that originated the serial request. For this project, the Arduino communicated with an Android smartphone.

In order to communicate with the Arduino, the smartphone needed a mobile app. The mobile app was programmed in C# through Visual Studio 2017. The app required that the smartphone and the Arduino monitor be connected by a USB OTG cable for communication. The app sent a serial request to the monitor every time an onscreen button was pressed. When the data from the device arrived, it would display it in corresponding boxes on the mobile screen alongside colored bars representing gradient air quality. Furthermore, the mobile app also sent all collected data, with a timestamp and location stamp, to a centralized database online as long as it had access to the internet and location services. All data in the database was mapped and made publicly available for analysis.

The next phase of development involved testing sensors to determine sensitivity, accuracy and spread. To begin with, sensitivity tests were performed on the VOC and SPM sensors. The VOC sensors were tested in clean backyard air, and then in the fumes from ammonia and isopropyl alcohol. The SPM sensors were tested in clean backyard air, and then in the smoke from burning leaves. The tests showed that all of the sensors were responsive to the target pollutant. Subsequently, the VOC and CO sensors were calibrated using calibration gases that held specific concentrations of known gasses. Zero Air cylinder with 20.9% O_2 balance N_2 and Ethylene cylinders with concentrations of 50 ppm Ethylene and 100 ppm Ethylene balance N_2 were used to calibrate the VOC sensor. Zero Air, 100 ppm CO and 1000 ppm CO, balance Air cylinders were used to calibrate the CO sensor.

Ozone's reactivity made it nearly impossible to calibrate using calibration gases. The workaround was to take sensor readings on multiple occasions, at the Beacon Hill EPA monitoring station in Seattle, WA which measures O_3. These readings were compared to the readings the EPA monitor produced and the relation was used to create a mathematical equation that would convert the raw sensor output to parts per billion (ppb), also known as a calibration curve.

Due to the difficulty of obtaining SPM of known concentration outside of a lab setting, a calibration curve was taken from scientific review of this sensor[1]. To test this curve, sensor readings were taken at the location of an EPA monitor in Kennewick, WA that measured SPM. Readings were taken both during normal conditions, and during the height of a local dust storm. The existing curve proved valid due to the close relation between the data from the tested monitor and the data from the EPA monitor.

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1 https://www.tandfonline.com/doi/pdf/10.1080/02786826.2015.1100710

Since the raw output for VOC sensors varied widely, the calibration curves were used to help reduce the variation. Even though each sensor was calibrated individually, sensor to sensor variation was still present. To overcome this, potentiometers were wired to each gas sensor, so that the load resistance of each sensor could be manually adjusted. Once all of the potentiometers were adjusted, the sensors were recalibrated. The recalibration reduced sensor to sensor variation to acceptable levels for health and safety purposes. In a nutshell, it meant that any two randomly chosen devices would return similar values for the pollutant being measured for one location at a given point in time. This was a major improvement since one of the most frequently observed drawbacks of low cost monitors was the variability in the data measured under same conditions among different units.

Based on tests performed over a period of two weeks the SPM sensors varied by less than ±7 μg/m^3 with the local EPA monitor. The VOC sensors have a sensor to sensor variation of less than ±5 ppm.

Conclusion

The project met all initial goals. A low-cost portable air quality monitor was successfully developed and tested. The key achievements of this project were in the elimination of sensor to sensor variation, the collection of air-quality data at the block level, and the transmission of data to the cloud for public mapping. This project has proven that low-cost sensors can be standardized and used to crowdsource air quality data for health and safety purposes.