Towards Fine-Grained Air Quality Sensing in Urban Environments

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Introduction

Background

The World Health Organization (WHO) estimates that each year, 7 million people die prematurely due to ambient and indoor air pollution [9]. Recently, a landmark ruling classified air pollution as the cause of death of a child [10]. While scientists are starting to understand why air pollution causes cancer [6], it has been established that particulate matter, specifically that which is 2.5 micrometers in thickness (PM 2.5), contributes to premature death, heart attack, decreased lung function, and other health effects [2]. While residents can make limited decisions based on reported air quality by visiting AirNow [7], air quality monitoring stations are sparsely deployed (See Figure 1) and may not provide accurate air quality data in their community. Previous research has shown that air quality can differ between street blocks and even the orientation of bus shelters [3, 8]. Fortunately, with low-cost particulate matter sensors combined with Internet of Things (IoT), fine-grained sensing can provide the community with more accurate and informed data. Previous research has shown that deploying monitors as fixed or mobile units provided insights of air pollution that would not have otherwise been captured [1, 4, 5]. However, what most of these solutions have lacked is engagement with the community and a focus on maintaining and scaling a solution to other communities.

To provide fine-grained air quality sensing that is low-cost and provides real-time and historical data, we created an Internet of Things (IoT) sensor that is a fraction of the cost of commercial sensors. We utilize generally available boards including Arduino and Raspberry Pis with the goal of sustaining the project by partnering with local schools to create Computer Science curriculum that will allow students to create their own sensors to be deployed in their community. Additionally, in a pilot deployment we engaged with a community partner, PCs for People, who provides both refurbished computers and internet access to the community at low to zero cost. By partnering with PCs for People, we are leveraging existing infrastructure to deploy sensors at wireless hotspots deployed in the community which can provide both power and connectivity.

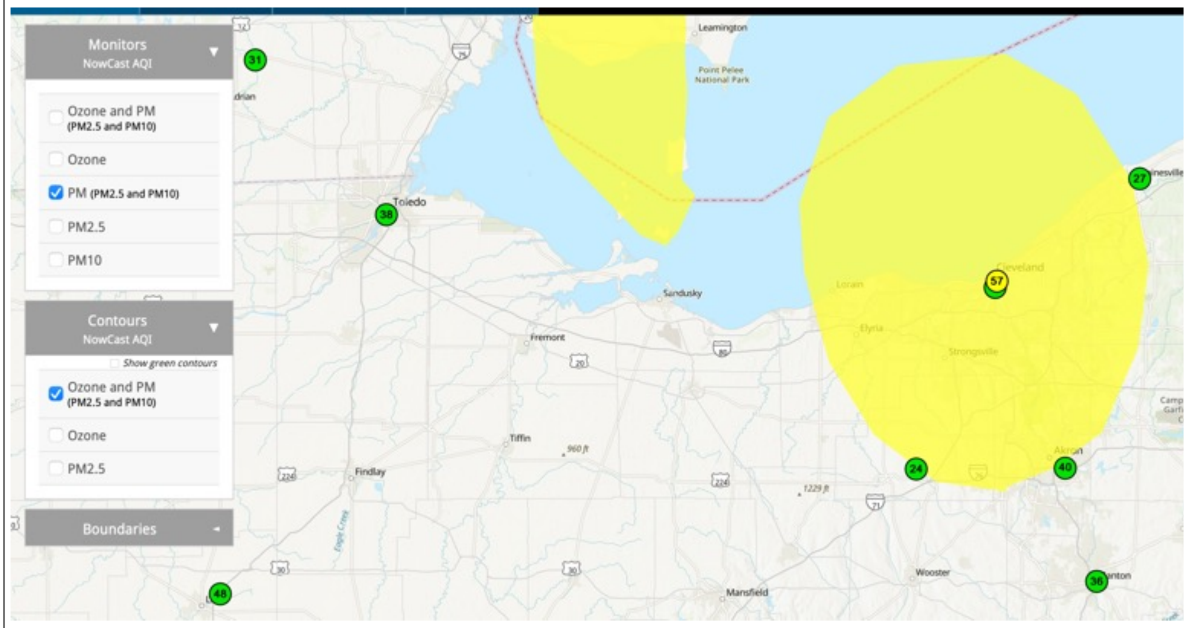

Figure 1 – Deployment of Regulatory Air Quality Stations in Northeast Ohio from AirNow.gov

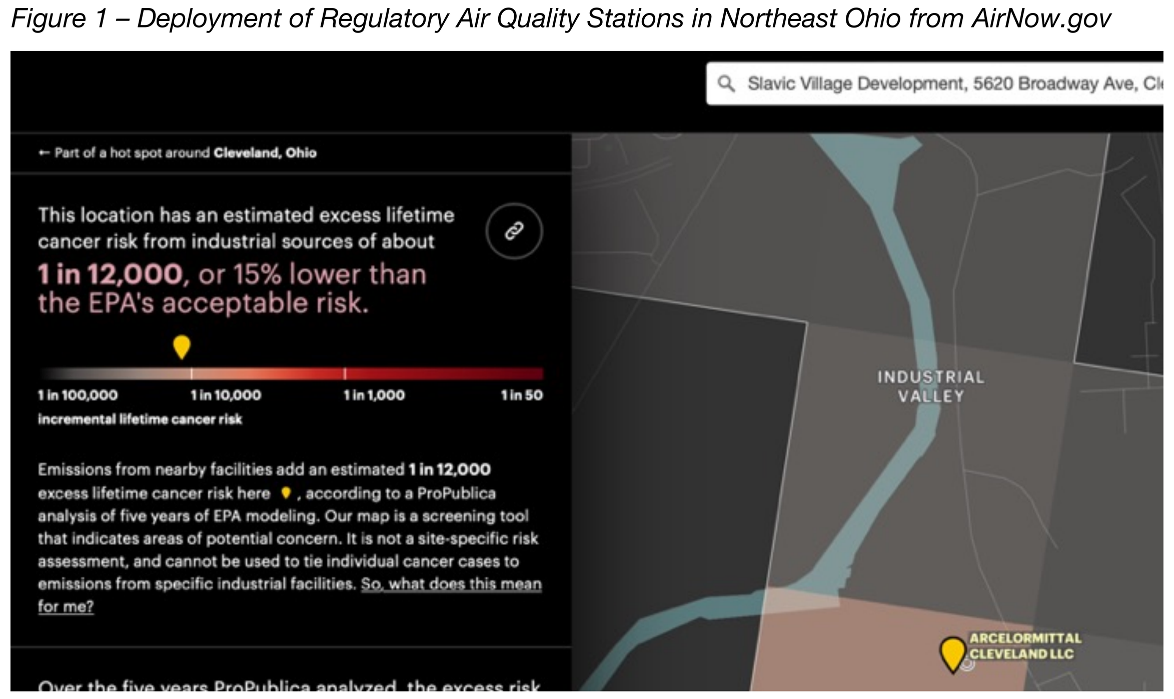

Figure 2 – Screenshot of ProPublica's "Most Detailed Map of Cancer-Causing Industrial Air Pollution in the U.S." that shows Slavic Village near a polluting steel plant.

System Design

The sensor modules utilize generally available microcomputers and single board computers. In our evaluation and test deployment, we used two Raspberry Pi Model 3 B+, two Raspberry Pi Zero W, and two Adafruit Metro M4 Airlift Lite boards. To detect air quality, we focus on particulate matter and measure PM 2.5, PM 10.0, and PM 1.0. All boards utilize a Plantower PMS5003 particulate matter sensor which uses light scattering to measure particulate matter. The Raspberry Pi boards were programmed using Python, and the Adafruit Metro M4 boards were programmed using C.

To capture data from the sensors, we created a web service that receives the sensor ID, each particulate matter reading, and an optional volatile organic compound (VOC) reading. This data is stored in a MySQL database. To visualize the data, we created a web dashboard that shows the readings from each sensor in a line chart. To create the line chart, we use Plotly JS, which allows us to pan and zoom into areas of interest and examine different trends.

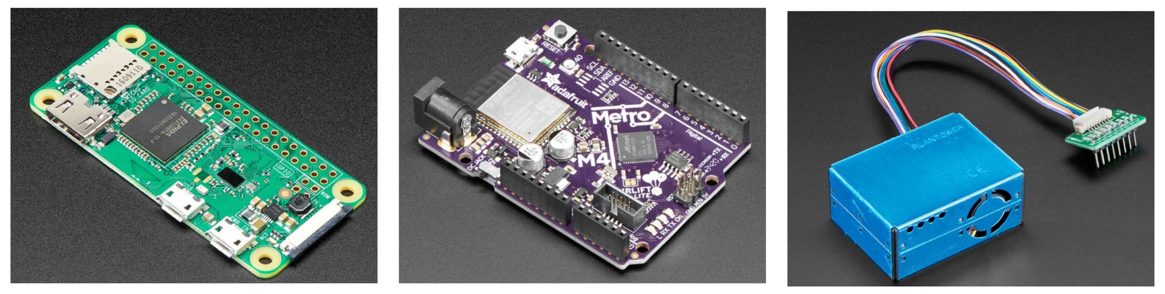

Figure 3 – Sensors Utilize Commonly Available Microcontrollers and Microprocessor Boards and Sensor is a Plantower PMS Sensor

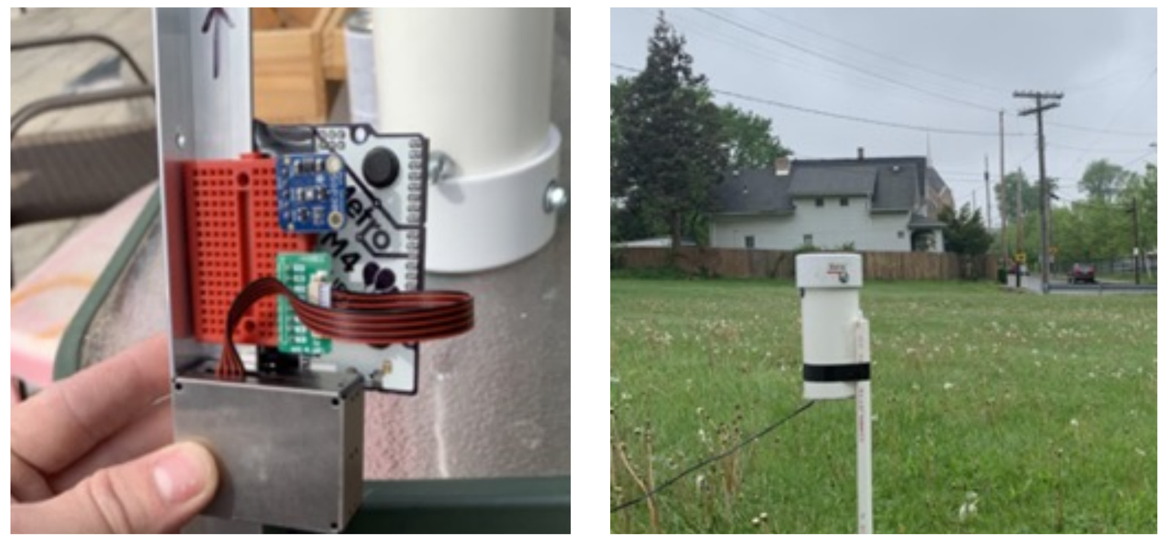

Figure 4 – First Prototype of Sensor Deployed in Slavic Village for a Short Period of Time.

Figure 5 – Particulate Matter Sensors in a Controlled Environment Showing Similar Results

Evaluation

Controlled Experiment

Four sensors were placed in a lab environment to measure the consistency of sensed particulate matter. These included both of the Pi 3 B+ and Pi Zero W models. Earlier testing found that the Arduino-based Airlift boards were not suitable as the WiFi library would timeout on sending readings to the server and would hang indefinitely. A workaround was implemented by implementing a watchdog timer, but with the focus on testing the consistency of the PM sensors, we utilized only Pi boards for testing consistency. The sensors reported for 14 straight days in the lab environment. At the beginning, one of the sensors was not reporting data that was consistent with the others. However, within three hours, reported data was consistent with the other sensors.

Enclosure

To accommodate future community deployments, we have developed a prototype enclosure that will house the electrical components and provide access for power connections. The initial enclosure design has four primary constraints: 1) have sufficient room for the sensor components (Raspberry Pi, power supply, PM2.5 sensor), 2) provide protection from the environment (i.e., rain), 3) allow sufficient air flow for accurate PM2.5 readings, and 4) be able to be fabricated at large scale and with low cost. In addition, the design of the enclosure is modular so that communities may choose to add additional sensors based on the population's needs and interests.

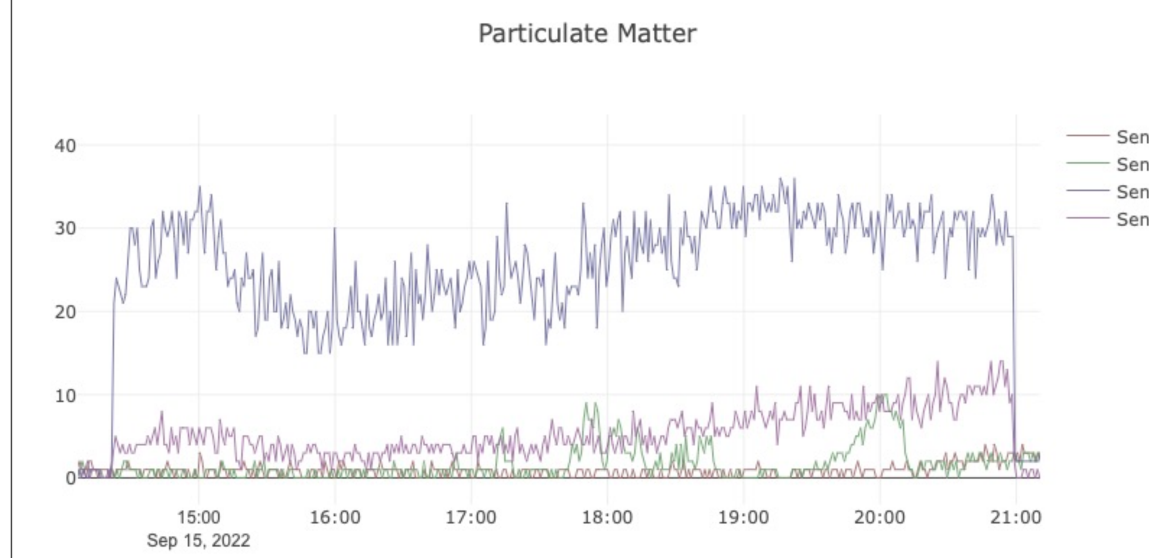

Figure 6 – Results Show Dispersion of Particulate Matter with Fan Show a Linear Offset

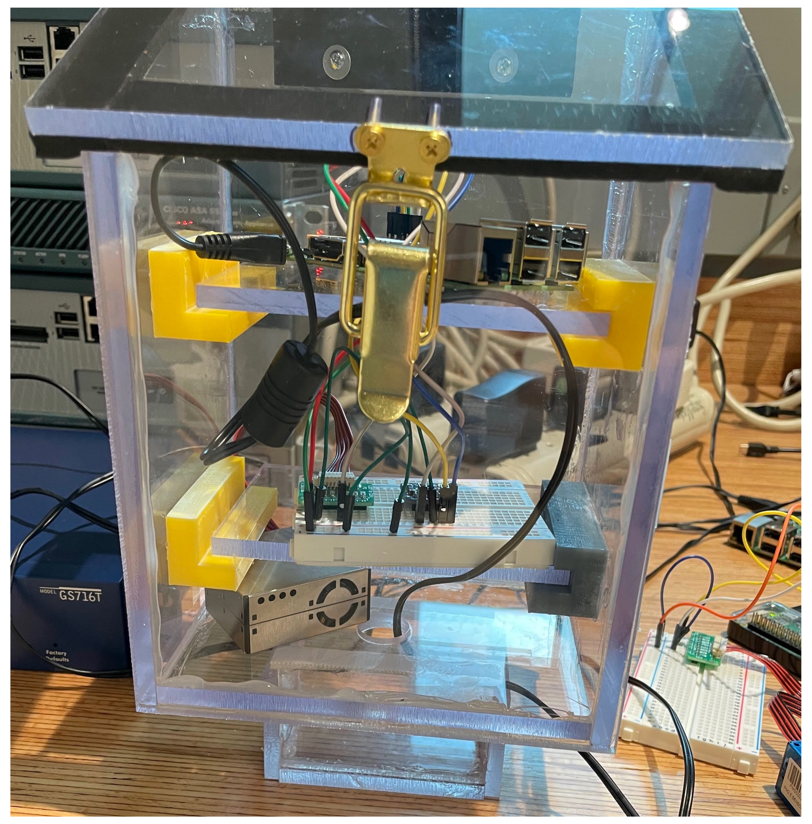

Figure 7 – Prototype of Enclosure with Modular Design for Additional Sensors

Test Deployment

A sensor module was deployed in partnership with PCs for People at their office location near downtown Cleveland from June 15th to August 1st. Readings from this deployment are shown in Figure 9. From these readings, we noticed a considerable spike on the 4th of July at approximately 9:30pm, which coincided with a fireworks show in downtown Cleveland. We also noticed that between 5am-8am and 4pm-7pm, the PM 2.5 readings peaked for the day, which matches the time of rush hour traffic in Cleveland. Overall, for the days the sensor was at the PCs for People office location, the average PM 2.5 reading was 5.42. Then, on August 11th, the sensor was moved to a new location that is less than 4 miles south from the original location, but in close proximity to a steel plant, ArcelorMittal Cleveland LLC. Through discussions with Slavic Village Development (that works closely with the Slavic Village community), residents shared concerns of their air quality. Understandably so, since the average PM 2.5 level in was 12.68 (as of September 22nd), which is more than double the average measured at PCs for People. Figure 2 shows this noticeable difference.

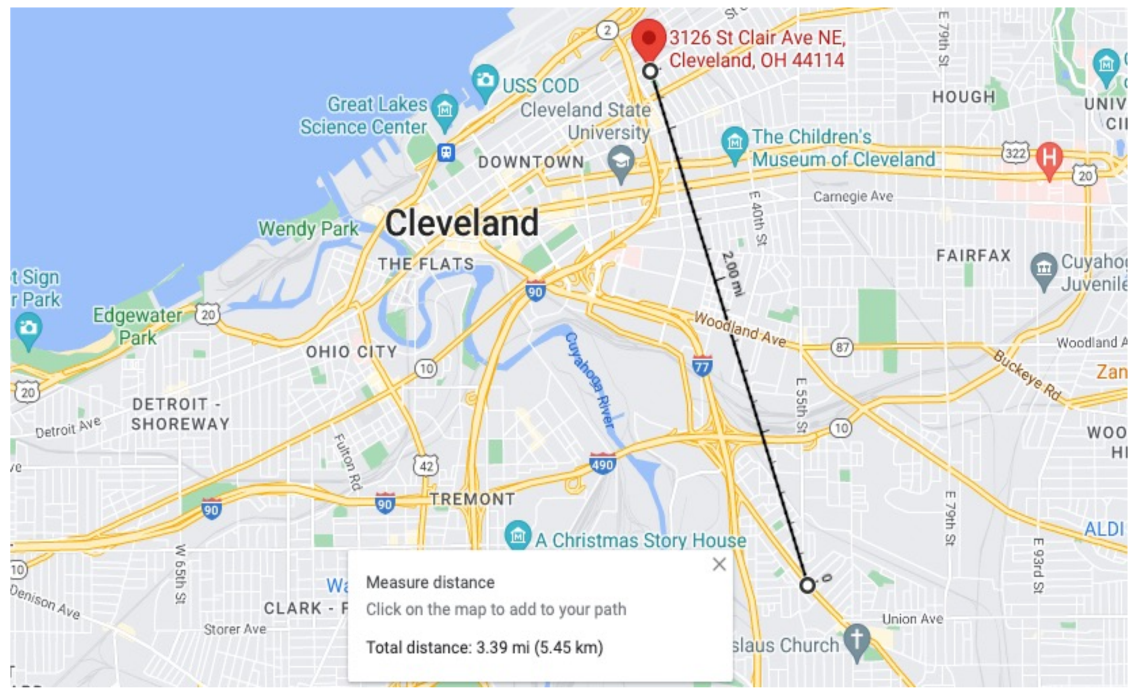

Figure 8 – Two Installed Locations for PM Sensor Located at PCs for People's Office Location and Slavic Village Location (< 4 Miles Apart)

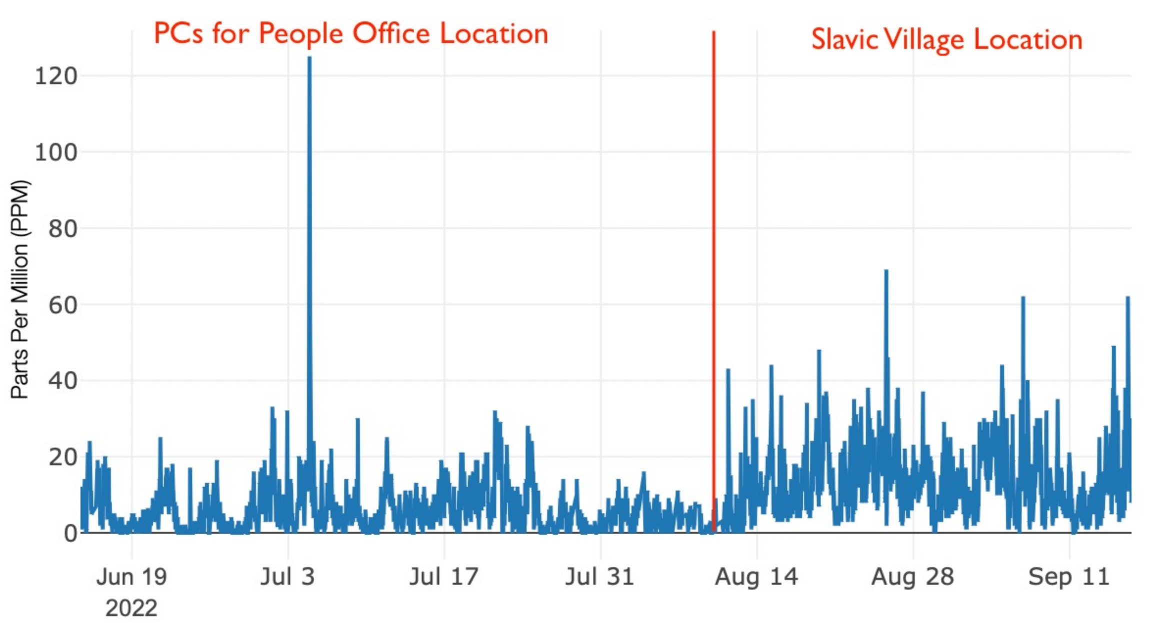

Figure 9 – Readings from Two Installed Locations Within 3.39 Miles Show Significant Difference in PM 2.5 Readings

Conclusions and Future Work

Preliminary data demonstrates that reported air quality data differs from what is reported by deploying fine-grained air quality sensors in a community. This shows the air quality data that is being provided to communities may not accurately describe the air they breathe. Future work will deploy additional sensors in partnership with PCs for People and analyze data collected over a longer period. In addition, we will partner with Slavic Village Development to meet with the community to better understand how community members perceive air quality and how it impacts their daily lives. While the sensors we deployed may not be as accurate as regulatory sensors, previous research has demonstrated that low-cost sensors' accuracy is sufficient to provide general trends and insights.

More Information

https://mops.bw.edu

References

[1] Dhruv Agarwal, Srinivasan Iyengar, Manohar Swaminathan, Eash Sharma, Ashish Raj, and Aadithya Hatwar. 2020. Modulo: Drive-by Sensing at City-Scale on the Cheap. Association for Computing Machinery, New York, NY, USA, 187–197.
[2] Environmental Protection Agency. 2022. Criteria Air Pollutants. EPA. Retrieved March 21st, 2022 from https://www.epa.gov/criteria-air-pollutants
[3] JoshuaS.Apte,KyleP.Messier,ShahzadGani,MichaelBrauer,ThomasW.Kirch- stetter, Melissa M. Lunden, Julian D. Marshall, Christopher J. Portier, Roel C.H. Vermeulen, and Steven P. Hamburg. 2017. High-Resolution Air Pollution Map- ping with Google Street View Cars: Exploiting Big Data. Environmental Science & Technology 51, 12 (2017), 6999–7008.
[4] Nuria Castell, Franck R. Dauge, Philipp Schneider, Matthias Vogt, Uri Lerner, Barak Fishbain, David Broday, and Alena Bartonova. 2017. Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates? Environment International 99 (2017), 293–302.
[5] Francesco Concas, Julien Mineraud, Eemil Lagerspetz, Samu Varjonen, Xiaoli Liu, Kai Puolamäki, Petteri Nurmi, and Sasu Tarkoma. 2021. Low-Cost Outdoor Air Quality Monitoring and Sensor Calibration: A Survey and Critical Analysis. ACM Trans. Sen. Netw. 17, 2, Article 20 (may 2021), 44 pages.
[6] Hannah Devlin. 2022. Cancer breakthrough is a 'wake-up' call on dan- ger of air pollution. The Guardian. Retrieved September 10th, 2022 from https://www.theguardian.com/science/2022/sep/10/cancer-breakthrough- is- a- wake- up- call- on- danger- of- air- pollution
[7] EPA. [n.d.]. AirNow Interactive Map of Air Quality. Retrieved February 4, 2022 from https://gispub.epa.gov/airnow/
[8] Adam Moore, Miguel Figliozzi, and Christopher M. Monsere. 2012. Air Quality at Bus Stops: Empirical Analysis of Exposure to Particulate Matter at Bus Stop Shelters. Transportation Research Record 2270, 1 (2012), 76–86.
[9] World Health Organization. [n.d.]. Air pollution data portal. Retrieved February 4, 2022 from https://www.who.int/data/gho/data/themes/air-pollution
[10] ElianPeltier.2020.InLandmarkRuling,AirPollutionRecordedasaCauseofDeath forBritishGirl. https://www.nytimes.com/2020/12/16/world/europe/britain-air- pollution- death.html