Human Computation (2016) 3:1:235-241

ISSN: 2330-8001, DOI: 10.15346/hc.v3i1.14

A Crowdsourcing-based Air Pollution Measurement System Using DIY Atomic Force Microscopes

DANIEL LOPEZ MARTINEZ, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DANIEL LOMBRAÑA GONZÁLEZ, SCIFABRIC

FRANCOIS GREY, UNIVERSITY OF GENEVA

EN-TE HWU, INSTITUTE OF PHYSICS, ACADEMIA SINICA

ABSTRACT

Air pollutants have become the major problem of many cities, causing millions of human deaths worldwide every year. Among all the noxious pollutants in air, particles with a diameter of 2.5 micrometers or less (PM2.5) are the most hazardous because they are small enough to penetrate to the lungs and invade the smallest airways. Since the presence of dangerous levels of PM2.5, commonly reported in newspapers and on TV, is intertwined with the global pattern of production and consumption, there is a need for citizen science projects that engage the young generations in efforts toward reducing air pollution as they will become the future leaders of society. With this goal, and to enable the geo-temporal characterization of PM2.5, we present a crowdsourcing-based air pollution measurement system that uses affordable DIY atomic force microscopes to measure and characterize PM2.5, exploiting the power of human computation through an online crowdsourcing platform to study how PM2.5 varies over time and across geographical locations. Our system is intended as both a scientific platform and a teaching tool for children to engage in environmental policy.

1. INTRODUCTION

Air pollutants have become the major problem of many cities, causing millions of human deaths worldwide every year (more than AIDS, malaria, breast cancer, or tuberculosis) (Lim et al., 2012; Yang et al., 2013; World Health Organization, 2014, 2012) primary by worsening cardiovascular disease and by contributing to the large global burden of respiratory and allergic diseases, including asthma, chronic obstructive pulmonary disease, and pneumonia (MPH and MPH, 2012; Hoek et al., 2013). Among all the noxious pollutants in air, fine-particulate matter with an aerodynamic diameter of 2.5 micrometers or less (known as PM 2.5) are the most harmful for human health because they are small enough to penetrate deeply into the alveolar region of the lung and may even cross into the blood (Marshall, 2013). Therefore, air pollution measurements commonly include PM2.5 concentration and its reduction has become a major environmental policy target.

Sources of PM2.5 include electric power plants, industrial facilities, automobiles, biomass burning, and fossil fuels used in homes and factories for heating. Therefore, the problem of high PM2.5 levels is intertwined with the global pattern of production and consumption, making necessary the engagement of the public in efforts toward reducing air pollution and, particularly, the young generations since they will become the future leaders of society. Researchers argue that late childhood and early adolescence are vital when it comes to developing an interest in global environmental problems (Ojala, 2012). Therefore, citizen science projects that engage the public and specially the young in the reduction of PM2.5 could help spark an interest in global environmental problems, hence shaping future environmental policies.

Unfortunately, although PM2.5 is commonly reported in newspapers and on TV, current techniques for its measurement (Cao, 2013) do not allow for visual inspection of these particles, hampering the engagement of the young, who favor hands-on experiments whose results they can visually explore. Furthermore, current techniques for measuring PM2.5 are limited to reporting the total concentration of this particulate matter in air, ignoring other important features such as the different sizes and shapes of these particles, which might be related to different sources and patterns of production.

Therefore, there is a need for citizen science projects that engage children in the reduction of PM2.5 and, at the same time, for a system that can be used to study the different characteristics of PM2.5. With this goal, we present a crowdsourcing-based air pollution measurement system using DIY atomic force microscopes. Our system involves the children in the process of creating the hardware, taking the sample, and then analyzing it through crowdsourcing. This provides a hands-on way for children to visually explore PM2.5 that challenges them to put their creativity and problem solving skills into play in content-rich activities, therefore engaging them at a deeper level than with traditional teaching methods.

At the same time, our system results in a valuable scientific platform that might enable the geo-temporal characterization of different morphological features of these particles through crowdsourcing. By leveraging the power of human computation through a crowdsourcing platform, our system overcomes the complexities of collecting and properly identifying and analyzing PM2.5 particles at a large scale. Although the project is still in its infancy, as more data is collected, we expect that we will be able to identify patterns in the distributions of PM2.5 never reported before.

2. DO-IT-YOURSELF ATOMIC FORCE MICROSCOPE AND PARTICLE COLLECTION SYSTEM

Common methods to measure PM2.5 include inlets and filter cups, cyclones, dichotomous impactors and cascade impactors. While these methods can report total concentrations of PM2.5, studying other important information such as the surface roughness, stickiness, deformation, elasticity or morphology of these particles require more advanced methods. One such method is atomic force microscopy (AFM), which has recently been used to study the nanomechanical properties of

PM2.5 (Shi et al., 2015). Atomic force microscopes (AFMs) use a nanoprobe to produce three dimensional maps of a given sample surface with lateral and vertical resolutions on the order of fractions of a nanometer, more than 1000 times better than the optical diffraction limit, therefore providing high resolution images of PM2.5 particle morphology. Furthermore, in contrast to other microscopy techniques such as optical and electron microscopy that require complex optical or electromagnetic lens components, AFMs rely on sensing the direct action between the nanoprobe and the sample surface. This enables the visualization and morphological characterization of PM2.5 particles, together with other nanomechanical properties.

Unfortunately, atomic force microscopes, due to their high cost, are out of the reach of most educational centers. To solve this, the LEGO Foundation sponsored a summer school program that sought to develop an affordable do-it-yourself atomic force microscope suitable for use in schools by children, for under US$1,000 (Grey, 2015). The result of this program has been a low-cost open-source AFM that children can build using LEGO, Arduino, cheap 3D printable parts and local components. While the system is still being improved, its ability to produce high resolution images of PM2.5 particles has been shown. At the same time, a closed-source version of the DIY AFM, the Strømlingo DIY AFM kit, has reached the market. Now, children can assemble AFM microscopes and start operating them in less than a day, making this technology reachable for most schools and educational centers, opening it up for the user's creativity to come into play.

The system presented in this report uses these affordable DIY AFM kits, which can operate in both contact and non-contact mode and achieve better than 20nm resolution, to image PM2.5 particles. Unfortunately, these systems use open loop scanners, which means that the measurement of any feature within the images produced needs to be calibrated with a feature of known distance. In order to solve this problem, the particle collection protocol involves using DVD disks without the protective layer as a flat substrate for particle collection, sampling and measurement. Because the distance between two data tracks on the disk surface is fixed (740 nm), the DVD tracks can be used to calibrate the AFM images, enabling accurate morphological characterization of PM2.5 particles.

To collect the particles, a piece of a DVD (the Lego2Nano DIY AFM has a typical scanning area of 15 μm x 15 μm) without protective layer is placed outdoors for at least 10 minutes (see Figure 1, showing school children collecting and scanning PM2.5 particles). This suffices for particles to accumulate in the DVD piece, which then can be easily scanned to produce 128 pixels $\times$ 128 pixels images in under 15 minutes.

3. CROWDSOURCING-BASED PM2.5 DETECTION SYSTEM

Crowdsourcing is a fast and cheap method for engaging large populations of individuals in human computation, commonly used in citizen science projects in which the public participate in scientific research by providing and making meaning of their collective data (Wiggins, 2010; Brabham, 2008).

Our citizen science project was hosted by Crowdcrafting[1], a free, open source, crowdsourcing platform in which volunteers are asked to contribute to scientific projects developed by citizens, professionals or institutions that need help to solve problems, analyze data or complete challenging tasks that cannot be done by machines alone, but require human intelligence.

[1] http://crowdcrafting.org/project/lego2nano

Figure 1. ***Schoolchildren collecting and scanning PM2.5 particles using a DIY AFM. The image on the left shows a piece of a DVD disk without protective layer placed outdoors (shown next to an air quality meter for reference). In the right, the AFM is being used to image PM2.5 particles.***

Figure 2. ***Crowdcrafting interface of our Lego2Nano particle measurement project.***

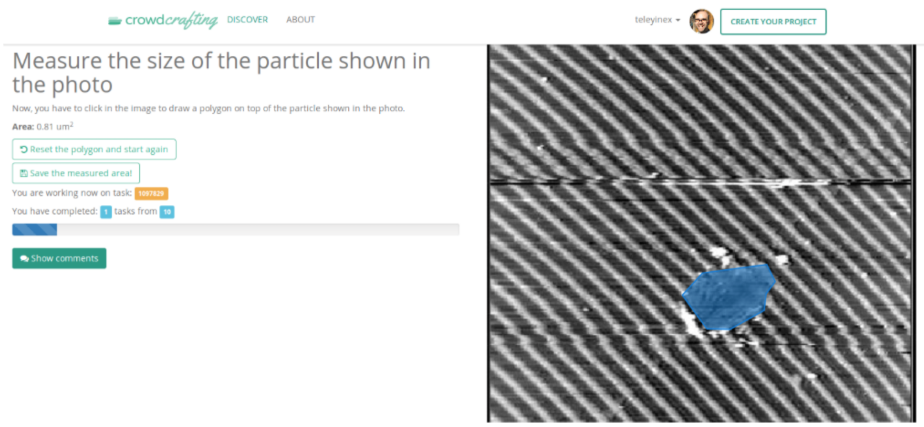

Figure 3. ***Crowdcrafting interface, where the user is asked to draw a polygon over the particle in order to measure its size and shape.***

Crowdcrafting is powered by PyBossa[2], an open source Python engine for distributed-tasks projects with very simple architecture and usability that has been used in different types of projects from pattern recognition in images, sound and videos, to geo-coding places. A PyBossa project consists in one or more tasks that are analyzed by a multitude of people so that valid statistical results are obtained.

In our project, contributors upload AFM images of the DVD sections, together with the geographical and temporal information corresponding to when the particles were collected. Each of these images generates a task in PyBossa. When volunteers access our project in Crowdcrafting, they are presented with several tasks. For each of them, they are asked to report whether they see any particles in the image and, if so, how many such particles are present. If particles are present, then they are asked to draw a polygon over an area of the image with no particles and good image quality for automatic calibration of the measurements, and then polygons over each of the particles detected.

Calibration is performed on the selected area by calculating the autocorrelogram of this area and selecting the x and y peak frequency components, which can be used to infer the number of pixels between DVD tracks. Since the distance between tracks is fixed (740 nm), we can obtain the width in nm of the pixels in the image.

Once the user has identified and measured all particles, the data is saved in Crowdcrafting. In order to obtain accurate measurements, for each image this process is repeated by at least 10 different people. Once all the answers have been collected agreement scores are computed and outliers are removed from the data before reporting average particle sizes and shapes. The results can then be used to calculate particle size distributions and study their morphology.

[2]http://pybossa.com

4. CONCLUSIONS AND FUTURE WORK

We have developed a crowdsourcing-based air pollution measurement system based on DIY atomic force microscopes. The system can be used to measure particle size distributions and morphology, as well as how these change over time and across geographical locations.

The system is primarily intended as a teaching tool for children to engage in environmental policy. While it is not a replacement for traditional methods of teaching about pollution, its sources and its negative consequences, it can be an excellent and important augmentation. In particular, it may be able to inspire, engross and engage students in ways different from traditional classrooms.

At the same time, it also serves as a powerful scientific platform for scientists to study the geotemporal patterns of PM2.5 generation, such as seasonal variations or other long-term trends, by leveraging the combined processing power of a multitude of children to analyze the data contributed from different schools across the globe.

Although the project is still in its infancy, as DIY AFM kits become mainstream and educational centers adopt them, we expect our Crowdcrafting platform[3] to be populated with images of pollution particles from all over the world. Once sufficient images are collected, our platform will enable children to contribute to the discovery of trends and patterns of PM2.5 through crowdsourced human computation . By actively involving them in the discovery of these trends, we hope to engage them in the development of novel strategies that exploit the crowdsourced data and the heterogeneity of source locations for the reduction of a problem that causes millions of human deaths worldwide every year.

5. ACKNOWLEDGEMENTS

This project was supported by the Lego Foundation. We also thank our colleagues from the UCL Institute of Making and the London Centre for Nanotechnology, Tsinghua University and Peking University, who participated in the 2015 LEGO2NANO summer school program in China coordinated by the Citizen Cyberlab. Their insight and expertise greatly assisted this project.

6. REFERENCES

Brabham, D. C. (2008). Crowdsourcing as a Model for Problem Solving: An Introduction and Cases. *Convergence: The International Journal of Research into New Media Technologies* 14, 1 (2008), 75–90.

Cao, J. (2013). Evolution of PM2.5 Measurements and Standards in the U.S. and Future Perspectives for China. *Aerosol and Air Quality Research* (2013), 1–15.

Grey, F. (2015). Creativity unleashed. *Nature Publishing Group* 10, 5 (May 2015), 480–480.

Hoek, G, Krishnan, R. M, Beelen, R, Peters, A, Ostro, B, Brunekreef, B, and Kaufman, J. D. (2013). Long-term air pollution exposure and cardio-respiratory mortality: a review. *Environmental Health* 12, 1 (May 2013), 1–1.

Lim, S. S, Vos, T, Flaxman, A. D, Danaei, G, Shibuya, K, Adair-Rohani, H, AlMazroa, M. A, Amann, M, Anderson, H. R, Andrews, K. G, Aryee, M, Atkinson, C, Bacchus, L. J, Bahalim, A. N, Balakrishnan, K, Balmes, J, Barker-Collo, S, Baxter, A, Bell, M. L, Blore, J. D, Blyth, F, Bonner, C, Borges, G, Bourne, R, Boussinesq, M, Brauer, M, Brooks, P, Bruce, N. G, Brunekreef, B, Bryan-Hancock, C, Bucello, C, Buchbinder, R, Bull, F, Burnett, R. T, Byers, T. E, Calabria, B, Carapetis, J, Carnahan, E, Chafe, Z, Charlson, F, Chen, H, Chen, J. S, Cheng, A. T.-A, Child, J. C, Cohen, A, Colson, K. E, Cowie, B. C, Darby, S, Darling, S, Davis, A, Degenhardt, L, Dentener, F, Des Jarlais, D. C, Devries, K, Dherani, M, Ding, E. L, Dorsey, E. R, Driscoll, T, Edmond, K, Ali, S. E, Engell, R. E, Erwin, P. J, Fahimi, S, Falder, G, Farzadfar, F, Ferrari, A, Finucane, M. M, Flaxman, S, Fowkes, F. G. R, Freedman, G,

[3]http://crowdcrafting.org/project/lego2nano

Freeman, M. K, Gakidou, E, Ghosh, S, Giovannucci, E, Gmel, G, Graham, K, Grainger, R, Grant, B, Gunnell, D, Gutierrez, H. R, Hall, W, Hoek, H. W, Hogan, A, Hosgood III, H. D, Hoy, D, Hu, H, Hubbell, B. J, Hutchings, S. J, Ibeanusi, S. E, Jacklyn, G. L, Jasrasaria, R, Jonas, J. B, Kan, H, Kanis, J. A, Kassebaum, N, Kawakami, N, Khang, Y.-H, Khatibzadeh, S, Khoo, J.-P, Kok, C, Laden, F, Lalloo, R, Lan, Q, Lathlean, T, Leasher, J. L, Leigh, J, Li, Y, Lin, J. K, Lipshultz, S. E, London, S, Lozano, R, Lu, Y, Mak, J, Malekzadeh, R, Mallinger, L, Marcenes, W, March, L, Marks, R, Martin, R, McGale, P, McGrath, J, Mehta, S, Memish, Z. A, Mensah, G. A, Merriman, T. R, Micha, R, Michaud, C, Mishra, V, Hanafiah, K. M, Mokdad, A. A, Morawska, L, Mozaffarian, D, Murphy, T, Naghavi, M, Neal, B, Nelson, P. K, Nolla, J. M, Norman, R, Olives, C, Omer, S. B, Orchard, J, Osborne, R, Ostro, B, Page, A, Pandey, K. D, Parry, C. D, Passmore, E, Patra, J, Pearce, N, Pelizzari, P. M, Petzold, M, Phillips, M. R, Pope, D, Pope III, C. A, Powles, J, Rao, M, Razavi, H, Rehfuess, E. A, Rehm, J. T, Ritz, B, Rivara, F. P, Roberts, T, Robinson, C, Rodriguez-Portales, J. A, Romieu, I, Room, R, Rosenfeld, L. C, Roy, A, Rushton, L, Salomon, J. A, Sampson, U, Sanchez-Riera, L, Sanman, E, Sapkota, A, Seedat, S, Shi, P, Shield, K, Shivakoti, R, Singh, G. M, Sleet, D. A, Smith, E, Smith, K. R, Stapelberg, N. J, Steenland, K, Stöckl, H, Stovner, L. J, Straif, K, Straney, L, Thurston, G. D, Tran, J. H, Van Dingenen, R, van Donkelaar, A, Veerman, J. L, Vijayakumar, L, Weintraub, R, Weissman, M. M, White, R. A, Whiteford, H, Wiersma, S. T, Wilkinson, J. D, Williams, H. C, Williams, W, Wilson, N, Woolf, A. D, Yip, P, Zielinski, J. M, Lopez, A. D, Murray, C. J, and Ezzati, M. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet* 380, 9859 (Dec. 2012), 2224–2260.

Marshall, J. (2013). PM 2.5. *Proceedings of the National Academy of Sciences of the United States of America* 110, 22 (May 2013), 8756–8756.

MPH, R. J. L. M and MPH, H. M. K. M. (2012). Respiratory health effects of air pollution: Update on biomass smoke and traffic pollution. *Journal of Allergy and Clinical Immunology* 129, 1 (Jan. 2012), 3–11.

Ojala, M. (2012). How do children cope with global climate change? Coping strategies, engagement, and well-being. *Journal of Environmental Psychology* 32, 3 (Sept. 2012), 225–233.

Shi, Y, Ji, Y, Sun, H, Hui, F, Hu, J, Wu, Y, Fang, J, Lin, H, Wang, J, Duan, H, and Lanza, M. (2015). Nanoscale characterization of PM2.5 airborne pollutants reveals high adhesiveness and aggregation capability of soot particles. *Nature Publishing Group* (June 2015), 1–10.

Wiggins, A. (2010). Crowdsourcing science: organizing virtual participation in knowledge production. *Proceedings of the 16th ACM international conference on Supporting group work* (2010), 337–338.

World Health Organization, . (2012). Burden of disease from the joint effects of Household and Ambient Air Pollution for 2012. (2012). http://www.who.int/phe/health_topics/outdoorair/databases/AP_jointeffect_BoD_results_March2014.pdf

World Health Organization, . (2014). WHO methods and data sources for global causes of death 2000-2012. (2014). http://www.who.int/entity/healthinfo/global_burden_disease/GlobalCOD_method_2000_2012.pdf

Yang, G, Wang, Y, Zeng, Y, Gao, G. F, Liang, X, Zhou, M, Wan, X, Yu, S, Jiang, Y, Naghavi, M, Vos, T, Wang, H, Lopez, A. D, and Murray, C. J. (2013). Rapid health transition in China, 1990–2010: findings from the Global Burden of Disease Study 2010. *The Lancet* 381, 9882 (June 2013), 1987–2015.