Networked Public Space: Open-Source Environmental Sensing

A Capstone Report
presented to the faculty of the
School of Engineering and Applied Science
University of Virginia

by

Teagan Le

May 9, 2023

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Teagan Le

Capstone advisor: Rosanne Vrugtman, Department of Computer Science

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CS4991 Capstone Report, 2023

Teagan Le
Computer Science
The University of Virginia
School of Engineering and Applied Science
Charlottesville, Virginia USA
vnl6rj@virginia.edu

ABSTRACT

The Networked Public Space (NPS) research project explored ways to develop and apply open-source software and hardware for environmental monitoring in public spaces, since existing commercially-available environmental sensing hardware is often inaccessible due to cost, and locked down to the manufacturer's specifications. "Sensenet" was the portion of NPS dedicated to developing technology and was a combination hardware and software endeavor. On the hardware front, a team of researchers and I applied circuit design and PCB layout to create a microcontroller board to control the sensors. We then wrote software for this board, extending the popular Arduino platform for prototyping microcontroller projects. We demonstrated several completed sensor boxes at an event in Richmond, Virginia, as well as at the Datapalooza conference at the UVA School of Data Science. The artifacts of this project are open-source. We assembled several kits for distribution to interested parties. Future work includes making the software portion of this project more accessible by developing better documentation and distributing it more widely.

1. INTRODUCTION

The community of Norco, Louisiana, lies in a region known as Cancer Alley, along with over 100 petrochemical plants which spew pollution over places like Norco (Castellón, 2021). For decades, demands to stop pollution in the region by area residents, largely impoverished African American, were unsuccessful (Castellón, 2021). In 2000, the Louisiana Bucket Brigade, searching for pollutants in the air, used buckets to collect air samples to be sent to a lab for analysis (Louisiana Bucket Brigade, n.d.; Smith, 2017). They released a report with their findings, and by 2002 were able to leverage Shell, which operated the Norco refinery, into buying out properties so residents could relocate.

The Louisiana Bucket Brigade is one successful case of citizens leveraging community environmental data collection in their pursuit of environmental justice. With the advent of lower-cost, off-the-shelf sensors for data such as noise, particulate matter, temperature, humidity, and carbon dioxide, it has become possible to develop environmental sensors at a price point accessible to more people, and thus democratizing environmental sensing.

Networked Public Space (NPS, n.d.) investigated how "smart" technologies and systems could be integrated into public space. This investigation focused on environmental justice in urban spaces, and as such was not a purely technical venture. A project of UVA School of Architecture's Next Cities Institute, NPS integrated urban planning and architecture with technology, culminating in an art installation in Shockoe Bottom, Richmond, Virginia. As an engineering student, my contribution to this project was in its technical aspects in a part of the project called “Sensenet.”

2. RELATED WORKS

Several students at the University of Virginia have contributed to community environmental sensing in their undergraduate theses. Mahmood (2021), along with his technical project team, created and deployed a sensor network that interfaced with cloud services to allow residents of Albemarle County, Virginia to monitor and be alerted about floodwaters.

Radhakrishnan (2020) wrote his STS research paper on the relationship of IoT environmental sensing, universities, and the communities they serve. He states that academics have, in the past, been overly concerned with scholastic issues, rather than the practical issues the community faces. He writes of successful past citizen science projects in environmental sensing, such as Safecast, a project to monitor radiation in the aftermath of the Fukushima Daichi disaster in Japan. According to Brown, et al, (2016), Safecast used open-source hardware and software to achieve its goal, and published all of its data publicly. Radhakrishnan (2020) also conducted a series of interviews with people who trialed the Sensenet system, and found that the desires of academics ~~differ~~ from the desires of laypeople from the community. Whereas citizens seemed interested in the goals, they were disinterested in the implementation. Notably, Radhakrishnan worked on Sensenet before I joined the team, so my work could be considered an extension of his.

The University of Virginia’s Arctic Research Center has been investigating environmental interactions in the village of Utqiagvik, Alaska (NSF, n.d.; University of Virginia Arctic Research Center, n.d.). The project’s NSF award abstract states that “community members are deeply involved in the planning process for placement of the sensors, ongoing maintenance, and interpretation of the data”. This project draws parallels with NPS, as both aim to collect and use data in accordance with the needs of a community.

Brubaker, et al. (2021) also worked in Alaska to expand the Local Environmental Observer Network, a program administered by the Alaska Native Tribal Health Consortium. The project is another instance of community-based environmental monitoring, although one that relies less on technology as sensors, and more on technology as an intermediary between community members and environmental experts.

Gabrys (2016) dedicated three chapters in her book to citizen scientists performing environmental sensing. She notes that the way researchers use data is different from the way other citizens might. She states that the projects in Alaska, such as that of Brubaker, et al., are incorporating new ways for citizens to participate in data collection: instead of using sensors, they submit their own experiences. Gabrys also addresses the use of environmental sensing in cities, raising questions of who participates, and what impact the data has. She investigates issues with getting non-technical people to participate in the “smart city” movement, and whether cities would even benefit from environmental sensing.

3. PROJECT DESIGN

There are two main components to the Sensenet project: the sensor kit, called “Big Dot,” and its firmware. This project was principally carried out by myself and my research advisor.

3.1 Big Dot

The main microcontroller board, called “Big Dot,” due to its circular shape, is designed to allow additional boards, called “shields,” to be installed on top of it. Big Dot’s heart is the SAML21 microcontroller, which was selected for its “ultra low-power” capabilities and similarity to the more common SAMD21 platform (Microchip Technology, 2020). Since Arduino platform specifications written for SAMD21, it would be straightforward to port to the SAML21. The SAML21's low power features were important since these kits were intended to be powered by small solar panels and battery packs, which require efficient use of power.

In addition to the SAML21, the main board has a few other major components: an RFM95 LoRa transceiver, a battery controller, debug pins, and a USB port for connecting to a computer or a power source. The board has connectors and supporting components and circuitry for the major components, including resistors, capacitors, and inductors. The RMF95 LoRa transceiver is used to transmit data collected by the environmental sensors to a LoRa gateway, which relays the data to an endpoint on the internet. LoRa is an open-source standard for low-power radio networking, aimed at the internet of things (LoRa Alliance, n.d.).

In addition to the main board, the project has a shield with several sensors, including ones for CO2, particulate matter, temperature and humidity. The shield also features a small OLED display, which users can use to display simple text or graphics.

My task was to design the boards. I placed each component on the board, routed the wires, and created the silkscreen printing. Design work was done in the PCB design software KiCAD. The process required iterations of manufacturing the board, assembling them, and fixing issues that arose. Manufacturing the bare boards was outsourced to OSH Park. I assembled all the components onto the bare boards by soldering, and then uploaded the firmware onto the board to check if I had assembled it correctly. We then identified issues with the circuitry, and ordered new circuit boards and components, and repeated the process. There were three iterations of Big Dot before we were ready to demonstrate.

3.2 Firmware

As we were working on the boards, we also worked on the firmware for Big Dot. This mainly involved adapting the Arduino platform to Big Dot. Arduino is a popular open-source platform for microcontroller programming, since it provides an "accessible user interface", yet is "flexible enough for advanced users to take advantage of" (Arduino, 2018). Users can write programs using the standardized Arduino programming features, then compile it for Big Dot. Porting Arduino involved modifying existing platform definitions, which are files that specify data about the boards, such as their name and version. They also specify the C language compiler toolchain for building software for the boards, options for processor features, and pin mappings from a human-readable macro to a register in the microprocessor, and other settings required by the Arduino platform.

The firmware also required adding new features to control the power settings available in the SAML21, in the form of a new C library that can be used in any program written for Big Dot. These changes allowed us to achieve very low power usage in the nano-amp range when the device was asleep.

We also created some demonstration programs for the board, which were intended to showcase its features in a ready-to-deploy package. The first one periodically took sensor inputs from all the attached sensors, then displayed their readings on the OLED display. In preparation for the installation at Shockoe Bottom and the demonstration at Datapalooza, we modified this program to also transmit the data over LoRa and set up a web dashboard to visualize it. The second demonstration program activated a color-coded ring of LEDs to visualize the amount of particulate matter measured by the PM sensor.

4. RESULTS

By the time the project was concluded at UVA, we had manufactured several kits and demonstrated the project. The first public demonstration of the project was at an installation at Shockoe Bottom, along with work by students from the UVA School of Architecture. These projects were themed around visualization for the environmental conditions of marginalized neighborhoods in Richmond. The Sensenet installation included a LoRa gateway and three fully assembled Big Dot modules placed around African Burial Ground and Richmond Main Street Station. The data from the sensors was used to visualize the air pollution in the area, which is nestled by Interstate 95 and a busy railway. Sensenet was also demonstrated during the Datapalooza conference at the UVA School of Data Science in late 2021, where a similar setup was used to visualize data. Audience members were invited to write a simple program for the boards as an introduction to prototyping with microcontrollers.

The source code and PCB CAD files are freely available online for anyone to use. If one has the manufacturing capability, then they can create the kits.

5. CONCLUSION

Networked Public Space sought to demonstrate the potential for citizens to collect environmental data in their own communities. To this end, I developed the necessary hardware and software to carry out this environmental sensing, and this work is now freely available for any to use in their own projects, related to environmental sensing or otherwise. With the basis that this project provides, others will have a place to start their own work. The results of NPS can inform others wishing to create and study smart city technologies and movements, especially those based around community environmental sensing, citizen science, and the internet.

6. FUTURE WORK

The hardware, Big Dot, is feature complete. The firmware for Big Dot is mostly complete, although there are some features that are not fully implemented. Future work on the project would mostly be completing the software to remove any bugs from the additional features of the SAML21. More in-depth documentation is also an area where more work can be done. Currently, there are a few instruction pages describing how to get everything up and running, but there is a lack of documentation on basic features, such as pin layouts and new software methods.

Since the project is open-source, anyone may modify the hardware and software for their own needs. If someone thinks the basis that Big Dot provides is suitable for their project, they can manufacture the boards for themselves, and modify the software for their purpose. People can also submit improvements for Big Dot, which would be integrated into the project.

7. UVA EVALUATION

The classes in the Computer Science Department that most benefited me in this project were CS 2150 Data Structures and Algorithms, CS 3501 and 3502 Embedded and Robotics I and II, and CS 4414 Operating Systems. It is regrettable that Embedded and Robotics was discontinued after Professor Dugan retired; I was a teaching assistant for that class for one semester. I believe it would benefit students in the Computer Science and Computer Engineering programs to have a similar class take its place.

8. ACKNOWLEDGMENTS

This project would not have been possible without the work of my research advisor, Luis Felipe R. Murillo, as well as the other researchers on the Networked Public Space project.

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