Cooling Urban Noise Pollution in 3D: Data-Driven, Community-Driven, Art-Driven

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In this paper we report on progress and on-going efforts of the Citygram project, which dynamically collects, maps, quantifies, and performs data analytics and visualization of soundscapes, and in particular urban noise. Citygram's hybrid sensor network utilizing geostationary (e.g. New York City's public LinkNYC payphone/WiFi system) and community-driven (any device with a web-browser and microphone) sensor designs aim to facilitate the creation of a scalable, real-time sound-mapping system that can be integrated into modern city infrastructures to help determine concurrently where, when, and what kind of noise is produced. Our approach to urban noise mitigation integrates data-driven, community-driven, and art-driven paradigms guided by adages of "you can't fix what you can't measure," "seeing is believing," as well as "life follows art follows life." Citygram approaches the quasi-objective nature of noise pollution through dynamic, highly granular spatio-temporal noise data acquisition, Big Data analytics and geo-spatial visualization. New York City (NYC) and Los Angeles (LA) currently serve as our primary labs.

Introduction: Soundscapes, Noise Pollution, and Citygram

In 2011, Park launched the Citygram (T. H. Park et al. 2012; T. Park et al. 2013; T. H. Park, Turner, Musick, et al. 2014; Shamoon and Park 2014; T. H. Park, Turner, You, et al. 2014) project with the aim of developing dynamic maps for capturing spatio-temporal, non-ocular energies beginning with acoustic energy: sound-maps. Since then, the project’s focus has further narrowed in scope and our current efforts thematically focus on urban noise pollution. we have found noise pollution to be one of the most important applications of sound-maps as it frames our research in the context of meaningful humanistic values and sustainability of urban environments. For the past six years, we have been developing a sensor network system for the masses, which necessitates the technology to be easy to use, accessible, participatory, cost-effective, and scalable. This has led to a concept called plug-and-sense allowing virtually anyone to simply “plug a device into the network” and “sense” the environment as an active participant, contributor, or user. More specifically, Citygram’s sensor network research module has led to the development of a “hybrid sensor network” comprised of fixed or mobile custom and crowd-sourced sensors, where the latter is simply any computing device with a web-browser and microphone. The team has thus spent significant effort in developing state-of-the-art technologies that can be adopted by the vast majority of hardware and user interfaces that the public can easily use. This effort was guided by the ultimate goal of capturing and understanding urban noise pollution with high spatio-temporal resolution and cost-effective designs.

Citygram is currently developing technologies to capture, automatically classify, geo-tag, and time-stamp urban soundscapes and noise agents such as traffic, construction, and music signals, which can then be analyzed, visualized and made available to noise code enforcement agencies
and the general public. Such noise data can also be combined with other spatio-temporal data sets (e.g. local health records, standardized educational test results, and census statistics) to shed light on relationships between different energy sources that occupy urban settings and citizen welfare. Urban noise has existed since the first urban agglomeration had formed. It has naturally increased with population growth and the integration of machinery as an essential component of urban infrastructure since the industrial revolution. However, this upward sonic trend has accelerated with modern urbanization as increasingly densely populated city centers require more businesses, more supplies, more traffic, and more people to be serviced per square mile. The urgency and need for understanding and capturing urban soundscapes can already be felt firsthand by positioning oneself at an intersection in Manhattan, but is most clearly demonstrated through the following stylized facts: (1) noise is quantified as urban residents’ #1 complaint\(^1\) in megacities like New York City (NYC); (2) more than 50% of the entire population now lives in cities; and (3) approximately 70% of the world is projected to live in such megacities by 2050(Organization 2015). This urgency is further escalated when considering a growing body of evidence that documents noise related health implications, effects on children’s education, and workplace performance of noise pollution, let alone livability factors integral to sustaining city life. Cities’ policies towards noise have been to create noise ordinances that are, however, difficult to enforce. A typical noise complaint in NYC, for example, starts with a 311 call that is sent to the New York Police Department (NYPD) or the Department of Environmental Protection (DEP). The NYPD writes summonses to control noise issue in the city that never sleeps, but it is put in a difficult position to serve the community in tackling noise complaints not only due to personnel shortages but also technical issues that are important to measure, analyze, and document the source of noise appropriately. Naturally, as compared to immediately recognizable and urgent emergencies, noise is categorized as a non-emergency event, which in turn lead to lower response rates for noise complaints. The situation at the NYC DEP is equally challenging: it only has approximately 50 inspectors for both air and noise, making day-to-day response to noise reports in New York challenging due to the spatio-temporal spread and frequency throughout the city. This leads to frustrating short, mid, and long-term consequences for city dwellers. The situation is further exasperated due to the futile, often non-permanent appearance of noise. As it is often a case of “now you hear it, now you don’t,” the noise that was present just moments ago may no longer be present upon arrival of inspectors ... and reappear shortly afterwards. The noise pollution issue is made even more difficult as “noisescapes” are the most complex acoustic signals we deal with on a daily basis as they virtually include every type of sound class including car honks, barking dogs, loud chatter, airplanes and trains passing by, music, and the infamous signature of early morning garbage pick-up truck sounds that echo and resonate their way up apartment buildings. But one type of noise is not necessarily equal to another of the same strength, it is rather in the ear of the beholder: 90 dB rainfall, wailing sirens, and blackboard-fingernail scratches are perceived substantially differently, making noise quantification nontrivial for both outdoor and indoor environments.

The Citygram project provides strategies and technologies to address many of the aforementioned issues simultaneously. This includes the development of a hybrid sensor network to collect noise data from fixed sensor stations and ubiquitously available “smart” mobile devices. This strategy allows the creation of spatio-temporally rich data (more is better) that is time- and geo-stamped and automatically analyzed on location forming an edge-compute analysis network model. This design provides a mechanism where only actionable data that meets pre-specified standards and criteria is sent to our server for further analysis rendering our system highly efficient. Also, our aim at this stage is not to comprehensively solve the noisescapes machine learning problem by automatically classifying all of its sound classes. Rather, we approach this issue by developing urban noise classification algorithms that can filter and classify the most (un)popular noise pollutants, benchmark results and progressively improve and grow the number of classes that our machine learning system can handle. We are thus approaching the automatic sound classification problem – an important component in quantitative analysis of soundscapes –

\(^1\) http://www.wired.com/2010/11/ff_311_new_york
Beyond Research: Urban Development, Sustainability, and Livability

Traditional research practices commonly follow models where research paper publications carry tremendous weight. And while this important and time-honored practice is indeed integral and effective for advancing research, development, and information dissemination, the readership circle can be narrow and the audience scope it targets can oftentimes be limited to specific communities within academic murals. Initiating change for larger community impact, however, requires bringing research and development into the realm of application and preferably doing so quickly; this begins with manageable, small-scale prototype development, followed by system design for scaling. We have embraced those requirements through a research, development, and get-ready-to-scale paradigm that follows two main philosophies: “you cannot fix what you can’t measure” and “seeing is believing.” To address issues concerning measurement of large urban spaces, we have developed a hybrid sensor network system prototype that can be activated by the public via their personal computing devices (e.g. desktop computers, laptop computers, tablets, phablets, smart phones, single board computers etc.) and also incorporated into existing city infrastructures as has been done in the case of the LinkNYC project. The lack of consistent, citywide WiFi infrastructures has been a significant barrier for the scaling component in our research, and still remains an obstacle today. However, with increasing home access to the Internet, falling costs of computing devices that are essentially powerful computers, exploiting community WiFi resources and growing public WiFi infrastructures, we believe that our efforts can be made practicable beyond academic laboratories by considering “cities” as our lab. In particular, efforts such as LinkNYC which has repurposed NYC’s obsolete payphone system that runs on an Android-based tablet hardware and provides free WiFi across NYC; the system offers a potential infrastructural model for creating a “fixed” sensor network solution as proposed by our Citygram project as our current system runs fully in JavaScript – the language of web-browsers. In other words, creating a fixed sensor network would be as easy as loading Citygram software as a background process in the LinkNYC’s main user interface: the web-browser … all other hardware is already addressed as part of the existing LinkNYC system including protection from adverse climate, power supply, high-speed communication, and sensors. Cities like New York, where LinkNYC nodes are being aggressively deployed, could potentially serve as an effective global role model for sensing modern urban environments which will ultimately elevate the welfare of its citizens and potentially have significant impact on urban sustainability.

Measuring alone, however, is insufficient, especially when the final demand needs actionable reports for decision-makers: the data needs to be accompanied by meaningful and high resolution spatio-temporal information based on analytics and visualizations while delivering insights to reflect patterns and trends in real-world environments as shown in Figure 1 and 2.

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2 https://www.link.nyc
3 https://nextcity.org/daily/entry/payphones-listening-devices-sensors-new-york-city-sound
Such tools, when fully operational, will have the capability to respond to noise complaints (e.g. loud restaurants, clubs, parties) currently infeasible due to understaffing issues at the NYPD and NYCDEP; provide urban dwellers real-time soundmaps to take their families to the quietest park in the city, or use our soundmaps to plan walks and jogging paths that fit within one’s “sound path” parameters.

Citygram can also be utilized to make programs like the NYC Department of Transportation’s (DOT) Off-Hour-Delivery Program (OHDP) practicable. This program has the potential to
augment quality-of-life, foster economic competitiveness and efficiency, and enhance environmental justice. The program takes advantage of reduced traffic during off-peak hours (e.g. after business hours) to deliver supplies mainly to local businesses. Pilot studies conducted between 2009 and 2010 show evidence of enormous advantages in implementing a robust OHDP program for large cities, including reduction of delivery times by half, reduction of service time by 1/3, significant annual environmental pollution reduction, and $100 - $200 million/year in travel time and pollution cutback in Manhattan alone. Currently, OHDP is still a double-edged sword as, on the one hand, it significantly reduces energy usage and environmental pollution for megacities like NYC but on the other, it contributes to noise pollution and disruption for residents: during off-hour delivery periods background noise is low, rendering any sound that would have been masked during the day acutely amplified during “off-hours.” Using Citygram’s noise sensing system (Stacey D. Hodge, Fernando M. Zingler, Cuiya Li, Charles Shamoon and Ukegbu, Joseph Dack, Jaswinder C. Lewis 2016), vehicular delivery noise could be sensed, actionable solutions developed and “in-situ” (e.g. noise absorption materials for delivery tools or delivery through electric or hybrid vehicles), and OHDP program put into practice. Such a situation will, we believe, be a win-win prospect where the city, businesses, and urban dwellers all benefit as it promises improvement in traffic flow and congestions that come with myriad of negative associated artifacts (e.g. air pollution, temperature increase, safety, etc.) , meaningful cost reduction for business, and peace-and-quiet for urbanites.

Measuring non-ocular energies as well as contributing to and developing solutions for salient issues prevalent in urban environments, however, is still not enough. The information should be made available to the public and stakeholders to facilitate understanding and shed light into urban complexities that are extremely difficult to expose without examining our data and combining it with other spatio-temporal data types (e.g. census data, school performance, locative health data, etc.). As stated earlier, noise pollution takes many forms, has many faces, and depends on objective criteria as much as on perception and subjectivity. Identifying, for example, the effects of noise on learning outcomes at various stages of education (e.g. kindergarten, primary school, college, etc.), on the multitude of health aspects it may possibly influence, as well as its impact on workers’ productivity across the large variety of occupational activities truly requires a Big Data approach with the specifications stated earlier. A prerequisite to such endeavors is a research agenda and path we have developed over the past six years, especially in the context of the Citygram project, which comprises four principal components: (a) technologies and mechanisms that facilitate cost-effective raw data collection, (b) interface designs to poll citizens for spatio-temporal noise sentiment mapping, (c) widely accessible portals such as web-browsers and visualizations for sharing information, and (d) technologies that facilitate dissemination, active participation, and public awareness.

Outreach and Awareness

Another major component of the research process we champion includes using the power of data-driven art to reach out, inform, and bring awareness to the environment.4 For example, in April 2015, we participated in Earth Day through our Soundscape Hackathon at NYC Spotify Headquarters; between 2014-2016 we have also presented Citygram data-driven installation artworks and workshops at various renowned international conferences and art festivals including New Instruments for Musical Expression (NIME), International Computer Music Conference (ICMC), Society for Electro-Acoustic Music in the United States (SEAMUS), International Conference on Auditory Display (ICAD), Storefront Gallery in New York City, and New York Electronic Arts Festival (NYEAF, logging 70,000 visitors); and this fall we are partnering with the United Nations Sustainable Development Solutions Network (SDNS) to organize documentary

4 Oscar Wilde has been credited to be one of the most notable proponent of life following art in his 1889 essay “The Decay of Lying”, where he explicitly states that “[... Life imitates Art far more than Art imitates life” (Capitalization from web version of Volume 7 of “The Complete Writings of Oscar Wilde” New York, the Nottingham Society, 1909), available at http://www.victorianweb.org/authors/wilde/decay.html, accessed 8/14/16
As part of our collaboration we are also partnering with the University of Redlands, which is currently planning the installation of a sensor network on campus to gather noise data. The University is known for the high degree of infusion of spatial thinking into their curriculum and research, as manifested through three centers at the University that particularly focus on spatial research and teaching, namely a center for spatial studies, a Center for Business GIS and Spatial Analysis and an Institute for Spatial Economic Analysis (ISEA). The data collected on campus through the Citygram sensor system furthers this agenda and is intended for use in education, research and administration: students learn how to use and interpret classified noise data in the context of a well-known geographic space – their campus. The ultra-high frequency, live-stream, and spatio-temporal characteristics of this data predestine it to be the ideal teaching vehicle for exploratory studies as the data-stream it produces allows investigating a plethora of questions of paramount importance in modern research: how precisely can location and spatio-temporal environmental measurements be classified when multiple data sources (sensors) are combined? How do lab results compare with real world results? How applicable is data science in practice? Can we develop predictable models to provide insights into urban development and sustaining future city life … and how large are the errors from our predictions? What is – figuratively and literally speaking – the signal to noise ratio? What needs to be filtered, what needs to be amplified? What data structure, precision, and granularity would be required to answer a particular question? How can we interpret and make best use of environmental Big Data?

While having access to highly spatio-temporally dense data stream is clearly useful for teaching, researchers can also significantly benefit from such data. The Internet of Things (IoT), Big Data, and remote sensing are discussed by many but are somewhat limited to communities that tend to be highly technical. Noise data, however, can be utilized by many other existing fields of research: from sociology to climatology and business, many questions otherwise only to be investigated in the aggregate can be now addressed on a micro-spatial, micro-temporal scale. For example, high-resolution spatio-temporal data in business and economics, previously restricted to stock markets and credit card sales records of large retail stores, can finally enter mainstream.

Summary and Conclusion
Noise is a ubiquitous urban pollutant that cannot be seen, smelled, touched, or tasted. Its immediate impact on the wellbeing of urbanites is not always instantaneously realized but its constant, day-to-day projection onto urban communities, and the cumulative long-term exposure effects can have serious consequences. Our efforts in contributing towards mitigation noise pollution and addressing sustainability of cities and urban life follows the principles of “you can’t fix what you can’t measure,” “seeing is believing,” and reaching out to the public through the power of art. We anticipate that our combined efforts, grounded in “research-led-practice” as well as “practice-led-research” will yield actionable outcomes where information and the research process itself is shared amongst large and diverse population segments. Our publically accessible technologies and community-engagement research empowers everyone to support health equity as practically any person interested and equipped with a computing device (smartphone, tablet, laptop, desktop, etc.) and Internet access can become a stakeholder, participant, activist, and beneficiary of the proposed research.

References

Park, Tae Hong, Jonathan Turner, Michael Musick, Jun Hee Lee, Christopher Jacoby, Charlie Mydlarz, and Justin Salamon. 2014. “Sensing Urban Soundscales.” In Workshop on Mining Urban Data.

