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# Audio Engineering Society Convention Paper

Presented at the 137th Convention  
2014 October 9–12 Los Angeles, USA

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## The design of urban sound monitoring devices

Charlie Mydlarz<sup>1,2</sup>, Samuel Nacach<sup>2</sup>, Tae Hong Park<sup>2</sup> and Agnieszka Roginska<sup>2</sup>

<sup>1</sup>NYU CUSP, New York, NY, 11201, USA

<sup>2</sup>NYU Steinhardt, New York, NY, 10012, USA

Correspondence should be addressed to Charlie Mydlarz ([cmydlarz@nyu.edu](mailto:cmydlarz@nyu.edu))

### ABSTRACT

The urban sound environment of New York City is notoriously loud and dynamic. As such, scientists, recording engineers, and soundscape researchers continuously explore methods to capture and monitor such urban sound environments. One method to accurately monitor and ultimately understand this dynamic environment involves a process of long-term sound capture, measurement and analysis. Urban sound recording requires the use of robust and resilient acoustic sensors, where unpredictable external conditions can have a negative impact on acoustic data quality. Accordingly, this paper describes the design and build of a self-contained urban acoustic sensing device to capture, analyze, and transmit high quality sound from any given urban environment. This forms part of a collaborative effort between New York University's (NYU) Center for Urban Science and Progress (CUSP) and the NYU Steinhardt School's Citygram Project. The presented acoustic sensing device prototype incorporates a quad core Android based mini PC with Wi-Fi capabilities, a custom MEMS microphone and a USB audio device. The design considerations, materials used, noise mitigation strategies and the associated measurements are detailed in the following paper.

### 1. INTRODUCTION

Noise pollution is an increasing threat to the well-being and public health of city inhabitants [17, 4, 3]. Large advances have been made in noise prediction over the last few decades, with applications utilizing Geographic Information Systems (GIS) technologies and sophisticated noise transmission modeling

[18, 7, 5]. However, the complexity of sound propagation in urban settings and the lack of an accurate representation of the distribution of the sources of this noise have led to an insufficient understanding of the urban sound environment. The presented project aims to continuously monitor and ultimately understand these urban sound environments. It is a multidisciplinary collaborative effort between

New York University's (NYU) Center for Urban Science and Progress (CUSP) and the NYU Steinhardt School's Citygram Project [11, 13, 14, 8, 12]. The impetus of the Citygram project is focused on the lack of sufficient mapping paradigms for non-ocular energies in urban settings. These energies, namely, sound can have a profound effect on a cities inhabitants and the key to understanding this effect firstly lies in the measurement of this energy. NYU CUSP's interests are focused on the noise of New York City, including how it impacts on the health of the city's population, correlates with urban problems ranging from crime to compromised educational conditions, and how it affects real estate values. While a number of past studies have focused on specific contexts and effects of urban noise [6, 10, 21, 16, 15, 1], no comprehensive city-wide study has been undertaken that can provide a validated model for studying urban noise in order to develop long-lasting interventions at the operational or policy level.

The project is currently using NYC as a "lab" with the aim of creating a model that can be utilized and implemented in other cities around the world. With its population, its agency infrastructure, and its ever-changing urban soundscape, NYC provides an ideal venue for a comprehensive study and understanding of the problem of urban noise. To achieve this goal an initial network of low cost acoustic sensing devices were designed and implemented to capture long-term objective acoustic measurements from strategic locations throughout the city using wireless communication strategies. These prototype remote sensing devices (RSD's) currently incorporate a quad core Android based mini PC with Wi-Fi capabilities, and a custom MEMS microphone, whose characteristics are detailed in an accompanying paper [9]. Acoustic data captured from each sensor node is comprised of a standard set of low-level audio descriptors for use in analysis, online mapping and visualization. The initial goal is to develop a comprehensive cyber-physical system<sup>1</sup> that provides the capability of capturing, analyzing and wirelessly streaming environmental audio data, along with its associated acoustic features and metadata - including automatic source identification.

The EU Directive (2002/49/EC) [2] resulted in the

<sup>1</sup>Network connected, distributed computing systems monitoring physical phenomena

production of noise maps for major urban areas across Europe in 2007, to inform strategic planning for noise control. However, many authorities across Europe found it difficult to use these noise maps for any kind of mitigation or action planning, due in part to a lack of confidence in the output data reflecting reality and the lack of any temporal variation. The solution to this relied on more extensive measurement initiatives, which were prohibitively expensive.

An example of a commercially available RSD is the Libelium Waspmote<sup>2</sup>. The Waspmote can be configured as a "Smart cities" acoustic sensing device with an externally attached microphone and internal audio capture and transmission capabilities. The system is designed to capture audio and extract basic level features for transmission to a central server via Wi-Fi or cellular networks. The unit is ruggedized and expandable via the multiple sensor input ports on the exterior of the case. Whilst this is a very capable solution to urban noise monitoring, it does not provide the processing power required for advanced acoustic feature extraction in-situ. With starting prices of \$620 as of June 2014, the unit would also necessitate a prohibitively large equipment budget if deploying densely across a large area. The development of a low cost RSD solution is therefore required for extensive urban noise monitoring. However, to adequately achieve this, the proposed system must firstly be physically resilient to the year round environmental conditions of NYC, and secondly, be robust to varying network connectivity situations. Discussed in this paper are the measurements, design considerations, and noise mitigation strategies employed, with respect to the sensor hardware to create the initial prototype RSD.

## 2. HARDWARE DESIGN AND TESTING

### 2.1. Computing and audio I/O

The projects sensor network is based around a consumer computing platform where low cost and high power are of paramount concern. The design philosophy is based on the creation of a network that provides dense spatial coverage over a large area, through the deployment of inexpensive and physically resilient sensors. The Citygram project considered and tested numerous hardware platforms for

<sup>2</sup><http://www.libelium.com/products/waspmote/>

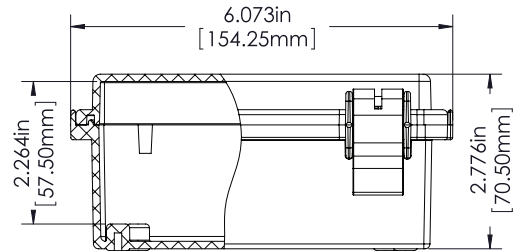


**Fig. 1:** Tronsmart MK908ii Android based mini PC

use in the projects RSDs [14]. These included Alix boards, Raspberry Pi, and a range of smart phones. The criteria for selection were: audio capture capabilities, processing power and RAM, low power consumption, a flexible OS, onboard storage, wireless connectivity, I/O options, robustness, low cost and setup simplicity. The Android mini-PC platform was eventually adopted as the hardware of choice as it best met the RSD selection criteria. A number of these mini-PCs incorporate an in-built microphone, however, the recording quality proved to be low in terms of the microphone itself and the addition of auto gain control in the signal chain on some devices.

At the core of the projects static remote sensing device (RSD) is a Tronsmart MK908ii mini PC running the Android 4.2, Linux based operating system. These small (87mm x 46.5mm x 14.3mm) and versatile devices shown in Figure 1 are priced at \$70 as of June 2014 and provide a quad core Rockchip Cortex A9 processor clocked at 1.6GHz, a quad core Mali 400 GPU, 2GB of DDR3 RAM, 8GB of NAND flash storage, USB I/O, Bluetooth 4.0 and Wi-Fi 802.11 b/g/n connectivity. The computing power offered by these units allows for complex digital signal processing to be carried out on the device, alleviating the need to transmit large amounts of audio data for processing on the project's servers.

Whilst the device does not include an inbuilt microphone, USB I/O allows for the inclusion of a USB audio device to handle all ADC work, thus providing the means to connect a custom microphone solution. The USB audio device chosen for this application



**Fig. 2:** Bud Industries NBF-32004 ABS NEMA case profile

had to be compatible with Linux based Android devices, low in price, provide input gain control and a clean signal path. The device selected was the eForCity USB audio interface which retails for \$4 as of June 2014. It provides a single microphone input channel with low noise and a software adjustable input gain stage. A swept sine signal was recorded via the USB audio device, then compared with the input signal which showed negligible differences.

## 2.2. Casing

In constructing the urban sound sensor device for large-scale deployment and fabrication, cost, environmental conditions, acoustic effects, and overall efficiency were considered. To move forward with the prototype and properly account for these conditions, the first critical component specified was the casing, responsible for housing all the sensor's components. The casing utilized was a NEMA 1, 2, 4 & 4X certified ABS plastic housing measuring 15cm x 10cm x 7cm.

The casing provides environmental protection for the sensor components and allows for mounting on different surfaces via attached metal brackets. The case includes a hermetically sealed, latch closed door allowing access to the sensor components inside. Its profile is shown in Figure 2. Additionally, the top and front facing panels of the casing were coated with impact absorbing felt to reduce structure borne rainfall noise transmitted to the microphone.

## 2.3. Microphone port

The MEMS microphone [9] was mounted on the underside of the casing, pointing down. In an effort to maximize frequency response and minimize directivity, two microphone ports of 5mm and 10mm

were drilled and tested under semi-anechoic conditions at the research laboratory at NYU Steinhardt. Figure 3 compares the frequency response effects of each port to the original MEMS response.

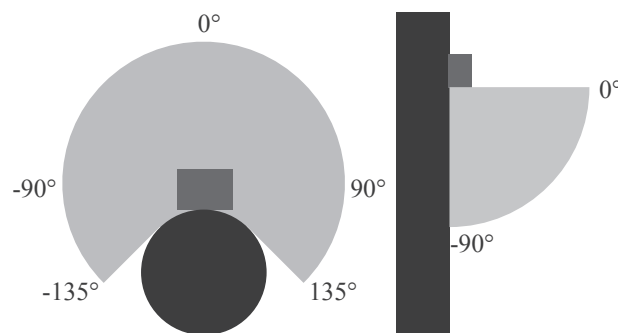
Figure 3 shows the minimal variation in frequency response between the 5mm and 10mm port sizes. The boxed microphone exhibits a raised response between 1kHz and 6kHz, corresponding to the first few dimensional resonances of the plastic enclosure. The rise in response after 10kHz, however, is a result of the Helmholtz resonance created by the microphone's inner chamber and PCB port [19]. Consequently, this results in an increase of perceived sibilance in the recordings, which can be filtered out in post processing or on the RSD itself.

To determine the directivity of the unit with varying port sizes, the sensor device was subjected to two 3 second sine sweeps from 20-20,000Hz at 15° angle increments from 0-90° in azimuth and elevation, with symmetry about 0° assumed. Speaker and room response were factored out by subtracting the same condition response of an Earthworks M30 measurement microphone assumed to be flat in frequency response from 20-20,000Hz. As expected the larger port size revealed marginally less directivity which was more pronounced at high frequencies. Unfortunately, due to the proposed mounting locations for these devices - lampposts and tree sides at a height of roughly 3.5m - directivity will be introduced. Inevitably, the unit's directivity will become more prominent as a result of the lamppost or tree's shadowing effect. Though the sensor itself is omni-directional in nature, the physical attributes of the system limit its acoustic field of view to roughly 90° in elevation from -90° to 0° and approximately 270° in azimuth from 0° to 135° and 0° to -135°, as shown in Figure 5.

To reduce the effect that this shadowing will have on the capture of the overall soundfield, the placement of multiple RSD's will need to be carefully considered in order to provide sufficient coverage of a spaces sound environment.

#### 2.4. Mounting conditions

As previously mentioned, the microphone was mounted on the underside of the casing, facing down. To alleviate structure borne sound and vibration from rainfall, a sheet of vibration dampening vis-



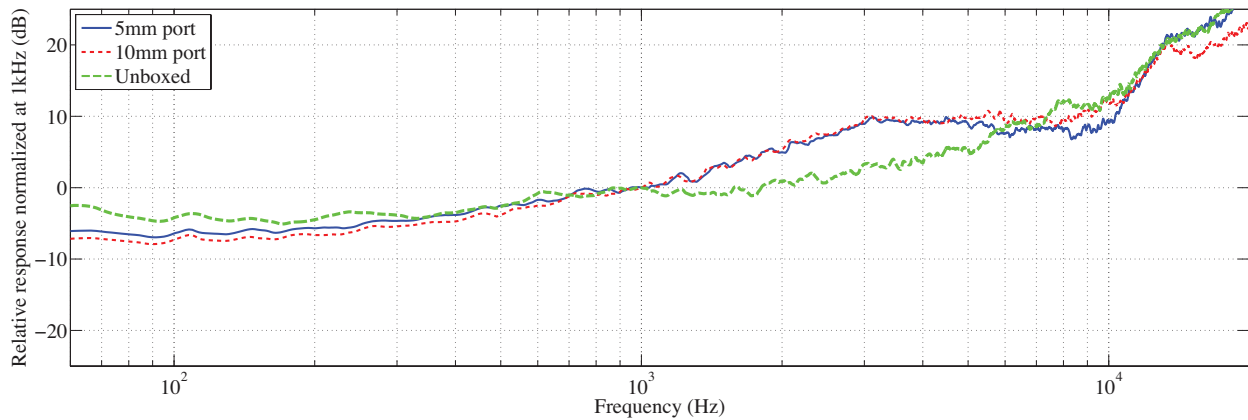
**Fig. 5:** Mounted sensor acoustic field of view

coelastic urethane was placed between the microphone board [9] and the interior of the casing. As with the selection of the 10mm microphone port, two sheets of 0.1inch and 0.04inch in width, were tested and measured to select the less acoustically influential design.

The addition of the 0.1inch sheet had the effect of extending the port depth, resulting in an increased resonance at high frequencies, as shown in Figure 6. Due to this, the thinner sheet of 0.04inch was used, shifting the resonance up to the more acceptable 17kHz region. A further stage of testing to reveal the vibration reduction properties of this material will be carried out.

#### 2.5. Wind and weather protection

A major concern in environmental acoustic monitoring is wind shielding, given the dynamic changes in wind currents. In order to mitigate the effect this may have on the recorded audio signals, an electric fan was used to blow air across the microphone port in such a way that the maximum wind noise was produced on the signal. Recordings were made without protection and then using: craft felt, nylon tight material (two layers) and a section from a standard microphone windshield. These materials were mounted flush on the outside of the housing, covering the microphone port. RMS levels were calculated for a 3 second portion of each recording where the signal was in a steady state in terms of its level. Interestingly the microphone windshield produced more frequency coloration than the other materials tested as shown in Figure 7, which had a minimal effect on frequency response.



**Fig. 3:** Comparison of device frequency response when unboxed and boxed with 5mm and 10mm port size

Felt provided the least amount of wind attenuation at 7dB compared to the windscreen and nylon reduction of 9dB. Based on these findings, the double-layered nylon was chosen for our application, due to its relatively high wind noise attenuation, low absorbcency, ease of mounting, and low cost. Excess water retention and potential freezing when soaked into a windshield can have a profound effect on acoustic signal quality [20], which can be mitigated when using a thin layer of windscreen such as the nylon selected for this application. In addition, a hydrophobic coating was applied to the port area of the casing to provide further weatherproofing around the sensitive microphone area. This coating repels rainwater so as to not allow any raindrops to collect on the underside of the housing and potentially soak into the microphones nylon wind shield.

## 2.6. Device power

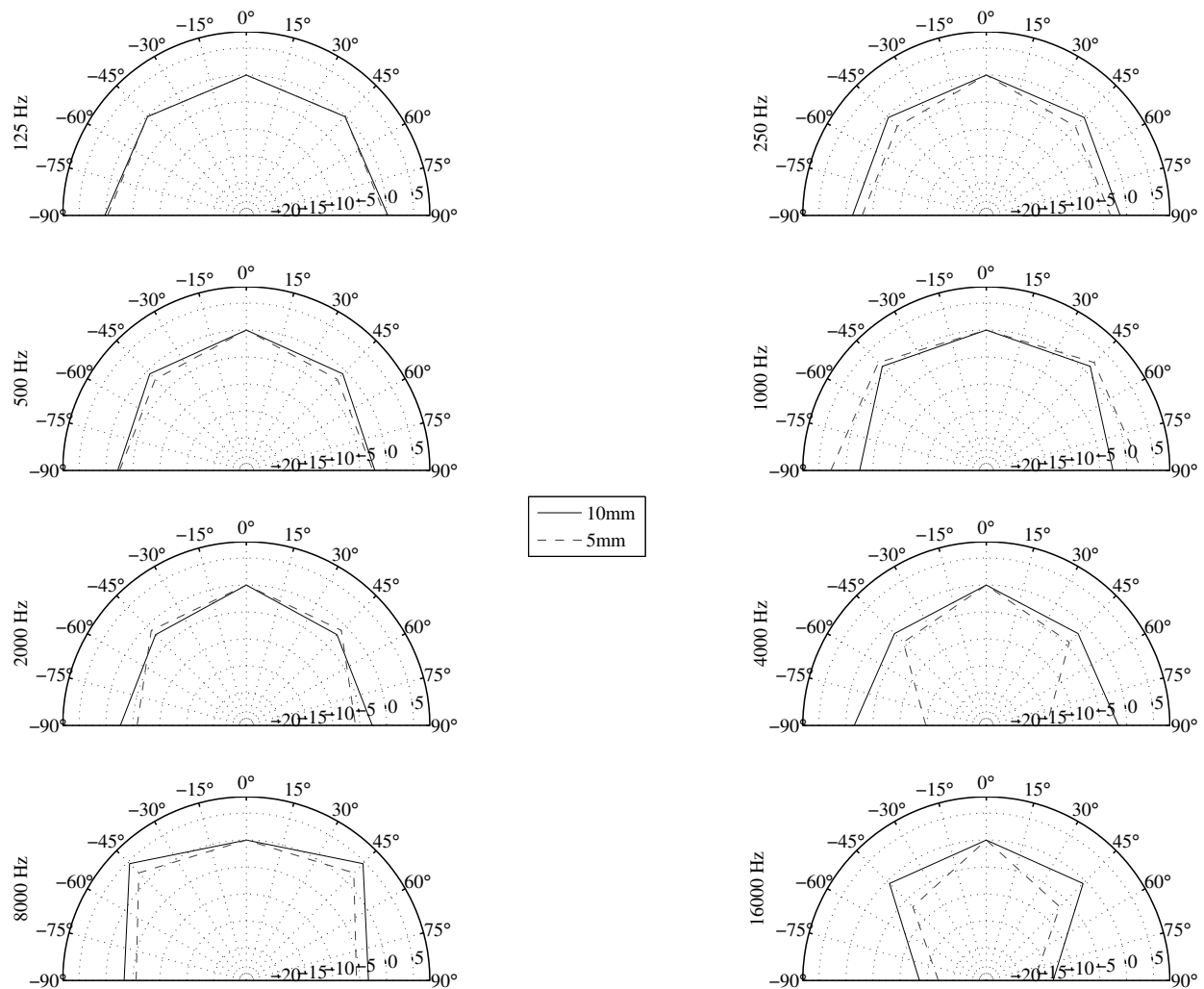
One of the benefits of deploying this system in an urban environment is the potential for continuous 24/7 power supply. However, though mounting the sensors on urban lamp posts is ideal in terms of location and height, the poles themselves may only be powered during nighttime hours. Because the first prototype sensor unit relies on a constant 120v grounded power supply, this means a stage of battery powering is necessary to ensure a continuous 24/7 data stream can be produced from the deployed sensors. The current draw from the sensor unit ranges from roughly 200mA at idle to 750mA when processing and transmitting data. As such, a battery solution that could

provide at least 8000mAh to keep the sensor unit operational for the daylight periods was implemented. Furthermore, to account for any extraordinarily demanding periods of operation, a 12000mAh lithium polymer battery pack was selected to provide the extra supply needed for these unexpected situations. Further testing will be carried out on the battery powered RSD to ensure its functionality and stability when deployed in varying environmental conditions, discussed in Section 3.

## 2.7. RFI mitigation

The internal components of the acoustic sensor had to be strategically placed to minimize radio frequency interference (RFi) from the Android mini PC's Wi-Fi antenna. Any low level audio components were located at the maximum distance from any RF components, as well as the AC power supply. Additionally, the length of the low level audio cabling was minimized to reduce the effects of RFI interference on the system as shown in Figure 8.

Nonetheless, at the minute interval of data upload to the server, RFI would taint the signal, due to the high power upload stage. To solve this, a small port was drilled on the face of the casing to maximize the distance between the antenna and audio components. In addition, the inside of the casing was coated with grounded aluminum tape, thus creating an RFI shield. After testing, this reduced RF interference. In future work, however, we propose the use of a metal casing with an antenna port, ensur-



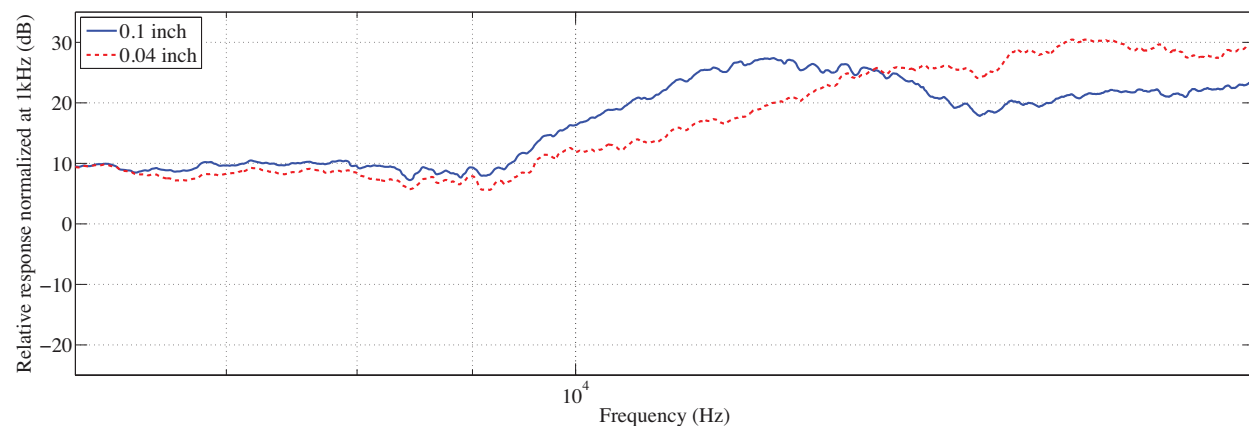
**Fig. 4:** RSD directivity polar plots varying azimuth and port diameter

ing a fully sealed and RFI resistant housing. Lastly the audio ground and power ground were matched to eliminate excess RFI and PSU noise.

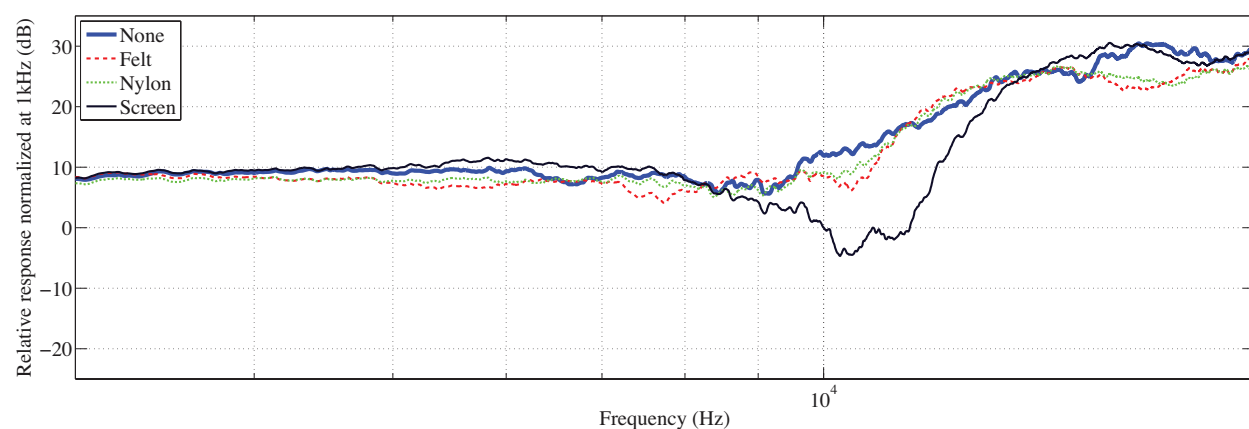
### 3. FUTURE WORK

In collaboration with the Brookhaven National Laboratories, a stage of environmental testing will be performed on the complete sensor unit to ensure its resilience and consistent functionality under extreme variations in temperature. High ambient temperatures and direct sunlight falling on the casing

will raise internal temperatures, as well as the heat generated by the mini-PC itself, which is minimal as it only operates at up to 5 watts running at full load. The current plastic prototype will be subjected to temperatures in excess of 50 °C to firstly test for hardware functionality and also to identify any variations in microphone sensitivity and frequency response. Battery performance will also likely be affected by lower (sub zero Celsius) temperatures, something that will have to be tested for to ensure sustained operation of the lamppost mounted RSDs in winter periods. Heat ventilation is also an-



**Fig. 6:** Effect of 0.1inch and 0.04inch vibration dampening sheet on sensor frequency response (6kHz-20kHz)



**Fig. 7:** Effect of different wind shield strategies on sensor frequency response (3kHz-20kHz)

other key consideration that will be considered. A fan based system would obviously not be applicable due to the noise they produce, however, a passive vent cut into the casing that relies on the wind to replace the internal air within the housing may provide an adequate solution. An aluminum casing has also been considered to further attenuate RFI noise on the signal chain by providing a surrounding earth shield and common ground for all components. The issue of solar heat gain from incident sunlight will also be increased when using a metal case, however, the color that the casing is painted will have more of an effect on this, so lighter shades will be used if possible.

A further stage of lab tests will be carried out to reveal the complete audio systems response to varying signal levels in comparison to a calibrated Type 1 sound level meter. This will identify any nonlinearities in level response and allow for the calibration of each RSD before deployment. The varying environments these RSDs will be deployed in may also require the addition of an automatic gain control which can adapt to the ambient level of an urban space. For example, a busy roadside RSD may require the USB audio device's input gain to be reduced to avoid any clipping on the resultant signal. The amount of attenuation applied could be learnt over time by the system and would be stored along-





**Fig. 8:** Internal prototype sensor layout (1 = mini PC, 2 = PSU, 3 = USB audio device, 4 = MEMS microphone)

side each level measurement.

The current stage of the project is focused on small scale deployments in urban parks in NYC. These will allow the project sensors and infrastructure to be rigorously tested under outdoor weather conditions, providing valuable insights into Wi-Fi connectivity, equipment malfunction/damage, external system performance and power supply issues. The objective acoustic data obtained through the project's sensor network will be used to investigate connections between spatial and temporal acoustic characteristics and existing geolocated datasets, such as crime statistics, weather patterns, school attainment metrics, municipal/census data and public social network feeds, and real estate statistics which can provide rich quantitative and contextual location-based information. Through a process of subjective data collection in and around the deployed sensor locations, the effects and influences of the urban soundscape can also be investigated in terms of human perception and objective characteristics.

#### 4. CONCLUSION

The design of a resilient urban acoustic sensor presented in this paper revealed, through a process of acoustic measurements, the effects of differing port sizes, wind-shielding strategies, mounting design and

power supply conditions. In conclusion a weatherized housing has been selected that exhibits minimal frequency coloration on the recorded audio signals at differing angles of incidence. Additionally, a wind shielding solution has been devised resulting in a reduction of wind noise with the added benefit of low absorbency under humid conditions. Lastly, a series of carefully arranged components and power supplies, including a battery, were positioned within the plastic casing to minimize RFI, AC interference, and to generally isolate the audio components from any detrimental noise.

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