# Monitoring the urban noise environment

## joint with the IoT Lab, Civic Innovation YYC

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# Outline

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# Project Motivation - LPWAN Project

- Establish the City of Calgary as a leader in the smart city movement
- Assess how LPWAN technology can be used to improve the quality of life for citizens of Calgary
- Test the capabilities of LPWAN to determine which smart city applications the technology is best-suited for
- Speed up concept-to-development and minimize costly mistakes of adopting the wrong IoT solution
- Implement and validate futuristic algorithms on a real sensor network
- Strengthen the relationship between Civic Innovation YYC and the U of C

# Project Motivation - acoustic monitoring

- Unwanted noise in urban environments has negative health effects
  - loss of sleep, disruption to relaxation and social gatherings, hearing loss, high blood pressure, and more
- City noise codes aim to reduce noise pollution, but violations of the code are difficult to catch
- Continuous monitoring of noise is rare. Noise assessments are complaint driven.
- Noise data also contains information about the happenings within a city.
  - traffic noise, construction noise, persons in distress, car accidents, etc.
- Acoustic monitoring promises to be a good application for environmental monitoring using LPWAN.

# Outline

# Sounds of New York City (SONYC) - project objectives

From the project website...

Objectives: to create technological solutions for

- the systematic, constant monitoring of noise pollution at the city scale
- the accurate description of acoustic environments in terms of its composing sources
- broadening citizen participation in noise reporting and mitigation
- enabling city agencies to take effective, information-driven action for noise mitigation.

# Sounds of New York City (SONYC) - project overview





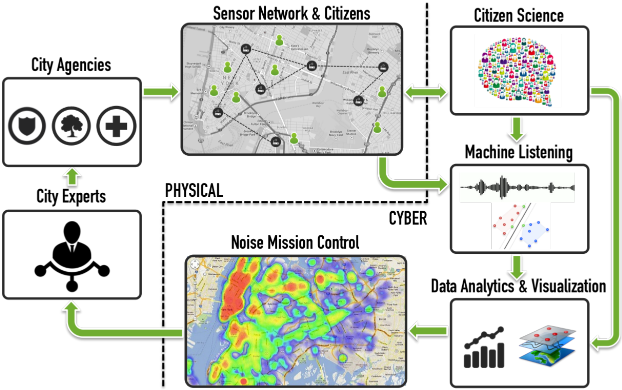



Figure: SONYC project overview (image taken from the project website)

# Sounds of New York City (SONYC) - prototype

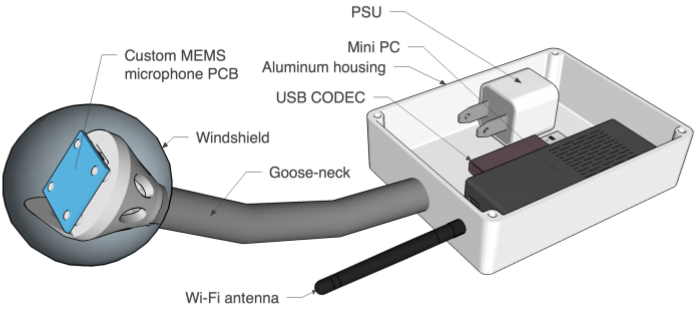



Figure: SONYC sensor unit prototype (image taken from the project website)

# Sounds of New York City - project impact & results

- granted a $4.6 million Fontier award from the NSF to advance research in cyber-physical systems for smart cities
- NYC BigApps finalist - a civic innovation competition in NYC to improve the city.
- supports 15 academics
- partners with NYC Environmental Protection, NYC Health, and Downtown Alliance.

# RUMEUR network - project objectives

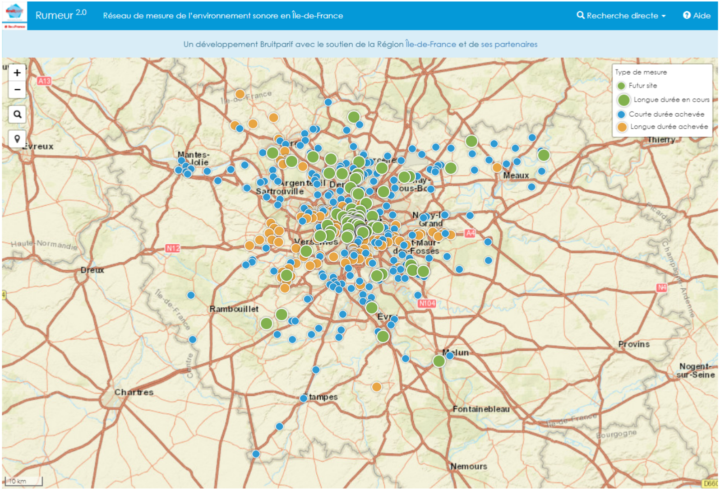
Designed and maintained by Bruitparif, a non-profit based in Paris. Project objectives (from the project's EuroNoise conference paper)

- Better understand noise phenomena: factors that influence noise, changes over time, exposure data correlated to socio-economic impacts
- Evaluate noise mitigation measures: obtain indicators for tracking the impact of mitigation policies, anticipate impact of future projects.
- Disseminate noise information to the public

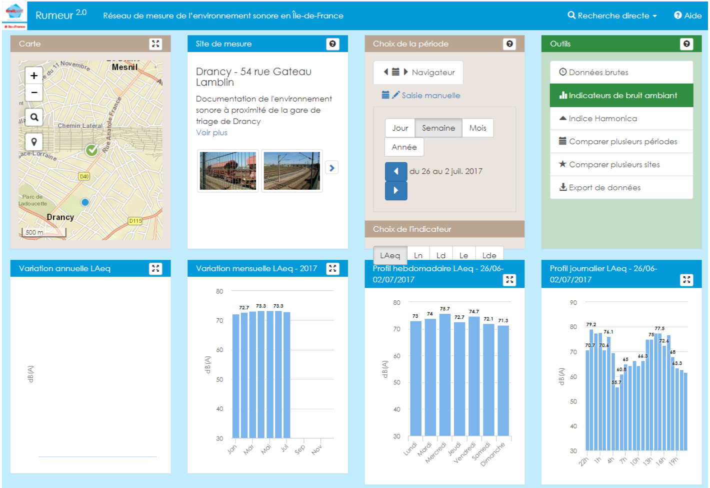
# RUMEUR network - project overview

- 45 long-term high precision monitoring terminals and 350 short-term terminals
- Focus is on traffic and aircraft noise
- Data transmission over cellular network
- Real-time data dissemination through their web application

# RUMEUR network - data dissemination



# RUMEUR network - data dissemination



# RUMEUR network - project impact & results

- recipient of the Best Life Environment Project
- recipient of the Decibel D'Or award by the National Council of Noise

# Outline

# Acoustic sensing basics

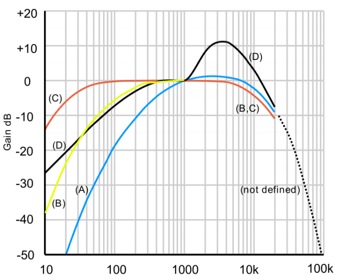
- Frequency range of human hearing is 20Hz-20kHz, but most sensitive in the 2-5kHz range
- Sound level range of human hearing 0dB - 85dB (above 85dB is dangerous)
- What is a dB? A logarithmic ratio of two values. In acoustics, the equivalent sound pressure level is used:

$$L_{eq} = 20 \log_{10} \left( \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p_1}{p_0} dt \right)$$

where $p_1$ is the rms sound pressure and $p_0$ is a reference sound pressure ($20 \mu Pa$).

# Acoustic sensing basics

- For environmental monitoring, a weighted sound level is used (dBA, e.g.)
- The (lower) threshold of human hearing is frequency dependant - at the same sound pressures, lower & higher frequencies seem quieter to a human
- Weighting lower & higher frequencies less give a more representative sound level:



A-weighting (blue), B (yellow), C (red), and D-weighting (blk)

# Acoustic sensing basics - sound level meter standards

IEC 61672-1 is the sound level meter (SLM) standard for sensors used for legally enforceable acoustic monitoring purposes. Includes specifications for device:

- frequency response tolerance limits
- self generated noise
- linearity
- type 1 devices (precision) vs. type 2 devices (general purpose)
- industry standard tests that can be used to evaluate sensor performance

# Acoustic sensing basics - sound level meter standards

- **Class 1 - precision measurements**: accurate, reliable, enforceable acoustic monitoring. Sensors alone cost $1,000-2,000. Required accuracy of ±1dBA at 1kHz. Pre-amplifiers and high voltages required for operation.
- **Class 2 - general purpose measurements**: minimum requirement for OSHA noise measurements and general purpose noise surveys. Required accuracy of ±2dBA at 1kHz.
- **Class 3 - low-cost**: Sensors can be very cheap (as low as $1). Measure noise levels in the 40-100dBA range with ±3dBA accuracy or worse. Enables scalablity.

# Acoustic sensing basics - City of Calgary Bylaws



- City of Calgary Bylaw - continuous sound in downtown, for example:

  > *No person shall cause continuous sound that exceeds 75dBA during the day-time (60dBA during the night-time)*

  - Continuous sound = continuous duration over a 3 minute period, or sporadically for a total of 3 minutes over a 15 minute period.
  - Sound level must exceed 5dBA over ambient before it becomes an offence
- For enforcement purposes, a type 2 sound level meter must be used

# Outline

# LPWAN - a type of wireless telecommunication

- Low data throughput. Mostly uplink traffic with small 10-200B packets
- Low power (several years of operation with a single battery charge is theoretically possible)
- Long range ($\approx$ 5km in urban areas, $\approx$ 15km in open areas)
- LoRa is a specific LPWAN technology (SIGFOX is another, for example)

# LoRa - proprietary physical layer

Semtech Long Range physical layer

- Sub-GHz (unlicensed ISM radio bands, 902-928MHz in Canada) bi-directional point-to-point wireless link
  - The band is divided into 8 sub-bands that each have 8x125 kHz uplink channels, 1x500 kHz uplink channel and 1x500 kHz downlink channel.
- 13.5mA RX current, 124mA TX current

# LoRaWAN - medium access control

- Devices are asynchronous and transmit when they have data available to send (ALOHA protocol).
- Data transmitted by an end-node device is received by multiple gateways, which forward the data packets to a centralized network server.
- The network server filters duplicate packets, performs security checks, and manages the network.

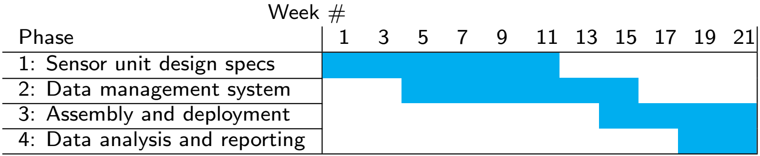
# Outline

# Agreed upon deliverables

From the project proposal:

- Design and construction of 15 acoustic sensing units
- Deployment of sensing units
- Real-time reporting of data to LoRaWAN gateway
- Data storage on cloud database
- Model for characterization of acoustic sources (used for in-situ processing)
- Data visualization and automated dashboard tool for real-time mapping of data
- Spatial and temporal model of acoustic emissions within study area
- Report on the project outcomes and future directions

# Project timeline: Aug. 28 - Jan. 31



# Outline

# Functional specifications - hardware

The sensor unit shall ...

- measure sound pressure levels with a comparable level of accuracy to City of Calgary Bylaw standards
- transmit processed audio data and metadata to a City of Calgary LoRaWAN radio gateway
- receive acknowledgment and control signals from a City of Calgary LoRaWAN radio gateway
- maintain its full functionality for at least 8 weeks without human intervention
- operate year round in typical Calgary weather (electronics and battery should operate down to -20°C).
- cost less than \$200 per sensor node
- not require a wired connection to any utility
- be capable of being deployed within 30 minutes of arriving at a proposed location

# Functional specifications - algorithms

The sensor unit shall ...

- randomly sample 30 seconds (?) of acoustic data
- increase the sampling frequency autonomously when changes are detected in the acoustic environment
- perform in-situ signal processing on audio measurements, including:
  - filtering
  - spectral decomposition
  - A-weighting
  - noise source characterization
- transmit data to the LoRaWAN gateway when changes in the acoustic environment are detected
- autonomously update sensor unit parameters based on control signals received from the LoRaWAN gateway

# Outline

# Proposed hardware - off-the-shelf options

There are no off-the-shelf solutions that will satisfy the functional specifications. The best candidates include:

- Waspmote by Libelium: $\approx$ \$300, minimum operating temperature is $-10°$C, limited ability to add custom functionality.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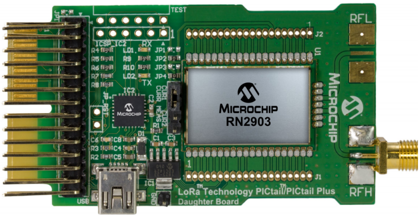
- Adeunis RF LoRaWAN transceiver: barebones and rugged design, in-situ processing not possible.

# Proposed hardware - prototype

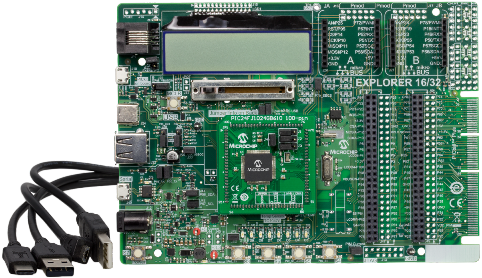
LoRa Tx/Rx: Microchip RN2903 LoRa Technology PICtail




- Features Microchip's RN2903 LoRa 915MHz transceiver module
- PICtail connection interface
- On-board PIC18 MCU
- supply current measurement points
- $82

# Proposed hardware - prototype

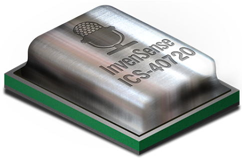
Development kit: Microchip Explorer 16/32

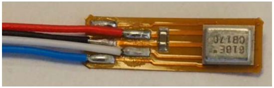



- Supports processor plug-in modules
- PICtail connection interface
- LCD display
- supply current measurement points
- \$138 (Dev. kit) + \$32 (processor) + \$68 (programmer)

# Proposed hardware - prototype

Microphone sensor: InvenSense ICS-40720 Evaluation Board



- accuracy of $\pm$2dB
- frequency response from 75Hz-20kHz
- 285$\mu$A supply current, 1.5-3.6V supply voltage
- high SNR of 70dBA
- dynamic range of 124dB
- sensitivity of -32dBV
- $44

# Proposed hardware - final design

| Part (with URL) | Price |
|---|---|
| LoRa Tx/Rx (Microchip RN2903) | $14.57 |
| Microphone (InvenSense ICS-40720) | $5.00 |
| Microcontroller (Microchip PIC24FJ1024GB610) | $5.41 |
| Protective case (Hammond Manufacturing 1550WE) | $18.70 |
| Antenna (Microchip RN-SMA4-RP) | $7.65 |
| Microphone mount & windshield | $5.00 |
| Lithium-thionyl chloride battery (Tadiran SL-2790) | $42.00 |
| Miscellaneous (parts & assembly) | $20.00 |
| Total: | $118.33 |

# Outline

- Project Motivation
- Relevant case studies
  - SONYC
  - RUMEUR network
- Acoustic sensing basics
- LPWAN basics
- Project deliverables & timeline
- Sensor unit functional specs
- Proposed hardware
- Questions/feedback

# Questions/feedback

# Our questions

- What is the current state of the LoRaWAN gateway installation?
- What, if any, other LPWAN projects are being pursued?
- Who are the City contacts?
- What are the City's expectations of this project? What are specific questions that the City would like answered by this project?