Active Noise Cancellation for Windows using Audio Exciters

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Overall Project Goals

Investigate the feasibility of an affordable active noise cancellation system that reduces noise levels transmitted into buildings through windows

- Investigate and test hardware components
  - Audio capture and processing
  - Amplification and delivery of noise-cancelling vibrations

- Investigate the software capabilities for ANC applications
  - Linux-based systems
  - Sound cards, drivers, neural network ANC algorithms

- Test hardware components to understand system dynamics
  - Mount audio exciters and attempt to cancel vibrations

Specific Contributions

Implemented generic active noise cancellation on a Raspberry Pi

- Implemented using low-level ALSA (Advanced Linux Sound Architecture) APIs
- Identified latency limitations

Created Keras/TFLite programs for neural network based ANC algorithms

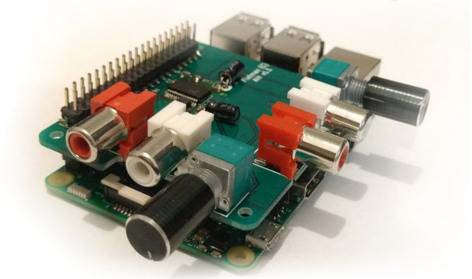
- Time series forecasting with neural networks
- Residual noise prediction accounts for system delay

Tested different hardware devices with audio exciters to cancel window noise

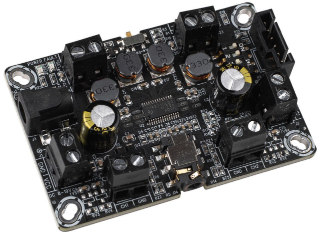
- Identified key issues when applying in the real world

Technical Approach

Hardware



- Raspberry Pi 4B, 4GB
    - Raspberry Pi OS
- Audio Injector Stereo Soundcard
    - Stereo input/output RCA
- Microphones
    - MEMS microphone x2 (Adafruit 3421)
    - Electret microphone x2 (Adafruit 1063)
- Dual channel amplifier board (Sure Electronics AA-AB32231)
- Audio exciter pair (Dayton Audio DAEX25)



Technical Approach

Software

- ALSA (Advanced Linux Sound Architecture) APIs
  - Capture input and process with ANC algorithm in real time
  - Output to amplifier to power audio exciters
  - Calculate driver latency

- JACK (JACK Audio Connection Kit) APIs
  - Measure hardware latency

- Neural network model for active noise cancellation
  - Develop with Keras/Tensorflow, TFLite for inference
  - Capture system dynamics, frequency response

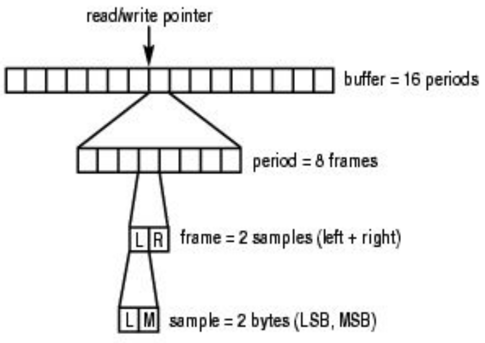
Analysis and Results

Raspberry Pi based active noise cancellation

- ALSA (Advanced Linux Sound Architecture)
    - Inherit latency due to buffer structure
    - Minimum period size achieved: 32 frames

- Difficult to achieve small period sizes
    - Issues with “supported” device modes
    - Minimal documentation on settings that work

- Audio Injector latency measured with JACK
    - ~0.8059 ms (0.5833 ms - 0.9750 ms)



Sampling rate	Driver latency	Frequency
48000 Hz	0.6667 ms	1500.00 Hz
44100 Hz	0.7256 ms	1378.13 Hz
22050 Hz	1.4512 ms	689.06 Hz
16000 Hz	2.0000 ms	500.00 Hz

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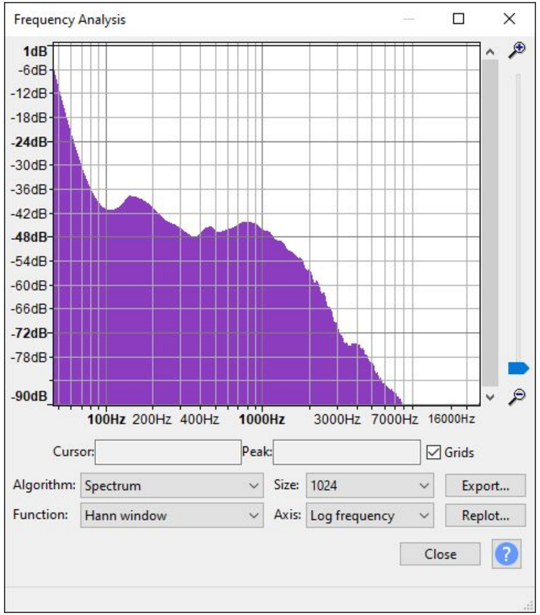
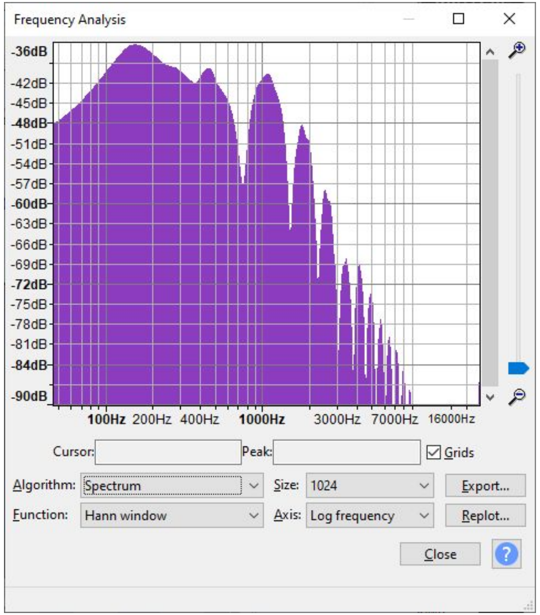
https://www.linuxjournal.com/article/6735

Analysis and Results

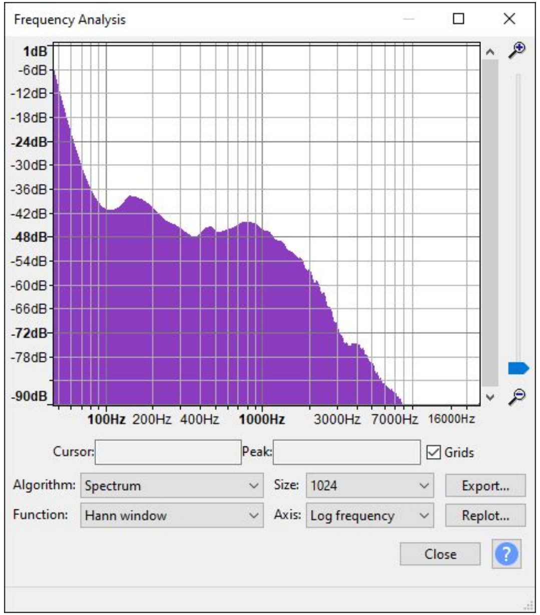
Naive ANC with 64-frame delay (32 for buffer, 32 for hardware)

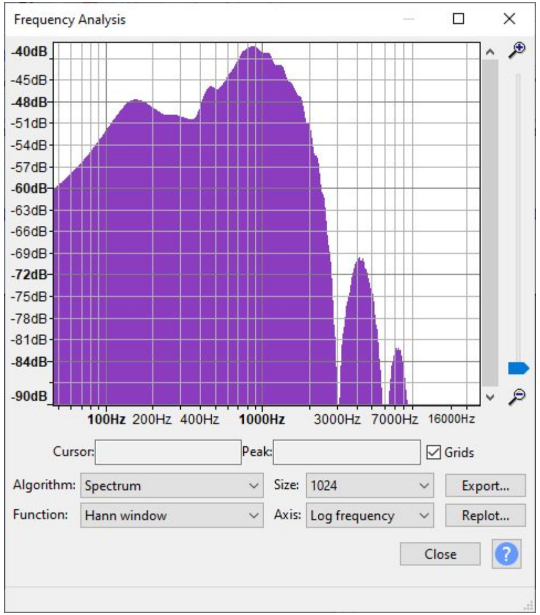




Analysis and Results

Naive ANC with 16-frame delay (not possible)





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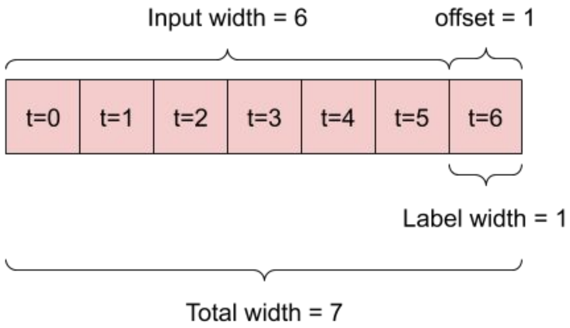
Analysis and Results

Neural network algorithms for active noise cancellation

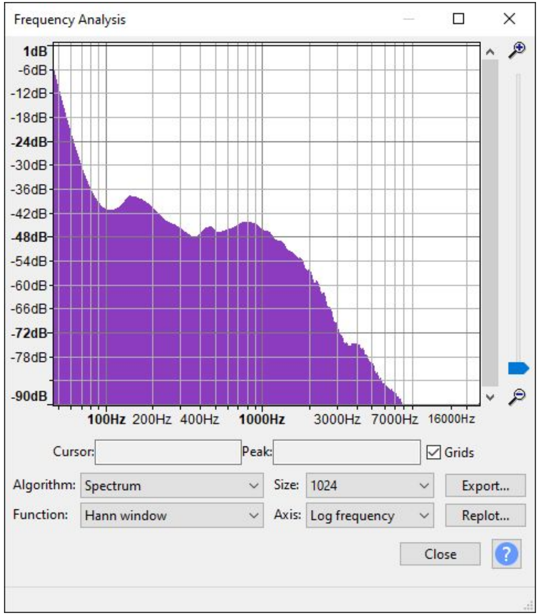
- Generic program to test different parameters
- Parameters
  - Input width
  - Offset
  - Output (label) width
  - Delay
- Specify neural network architecture
  - Simple CNN used here
- Train network, test, output residual waveforms

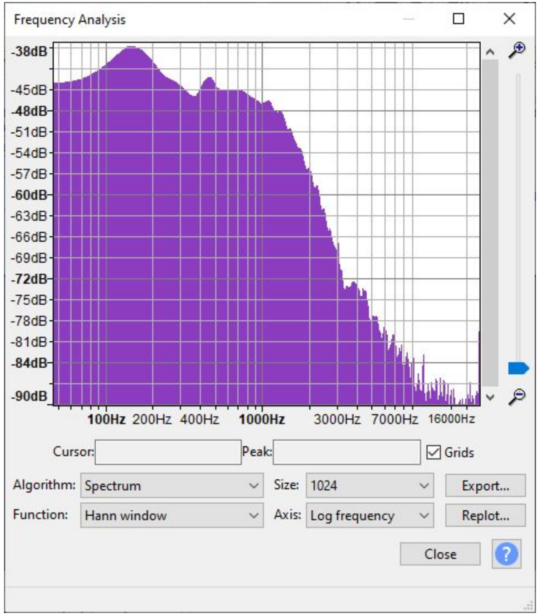


https://www.tensorflow.org/tutorials/structured_data/time_series

Analysis and Results

ANC with prediction to account for 64-frame delay

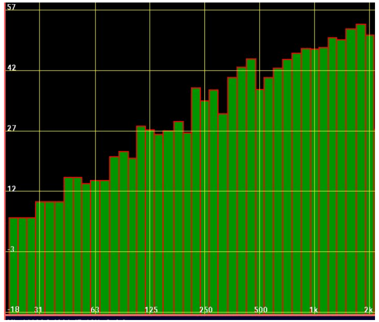




Analysis and Results

Audio exciters for active noise cancellation on windows

- Mounted DAEX25 audio exciter on window
- Observed issues with standing waves
  - Frequency response ok from a distance
  - At 1 cm, 200 Hz tone ranged from 53 - 61 dB(A)
- Other potential issues
  - Main noise source comes from top right
  - Indoor microphones too quiet



Related Work

DeNoize

- Product in development from a start-up
- Integrates sensors and actuators inside double-paned window
- Publically available technical details are limited

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https://denoize.com/press-kit/

Related Work

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Sono noise cancelling system

- Mounts on the inside of any window
- Concept design that never materialized

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https://www.ippinka.com/blog/sono-peace-quiet-home/

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Latency Performance for Real-Time Audio on BeagleBone Black

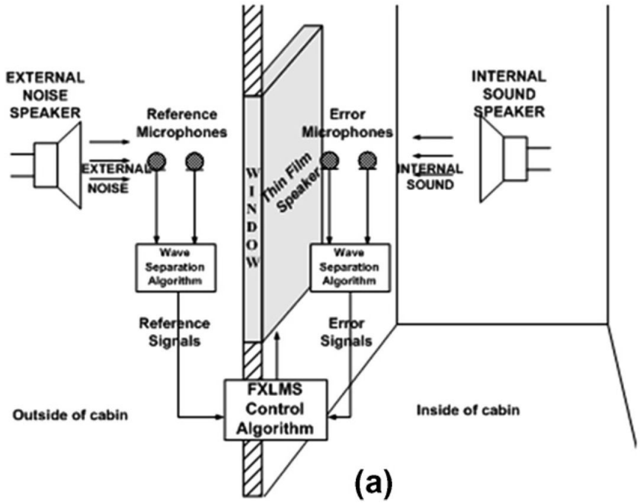
- Authors: James William Topliss, Victor Zappi, Andrew McPherson
- ALSA and JACK benchmarks on Linux

https://api.semanticscholar.org/CorpusID:3305184

Related Work

Directional cancellation of acoustic noise for home window applications

- Authors: S. Hu, R. Rajamani, X. Yu
- Transparent acoustic transducers
- Focuses on identifying source direction



https://www.sciencedirect.com/science/article/abs/pii/S0003682X12002599

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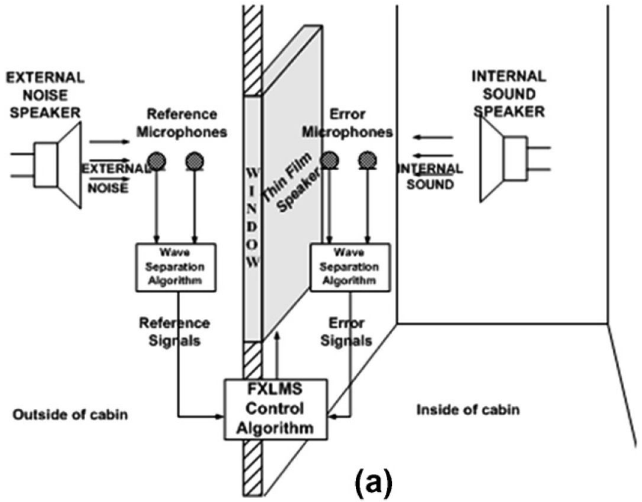
Long Short-Term Memory and Convolutional Neural Networks for Active Noise Control

- Authors: Samuel Park, Eric Patterson, Carl Baum
- Neural network architecture comparison for ANC
    - Compared MLP, RNN, LSTM, and CNN
- Noise from Signal Processing Information Base (SPIB)
- CNN performed the best, especially at high frequencies



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Remaining Work

Document latest findings on GitHub website

- Hardware latency
- Frequency analysis plots

Clean up and generalize ANC testing script

- Facilitate testing with naive ANC
- Expand residual waveform generation and analysis

Additional Ideas for Exploration

Explore processing hardware with lower latency

- BeagleBone
- Sound cards that support smaller periods
- Baremetal/RTOS systems

More advanced neural networks to predict audio further in the future

- Make up for delays caused by driver, hardware
- Consider hardware accelerators such as the Neural Compute Stick 2

Test audio exciters in a controlled environment

- Quiet environment
- Manual noise generation
- Use more microphones/exciters to help with directional noise, standing waves